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Contemporary Natural Philosophy and Philosophies—Part 1

Edited by

Gordana Dodig-Crnkovic and Marcin J. Schroeder

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Special Issue Editors

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About the Special Issue Editors

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Editorial

Contemporary Natural Philosophy and Philosophies

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Abstract: In this Editorial note, Guest Editors introduce the theme of the Special Issue of the journal *Philosophies*, titled *Contemporary Natural Philosophy and Philosophies*.

Keywords: natural philosophy; philosophy of nature; naturalism; unity of knowledge

1. Introduction

From the Philosophies program [1], one of the main aims of the journal is to help establish a new unity in diversity in human knowledge, which would include both "Wissen" (i.e., "Wissenschaft") and "scīre" (i.e., "science"). As is known, "Wissenshaft" (the pursuit of knowledge, learning, and scholarship) is a broader concept of knowledge than "science", as it involves all kinds of knowledge, including philosophy, and not exclusively knowledge in the form of directly testable explanations and predictions. The broader notion of scholarship incorporates an understanding and articulation of the role of the learner and the process of the growth of knowledge and its development, rather than only the final product and its verification and validation. In other words, it is a form of knowledge that is inclusive of both short-term and long-term perspectives; it is local and global, critical and hypothetical (speculative), breaking new ground. This new synthesis or rather re-integration of knowledge is expected to resonate with basic human value systems, including cultural values.

Since knowledge tends to spontaneously fragment while it grows, Philosophies takes existing diversity as a resource and a starting point for a new synthesis. The idea of broad, inclusive knowledge is in fact not so new. From the beginning, natural philosophy included all contemporary knowledge about nature. Newton was a natural philosopher, as were Bohr, Einstein, Prigogine, Weizsäcker, and Wheeler—to name but a few. Today, the unifying picture of the natural/physical world is sorely missing among the isolated silos of particular scientific domains, each with its own specific ontologies, methodologies, and epistemologies.

From the profound need for connected and common knowledge, new trends towards synthesis have emerged in the last decades. One major theme is complexity science, especially when applied to biology or medicine, which helps us to grasp the importance of connectedness between present-day disparate pieces of knowledge—frameworks, theories, approaches, etc. Related to this is the emergence of network science, which studies structures of nodes (actors) and edges as connections between them.

In an adage ascribed to Einstein, but also some others such as Hawkins, it has been recognized that problems are solved not in the framework in which they appear but rather in a new framework, at the next level of abstraction.

This Special Issue responds to the call from Philosophies to build a new, networked world of knowledge with domain specialists from different disciplines interacting and connecting with the rest of knowledge-producing and knowledge-consuming communities in an inclusive, extended natural-philosophic manner. In this process of synthesis, scientific and philosophical investigations enrich each other—with sciences informing philosophies about the best current knowledge of the world, both natural and human-made—while philosophies scrutinize the ontological, epistemological, and methodological foundations of sciences, providing scientists with questions and conceptual analyses. This is all directed at extending and deepening our existing comprehension of the world, including ourselves, both as humans and as societies, and humankind.

2. Obstacles to a New Synthesis

Historically, attempts were made to search for a unity of knowledge originating from insights into the need to understand the world in a holistic manner, notably Snow's critique of "The Two Cultures" [2] and "Consilience: The Unity of Knowledge" by biologist Wilson [3]. However, the strong development of disciplinary research continued as if nothing had happened. It was still possible to continue to dig deeper into isolated domains, and the results were still interesting even though a common view was missing. However, new developments in sciences and technology, such as artificial intelligence, neurosciences, and cognitive science, called for unified views of the "body" and mind", the physical and the mental as archetypes of the divide between "two cultures".

The dialogue between sciences and philosophy has become especially interesting when it comes to the philosophy of science and the question of what constitutes the scientific method, which has become less and less clear. There are three major methodological challenges:

- *The demise of natural philosophy*: this is a very conservative position, still quite common, held by those who believe, as was fashionable in the late 19th and early 20th centuries, that science needs to emancipate itself from the "philosophical nonsense" that conflates philosophy with metaphysics, where metaphysics is understood as a priori knowledge about the nature of reality. Philosophy is of course much more than metaphysics understood in this narrow sense. Recently, a strong interest in ontology and epistemology within artificial intelligence and robotics has demonstrated how important those branches of metaphysics can be not only for science but even for technology. The study of space and time, causality, necessity, and chance are other examples where sciences (physics, biology) expand into traditional territories of metaphysics.
- *"Idol of Numbers"*: today, this can be added to Bacon's four Idols of the Mind (Idols of the Tribe, Idols of the Cave, Idols of the Marketplace, and Idols of the Theater) [4]. This is not less conservative, and possibly even more dangerous in the era of "big data" and data-driven science. Followers of this cult dismiss everything that is not presented in terms of numbers and trust only in the "objective character" of that which is given in numerical form, for example, as expressed in the maxim "let the data speak for themselves". It became more important "that" we can provide numerical values than "what" these numerical values represent and "what" these numbers tell us about reality.
- *Isolationism and the self-sufficiency of research disciplines*: Along with the previous two obstacles to this new synthesis, a third, associated one must also be added. This relates to the difficulty of communication between different domains of knowledge, which makes the role of interdisciplinarity/crossdisciplinarity and transdisciplinarity central to the construction of our contemporary knowledge of the world.

3. Possible Avenues of Re-Connection

When modeling a phenomenon, multiple connected theories, seen from a common perspective, contribute to our multifaceted understanding of its structures and temporal behavior.

One very successful approach in this direction was the development of multiscale models for complex physical, chemical, biological, and cognitive systems, including the human brain. Multiscale models [5] combine and connect earlier approaches focused on single scales of time, space, and topology through the integration of data across spatial, temporal, and functional scales.

Another promising path is the reconceptualization (i.e., conceptual engineering) of the basic concepts used to describe different natural and artifactual systems—physical, chemical, biological, and cognitive. In this new framework, information is considered as the fabric of reality (Deutsch) [6], for an observer, Floridi [7]. The dynamics of information can be modeled as computation, thus forming the basis for the info-computational modeling of a variety of systems, from the physical to the cognitive [8]. According to Kun Wu and Brenner [9], the philosophy of information presents a revolution in philosophy and provides a means of informational metaphilosophy of science that is philosophy of the philosophy of science. We might also add that information, together with its dynamics (computation), presents a new possibility for the development of the modern philosophy of nature/natural philosophy.

4. Topics Addressed in This Special Issue

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Conflicts of Interest: The authors declare no conflict of interest.

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Article

Philosophia Naturalis Rediviva: Natural Philosophy for the Twenty-First Century

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Abstract: A revitalized practice of natural philosophy can help people to live a better life and promote a flourishing ecosystem. Such a philosophy is natural in two senses. First, it is natural by seeking to understand the whole of nature, including mental phenomena. Thus, a comprehensive natural philosophy should address the phenomena of sentience by embracing first- and second-person methods of investigation. Moreover, to expand our understanding of the world, natural philosophy should embrace a full panoply of explanations, similar to Aristotle's four causes. Second, such a philosophy is natural by being grounded in human nature, taking full account of human capacities and limitations. Future natural philosophers should also make use of all human capacities, including emotion and intuition, as well as reason and perception, to investigate nature. Finally, since the majority of our brain's activities are unconscious, natural philosophy should explore the unconscious mind with the aim of deepening our relation with the rest of nature and of enhancing well-being.

Keywords: natural philosophy; philosophy of science; Jungian psychology; depth psychology; analytical psychology; phenomenological psychology; evolutionary psychology; active imagination; Aristotle's four causes; aesthetics in science; philosophy as a way of life

1. Philosophia Naturalis

In the triumphant advance of science, something essential has been lost, but I believe we can recover it by re-examining the idea of natural philosophy. I will begin my exploration with the term philosophia naturalis itself. Originally, philosophia meant, of course, love of wisdom. According to tradition, Pythagoras coined the word because only the gods are truly wise; the best that mortals can do is to desire wisdom and to seek it. This realistic humility is reinforced by the last 2500 years of philosophical and scientific investigations with their continuing revision of previous conclusions. From its beginning, philosophy recognized the limitations of human knowledge.

Traditionally, philosophia was much more than a technical inquiry into the sorts of problems now considered philosophical, and recent commentary has reminded us that ancient philosophy was an all-inclusive way of life [1,2]. Students came to the ancient philosophers and joined their schools in order to live a better life guided by wisdom. The dogmas and technical investigations were important, but primarily as a basis for the art of living well. This goal was also supported by mental and spiritual exercises [1]. We are still concerned with how to live well, and there is growing recognition that philosophy in this broad sense can help us to do so [3–8].

At least from the First Century CE, ancient philosophy was divided into logica (how to understand), physica (understanding of nature, physis) and ethica (character and how to behave) ([9], vol. 1, pp. 158–162). Something like this could be a framework for a future natural philosophy as well. How do we learn and understand? What is the nature of existence? How then do we live? In reconsidering the concept of natural philosophy, I think it is important to take this wider view of philosophy, for we have learned that science and our attitude toward nature have important consequences for our lives. Therefore, in this paper I will consider a natural philosophy that will help us live better now and help our children to live better in the future. As indicated by the citations, few of the individual ideas are original, but I believe that this comprehensive synthesis into a revitalized natural philosophy is worth defending.

Traditionally, philosophia naturalis could denote the philosophical investigation of the natural world, as opposed to philosophia rationalis (logic), philosophia moralis (ethics) or philosophia divina (theology). But, I think we can construct a more contemporary understanding of natural philosophy by contemplating the adjective naturalis ([10], s.v. naturalis). One meaning of naturalis is "concerning nature" (4b), and therefore, philosophia naturalis has the traditional sense of an inquiry into nature. However, I think it is essential that we understand "nature" in the broadest way, encompassing all the phenomena of our experience, including not just the objective and physical phenomena, but also those considered subjective, personal or mental. A deep understanding of nature, which we require to live wisely, will require exploring outside narrowly empirical and physical phenomena. Later, I will review some means for doing so.

Like the English word "natural", the Latin naturalis has another range of meanings that are especially important for our project. These describe things that have arisen from nature in general or are grounded in it in some way. Such things occur in nature, are part of nature, are produced by natural causes or are determined by natural processes (1, 4a, c, 5a). Then again, naturalis describes characteristics inherent or innate in a thing's nature or typical of it (5e, 7a, 9). From this perspective, philosophia naturalis is naturalized philosophy: philosophy grounded in nature, that is informed by our understanding of nature in general and of human nature in particular. Therefore, in the pursuit of wisdom and knowledge, with the goal of living a better life, we must be cognizant both of nature as a whole and of our own nature. Hence, philosophy grounded in nature depends on philosophy about nature. On the other hand, our investigation of nature depends both on the nature of ourselves as epistemic agents and on the nature of the objects of our investigation, and so philosophy about nature reciprocally depends on philosophy grounded in nature. Therefore, the practice of natural philosophy can be expected to evolve as our consensus understanding of nature and human nature continue to evolve through science and other means of empirical inquiry. Of course, there may be disagreements about the conclusions, as is common in science, but this conception of natural philosophy presumes a fundamental commitment to empirical inquiry, otherwise it cannot, I think, be considered natural philosophy.

As a means of living better, with the goal of human flourishing, natural philosophy should encompass an ethics and morality grounded in human nature and in nature as a whole. Natural morality and ethics and even natural religion and theology are old ideas, perhaps born prematurely, but we know much more now about human evolution, neuropsychology and behavior, and so, the time may be right for their reconsideration and renovation as components of a twenty-first century natural philosophy. This is simply to acknowledge that the characteristics of *Homo sapiens* as a species are relevant to the formulation of ethical norms and to understanding human religious and spiritual beliefs and practices.

2. Human Nature

"Know Thyself". A natural philosophy of the sort I am describing depends on an understanding of human nature, which depends on research in psychology, neuroscience, human biology and evolutionary biology. Research in these disciplines is a large and ongoing project; however, there is much that we know, and I will briefly mention some of the characteristics of *Homo sapiens* that are relevant to a future natural philosophy. For the most part, they are uncontroversial and obvious, but we need to call them to our attention.

Certainly, one of the most distinctive characteristics of humans is our ability to learn and adapt; our behavior seems to be more flexible than that of any other animal. This flexibility is a double-edged sword; whereas other species know instinctively how to live authentically as whatever they are, we have to discover and refine continually what it means to live most fully an authentic human life. For us, living a natural life entails investigating and understanding human nature, so that we can guide our thoughts and behaviors to promote human flourishing. Therefore, in order to serve its traditional function of helping us to live well, natural philosophy should also guide educational philosophy so that we develop and learn well.

Because our learning and adaptation are fueled by knowledge, understanding, insight, wisdom and experience, we are naturally curious. Our natural need to know should be considered a requirement for psychological well-being as essential as are our needs for companionship, love, care, security, stimulation, freedom and peace. Therefore, the quest for wisdom, which is central to natural philosophy, needs no further justification.

Unfortunately, humans have limited cognitive capacity, a characteristic of our species all too familiar to most of us. Our perception, memory and reason are limited in scope and subject to both systematic and random distortion. Our attention is limited and apt to be distracted. Therefore, in our pursuit of wisdom, we need to develop cognitive and other tools to help prevent errors and to detect and correct them when they occur. The methods of logic, mathematics and science are specific examples, but more generally, the social process of scholarship, in which parties with competing interests and agendas critique each other's work, is a means toward eliminating, or at least identifying and mitigating, individual, group and cultural biases. This is perhaps the best we can do.

We are far from understanding the psychological complexity of human nature, which has profound effects on our understanding of ourselves and of the rest of nature, and therefore on our well-being. Humans are sentient beings, by which I mean that they are sensitive to their environments, to their own bodies and to their own interior states, and that this sensitivity is manifest in conscious awareness. Therefore, the natural phenomenon of consciousness, which was ignored by much of Twentieth-Century science, is a fundamental topic for any future natural philosophy. Consciousness has a rich phenomenology including perceptions, thoughts, memories, imagination, inner discourse, feelings, intentions, moods, and much more. In particular, our emotional response, which has often been neglected or even rejected by the philosophy of science, is crucial to our happiness and an important factor in how we reach conclusions, live our lives and interact with other people and the world at large [11,12].

On the other hand, much of what goes on in our brains is unconscious, and so, it is essential that natural philosophers strive to understand these unconscious processes and how they affect philosophers' own psychology, as well as that of other people. We are still, a century or so after the invention of depth psychology, explorers of the complex structure of the unconscious mind, which has enormous effects on all aspects of human life. Central to human nature, it is still poorly understood.

Homo sapiens is a social species; we have evolved to survive best in groups, and therefore, social organization is fundamental to our being in the world. Natural philosophy is also a social enterprise, benefiting from the diverse contributions of many people. As a consequence, humans are encultured psychologically and socially through their participation in various communities, and this affects their background assumptions, attitudes, expectations, skills, insights, etc. These cultural characteristics are largely unconscious, slowly acquired and difficult to change. Ultimately, no human activity is culture-free or culture-independent, and it is important that the natural philosopher be aware of this fact (or they will be blindsided by it).

We humans are unique among animals in the complexity and precision of our communication. Language is a cultural artifact that promotes the growth and continuation of culture. It is also an important factor in cognition and even perception, with both positive and negative consequences. Therefore, natural philosophy has to pay special attention to language as an essential characteristic of human nature.

Human beings are embodied, and the significance of that fact is that our brains have evolved to control our bodies in a physical world [13–16]. Our psychological structures are strongly conditioned on embodiment generally and on the specifics of human embodiment. Natural philosophy should not make the old mistake of treating humans as incorporeal minds contingently and inconsequentially attached to a body. Moreover, as in other animals, human cognition is fundamentally situated, that is rooted in particular situations. Our cognitive faculties are better adapted to concrete physical, social and cultural situations than to abstractions. General insight is harder to achieve and often derived from situated thinking and understanding. Narratives are often more convincing than abstract arguments.

Like other living things, humans have evolved, which means that we have inherited many characteristics that aided our survival in our environment of evolutionary adaptedness, but may be less adaptive in our present, very different environment. It behooves the natural philosopher to be aware of these characteristics of human nature and to take account of them. For example, for 95% of the history of *Home sapiens*, we survived as hunter-gatherers in small groups of related individuals ([17], pp. 87–88). That is our environment of evolutionary adaptedness, but that does not imply that we should live as paleolithic foragers or that we should accept today the behaviors that were adaptive then. Important characteristics of human nature are that we learn, adapt, cooperate and pass on our collective experience through culture, which itself evolves. Therefore, for us to live now as paleolithic foragers would be profoundly unnatural, contrary to authentic human nature. Indeed, I expect that the natural philosophy of the future will be an important contribution to the evolution of culture.

Finally, human beings are mortal, and so, the continuation of humanity depends on reproduction and the ability of our offspring to survive and flourish. Therefore, a natural philosophy should be forward-looking and focus on future generations. Like other animals, humans must act purposefully for their own survival and to ensure the survival of the species. Also in common with other species, human survival depends on the health of the ecosystem, and beyond mere survival, the well-being of humanity depends on a flourishing ecosystem. Indeed, biophilia is an evolved appreciation for a healthy environment, which is part of human nature and fundamental to our well-being [18].

As a future natural philosophy should be informed by human nature, so also it should start from the fact that humans are a part of nature. The global ecosystem is an integrated and organized whole, and as such, we may ask what role humans play in it [19]. On the one hand, we now understand that humans have a greater effect on the environment than do other species. On the other, humans have unique capacities for understanding and influencing nature, and we may use them to enhance the survival and flourishing of the global ecosystem, on which we all depend. Just as we individually use our sense organs and minds to better adapt to our environments, so humankind can serve as an organ for the adaptation of the ecosystem as a whole. That is, we can make ourselves part of the global ecosystem feedback loop and work to enhance its health rather than to harm it. However, if humanity is going to fulfill this function well, it will need to strive to understand the whole of nature, and we may consider what that entails.

3. Three Perspectives

One of the facts about nature that a complete natural philosophy must accommodate is the existence of sentient beings, including of course human beings, but also many—if not all—other animal species. Sentient beings have two aspects: an exterior as a physical object and an interior as a consciously-aware subject. These aspects necessitate two perspectives, commonly termed third-person and first-person.

From a third-person perspective, a sentient subject or observer seeks to understand a physical object in terms of its external behavior and physical structure, that is by addressing its non-sentient aspects. This is the perspective of the physical sciences and of behaviorist psychology, but also of much cognitive science and neuroscience, which treat cognition as physico-chemical information processing and control.

Certain natural phenomena cannot be observed directly from a third-person perspective, and these include the subjective structure of sentience and phenomenal consciousness. For understanding these phenomena, first-person methods have been developed, as in phenomenological psychology and experimental phenomenology [20–22]. While third-person investigations can address these phenomena indirectly, the most fundamental problems (such as the Hard Problem of consciousness [23]) cannot be solved without evidence available only from a first-person perspective.

First-person investigations are more difficult than third-person research for several reasons. First of all, first-person methods have not been so extensively developed and refined as third-person techniques. Second, due to the private nature of first-person investigations, there is a greater danger of personal biases, presuppositions and other subjective factors affecting observation. Third, and most importantly, this privateness makes public observation in principle impossible. Nevertheless, publicly-validated understanding can emerge in a community of investigators through shared practices of introspection and experimentation [24] (we already find this shared understanding in well-established contemplative and meditative communities). Moreover, first- and third-person approaches can be combined, as in neurophenomenology [24–26].

The first-/third-person grammatical analogy encourages us to consider whether there is also a second-person perspective, and I believe that there is and that it will become an important part of natural philosophy [19]. The first-person perspective has a sentient subject striving to understand his/her own subjectivity, that is to understand his/her interiority from the inside; and the third-person perspective has a sentient subject striving to understand an object from an external standpoint, that is qua non-sentient thing. The second-person perspective, in contrast, has two or more sentient beings striving to understand one another qua sentient beings, that is each understanding their own interiority in relation to the interiorities of the others. It is a cooperative activity of mutual growth.

I believe that the second-person perspective is fundamental to phenomenology, for we are social beings relating to other sentient beings before we ever undertake first-person phenomenology, which has a solipsistic orientation. The first-person perspective is a bracketing of experience from everyday second- and third-person relationships. If we are to obey Husserl's "Back to the phenomena!", then we must acknowledge the second-person perspective.

An everyday example of the second-person perspective is the mutual understanding that develops between close friends, lovers and family members. Good examples of systematic formal second-person investigations might be the relation of the Jungian analyst and analysand and other psychotherapeutic or long-term counseling relationships. Second-person understanding can also develop between humans and non-human sentient beings. A familiar example is the understanding that arises between people and their companion animals. There is a partial recognition of the second-person relationship in contemporary rules and guidelines in human subjects research and in animal research, which acknowledge the objects of the research as sentient beings whose experiences, sensibilities and autonomy should be considered.

In summary, natural philosophy should investigate nature from first-, second- and third-person perspectives, which may be described as intrasubjective, intersubjective and objective (more properly, subjective-objective) investigations. These three perspectives are necessary for complete understanding in a world in which there are sentient beings.

4. Four Explanations

Understanding the why of things is central to natural philosophy, but there are several sorts of answers to why questions. In any given context, some kinds of answers, or explanations, may be more or less informative—more or less able to improve our understanding—than others. However, the contraction of natural philosophy that accompanied the expansion of modern science in the Sixteenth through Eighteenth Centuries led to a corresponding contraction in the notion of causality. The newly dominant mechanical philosophy explained all causation in terms of efficient causation, which is still the common scientific approach. In the broader context of natural philosophy, the efficient cause of an event is not always the most informative explanation. Therefore, as a first step toward a broader understanding, we can reconsider Aristotle's analysis of answers to why questions (Aris., *Phys*. II 194b–195a, *Met*. 983a–b, 1013a–1014a). These are commonly known as Aristotle's four causes, but that terminology can be misleading due to the limited notion of causality typical of contemporary science. Therefore, I prefer to call them the four whys or, compromising with tradition, the four (be)causes. Nevertheless, it is important to understand that the four whys are not a theory of causation, but a taxonomy of explanation. A brief review follows, which puts them in the context of future natural philosophy.

One fundamental kind of explanation can be termed the "what" (Greek, to ti esti), which answers the question "What is it?" Traditionally, this is called the formal cause (causa formalis) because the answer refers to the form, class or category to which something belongs (Grk., eidos). Why does this thing have feathers? Because it is a bird, and birds have feathers. Why did this animal pounce on the bird? Because it is a cat, and cats prey on birds. Why did this tissue contract? Because it is a muscle.

In the context of formal causation, "formal" refers to the Platonic forms or ideas (Grk., eidos, idea), and so, formal causes also include mathematical explanations, which have been essential in science since Galileo's time. Why do these two electrons repel each other with such and such a force? Because electrons are charged objects, which obey Coulomb's law, and so, the force is proportional to the product of their charges and inversely proportional to the square of their distance. Why is $D_x(x^2 + \sin x) = D_x x^2 + D_x \sin x$? Because differentiation is a linear operator.

A second sort of explanation is the "from what" (Grk., to ex hou), which answers a why question in terms of the material from which something is formed; this is the material cause (causa materialis). In this context, "material" (Grk., hulê) is not limited to the sort of physical matter from which something is made, but is relative to a thing's form. That is, the thing we are seeking to explain is analyzed in terms of some form imposed on an underlying substrate, its "matter". The formal (be)cause refers to a specific abstract class, category or form; the material (be)cause refers to the generic unformed stuff from which the thing is formed. Why did the house burn down? Because it was made of wood. Why did the cat fall? Because it is made of flesh and blood (which have mass, etc.). Why did the muscle contract? Because it is composed of thousands of muscle fibers, each of which can contract.

Form and matter are often relative terms, for the formed matter at one level becomes the generic substrate for higher levels of formation. A statue (to use an old example) has many properties, some better explained by its form (it is a statue of Apollo), others better explained by its material (bronze). But, the bronze metal is itself formed matter, for it is an alloy of copper and tin in a particular proportion, and copper and tin are themselves structures of more elementary matter (protons, neutrons, electrons) with a certain crystal structure, and so forth. At a higher level, statues may be the matter of a museum exhibition.

A third sort of explanation is the "by what" (Grk., to hupo tinos) or efficient cause (causa efficiens), which is the sort of explanation privileged by contemporary science. Aristotle tells us that this answer to a why question explains a change in terms of what initiated the change, maintains it or brought it to completion. Thus, it explains a change, typically in terms of another change (Grk., kinoun), either antecedent, concurrent or terminating. Why did the ball fly over the net? Because it was struck by the racket. Why did the cat pounce? Because it saw a bird in range. Why did the muscle contract? Because it was stimulated by motoneurons.

The most controversial kind of explanation, from a contemporary perspective, is the "for sake of what" (Grk., to hou heneka), or final cause (causa finalis), which explains something in terms of its end or purpose (Grk. telos). Why does the heart beat? To pump the blood. Why are there antibiotics? To fight infection. Why did the cat pounce on the bird? In order to eat it. Why did this muscle contract? To extend the cat's legs so it could pounce.

Indeed, many things in nature—especially in living nature—exhibit teleonomic behavior; that is, they behave in such a way that they fulfill purposes or achieve relevant ends ([27], pp. 9–20). Contemporary science prefers to explain them in terms of antecedent efficient causes (e.g., natural selection and myriad contingencies), but especially in biological and technological contexts, final (be)causes are often more explanatory. In fact, contemporary evolutionary theory explains how teleonomic processes arise in the natural world, and all four be(causes) are essential to explanation in modern evolutionary biology [28,29]; as Pigliucci observes,"Darwin made it possible to put all four Aristotelian causes into science" [30].

In summary, all four whys or (be)causes are necessary for a complete understanding of anything. The material and formal explanations say what a thing is in generic and specific terms; the efficient cause addresses the motive forces of its change; and the final explanation identifies the purpose or function of the change. Certainly, for any particular thing and for any particular purpose, some explanations will be more relevant, some less. But, in order to achieve better understanding and greater wisdom, natural philosophy should be open to them all.

We should not assume, however, that Aristotle said the first and last words on the categories of explanation. Certainly, natural philosophy should be open to new forms of questions and answers that better enable us to understand nature in all its manifestations. Nevertheless, there is something fundamental about Aristotle's framework, which looks for explanations in the past (efficient), in the future (final) and in present nature combining general law (formal) and particular substance (material).

5. Philosophical Practice

How should we practice natural philosophy? I have argued that it is a philosophy grounded in nature and, in particular, in human nature. Therefore, we must take account of all of human nature, and not ignore some aspects of it or attempt to wish them out of existence. Rather, we should consider every aspect of human nature as a means of achieving greater understanding with wisdom as our ultimate goal. As our understanding of human nature extends and deepens, so also will our understanding of how to pursue wisdom.

5.1. Four Functions

The characteristic of human nature most immediately apparent to us is our conscious mind, and therefore, we may begin with its faculties and how they may be applied to natural philosophy. C. G. Jung identified four orienting and adaptive functions of the conscious mind: thinking, sensation, feeling and intuition ([31], CW 6, ¶¶ 7, 983–985).[1] Although Jung's taxonomy might not be exhaustive, it has stood the test of time, and I will use it here. Sensation refers to conscious perception of the external world, and thinking refers to our ability to reflect on our mental content, especially by discursive and rational means. Sensation and thinking have been the faculties most obviously applied in science for the last several centuries and broadly align with empirical and theoretical investigation. The former is more extroverted in its orientation, the latter more introverted. Less obviously useful in science are the other two faculties—feeling and intuition—but we have testimony to their importance from some of the greatest scientists.

The feeling function provides an assessment of something that has the immediacy of sensation (indeed, its biological function is to provide an actionable assessment when more thorough, but slower thinking is not practical). Feeling has a valence: positive or negative, attraction or avoidance, good or bad, but also other dimensions that are difficult to characterize ([32], p. 90).

Many scientists have commented on the importance of aesthetic considerations in guiding their own work [33], even sometimes in opposition to empirical evidence, with eventual vindication of the more aesthetic theory ([34], pp. 65–66). There does not seem to be any a priori reason to prefer the more aesthetic theory, unless one takes the Platonic view that Truth, Beauty and the Good are aspects of the ultimate principle of existence, but aesthetics is often a reliable guide. Perhaps it is simply that our brains work better on aesthetically-appealing material. We are more likely to dwell on and even contemplate the beautiful, and thus find aesthetic theories more fruitful. Especially in mathematics and mathematical sciences, beauty is associated with order, symmetry and harmony,

[1] Jung's work is cited by paragraph number (¶) and volume in his Collected Works (CW).

which facilitate thinking. The pursuit of truth may be guided by aesthetics more efficiently than by slower discursive reasoning.

In any case, the role of aesthetics in understanding should be a topic of investigation for natural philosophers; it is a characteristic of human nature that needs to be better understood. Aesthetic cultivation is an implicit part of the training of most mathematicians and scientists, but it could be taught more explicitly. Now, it is learned through apprenticeship and individual discovery, but we could have courses intended to cultivate the natural philosopher's aesthetic judgment. Different cultures and even different scientific and philosophical communities have different aesthetic values, and studying this diversity will expand the aesthetic horizons of natural philosophers.

Aesthetics is just one aspect of the feeling function, which has components that are both innate and learned. Our emotional responses have evolved over millions of years to make rapid—and on average, reliable—evaluations in our environment of evolutionary adaptedness [35]. These responses are not necessarily adaptive in our contemporary, very different environment, and so, we regulate and modify our emotional responses through cultural conditioning and learning. Nevertheless, as perceptual organs, our emotions give us valuable information, especially about people and, to a lesser extent, other animals. Therefore, they are especially important in second-person investigations.

As perception makes use of sense organs, which process sensory information unconsciously before it becomes present in conscious perception, the feeling function is also embodied in brain structures such as the amygdala and other parts of the limbic system, with unconscious effects on the physiological state. Before an emotional response rises to the level of consciousness and becomes present to the feeling function, it has already had physiological effects, such as activation of the sympathetic nervous system, hormone secretion (e.g., adrenalin) and alteration of breathing and heart rate. Our conscious awareness of such effects is essential to the phenomenology of the feeling function ([36], ch. 7) ([37], ch. 9). Therefore, cultivation of the feeling function involves greater awareness of the somatic correlates of emotion. Where am I feeling this? In my gut? In my heart? In my breathing?

From ancient times up to the present day, science and to a large extent also philosophy have been prejudiced against the feeling function, but it is essential. Indeed, people with a pathological absence of feeling cannot make decisions effectively ([36], p. 67). Nevertheless, the emotional faculties, which evolved in a very different environment from modern civilization and often develop in the individual without much conscious reflection, cannot be relied upon blindly. Like our sense organs and indeed our thinking, our feelings can be misleading. Therefore, it is important to treat our emotional responses critically and to cultivate them to respond more appropriately in contemporary and future society.

In natural philosophy, the feelings are not sufficient on their own (nor are the other three functions), but they are often necessary for complete understanding. In particular, when properly cultivated, they may give us an early assessment of an idea and help us to decide whether it is worth pursuing by means of perception and thought. Moreover, after perception and thought have done their job, the feelings can help us evaluate the quality of the result.

This brings us to the fourth function, intuition, which is perhaps the least familiar. Jung compares intuition with the other functions as follows: "The essential function of sensation is to establish that something exists, thinking tells us what it means, feeling what its value is, and intuition surmises whence it comes and whither it goes" ([31], CW 6, ¶983). He also defines intuition as "perception by way of the unconscious, or perception of unconscious contents" ([31], CW 6, ¶899); it "should enable us to divine the hidden possibilities in the background, since these too belong to the complete picture of a given situation" ([31], CW 6, ¶900). Intuition is the faculty that brings new possibilities into conscious awareness; it is the fundamental organ of creativity. From it arise novel ideas, hypotheses, images and visions, which then may be subjected to critical evaluation by the thinking, sensation and feeling functions.

To make full, conscious use of their intuitive faculties, natural philosophers need to learn and practice techniques for bringing unconscious content and processes into conscious awareness. These techniques include active imagination and attention to dreams [38]. This may seem far outside the bounds of traditional science and philosophy, but there are many examples from history of the creative potential of intuition. Perhaps the most familiar is Kekulé's discovery of the benzine ring; "Let us learn to dream", he advised, "then perhaps we shall find the truth" [39,40].

A fundamental conclusion of the Jungian psychological typology is that most people have one dominant function, which is the principal mode of their conscious engagement with the world. It is their most differentiated function, the most fully developed and precise and the one they habitually use. The opposite function (thinking and feeling are opposites, as are sensation and intuition), which is called the inferior function, then is the least differentiated and developed and may be quite primitive in its functioning, which is often largely unconscious ([41], pp. 10–18). A person is least likely to use his/her inferior function, and when they do, he/she often does not use it effectively, due to its underdevelopment. The remaining two functions are called secondary or auxiliary and have intermediate degrees of differentiation and use.

Thinking is the dominant function for most scientists and philosophers, with sensation an auxiliary function, especially for empiricists. Feeling and intuition are usually the less developed functions. All four functions, however, are human faculties for conscious adaptation and orientation in the world, and Jung informs us, "For complete orientation all four functions should contribute equally" ([31], CW 6, ¶900). In this way, we have complementary perspectives on any phenomenon, essentially seeing it from all four sides. Developing the secondary and inferior functions is part of the psychological process of individuation, of becoming psychologically whole and undivided (Latin, individuus), which is the goal of Jungian analysis [42]. An especially challenging, early phase of individuation is familiarization with and recruitment of the Shadow complex, which incorporates consciously-rejected characteristics such as the inferior function ([42], pp. 38–42, [43]). The engagement with the Shadow integrates these unconscious characteristics into consciousness. So, a thinking-dominant scientist would need to become more consciously aware of his/her largely unconscious feeling function, and to work with it so that it is a more adaptive, differentiated and useful faculty. A goal for the education of future natural philosophers should be the cultivation of all four functions, so that they have all their conscious faculties available for understanding the world and living better in it.

5.2. Unconscious Faculties

Much of what takes place in our brains is unconscious, and it behooves us as natural philosophers to understand our unconscious faculties, both from the third-person perspectives of neuroscience and behavioral psychology and from the first-person perspectives of phenomenology and analytical psychology. In fact, all the conscious faculties have roots in the unconscious. We have seen that early phases of emotional processing are unconscious, and in perception, both early stages (e.g., pattern recognition) and top-down processes (e.g., "seeing as") are unconscious. So, also the possibilities presented to the intuition arise from the unconscious. Even the thinking function leans heavily on largely unconscious processes, such as categorization and concept formation, memory and language.

Like other animals, humans have evolved behavioral adaptations ("instincts") that are characteristic of *Homo sapiens* (i.e., phylogenetic). They are encoded in the human genome and the subject of ongoing research in evolutionary psychology [44]. These innate adaptations lie deep in our nature and define the phylogenetic core of our unconscious minds; Jung called it the objective psyche ([31], CW 7, ¶103n, [45], p. 65, [46]) and the collective unconscious because it is common to all people ([31], CW 8, ¶270). The particular instincts structure our perception, affect, motivation and behavior to achieve biological ends (e.g., reproduction, child rearing, cooperation, social hierarchy, protection). Instincts can be studied from a third-person perspective by observing behavioral regularities characteristic of a species. They regulate behavior, however, by means of their effect on conscious and unconscious processes in the animal's brain. Experienced from a first-person perspective, these structures are the archetypes of the collective unconscious, which Jung described as "active living dispositions, ideas in the Platonic sense" ([31], CW 8, ¶154).

The archetypes are often misunderstood as innate images; indeed, this was Jung's initial understanding of them ([31], CW 8, ¶435), but in his later work, he stressed that they are not images, but innate regulators of psychological processes ([31], CW 9i, ¶155). Therefore, the archetypes are less like static patterns and more like programs or control systems that regulate behavior by means of the nervous system; they are dynamic psychological forms, that is structured regulators of behavior and experience.

As dynamic psychological forms, the archetypes shape the particular "matter" of our behavior and experience ([31], CW 9i, ¶155). Together, that is, they are (partial) formal and material explanations of our thought, feelings and action. The final explanation lies in the biological ends served by the archetypes. The efficient explanation is the releasing stimulus that has activated the archetype, that is engaged a cognitive-behavioral regulatory mechanism ([45], pp. 64–65). Of course, I am not claiming that every human thought, feeling or action can be explained by the archetypes, but as evolved characteristics of our species, understanding them is essential to any natural philosophy.

There is more to the unconscious mind than the collective unconscious, for each of us also has a personal unconscious, which is ontogenetic rather than phylogenetic ([42], p. 150n13). It develops in each of us as individuals in particular families, communities, groups and cultures. The personal unconscious is largely an adaptation of phylogenetic archetypes to the particularities of an individual's life. This adaptation takes the form of unconscious complexes, each developing around an archetypal core. In common usage, the word "complex" has a negative connotation, but in the context of analytical psychology, complexes are normal components of the unconscious ([41], pp. 36–39). They are what makes the human instincts flexible and subject to individual, social and cultural modification. Nevertheless, because complexes develop unconsciously through a person's life experiences, they can become maladaptive. Therefore, an important goal of Jungian psychoanalysis is to bring the complexes into conscious awareness, so that the analysand can engage with them and so that their unconscious effect is mitigated (this has been discussed above in Section 5.1 for the specific case of the inferior function and the Shadow complex).

5.3. Active Imagination

Archetypes and complexes are unconscious and therefore not directly observable, even by first-person methods. But, like other theoretical entities in science, they may be investigated through their observable effects, which allows hypotheses about them to be confirmed or refuted. When archetypes and complexes are activated or engaged, they have effects on experience, and we can come to understand them through these experiences. In particular, Jung observed that archetypes and complexes often behave as autonomous subpersonalities with their own purposes (deriving from their biological function) ([31], CW 8, ¶253). Their inner workings and motivations are not directly accessible to consciousness (for they are opaque to us, like the phenomenological interiors of other sentient beings), but we can engage them in a second-person investigation. More concretely, the conscious ego and an unconscious complex/archetype can engage in a dialogue directed toward mutual understanding: the ego of the complex's goals and needs, the complex of the ego's individual life and needs in the here and now, with the goal of a mutual accommodation ([38], pp. 179–188). In this way, a cooperative relationship is established, rather than a situation in which the components of the psyche work at cross-purposes.

Active imagination is the name given in analytical psychology to the principal technique for achieving this accommodation [38,47]. The practitioner consciously interacts in his/her imagination with a personification of an activated complex or archetype. The dialogue (and, indeed, negotiation) is only partly under the control of the ego, for the activated unconscious personality is governed by its own autonomous structure. Active imagination depends on a complex or archetype being activated in the unconscious. Sometimes, this happens spontaneously, for example when a person has had an especially impressive dream. In this case, a significant person, animal or object from the dream can be used as an imaginative stimulus to reactivate the relevant complex or archetype. In other cases, a person may invite a personification of a particular affect or condition (such as a mood or illness) that is intervening in their life.

More generally, complexes and archetypes are activated by symbols, which acquire their numinous character because they are the releasing stimuli of these deep psychological structures ([48], pp. 12–44). Symbols seem significant because they are significant, signifying situations in which some associated archetype or its derivative complexes should be engaged. The symbol's numinosity is a conscious manifestation of the activation of an archetype or complex in the unconscious psyche. Some symbols are apparently innate, wired into our psyches through hundreds of thousands of years of evolution. Others are more particular—cultural or even individual—and become associated with archetypes by means of their mediating complexes. These are not new ideas. In particular, Neoplatonic theurgists used symbols (sumbola) and signs (sunthêmata) to engage with archetypal figures and complexes, which they understood as gods and daimones (mediating spirits) [49,50]. They accomplished this through ritual, which may be defined as "symbolic behavior, consciously performed" ([38], p. 102).

Active imagination and similar techniques are not just for dealing with psychological problems, but can be valuable philosophical tools, as the Neoplatonists knew. The unconscious mind has long been recognized as a source of creativity [51–55], but creators have had to wait for the unconscious to offer on its own terms new possibilities to intuition. Active imagination enables conscious engagement with the wellsprings of creativity in order to discover new possibilities, which then may be evaluated according to the criteria of the other three functions (thinking, sensation, feeling). This too is an old idea, and ancient poets' invocation of the Muses as a source of inspiration could be more than a literary convention. By symbolic actions, a person can activate the relevant archetypes and complexes and seek inspiration from them. So, also the natural philosopher may seek insights about himself/herself and the rest of nature. Archetypes, complexes and symbols are characteristics of human nature that we, as natural philosophers, need to understand better, both to understand ourselves more deeply, but also to understand their effect on our understanding of other things.

5.4. Natural Philosophy of Mathematics

The natural philosophy of mathematics illustrates the importance of the unconscious. It has been argued convincingly that the only viable philosophies of mathematics are fictionalism and full-blooded Platonism, but that there is no fact of the matter to decide between them ([56], pp. 4–5 and ch. 8). In both cases, mathematical objects exist (roughly speaking) if there is a consistent theory about them. This seems to be an impoverished view of mathematical reality compared to the experiences of many mathematicians and scientists. The gap arises from the fact that in philosophy, mathematical objects are treated purely formally; in the case of the natural numbers, they are understood as pure quantities. In fact, Wolfgang Pauli argued that contemporary work in the foundations of mathematics had failed because its formal approach "was one-sided and divorced from nature" ([57], p. 64).

However, if we take the perspective of natural philosophy, we see that the natural numbers also have a ground in human nature; for humans (like some other animals) exhibit innate numerosity [58,59], that is the ability to directly perceive small numbers. There are regions of our brains that respond to the numbers of things independently of their other properties (size, arrangement, density, etc.) [60]. Like our phylogenetic capacity to see form, color and arrangement, we have a phylogenetic capacity to see number (up to about seven). Innate numerosity together with innate symmetry perception [61] imply that these mathematical concepts are not arbitrary constructions for us; they are implicit in the human genome and have been with us for a very long time. They are archetypal.

Therefore, certain small numbers have inherent qualitative aspects in addition to their more familiar quantitative aspects. This has been recognized by mathematicians such as Henri Poincaré, who said, "Every whole number is detached from the others, it possesses its own individuality, so to speak" ([62], p. 60) and by physicists such as Pauli, who said the archetype concept should include "the continuous series of whole numbers in arithmetic, and that of the continuum in geometry" ([62], p. 18n10). In psychological terms, the first few numbers are individually archetypal, and they have psychological potency like the other archetypes. Indeed, "Jung devoted practically the whole of his life's work to demonstrating the vast psychological significance of the number four", according to his colleague Marie-Louise von Franz ([62], p. 115). Jung remarked that number "may well be the most primitive element of order in the human mind" ([31], CW 8, ¶870).

A complete natural philosophy of mathematics should acknowledge and incorporate the archetypal character of small numbers and geometric objects, for they are grounded in human nature. The more abstract qualities of symmetry are of course fundamental to the aesthetics of mathematics and physics. Pauli emphasized the importance of the archetypes in natural science; he concluded, "the archetypes thus function as the sought-for bridge between the sense perceptions and the ideas and are, accordingly, a necessary presupposition even for evolving a scientific theory of nature" ([63], p. 221).

6. The Reanimation of Nature

The last natural philosopher, in the sense presented here, was perhaps Johann Wolfgang von Goethe, and the present proposal could be viewed as an attempt to pick up where he left off, but in the context of a Twenty-First Century understanding of nature. His approach, which he called a "delicate empiricism" (zartre Empirie) involved an empathetic identification with the object of study, so that exterior perception and interior cognition move in tandem harmony; he said, "my perception itself is a thinking, and my thinking a perception" ([64], p. 39). His method was holistic and participatory ([63], pp. 146, 258, [65], pp. 3–26, 49–76, 321–330, [66], pp. 12, 22, 28, 41, 48). Archetypal patterns provide the unifying bridge between external forms and processes and an empathetic participation in them. Pauli agrees that understanding, and in fact the joy of understanding, arises from "a correspondence, a 'matching' of inner images pre-existent in the human psyche with external objects and their behavior" ([63], p. 221) (I have discussed Goethe's natural philosophy more elsewhere [19,50]).

Natural philosophers, as described here, will interact with nature in a way that is more holistic, participatory and sensitive than is the norm in science now. They will engage all four of their conscious functions with a goal of understanding phenomena that are intrasubjective, intersubjective and extrasubjective (objective). They will cultivate relationships with the complexes and archetypal structures of the unconscious mind and will be aware of the projection of these structures outside themselves. In this way, they will attune their psyches to nature to achieve a fuller, more comprehensive understanding and to gain the wisdom that is built on it. This resonance between inner and outer form and process will allow them to experience nature as animate, which can be grasped and appreciated not just intellectually, but also sensually, emotionally and intuitively [67]. I anticipate this will change the relationship of humanity to the nature of which it is part to the benefit of both.

7. Conclusions

In this paper, I have presented what I believe natural philosophy should be in the Twenty-First Century. First of all, it should be a philosophy in the ancient sense, that is a way of living better, of human flourishing grounded in the pursuit of wisdom.

Second, it should be a natural philosophy in that it finds wisdom by seeking to understand all of nature, which includes all the experiences we have, both individual and collective. In particular, in addition to understanding objects qua objects from an exterior, third-person perspective, it seeks to understand experience from an interior, first-person perspective, and it seeks mutual understanding among sentient beings through a second-person perspective. No phenomenon should be outside the scope of a future natural philosophy. Moreover, natural philosophers understand that phenomena have many explanations, and the most informative explanation of a phenomenon may lie in antecedent changes, but also in specific structure or organization, in generic constituents or in the purpose or function of the phenomenon, as well as that full understanding often depends on all of these.

Third, it should be a natural philosophy in that it is grounded in our nature as human beings. This means that it is a natural philosophy developed in an ever-improving awareness and understanding of human nature, in particular of human capacities and limitations. Therefore, future natural philosophers should use all their faculties in the pursuit of wisdom: conscious and unconscious, individual and collective. We are situated, embodied living agents with capacities for thinking, sensation, feeling and intuition, all of which are informative. Part of natural philosophy as a way of life, then, is the cultivation of these capacities so that they function more effectively. In particular, feeling and intuition need more attention than usually granted by science. To this end, particular contemplative practices and exercises will be helpful.

As human animals who are part of nature, we may use our innate capacities to enter into a comprehensive, empathetic understanding of nature, which is intellectually and emotionally satisfying and which leads to humanity better fulfilling its function as an organ of nature. A better understanding of nature, including human nature, will show us how to fulfill our role better, and a better understanding of our own nature will enable us to understand better nature as a whole. It goes without saying that most if not all of these ideas have been proposed before, but the goal of a philosophia naturalis rediviva must take the best of the past while establishing a new foundation on which to erect a revitalized structure.

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philosophies

Article

We Need to Recreate Natural Philosophy

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Abstract: Modern science began as natural philosophy, an admixture of philosophy and science. It was then killed off by Newton, as a result of his claim to have derived his law of gravitation from the phenomena by induction. But this post-Newtonian conception of science, which holds that theories are accepted on the basis of evidence, is untenable, as the long-standing insolubility of the problem of induction indicates. Persistent acceptance of unified theories only in physics, when endless equally empirically successful disunified rivals are available, means that physics makes a persistent, problematic metaphysical assumption about the universe: that all disunified theories are false. This assumption, precisely because it is problematic, needs to be explicitly articulated within physics, so that it can be critically assessed and, we may hope, improved. The outcome is a new conception of science—aim-oriented empiricism—that puts science and philosophy together again, and amounts to a modern version of natural philosophy. Furthermore, aim-oriented empiricism leads to the solution to the problem of induction. Natural philosophy pursued within the methodological framework of aim-oriented empiricism is shown to meet standards of intellectual rigour that science without metaphysics cannot meet.

Keywords: natural philosophy; metaphysics; physics; problem of induction; physicalism; theoretical unity; philosophy of science; scientific method; scientific progress; pessimistic induction

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1. Newton Kills Natural Philosophy and Creates Modern Science

Modern science began as natural philosophy, an admixture of philosophy and science. Today, we think of Galileo, Johannes Kepler, William Harvey, Robert Boyle, Christiaan Huygens, Robert Hooke, Edmond Halley, and of course Isaac Newton as trailblazing scientists, while we think of Francis Bacon, René Descartes, Thomas Hobbes, John Locke, Baruch Spinoza and Gottfried Leibniz as philosophers. That division is, however, something we impose on the past. It is profoundly anachronistic. At the time, they would all have thought of themselves as natural philosophers.

And then natural philosophy died. It split into science and philosophy. Both fragments suffered from the split, but philosophy suffered far more than science.

How and why did natural philosophy die? It was killed by Newton. Or rather, it was killed off by those Enlightenment and post-Enlightenment natural scientists who, following Newton, eschewed metaphysics, and sought to arrive at laws and theories solely on the basis of evidence.

Paradoxically, the first edition of Newton's *Principia*, published in 1687, was quite explicitly a great work of natural philosophy. There are, in the first edition, nine propositions all clearly labelled as "hypotheses," some quite clearly of a metaphysical character. By the third edition, the first two of these hypotheses become the first two "Rules of Reasoning," and the last five hypotheses, which concern the solar system, become the "Phenomena" of later editions. One hypothesis disappears altogether, and one other, not required for the main argument, is tucked away among theorems. In the third edition there are two further "rules of reasoning," both inductive in character. In connection with the second of these, Newton comments, "This rule we must follow, that the argument for induction may not be evaded by hypotheses" [1] (p. 400). Newton adds the following remarks concerning induction and hypotheses: "whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical . . . have no place in experimental philosophy. In this philosophy, particular propositions are inferred from the phenomena, and afterwards rendered general by induction. Thus it was that . . . the laws of motion and of gravitation were discovered" [1] (p. 547). In these and other ways, Newton sought to transform his great work in natural philosophy into a work of inductive science.

Newton hated controversy. He knew his law of gravitation was profoundly controversial, so he doctored subsequent editions of his *Principia* to hide the hypothetical, metaphysical and natural philosophy elements of the work, and make it seem that the law of gravitation had been derived, entirely uncontroversially, from the phenomena by induction. Because of Newton's immense prestige, especially after his work was taken up by the French Enlightenment, subsequent natural philosophers took it for granted that success required they proceed in accordance with Newton's methodology. Laws and theories had to be arrived at, or at least established, by means of induction from phenomena. Metaphysics and philosophy had become irrelevant, and could be ignored. Thus was modern science born, and natural philosophy, which had given rise to modern science in the first place, was quietly forgotten.[1]

Newton's inductivist methodology is still with us. It is known today as "inference to the best explanation" [3]. (Newton did not ignore explanation. His Rules of Reasoning stressed that induction required one to accept the theory that is simplest and, in effect, gives the best explanation of phenomena.) Scientists today may not hold that theories can be "deduced" from phenomena by induction, but they do hold that evidence alone (plus explanatory considerations) decides what theories are accepted and rejected in science. They take for granted a doctrine that may be called *standard empiricism*: evidence decides in science what theories are to be accepted and rejected, with the simplicity, unity or explanatory power of theories playing a role as well, but not in such a way that the world, or the phenomena, are assumed to be simple, unified or comprehensible. The crucial point, inherited from Newton, is that *no thesis about the world can be accepted as a part of scientific knowledge independently of evidence, let alone in violation of evidence*. In essence, Newton's methodology of evidence and theory still dominates the scene. The split between science and philosophy, which was one outcome, persists.

But Newton bequeathed to philosophy a fundamental problem about the nature of science that, for most philosophers, remains unsolved today. It is the problem of induction, brilliantly articulated by David Hume.[2] This problem cannot be solved as long as we hold on to Newton's conception of science. Hume, in effect, refuted the Newtonian conception of science—the standard empiricist conception scientists and non-scientists still take for granted today. In order to solve Hume's problem of induction, we must reject this orthodox conception of science we have inherited from Newton, and adopt *natural philosophy* instead, a conception of science that brings science and metaphysics[3] intimately together again. We need to bring about a revolution in science, and in our whole conception of science—one that leads to the recreation of natural philosophy—if we are to have a kind of science (or natural philosophy, rather) that is free of Hume's problem of induction. Science may seem to be more intellectually rigorous than natural philosophy because it dissociates itself from questionable metaphysical hypotheses, whereas natural philosophy does not. Actually, it is all the other way around. Because science dissociates itself from metaphysics, it is unable to provide a solution to the problem of induction. It lacks intellectual rigour. Natural philosophy, on the other hand, because it openly acknowledges metaphysical hypotheses, can solve the problem of induction. It is more rigorous than

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1 For a much more detailed account of Newton's involvement in the demise of natural philosophy and the rise of science, see [2] (Chapters 1 and 2).
2 See [4] (Volume 1, Part III, especially Section VI). For a good, fairly recent discussion of the problem, see [5].
3 As I employ the term, a thesis is "metaphysical" if it is about the nature of the universe but is too imprecise to be empirically verifiable or falsifiable.

science. Reason demands that we push through a revolution in our whole understanding of the nature of science.

2. Natural Philosophy Required to Solve Hume's Problem of Induction

The problem of induction can be put like this: How can evidence ever verify a scientific theory? In particular, how can any theory of physics ever be verified by evidence? Given any such theory, however "well established" it may be by evidence, there will always be endless rival theories that will fit the available evidence even better. On what grounds can all these rival theories be ignored? Granted that they always exist, how can any physical theory ever be empirically confirmed by evidence, to any degree of probability above zero? How can theories even be *selected* by evidence, let alone *verified*?

Proponents of "induction to the best explanation" may think they have an answer. Physics only ever accepts theories that are *explanatory* or *unified*. All the rivals that can readily be formulated that fit the phenomena even better than any accepted physical theory are all hopelessly, grotesquely ad hoc, disunified and non-explanatory, and are ignored for that reason. If, for the sake of argument, we take Newton's law of gravitation as the accepted theory, then one kind of grotesquely ad hoc, disunified rival theory would postulate, arbitrarily, that at some time in the future, Newton's law will become an inverse cube law; another kind of theory would postulate that, for systems never observed (for example, gold spheres with a mass of 10,000 tons), gravitation becomes a *repulsive force*. Independent postulates that have been empirically confirmed independently are added on to these grotesquely disunified rivals to make them fit phenomena (for the time being) even more successfully than Newton's law. All such laws and theories, grotesquely disunified versions of Newton's theory that fit the evidence even better than Newton's theory, are ignored by physics in practice precisely because these rivals are all hopelessly disunified.

Does this solve the problem—Hume's problem of induction? It does not. We may grant that a theory of physics, in order to be accepted, must satisfy *two* requirements. It must be (i) sufficiently empirically successful, and it must be (ii) sufficiently unified—the second requirement even over-riding the first (in that unified theories are persistently preferred to empirically more successful but disunified rivals). But at once two new problems demand attention. First, what does it *mean* to declare of a theory that it is *unified* (or disunified)? Second, what possible justification can there be for persistently accepting *unified* theories when empirically more successful disunified rivals can always be formulated?

Philosophers of science have long struggled to solve these two problems, especially the second one.[4] But these attempts have almost always missed the following crucial, extremely simple point. *If physics only ever accepts unified theories when endlessly many empirically more successful disunified rivals are available, then physics must thereby make a big assumption about the nature of the universe: the universe is such that all disunified theories, whatever their empirical success may be, are false*. There is some kind of underlying unity in nature.[5]

Some philosophers have indeed tried to solve the problem of induction by proposing that science does indeed adopt some sort of metaphysical conjecture concerning the uniformity or unity of natural phenomena: see [17] (pp. 255–293); [18]; [19] (pp. 254–268); [20] (pp. 100–101). Most philosophers have reacted to these suggestions with scorn. Thus Bas van Fraassen has remarked, "From Gravesande's axiom of the uniformity of nature in 1717 to Russell's postulates of human knowledge in 1948, this has been a mug's game" [21] (pp. 259–260).

In fact it is all the other way around. Precisely because this assumption of underlying unity is a pure conjecture, which may well be false, it is absolutely essential that it is acknowledged by physics so that it can be critically assessed and, we may hope, improved. It is a mug's game not to acknowledge

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4 For the solution to the first problem—the problem of what it means to say of a physical theory that it is unified—see [6] (Chapters 3 and 4); [7] (Appendix, Section 2); or [8] (Chapter 5).

5 This simple but, it seems to me, decisive point, with profound ramifications for our understanding of the nature of science, is one that I have sought to communicate for decades: see [2,6–16].

this profoundly problematic metaphysical presupposition implicit in physicists' persistence acceptance of unified theories only, when many empirically more successful disunified rivals exist. Intellectual rigour and rationality demand that this problematic implicit assumption be made explicit so that it can be critically assessed and, we may hope, improved.

Most philosophers of science take it for granted that appealing to any such metaphysical thesis concerning uniformity or unity "is a mug's game" because there can be no hope of demonstrating that any such thesis is true, or even probably true. It could only be an unfounded conjecture. But they thereby profoundly miss the point. To repeat: it is precisely because this metaphysical thesis, this presupposition, *is only an unfounded conjecture*, and a profoundly problematic one at that, that it is so vital that it be made explicit within physics so that it can be subjected to sustained critical scrutiny in an attempt to improve it. It is vital to make the assumption explicit because, though almost bound to be false given the specific version accepted by physics at any stage in its development, it nevertheless exercises a profound influence over theoretical physics—over what kind of new theories physicists seek to develop, and over what theories they accept.

Three points need to be appreciated: (1) The metaphysical conjecture of uniformity or unity *is actually made* by physics, whether this is recognized or not. It is made as a consequence of the way physics only ever accepts unified theories when many empirically more successful disunified rivals exist. (2) The conjecture is, at best, an *unfounded conjecture*, quite likely to be false. Given the specific version of the conjecture implicitly accepted by physics at any stage in its development, it is almost bound to be false—as the historical record reveals.[6] (3) The conjecture concerning uniformity or unity, though quite likely to be false, nevertheless exercises an immense influence over both the search for new theories, and what theories are accepted and rejected. It is this combination of (1) being implicitly accepted by physics, (2) being no more than an unfounded conjecture quite likely to be false, and (3) nevertheless exercising an immense influence over physics, which makes it so vital, for physics itself, that the conjecture is made explicit so that it can be explicitly criticized and, we may hope, improved.

The upshot is that we need to put physics and metaphysics together again to create a modern version of natural philosophy. We need to recreate the vision of science of Galileo, Kepler, Boyle, Huygens, and above all of Newton of the first edition of the *Principia*, a vision that sees science wedded to problematic metaphysical speculations about the ultimate nature of the physical universe. These speculations need to be subjected to sustained imaginative and critical exploration, as an integral part of the scientific enterprise, in an attempt to improve a thesis that can be accepted at any stage in the development of physics.

But how, it may be asked, can the problematic metaphysical presuppositions of physics be improved? What methods can best facilitate such improvement?

Elsewhere, I have shown in detail how this problem is to be solved. We need to adopt, and put into scientific practice, a view that I have called *aim-oriented empiricism* (Figure 1): see [2,6–16].

6 See for example [8] (pp. 64–65).

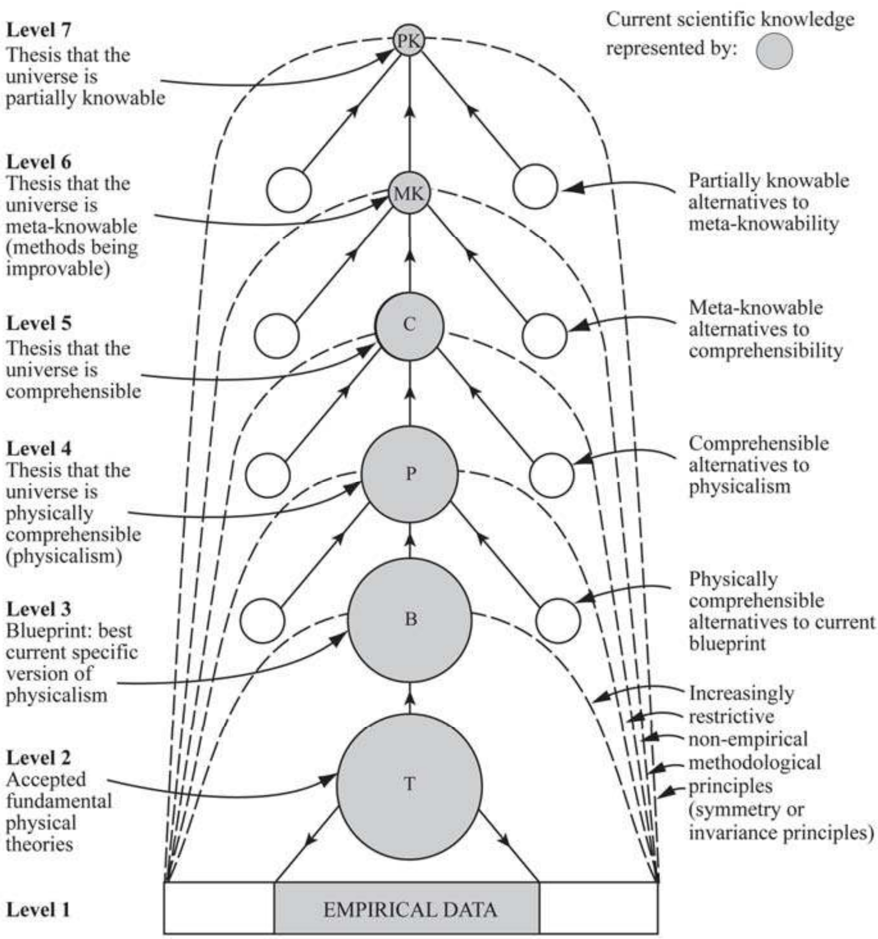

Figure 1. Aim-oriented empiricism.

3. Aim-Oriented Empiricism: The Methodological Backbone of the New Natural Philosophy

The basic idea of aim-oriented empiricism (AOE) is that we need to represent the influential, problematic metaphysical presupposition of physics concerning underlying unity in the form of a *hierarchy* of assumptions. As we go up this hierarchy, assumptions become less and less substantial, and so more and more likely to be true, and more and more nearly such that their truth is required for science, or the pursuit of knowledge to be possible at all. In this way, we create a framework of assumptions (and associated methods) high up in the hierarchy, very likely to be true, within which much more substantial assumptions (and associated methods) low down in the hierarchy, very likely to be false, can be critically assessed and, we may hope, improved.

How does this hierarchical framework facilitate *improvement* of metaphysical presuppositions of physics, so that they become closer to the truth, more fruitful for physics itself? It does so by concentrating imaginative exploration and critical scrutiny where it is most likely to be fruitful for scientific progress, low down in the hierarchy of assumptions where assumptions are most likely to be false. It does so by ensuring that new possible assumptions, worth considering, low down in the hierarchy, are fruitfully constrained, partly by assumptions higher up in the hierarchy, partly by physical theories that have met with the greatest empirical success. Those metaphysical assumptions, low down in the hierarchy, are chosen that stimulate, or are associated with, the most empirically progressive research programmes in physics, or hold out the greatest hope of that. In these ways, the hierarchical framework of AOE facilitates improvement in metaphysical theses that are accepted low down in the hierarchy. As theoretical knowledge in physics improves, metaphysical presuppositions improve, and even lead the way. There is something like positive feedback between improving metaphysical assumptions and associated methods, and improving theoretical knowledge in physics. As we improve our scientific knowledge and understanding about the universe, we correspondingly improve the nature of science itself. We improve methods for the improvement of knowledge.[7]

AOE is depicted in the Figure.[8] At the top, at level 7, there is the thesis that the universe is such that we can acquire some knowledge of our local circumstances sufficient to make life possible. If this is false, we have had it, whatever we assume. It can never, in any circumstances, imperil the pursuit of knowledge to accept this thesis as an item of scientific knowledge—and may help promote scientific knowledge—even though we have no reason to hold it to be true, or probably true. Thus, we are rationally entitled to accept the thesis as a part of scientific knowledge even though the thesis is a pure conjecture. We are rationally entitled to accept the thesis on pragmatic grounds: in accepting the thesis, we have nothing to lose, and may have much to gain.

At level 6 there is the thesis that the universe is such that we can *learn* how to learn. It is not just that we can acquire new knowledge. We can acquire new knowledge *about how to acquire new knowledge*. The universe is such that we can make a discovery about it which makes it possible for us to *improve* our methods for the improvement of knowledge. This thesis deserves to be accepted, again, on pragmatic grounds: we have little to lose, and may have much to gain, in our search for improved knowledge about the universe.

One possibility, which accords with the level 6 thesis of meta-knowability, is that the universe is comprehensible in some way. The universe is such that there is some standard kind of explanation as to why natural phenomena occur as they do. It might be that natural phenomena occur in response to the intentions of gods; or of one God; or in accordance with some cosmic purpose. Or it might be that they occur in compliance with some cosmic "computer programme" as some have suggested. Or it might be that natural phenomena occur as they do to accord with some unified pattern of physical law.[9]

This level 5 thesis of comprehensibility accords with the level 6 thesis of meta-knowability because, if the level 5 thesis is true, then there is every hope that, by choosing and developing that version of the comprehensibility thesis that best stimulates progress in empirical knowledge, it will be possible progressively to improve methods for the improvement of knowledge, as we proceed. Granted we have accepted the level 6 thesis, it makes good sense to accept the level 5 thesis, provisionally at least, until all more specific versions of the thesis provide no help whatsoever with improving empirical knowledge. But if, on the contrary, some specific version of the level 5 thesis of comprehensibility seems to facilitate rapid improvement in empirical knowledge, then this deserves to be accepted, in accordance with theses at levels 6 and 5, until something better turns up.

At level 4 there is the thesis that the universe is physically comprehensible. The universe is such that the as-yet undiscovered true physical theory of everything is *unified*. A physical theory is unified if its content, what it asserts about the world, is the same throughout all the actual and possible physical

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7 This positive feedback process of improving presuppositions and methods, or aims and methods, in the light of what stimulates empirical progress and what does not, has actually gone on in physics, and in natural science more generally—or we would still be stuck with Aristotelian science. But because the scientific community has taken standard empiricism for granted, it has only been possible for this scientifically fruitful, positive feedback process to proceed in a somewhat furtive, constrained manner.

8 In what follows I give only a brief sketch of AOE, and reasons for accepting AOE. The best detailed argument for AOE is given in [8]. See also [2] (especially Chapter 5); and [22]. I must stress, however, that AOE was first expounded and argued for in publications that appeared much earlier: see [6,9–13].

9 This last possibility can be interpreted in the way that has been argued for in [23].

systems to which it applies. If these physical systems divide up into N groups such that, the content of the theory is the same throughout any one group, but different from the content in all the other groups, then the theory is disunified to degree N. For unity we require N = 1. Above we have seen that a theory can be disunified in different ways: its content (1) can differ at different times, or space-time regions; or its content (2) can differ from one kind of physical system to the next. There are further ways in which the content of a physical theory can change as we move from one range of possible phenomena to which the theory applies to another range. (3) The theory may postulate one or more spatially restricted objects, each with its own unique dynamic properties. (4) The theory may postulate two or more forces, one force law operating in one range of possible phenomena, another force law operating in another range. (5) The theory may postulate one force, but two or more kinds of physical entity, with different masses or charge, for example, one kind of entity in one range of possible phenomena, another kind of entity in another range of phenomena. (6) A theory disunified in ways (4) or (5) may be unified if the theory satisfies a symmetry that is such that a symmetry transformation has the effect of transforming strengths of forces from one kind to another, or the effect of transforming one kind of physical entity into another kind. Elsewhere I have distinguished eight different ways in which a physical theory can be disunified, all variants of the same basic idea of theory disunity or unity: see [6] (Chapters 3 and 4); [7] (Appendix, Section 2); [8] (Chapter 5). The level 4 thesis that the universe is physically comprehensible is to be interpreted as asserting that the true physical theory of everything is unified, with N = 1, in the strongest of the eight ways in which a theory can be unified.

Granted that theses at levels 6 and 5 have been accepted, there are overwhelming grounds for accepting this level 4 thesis of physical comprehensibility, or physicalism.[10] For the theses at levels 6 and 5 imply that if a precise version of the level 5 thesis begins to stimulate the growth of empirical knowledge, then that thesis deserves to be accepted and pursued—until something better turns up. It is worth reminding ourselves, at this point, just how astonishingly empirically fruitful physicalism has been over the centuries. As physics has evolved since the time of Kepler and Galileo, the totality of accepted fundamental physical theory has become (a) vastly more extensive in predictive scope, and at the same time has brought about astonishing theoretical unification in the dramatically increasing range of phenomena known to us.

A metaphysical thesis such as physicalism is not empirically verifiable or falsifiable. It may, however, be empirically *fruitful*. A metaphysical thesis, M, is empirically fruitful if there is a succession of physical theories, $T_1, \ldots T_n$, that are increasingly successful empirically (successfully predicting ever wider ranges of phenomena with ever increasing accuracy), the succession of theories being such that they draw ever closer to capturing M as a testable physical theory. The whole way in which theoretical physics has developed since Kepler and Galileo renders physicalism astonishingly empirically fruitful. For all advances in theory in physics since the scientific revolution have been advances in unification.

Thus Newtonian theory (NT) unifies Galileo's laws of terrestrial motion and Kepler's laws of planetary motion (and much else besides). Maxwellian classical electrodynamics, (CEM), unifies electricity, magnetism and light (plus radio, infrared, ultra violet, X and gamma rays). Special relativity (SR) brings greater unity to CEM, in revealing that the way one divides up the electromagnetic field into the electric and magnetic fields depends on one's reference frame. SR is also a step towards unifying NT and CEM in that it transforms space and time so as to make CEM satisfy a basic principle fundamental to NT, namely the (restricted) principle of relativity. SR also brings about a unification of matter and energy, via the most famous equation of modern physics, $E = mc^2$, and partially unifies space and time into Minkowskian space-time. General relativity (GR) unifies space-time and gravitation, in that, according to GR, gravitation is no more than an effect of the curvature of space-time. Quantum theory (QM) and atomic theory unify a mass of phenomena

[10] "Physicalism" has been interpreted in a number of ways by various philosophers of science. Here it means simply: the universe is such that the true physical theory of everything is unified in the strongest sense with N = 1, see [8] (Chapter 5).

having to do with the structure and properties of matter, and the way matter interacts with light. Quantum electrodynamics unifies QM, CEM and SR. Quantum electroweak theory unifies (partially) electromagnetism and the weak force. Quantum chromodynamics brings unity to hadron physics (via quarks) and brings unity to the eight kinds of gluons of the strong force. The standard model (SM) unifies to a considerable extent all known phenomena associated with fundamental particles and the forces between them (apart from gravitation). The theory unifies to some extent its two component quantum field theories in that both are locally gauge invariant.[11] Current research programmes in fundamental theoretical physics seek to unify SM and GR.[12]

In short, all advances in fundamental theory since Galileo have invariably brought greater unity to theoretical physics in one or other, or all, of the different kinds of unity I have distinguished, from 1 to 8. All successive theories have increasingly successfully exemplified and given precision to physicalism (as interpreted here) to an extent that cannot be said of any rival metaphysical thesis, at that level of generality. The whole way theoretical physics has developed points towards physicalism, in other words, as the goal towards which physics has developed.[13]

Granted acceptance of theses at levels 6 and 5, and granted the way theoretical physics has developed since Galileo, grounds for accepting physicalism at level 4 become irresistible.

At level 3 that metaphysical thesis is accepted that is as specific a version of physicalism as possible that (a) accords with physicalism, and (b) is the best current conjecture as to how accepted physical theories at level 2 are to be unified. What ought to be accepted at level 3 today constitutes a vital, open problem for theoretical physics and the metaphysics of physics. One possibility is string theory, or M-theory. Another is what I have called *Lagrangianism*.[14]

At level 2 those physical theories are accepted (a) that meet with sufficient empirical success, and (b) that sufficiently enhance the type and degree of unity of the totality of fundamental physical theory, and thus accord sufficiently well with the level 4 thesis of physicalism. At level 1 we have accepted empirical data—what are judged to be repeatable effects, and thus low-level empirical laws.

There are, as I have sought to indicate, very strong arguments for AOE, and very strong arguments against its rivals, all versions of the orthodox view of standard empiricism (SE). SE acknowledges that persistent preference is given in physics to unified theories, but dishonestly fails to acknowledge that that means physics makes a persistent *assumption* about the universe: it is such that disunified theories are false. SE fails to provide an acceptable account of what the *unity* of a physical theory is,[15] and fails to justify persistent acceptance of unified theories, especially given that many empirically more successful disunified rivals are always available. SE fails to solve the problem of induction.

By contrast, AOE acknowledges that physics does make a big, highly problematic, influential metaphysical assumption about the universe. The hierarchical structure of assumptions and associated methods of AOE is designed to facilitate development and acceptance of assumptions, low down in the hierarchy, most likely to promote scientific progress of theoretical physics, progress in knowledge and understanding. Not only does AOE make thoroughly explicit the considerations that govern acceptance of theories in physics (something SE cannot do). In addition, it provides a rational, if fallible, method for the discovery of new physical theories.[16] AOE specifies precisely what it is for a theory to be unified, and justifies acceptance of theories unified in this sense—granted they are sufficiently empirically successful. The hierarchical framework of AOE makes it possible for physics to modify its

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11 See [10] (2007, pp. 420–421).
12 For clarification of details and further discussion, see [6] (pp. 80–89, 131–140, and 257–265, and additional works referred to therein). See also [7] (Appendix, Section 2); [8] (Chapter 5).
13 See [10] (2007, p. 421).
14 See [6] (pp. 98–90); or [8] (pp. 127–128, Note 14).
15 Given the account of theory unity indicated here, it is dazzlingly clear that persistent acceptance of unified theories in this sense must inevitably commit physics to making a big metaphysical assumption about the world (the world is such that disunified theories are false whatever their empirical success may be). SE cannot very well acknowledge this account of theory unity for, to do so, destroys SE.
16 See [6] (pp. 219–223); [11] (pp. 275–305); and above all [2] (Chapter 5).

metaphysical assumptions and associated methods in the light of what it learns about the nature of the universe. As our knowledge improves, our knowledge about how to improve knowledge improves as well, a positive feedback feature of AOE that helps explain the explosive growth of scientific knowledge. And, in addition to all this, AOE solves the problem of induction: [6] (Chapter 5); [11] (pp. 61–79); and especially [8] (Chapter 9). There are good reasons why metaphysical theses at the various levels of AOE deserve to be accepted—briefly indicated above.

AOE ought to be adopted and implemented by scientists and philosophers of science alike. I hope the case for AOE, sketched here, will at least arouse interest. A convincing case for AOE is spelled out in some detail in [8], with [2] giving an account of some of the implications of putting AOE into scientific practice.[17]

There is, however, a well-known and apparently devastating objection to AOE—to the claim, in particular, that AOE solves the problem of induction. According to AOE, those metaphysical theses (low down in the hierarchy of theses) are accepted that best accord with accepted physical theories; at the same time, those physical theories are accepted that best accord with the metaphysical theses. Acceptance of empirically successful physical theories is justified by an appeal to metaphysical theses; acceptance of these metaphysical theses is then justified by an appeal to the astonishing success of physics! But such an argument is, it seems, viciously circular. It presupposes just that which it sets out to justify. What makes matters worse, is that AOE has this circularity built into it quite explicitly; it is even upheld as its greatest virtue and triumph. The whole point of the view, after all, is to facilitate the critical assessment of theses low down in the hierarchy in the light of the empirical success and failure of science. How can AOE survive this devastating criticism of vicious circularity?

The solution to this problem stems from the level 6 metaphysical thesis of meta-knowability. Permitting metaphysical assumptions to influence what theories are accepted, and at the same time permitting the empirical success of theories to influence what metaphysical assumptions are accepted, may (if carried out properly), *in certain sorts of universe*, lead to genuine progress in knowledge. Meta-knowability is to be interpreted as asserting that *this is just such a universe*. And furthermore, crucially, reasons for accepting meta-knowability make no appeal whatsoever to the success of science. In this way, meta-knowability legitimizes the potentially invalid circularity of AOE.[18]

In what follows, we need to consider possible universes in which the top two theses in the hierarchy of theses of AOE are true, but everything below these may be false. Something like the meta-methodology of AOE can meet with success, so that we can improve, not just knowledge, but also knowledge about how to improve knowledge, without being restricted to universes in which the level 4 thesis of physicalism is true, or even the level 5 thesis of comprehensibility. We need a generalized version of AOE—generalized AOE or GAOE—which has the hierarchical structure AOE, agrees with AOE as far as theses at levels 6 and 7 are concerned, but is open about what theses obtain at levels 2 to 5 (or even 1 to 5).

Relative to an existing body of knowledge and methods for the acquisition of new knowledge, possible universes can be divided up, roughly, into three categories: (i) those that are such that the meta-methodology of AOE, or GAOE, can meet with no real success, in the sense that new metaphysical ideas and associated methods for the improvement of knowledge cannot be put into practice so that success is achieved; (ii) those that are such that AOE, or GAOE, appears to be successful for a time, but this success is illusory, this being impossible to discover during the period of illusory success; and (iii) those that are such that GAOE, and even AOE, can meet with genuine success. Meta-knowability asserts that our universe is a type (i) or (iii) universe; it rules out universes of type (ii).

Meta-knowability asserts, in short, that the universe is such that AOE, or GAOE, can meet with success and will not lead us astray in a way in which we cannot hope to discover by normal methods of

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[17] For earlier expositions of the argument for AOE see [6,7,9,11–16]; [10] (pp. 94–100 and Chapter 9).
[18] See [10] (2007, p. 414).

scientific inquiry (as would be the case in a type (ii) universe). If we have good grounds for accepting meta-knowability as a part of scientific knowledge—grounds that do not appeal to the success of science—then we have good grounds for adopting and implementing AOE, or GAOE, (from levels 5 to 2). Meta-knowability, if true, does not guarantee that AOE will be successful. Instead it guarantees that AOE will not meet with illusory success, the illusory character of this apparent success being such that it could not have been discovered by any means whatsoever before some date is reached.[19]

We do, however, have good reasons for accepting meta-knowability that make no appeal to the success of science; meta-knowability renders the ostensibly invalid circularity of AOE valid and justified.

As I have already indicated, others have sought to solve the problem of induction by arguing for acceptance of metaphysical theses concerning the uniformity or unity of nature on what may be called "pragmatic" grounds: it is in the interests of the pursuit of knowledge of factual truth to accept the thesis in question, even though we have no reason to hold that the thesis is true, or probably true.[20] These attempts all appeal to just one metaphysical thesis, on one level. As a result, they can only provide one kind of reason for the acceptance of the thesis in question. The great advantage of AOE is that the metaphysical assumptions of physics are on five different levels. This means *different* sorts of reason can be given for accepting metaphysical theses at different levels. The top two theses are accepted for pragmatic reasons: it is in the interests of the pursuit of truth to accept these theses. The bottom three metaphysical theses are accepted because of their potential or actual empirical fruitfulness.

Three reasons can be given as to why AOE is absolutely essential for the solution to the problem of induction:

1. In order to solve the problem, we need an intellectually rigorous conception of science. AOE alone has the required rigor, in that it alone acknowledges and provides the means to improve problematic metaphysical assumptions of science.
2. The hierarchical structure of AOE is an essential requirement for the solution to the problem. It is needed, because quite *different* reasons need to be given for accepting theses, at the five different levels of the view. If these different levels are collapsed into *one* level, this can no longer be done.
3. AOE is required to solve the apparent vicious circularity involved in justifying acceptance of physical theory by an appeal to metaphysics, and then justifying acceptance of this same metaphysics by an appeal to the empirical success of physical theory. AOE alone solves this problem by accepting, at level six, a metaphysical thesis that asserts, in effect, that the universe is such that this apparently viciously circular procedure can meet with success, acceptance of this metaphysical thesis being justified in a way that makes no appeal to the empirical success of science whatsoever.

4. Revolutionary Implications of AOE for Science and the Philosophy of Science

In my publications I have demonstrated in some detail that the above considerations in support of AOE, have the following substantial implications:

1. AOE needs to be put into scientific practice in order to strengthen the intellectual integrity and success of science. The outcome would be a new kind of science, more rigorous and of greater intellectual and humanitarian value. Science itself would change, and be improved.[21]
2. All versions of standard empiricism are untenable.[22]

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19 See [10] (2007, p. 414).
20 See [17] (pp. 255–293); [18]; [19] (pp. 254–268); [20] (pp. 100–101).
21 [2,6–9,11–15,22]; [10] (Chapters 5 and 9).
22 [6] (Chapter 2); [8].

3. The relationship between science and the philosophy of science would be transformed. Philosophy of science would become an integral part of science itself.[23]
4. AOE reveals that science has already established, as a part of theoretical knowledge, the metaphysical thesis *physicalism* (as I have called it, the level 4 thesis of the diagram).[24] This asserts that the universe is physically comprehensible—that is, it is such that there is a yet-to-be-discovered physical "theory of everything" that is unified and true.
5. Physicalism, though incompatible with current knowledge in physics at the level of theory (general relativity plus the standard model), is nevertheless one of the most secure items of theoretical knowledge in physics that we have, so secure that any theory that clashes too severely with it is rejected, whatever its empirical success may be.[25]
6. Scientific method is revealed to have a hierarchical structure corresponding to the hierarchical structure of metaphysical presuppositions, or aims, of science. It is this hierarchical structure that makes it possible for methods, high up in the structure, to control evolving methods, low down in the structure.[26]
7. AOE carries the implication that orthodox quantum theory, or indeed any version of quantum theory that is about the result of measurement only and not, in the first instance, about quantum systems as such, is seriously defective (it lacks unity).[27] A fully micro-realistic version of quantum theory, probabilistic or deterministic, needs to be developed.[28]
8. The so-called "pessimistic induction" is no grounds for pessimism at all. The way in which physics has proceeded, from Newton to today (even though from one false theory to another), is just the way physics would proceed were it to be making splendid progress (and AOE is correct).[29]
9. AOE facilitates the progressive improvement of the metaphysics of science in the light of (a) *a priori*, and quasi a priori considerations (e.g., having to do with unity), and (b) considerations that have to do with empirical fruitfulness—the extent to which the metaphysical thesis in question has led to an empirically progressive scientific research programme.[30] According to AOE, science improves its metaphysical assumptions and associated methods as it improves its knowledge: there is something like positive feedback between them (which helps account for the explosive growth in scientific knowledge). The metaphysics of physics becomes an integral part of physics itself.
10. AOE solves the problem of induction—and is required to solve the problem.[31]
11. The problem of what it means to say of a physical theory that it is unified is solved within the framework of AOE. This solution provides the means to partially order physical theories with respect to unity. Unity and simplicity are sharply distinguished.[32]
12. Eight kinds of theoretical unity are distinguished, increasingly demanding versions of the basic notion of theory unity.[33]
13. Unification in theoretical physics is of two kinds: unification by (a) annihilation, and by (b) synthesis.[34]

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23 [7] (pp. 34–51); [10] (pp. 231–232, 235 and 240–42); [12].
24 [6] (especially pp. 19–20, 26, 98 and Chapter 5); [8] (Chapter 9).
25 See Note 24.
26 [6] (pp. 29–30); [7] (pp. 42–47); [8] (Chapter 10); [9]; [11] (pp. 275–305).
27 [6] (pp. 231–232); [24] (pp. 276–278); [25] (pp. 2–3).
28 For my own efforts at developing a fully micro-realistic, fundamentally probabilistic version of quantum theory, empirically testable, and free of the defects of orthodox quantum theory, see [24–30].
29 [6] (pp. 211–212); [8] (pp. 83–86).
30 For a lucid exposition of this point see [8] (pp. 74–82). See also [2] (Chapter 5).
31 For my early attempts at solving the problem of induction, see Maxwell [6] (Chapter 5); [9]; [10] (pp. 218–230); [11] (pp. 61–79). For a much improved exposition of the solution provided by AOE, see [8] (Chapter 9).
32 [6] (Chapters 3 and 4); [7] (Appendix, Section 2); and [8] (Chapter 5).
33 See Note 32.
34 [6] (pp. 125–126).

14. AOE solves the problem of why physics is justified in preferring unified theories to disunified ones.[35]
15. The problem of verisimilitude is solved within the framework of AOE.[36]
16. AOE provides physics—and science more generally—with a fallible, non-mechanical (i.e., non-algorithmic) but rational method for the discovery of good new theories.[37]
17. AOE is a synthesis of, and a great improvement over, the views of Popper, Kuhn and Lakatos.[38]
18. Instrumentalism (or constructive empiricism) is untenable because it cannot do justice to the requirement of unity. Unity demands scientific realism.[39]
19. AOE clarifies the role of symmetry principles in theoretical physics and provides a justification for the role that they play: a symmetry of a theory is a facet of its unity. The requirement that a physical theory, in order to be acceptable, must satisfy symmetry principles stems from (is an aspect of) the requirement that it be unified.[40]
20. AOE does justice to the fact that different branches of natural science employ different methods; it does justice to the fact that methods of a particular science evolve as that science makes progress over time: at the same time, AOE specifies meta-methods that are, ideally, common to all branches of science at all times, and as a result justifies adoption of differing and evolving methods.[41]

The upshot of all this is that a revolution is required in both science and philosophy. Scientists and philosophers need to collaborate in transforming research and teaching in both science and philosophy, so that the two branches of inquiry are brought together to create a modern version of natural philosophy.

5. Broader Considerations

I have argued so far that the long-standing failure of philosophy to solve one of its fundamental problems—the problem of induction—has led to the persistence of the split between science and philosophy, the failure to put science, metaphysics and philosophy back together again to create a modern version of natural philosophy. Another long-standing failure of philosophy has had even broader repercussions. This time, the failure is not to *solve* one of the fundamental problems of philosophy. It is the much more elementary *failure to formulate the problem properly.*

The problem I have in mind ought to be formulated like this: How can our human world, the world as it appears to us, the world we live in and see, touch, hear and smell, the world of living things, people, consciousness, free will, meaning and value—how can all of this exist and best flourish embedded as it is in the physical universe? This problem becomes serious the moment people begin to take versions of physicalism seriously. This began to happen when modern science—or rather natural philosophy—emerged in the 17th century. Natural philosophers began to take seriously the idea that the world is made up exclusively of corpuscles, devoid of colour, sound and smell; or, a bit more generally, the universe is such that everything occurs in accordance with precise laws, the book of nature being written in the language of mathematics, as Galileo put it.

Philosophy ought to have taken this *human world/physical universe problem*, as we may call it, as the fundamental problem of all of thought and life. A basic task of philosophy ought to have been to keep alive awareness of the fundamental character of this problem, the need to put it at the heart of academic thought and education so that fruitful interactions between this problem and all our more

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35 See Note 31.
36 Maxwell [6] (pp. 211–217); [8] (Chapter 8).
37 [6] (pp. 219–223); [9]; [10] (pp. 235–242); [11] (pp. 275–305). See especially [2] (Chapter 5).
38 [13,15,16].
39 Maxwell [11] (pp. 81–101); [31].
40 [6] (pp. 91–92, 94–95, 112–113, 262–264); [8] (pp. 38–45).
41 See [6] (pp. 155–156); [7] (pp. 41–47).

specialized, particular problems, may be explored. Philosophy ought to have kept alive rational—that is, imaginative and critical—attempts to solve the problem, or at least improve attempts to solve it.

If this had been done, long ago in the 18th century, let us say, perhaps as a fundamental idea and endeavour of the Enlightenment, we would today have a very different kind of academic enterprise, and a very different modern world, from what confronts us today. Our institutions of learning, our universities and schools, would have given intellectual priority to problems of living—problems of how what is of value in life is to be realized, at all levels from the personal, the institutional and social, to the global. Science would of course have been important, but not fundamental. "What is of value in life and how is it to be realized?" would have been the fundamental question. Scientific answers to questions about the world and ourselves as a part of the world, would have facilitated and constrained answers to the more basic questions about what is genuinely of value in life and how it is to be realized.

Why did philosophy fail to give due prominence to our fundamental problem—the human world/physical universe problem? Because philosophy became mesmerized by Descartes's attempted solution to the problem.

Descartes tried to solve the human world/physical universe problem by segregating the human and the physical into two distinct domains. On the one hand there is the physical universe; and on the other, there is mind—consciousness, the soul, all that which is of value. And having split asunder the two components of the original problem in this way, the problem then became to see how these two components could be related, or could interact. How could there be minds interacting with physical brains? Thus was born the mind-body problem of modern philosophy.

Most philosophers who came after Descartes agreed that Descartes's attempted solution is untenable. But, instead of returning to the original problem that, implicitly, gave rise to Descartes's attempted solution in the first place, paradoxically they struggled with the implications of Descartes's untenable solution. They agonized about how we can know anything about the physical universe if we are confined to the universe of mind. They struggled to understand how physical events in the brain could cause, and be caused by, mental events in the mind. They grappled with the problem of how there could be free will if determinism held sway in the physical universe. Singularly, they failed to return to the more fundamental human world/physical universe problem that Descartes may be construed to have tried, and failed, to solve. Having rejected Descartes's attempted solution, the rational thing to do would have been to return to the problem it sought to solve. Philosophy did not begin to do that. Instead it struggled to solve problems *generated* by Cartesian Dualism, even though Cartesian Dualism itself had been rejected!

Elsewhere, I have tried to spell out the consequences, for philosophy, for natural science, for social science, for academic inquiry as a whole, for our modern world, of returning to our fundamental problem, and placing that at the heart of education and academic thought: [2,7,10,22,32,33]. The outcome is not just natural philosophy, but a new kind of academic inquiry that gives intellectual priority to problems of living, and actively seeks to help humanity resolve conflicts and problems of living in increasingly cooperatively rational ways. The basic intellectual aim of inquiry becomes, not knowledge, but rather wisdom—wisdom being the capacity, active endeavour and desire to realize (apprehend and create) what is of value in life for oneself and others, wisdom in this sense including knowledge, technological know-how, and understanding, but much else besides.

We have failed to develop academic inquiry so that it is rationally designed and devoted to help promote human welfare by intellectual, educational and technological means. Academic inquiry as it exists at present is not best designed to help humanity learn how to resolve its conflicts and problems of living so that we may make progress towards a better, wiser world. And this failure is, at root, a philosophical failure, a failure to get clear about what the overall aims and methods of rational inquiry ought to be. Involved are two major philosophical failures: first, the failure to solve the problem of induction; and second, the failure even to formulate properly our fundamental problem—the human world/physical universe problem.

We urgently need to bring about a revolution in humanity's institutions of learning, so that humanity may be able to begin to learn how to make social progress towards a better, wiser world.

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philosophies

Article

Perspectives on Natural Philosophy

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Abstract: This paper presents a viewpoint on natural philosophy focusing on the organization of substance, as well as its changes as invited by the Second Law of thermodynamics. Modes of change are pointed to as definitive of levels of organization; these include physical, chemical, and biological modes of change. Conceptual uses of the subsumptive hierarchy format are employed throughout this paper. Developmental change in dissipative structures is examined in some detail, generating an argument for the use of final causality in studies of natural systems. Considerations of 'internalism' in science are presented along the way.

Keywords: compositional hierarchy; development; dissipative structures; final cause; internalism; Second Law of thermodynamics; subsumptive hierarchy

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1. Introduction

It is once again the task of natural philosophy (the philosophy of nature) to construct a story about the world and our place in it, based on knowledge from the 'natural' sciences. This requires input from any and all of these sciences that might contribute to the overall picture. My approach (a) follows the developmental impulse of Schelling [1] and (b) is derived mainly from physics and biology, which may generate some distortions in the unfolding picture.

Below, I present a general perspective on the material (including the physical) world using knowledge gained in the special sciences. This requires, in my view, concepts related to substance, change, and direction. Substance is complex, existing at different levels of scale at a single locale. Change 'happens', with, minimally, fluctuations. Directionality characterizes change statistically, leading to ever-new situations. I understand it to be entrained by the Second Law of thermodynamics. Substance tends toward change, while some substantial forms—those organized by energy dissipation—may become directionally transformed by sequentially occupying standard stages—i.e., by 'developing'.

Then, one needs a framework for the various findings of the several natural sciences. This necessitates that only the most basic findings of the sciences are taken up and woven into the overview. As well, it requires a format that is capable of uniting various unrelated concepts that are not known to be in direct interaction within a single framework. My own tool for this purpose has been the hierarchy concept—which actually is two logically different concepts [2]. The compositional hierarchy is based on differences in the scale of activities within a single complex system, while the subsumptive hierarchy is based in set theory, with subsetting representing sequential layering, as in time. This traces minimally an individual history, and, for dissipative structures, stages of development.

2. Five Basic Conceptual Perspectives

Hierarchy and Levels

The material world is not just complicated, it is also complex in the sense of being embodied at different levels of organization/scale in one locale. The two known logical forms of hierarchy—compositional (boxes within boxes) and subsumptive or specification (steps in construction)—are both useful (I think necessary) in order to properly understand activities at any one level of organization.

Thermodynamics

The law of nature that is overwhelmingly consequential at all levels of scale, from the smallest to the largest, is the Second Law of thermodynamics. In my view, the Second Law entrains all of the activities studied in natural science, and so may be understood as a final cause of the unfolding of all of the rest. A cosmological understanding of the universe that empowers the Second Law philosophically would be any version of the Big Bang involving an expansion of space.

Dissipative Structures

A consequence of the Second Law that is of prime importance to humans is the generation, given supportive energy gradients, of dissipative structures at many levels of organization or complexity [3]. All actions beyond some of those considered in fundamental physics lead to irreversible processes, and are initiated and/or mediated by dissipative structures, given appropriate supportive energy gradients.

Development

The general picture of the universal process is internal differentiation, entraining aggregations of unit processes, as well as resulting in increasing complication locally as the universe expands. The dissipative structures generated or activated by available energy gradients each undergo a characteristic developmental trajectory.

Aristotelian Causal Categories

The fundamental scenario is a field (formal cause) of possibilities (available material causes), where a momentary configuration or fluctuation elicits/enables an action (efficient cause) that releases local events resulting in a global increase in physical entropy (final cause) as well as changed situations locally. It is my view that the Second Law of thermodynamics in an expanding universe instantiates the importance of final causality in science.

A Note On Internalism

The general perspective of natural science has been, and is, externalist. The scientist almost universally examines a system from (or as if from) the outside, and is not a part of it, as observed. There have been some exceptions (e.g., the physiologist John Scott Haldane—Wikipedia), while some Buddhists claim to practice an internalist 'science'. Internalism is an attempt to understand a system from within, with the inquirer being a part. Internalism in this sense (not in the mode of the 'humanities') ought to be modest in scope, and focused only locally, as things are happening, and would most appropriately be reported in the present progressive tense [4]. Discursive tendencies that have been suggestive of the possibility of an internalist perspective include Maturana and Varela's [5] 'autopoiesis', dialectics, phenomenology, operationalism in physics, second-order cybernetics, the 'emic' approach in anthropology, and aspects of quantum mechanics.

From the quantum perspective, Rossler [6], noting the dependence of quantum phenomena upon human technological observation, proposed 'endophysics' as a framework for organizing an internalist perspective on the world within science. Elaborated in one way, this view suggests that observation defines the observed—which leads me to note as well Wheeler's [7] 'It from bit' gambit, wherein observation creates the observed, and this view too was stimulated by the dependence of quantum phenomena upon observation (measurement). I note that, as a plain fact, cosmology is necessarily an internalist science; perhaps the best model we have of such a discipline! What needs to be considered in that context is Pattee's [8] argument concerning the necessary 'epistemic cut' in science between the observer and the observed. In cosmology, might this be considered to be achieved when one part of the universe interrogates another, seemingly unconnected part?

Externally, in science generally, we test things rather than creating them, although we often create the observation platforms, and always create the perspectives from which we make our observations. The main philosophical reason for taking the internalist stance in my opinion would be that (leaving aside quantum mechanics) generativity cannot be approached externally. In the externalist context, nothing radically new is produced except by error. Internally, chance would not differ from choice. Internally, dynamical tendencies are continually under construction during the activities of system self-organization—as informed, not only by current configurations, but also, in my view, by final causes (see below). Of importance in the internalist context may be the concept of vagueness, which is difficult to define [9]. It may best be thought of as an ordinal property. Fuzziness [10] is a conceptual step in this direction, but it is clearly an externalist model. Any system during its development moves from being vaguer to becoming more definitely embodied. Internalism has been of occasional concern to me for some time [11], somewhat inconclusively.

3. Hierarchy

The two known logical formulations of hierarchy are important with respect to both substance (the compositional hierarchy) and change—that is free/open or constrained, i.e., history (the subsumptive, or specification, hierarchy).

Thus, scale is important in the compositional hierarchical perspective:

> [Larger scale constraints [level of action of interest (focal level) [smaller scale levels providing enabling conditions on the focal level]]].

> Otherwise: [boundary conditions [activities of interest [initiating conditions]]]

This, then, is the compositional hierarchy (Hsc) [2,12], which is most commonly, if not always explicitly, used or implied in scientific thinking, as in:

> [larger scale framework [action/observations [smaller scale provisions/affordances]]]

The compositional hierarchy can also be used to relate activities occurring at rates differing by order of magnitude. Rates are characteristically much greater in smaller scale actions than in larger scale activities. Thus, a single measurement of microscopic activities taken at a larger scale might register a small-scale entity as being in, say, two places at the same time, as in some quantum level observations. Activities of focal interest, though relying on and modifying lower-scale supports, generally lead to changes within the scale range of the actions themselves, and may occasionally have consequences as well for larger-scale situations, without changing the logical relations of the framework. Note that the larger-scale framework in science studies often or mostly includes experimental arrangements, and these reflect the nature and interests of the observer's community. This impacts the objectivity of the findings in a very general way.

Explicitly taking account of boundary conditions (more generally, context) in models that are not focused upon results that change the context may be rare in science discourse, even though scientific papers often require a 'Materials and Methods' section, and though the idea of boundary conditions is well established and upfront in physics discourse. Although not commonly appreciated, boundary conditions align with the concept of final cause, which will be discussed further below. Francis Bacon restricted final causality to human actions alone. The scientific observer (taken as an agent of the surrounding culture) is in fact the cause of a scientific observation, which is undertaken for some, mostly implicit, social purpose, as mediated by way of support for the studies. Here is where postmodernism (social constructivism) comes in: its position with regard to science is just that scientific observation cannot discover 'The World' as it would be without effects imported during interactions with particular observers. Scientific discoveries are then used to construct Nature, which, then, is actually nature as it relates to human—indeed, Western cultural—needs. This issue was raised implicitly in quantum mechanics, with the Copenhagen Interpretation. Since that proposal, and continuing now, this view has generated several efforts to obviate it, for example, by searching for ‘realism’ in QM. This can be viewed as a reaction against the implications of social constructivism, which are not much ‘appreciated’ by most scientists.

Then, concerning change, this can be represented as stages using a Specification Hierarchy, (Hsp) [2], as in (note the different brackets):

{primal or beginning situation {modifications accrued {current or final state}}}

delivering a sequential or historical account of stages in the construction of a present condition, and showing—importantly—also the continuing support of the prior/primal lower levels. A well-known example is the use of this formulation in biological systematics, as in, e.g.,

{living {animal {primate {human}}}

This particular application in biology was meant only to indicate relationships (humans are primates, etc.), which could be represented using the compositional hierarchy format, but I think it is important to realize that this formulation displays change over time as well. Consider for example, a sentence: ‘The boy ran up that hill’. Thus:

{boy {ran {there}}}

The boy is the focus of attention; then, his actions are recorded; then, the consequence of those actions is noted—in this case, the boy’s current location. The boy existed prior to his act of running, which preexisted its eventual direction. Each new subclass intensifies and focuses more fully upon a continuance of the originally designated object, class, or situation.

Then, consider an unfolding, as in biological development [2]. Thus:

{ovum {blastula {gastrula {neurula {etc. {etc.}}}}}}

In this case, the conventional labels for a developing individual label the stage of development achieved (e.g., ‘gastrula stage’) as development proceeds. This representation illustrates how upstream situations can be viewed as nesting downstream ones by way of their continuing to provide an increasingly modified basic framework.

For yet other possibilities, consult Salthe [11]. The number of subclasses is optional, depending upon the amount of detail required. This format could also be used to illustrate pathways of information flow. In that application, we see that this hierarchy branches as well. A currently active application of that kind is information flow in nervous systems [13–15]. Here, one finds ‘heterarchical’ relations as well, which I take to refer to the situation where several hierarchies (of either kind) are intersecting in common members. We might say that heterarchy refers to a kind of mashup of hierarchies, rather than an alternative to hierarchy.

Summing up on Hsp, it is used to represent precedence, either temporal, logical, or both. So, an increasingly more specified condition unfolds that continues being subsumed by prior conditions. Thus, a gastrula develops out of a blastula only in time, but insofar as a blastula is a necessary precursor to a gastrula, it is also necessary logically (used loosely here) as providing a prerequisite organization. More examples of use of this hierarchy will unfold in the following text.

4. Development

Evolution is mere change. As such, it would occur, even at the quantum level, if a prior condition is not fully recovered in time. In cases where prior conditions could be fully recovered, the definition of ‘evolution’ would become instead some version of ‘change unguided by conserved conditions’. Evolution is non-systematic, and it might impact systematicity only if its occurrence permanently alters a situation.

Development is guided or programmed change. This requires a concept of a system. Developmental change is an unfolding of what is already predestined (déroulement), or of what was implicit or immanent in a system. Here, no matter how elaborately a system might become as viewed from outside, it continues being itself AS a system, regardless of how extensive the changes undergone were.

All natural coherent dissipative systems develop intrinsically, and also insofar as they change without being destroyed when stimulated by environmental impingements. That is, they will react characteristically. However, they all evolve during their development as well. Their development is subject to becoming known, while their evolution, even during development, defies prediction. Thus, e.g., in bilaterally symmetric organisms, it is common to observe differences in opposite pairs, as in the right and left ear lobes of mammals, despite both being informed by the same genetic information. I note in passing that the current general discursive interest in evolution rather than development is itself of interest socially, considering that developmental constructions might be favored because they could lead to the possibility of some anticipation and control.

A conceptual application of development can be displayed using a subsumption-specification hierarchy (Hsp), as in:

{physical world --> {material world --> {biological world --> {social world}}}}

showing how the earth became progressively more complex over time. The brackets within brackets format indicates, e.g., that, in the case of the biological world, both the material and physical worlds are still present, underlying and supporting the biological. 'Social world' can be included here as a general category inasmuch as forms of sociality have been observed in most kinds of living systems. Importantly, again, this subsetting format shows that lower integrative levels continue operating within higher (more embedded) ones, as underlying supports. ('Lower' and 'higher' as used here is opposite to the usage in set theory.) Thus, this sequence shows that the social world is simultaneously an aspect of the physical world, a part of the material world, and an extension of the biological world.

Then, for all dissipative structures (located in the material world and above in this hierarchy) the process of development occurs, as:

{immature --> {mature --> {senescent --> {recycled/dissipated}}}}

In this case, unlike the previous one, sequential labels replace each other as development proceeds. However, what was achieved in an earlier stage is still present, even though modified and built upon. The individual referred to in all stages is still the same one.

This is the canonical developmental trajectory [16]. Its basic trajectory was first clearly described in a physical sense by Zotin [17].

A general description of the stages of development for dissipative structures is shown in Table 1 [15]:

Table 1. Developmental Stages of Dissipative Structures (from Salthe, 15).

IMMATURE STAGE
Relatively high energy density (per unit mass) throughflow rate Relatively small size and/or gross mattergy throughput Relatively high rate of acquisition of informational constraints, along with (when applicable) a high growth rate Relatively low internal stability (subject is changing fast), but dynamical stability (persistence) is high Relatively high Homeorhetic stability to same-scale perturbations
MATURE STAGE
Declining energy density flow rate is still sufficient for recovery from perturbations Size and gross throughput is typical for the kind of system Form is definitive for the kind of system Internal stability adequate for system persistence Homeostatic stability to same-scale perturbations adequate for recovery
SENESCENT STAGE
Energy density flow rate gradually dropping below functional requirements Gross mattergy throughput high, but its increase is decelerating Form increasingly accumulates deforming marks as a result of encounters, as part of continuing individuation Internal stability of system becoming high to the point of inflexibility Homeostatic stability to same-scale perturbations declining

As noted above, the specification/subsumption hierarchy

{physical world {material world {biological world {social world}}}}

describes stages in the development of the world, as a process of building new levels, leaving each of the earlier stages still in place (even if they themselves have continued to evolve during this sequence) as supporting presences. The 'lower' (more primal) are still supporting the emergent 'higher' levels. Each level brings in new constraints and opportunities. What each of these levels of specification brings in (or has added) to the universe can be listed as:

> the Physical organizational level (historically, the physical developmental stage of the world): Space expansion, gravity, action, waves, rarefaction/thermalization (this becoming prominent upon the expansion of space), initiating the pull of the Second Law of thermodynamics. It might be argued that this initiates time as well, as for example in the interpretation of Annila and Salthe. [18]

> the Chemical (material) organizational level or stage: strong force --> matter, electromagnetism, mass action, chemical transformations, clustering, ephemeral individuated locales, fugitive networks/energy gradients, dissipative structures, individual locale duration, local 'ecosystemic' flows.

> the Living organizational level or stage: symbolic coding, information, and meaning [8], relatively stable forms --> reproduction, individuated dissipative structures (functional uniqueness, individuality), adaptedness, levels of macroscopic organization locally, traditions/lineages, competitive exclusion, extinction. At this level, time becomes imprinted in nervous systems in ways suggested by Matsuno and Salthe [4].

Thus, as noted above, Hsp records change, whether guided or free:

{earlier condition {intermediate condition {later condition}}}

with new properties appearing with the emergent levels while the prior basis remains in place.

Could this progression continue 'forever', loading in new emergent levels as the universe expands? This would depend upon whether increasingly powerful dissipative systems will be enabled in order to further accelerate the dissipation of such systems, which might grow in size as time continues. At some point, such more powerful systems might destroy more than they create, in effect conspiring with the Second Law to obliterate all form. On that note, I have suggested [19] that dissipative structures were universally required to mediate the Second Law once diffusion was no longer fully effective, after the origin of material objects.

The still recognized relations among the sciences were already appreciated in the late 19th Century by, e.g., Comte, Spencer, and Peirce [16]. This understanding of relations between scientific disciplines can be displayed using a subsumptive hierarchy of disciplines within science.

{physics {chemistry {biology {sociology {psychology}}}}}

This shows that the prior subject (course contents immediately to the left) establishes a grounding upon which the next inward discourse relies, indicating, for example, that biology might be considered a special kind of chemistry. Some have argued for mathematics to be shown as the earliest stage in this hierarchy, but in my more materialist view, math is taken to be a product of human conceptual advance. Stated otherwise, I see math as an intellectual construct, while I am accepting the scientific view that the fields of scientific inquiry have uncovered (at least some of) Nature's 'true joints'. In this account then, physics is the basis of chemistry, while chemistry is the basis of biology, and so on. Or, looking the other way—top–down rather than bottom-up—biological systems can be viewed as harnessing chemistry, and physics, to produce and support their forms and activities. This hierarchy shows a tree of scientific knowledge with its root in physics, which might be elaborated further in this format to show branches. Thus, there might logically be more than one kind of biology—which could require a redefinition of what biology is—and, as is disturbingly evident around us, we know that there can be more than one kind of social system emergent with the sociological stage.

It is still not clear in my view that quantum mechanics, which some would place at the base of this hierarchy before classical physics, deals with natural physical activities rather than laboratory constructs (taking nature by the throat!). No consequences for the hierarchical tools described here would be impacted by the choice here. However, this statement depends upon another of my views—that notions of QM effects acting directly upon affairs at higher levels of scale must be false. This conclusion arises from my contention that, in the compositional hierarchy as used to model simultaneous activities at different scales, influences can only emanate upward by transformative steps from adjacent levels. Due to the vastly different rates of activity at the different levels, direct interaction is restricted to within one level. Thus, consider the impact that an amount of magnitude 2 would have upon an effect of magnitude 2,000,000. This opinion of mine will likely be challenged.

Logically, in a subsumptive hierarchy, the number of possible coordinate subclasses in the tree increases as we proceed inward. 'Inward' is an important descriptor here. Systems found further within—higher up in—the hierarchy are subject to more constraints than those located closer to the base of the hierarchy (in physical actions). These constraints are both restrictive and enabling. Thus, animal bodies can run or grow, turn, or swim, but cannot diffuse or—as such while living—oxidize. Then, since we have many more descriptors for biology than for physics, the number of possible meanings (the 'semiotic freedom' of Hoffmeyer [20]) increases in the higher levels of the hierarchy as well.

5. Causality

Of particular interest here, I have proposed [21] that the Aristotelian causal categories can often be interrelated in Hsc according to the scale of influence, thus:

[formal causes, final cause [efficient cause [material causes]]]

I have described finality at the different integrative levels in a subsumptive hierarchy {physicochemical {biological {social}}} as {teleomaty {teleonomy {teleology}}} (otherwise: {physical tendency {biological function {intentionality}}} [20,22]), providing a 'teleotalk' lexicon for the different integrative levels.

I believe it is no longer reasonable to ignore final causality in science. Minimally—inasmuch as all of science is carried out by interested parties—finality 'infects' science from the bottom–up (even on Francis Bacon's account!). Science is itself a natural process, and if it discovers a property or aspect of nature, that property is likely to have been present or foreshadowed in the natural world ante-civilization. Of sharpest importance here is my contention [11,23] that the Second Law of thermodynamics represents a final cause in nature, given that the Big Bang involves an expansion of space, continually producing new space into which entropic photons can flow, and which might, in my view, be represented as the universe 'calling for' the production of physical entropy.

6. Thermodynamics

Physics studies the basic processes and major tendencies in nature. That being the case, the phenomena that it studies would reasonably be understood to be the grounds from which all else emerges, and must have emerged historically as well. No systems that are susceptible to scientific examination exist that are not either physical neat, or grounded in physical processes. Dynamic natural systems change and in some cases move, utilizing energy to these ends, including during the construction of their own embodiments, and so appropriate available energies are required in order for them to exist. The most fundamental thermodynamic process might (as a model) be taken to be the net creation of free photons from electron-positron couplings (e.g., as in Compton scattering). This process would be mediated by spontaneous irreversible processes at many scales [24]. Irreversible processes have created whatever material things there are. Since everything depends upon (or is) energy flows, thermodynamics can be argued to be the most fundamental science, and energetics can be viewed as basic to phenomena at most scales. Thermodynamics has been observed in quantum mechanical constructions as well [25]. It is increasingly being argued by physicists that quantum phenomena underwrite everything else in the hierarchy of nature. That the results of some chemical experiments can be predicted using quantum mechanical principles [26,27] seems to argue for this suggestion.

Thus, the physical realm can reasonably be understood to underlie all systems, from quarks to galaxies, as well as affording the actions necessary for anything to happen at any scale. Energy itself is held in microscopic configurations, in (in some interpretations) bound electrons. As the energy is tapped, these configurations dissipate into energy flows, much of which, because of the low energy efficiency of any effective work [28], produces mostly just free photons—which embody the 'heat energy' not accounted for in the products of work anywhere in nature. These photons flow from regions of higher density of photons toward regions of lower density. This is one view [29,30] of the physical basis of the Second Law of thermodynamics. Irreversible processes are arranged for by the Big Bang as it produces both energy gradients in metastable formations of matter and an ever-increasing space of low energy density that welcomes (or 'calls for') the free photons produced by material interactions. An interesting exception to the generally free escape of photons from matter during energy flows is found in biology, where 'endergonic' chemical reactions capture some energy lost during neighboring 'exergonic' reactions before it escapes into the expanding universe.

Then, there is a philosophically important minority opinion in thermodynamics; the 'maximum entropy production principle' (MEPP), and its derivative, the 'maximum power principle' (MPP) [31]. This relates to the issue of the finality of the Second Law. When an energy gradient is tapped, will the rate at which it becomes depleted proceed as quickly as possible? I think it is reasonable to believe that whatever rate is imposed by a mode of dissipation, it would not be slower than the fastest possible given the constraints. The rate of dissipation would be maximized. Then, it becomes necessary to consider more broadly systems that tap the energy. The fastest possible rate might be explosive, and destructive to particular systems. Dissipative structures that operate in this mode do not survive long (e.g., forest fires, tornados and dust devils). Then it becomes necessary to examine more tenacious dissipative structures, such as organisms, in order to discover how the energy flows are moderated. Even when moderated, we can understand that the flows must be being maximized given the constraints [31]. As organisms age, their energy flows decline, and it is reasonable to suppose that this decline is what entrains the phenomena associated with aging, which in turn provides feedback for further decline. Senescence might be viewed as a negation of an organism's covenant with the Second Law. MPP [32,33] represents the activity levels of what may be referred to as 'delicate systems'—those, like organisms, that could not survive a full MEPP regime. Then, considering the implications of this argument, we could see that we are impelled to be as active as possible on pain of being 'discarded' from the universe—thus, we understand that the Second Law of thermodynamics is a final cause of all growth and activity. Fidgeting is a survival mechanism!

7. Summary

The two hierarchy types–Hsc (scale) and Hsp (important with respect to development), and finality are the three key conceptual elements informing my natural philosophy. They reflect form, change, and directionality. I distinguish 'development' from the more general concept 'change' (in which I include 'evolution'). Thus:

{change{development}}

Change per se has no form, resulting in occasional (but often, as in biological evolution, important) alterations historically. Development, characteristic of dissipative structures, entails sequential changes leading to senescence and elimination.

The overall conceptual framework assumed in my perspective is the expansion of space in the Big Bang concept. The ongoing 'Bang' gave rise to the emergence of embodiment at increasing size scales. Thus, (1) that which is modeled by the compositional hierarchy (Hsc) emerges during Universal expansion, with larger-sized objects being built from smaller ones as a result of gravitation. The rise of (2) dissipative structures at mesoscopic scales accompanies the emergence of energy density gradients as the universe expands so rapidly that matter cannot remain in equilibrium dispersion. These gradients 'materialize' the (3) Second Law of thermodynamics, which previously would have been effected by diffusion alone. Dissipative structures undergo (4) the canonical developmental trajectory, embodying (5) finality, in their entrainment by the global physical goal of universal equilibrium dispersion. This explains why (leaving open how) anything at all happens. The activities of dissipative structures disperse energy gradients, thus serving the finality of the Second Law, while senescence leading to recycling is their own dynamical attractor.

Then, for completeness sake, I note that evolution or individuation occurs at all material scales via unsystematic perturbations. These can give rise to adaptations among the living as mediated by natural selection. Given the way that large scale, or common, environments (oceans, deserts, etc) have a selective influence upon their denizens, they can by way of natural selection generate quasi-systemic effects such as fins, or plant spines, as examples of convergent evolution. In any case, a major result of evolution materially is that all locales have become unique in at least some dimensions.

Living systems bring in new manifestations via the genetic system: information and meaning. Their genetic system manifests an entirely new mode of action in the world: coding, resulting importantly in meaning [8]. Some physicists have opined that codon matching according to the genetic code is physically just another example of correlation. However, a biologist would note that the complex organization of the system that brings about 'correct' matching is where much of the fundamental interest in biological reproduction lies. The complexity of the genetic system, as well as the seeming arbitrariness of the codes, emphasize the difficulty of understanding how this system may have evolved—that is, of understanding the origin of life, which remains an open problem in science. Thus, we have historically a subsumptive hierarchy of natural activities:

{diffusion {chemical mass action {biological coding}}}

with each kind of activity dependent upon the simpler, more widely instantiated activities. Then:

{change (reflecting the Second Law of thermodynamics) --> {development --> {biological genetics: information --> {meaning }}}}.

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philosophies

Article

The Naturalization of Natural Philosophy

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Abstract: A new demarcation is proposed between Natural Philosophy and non-Natural Philosophy—philosophy *tout court*—based on whether or not they follow a non-standard logic of real processes. This non-propositional logic, Logic in Reality (LIR), is based on the original work of the Franco-Romanian thinker Stéphane Lupasco (Bucharest, 1900–Paris, 1988). Many Natural Philosophies remain bounded by dependence on binary linguistic concepts of logic. I claim that LIR can naturalize—bring into science—part of such philosophies. Against the potential objection that my approach blurs the distinction between science and philosophy, I reply that there is no problem in differentiating experimental physical science and philosophy; any complete distinction between philosophy, including the philosophy of science(s) and the other sciences is invidious. It was historically unnecessary and is unnecessary today. The convergence of science and philosophy, proposed by Wu Kun based on implications of the philosophy of information, supports this position. LIR provides a rigorous basis for giving equivalent ontological value to diversity and identity, what is contradictory, inconsistent, absent, missing or past, unconscious, incomplete, and fuzzy as to their positive counterparts. The naturalized Natural Philosophy resulting from the application of these principles is a candidate for the 'new synthesis' called for by the editors.

Keywords: common good; contradiction; ethics; information; logic; naturalization; realism; science; synthesis

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1. Introduction

In 1949, it was still possible for Alfred Ayer [1] to write: " . . . the function of the philosopher is not to devise speculative theories which require to be validated in experience, but to elicit the consequences of our linguistic usages. That is to say, the questions with which philosophy is concerned are purely logical questions; and though people do in fact dispute about logical questions, such disputes are always unwarranted. For they either involve the denial of a proposition which is necessarily true or the assertion of a proposition which is necessarily false."

Fortunately, this binary, apodictic position has been largely deconstructed by more recent philosophical work, especially by transdisciplinary, realist approaches to consciousness and mind. Examples are the concept of the embodied mind of Lakoff and Johnson [2], an extension of basic phenomenological positions introduced by Merleau-Ponty, and the philosophy of neuroscience of Bennett and Hacker [3]. This period has also seen the development of the philosophy of process, extensions of the work of Whitehead [4], Rescher [5], and Seibt [6]. Another current field of research is that of the philosophy of information, pioneered by Wu Kun in China [7] and Luciano Floridi in Italy [8].

Unlike Ayer, I expect of philosophy that, like science in a different way, it tells us something about nature, man's unique position in nature and his interaction with it. It is nevertheless a body of knowledge, a theory of reality that can fail in two major ways. It can overemphasize the difference with science, as in the anti-scientific aspects of phenomenology and idealism in general, and it can relegate all non-tangible phenomena, not demonstrable by physical experiment, to the realm of epiphenomenalism. The concept of a Natural Philosophy, which has evolved into science, raises the further complication of what *it* is and how it differs from philosophy *tout court*. The domain of philosophy is further in fact divided by its relation to science. Analytical philosophy recognizes the central role of science, but applies to it an inadequate conception of the logical operation of complex processes and living systems. Continental philosophers and anti-realists such as Bas van Fraasen ('Constructive Empiricism') are fundamentally anti-scientific and thus lack a necessary link to reality. Both kinds of theories thus fail for similar reasons.

1.1. Outline of Paper

In this paper, three lines of discussion will be pursued: (1) the demarcation of Natural Philosophy by a non-standard, non-propositional philosophical logic which I have called Logic in Reality [9] (LIR); (2) the application of LIR to stubborn problems within the philosophies of process and science, as well as in Natural Philosophy itself as previously delimited; and (3) the role of recently developed philosophies of information, consistent with LIR, in bringing a new ontological dimension to philosophy. I begin by a first exposition in Section 2 of the differences I see between Natural Philosophy and Philosophy in general, philosophy *tout court*. Section 3 is a brief outline of LIR. LIR is grounded in physics, but its elements are the evolving states of natural processes, biological, cognitive and social. Section 4 presents some of the conceptual precursors to LIR in relation to Natural Philosophy, including the ontological philosophies of physics and process [10] for comparison with speculative linguistic–epistemological philosophies. Section 5 centers on phenomenology and its relation to Natural Philosophy, and addresses the issue of naturalization as a hermeneutic strategy. The next Section 6 analyzes the developing philosophies of information of Floridi and Wu. I argue that the latter anticipates the convergence of science and philosophy foreseen for Natural Philosophy.

1.2. A New Synthesis

In their Introduction to this special issue for *Philosophies*, its editors, Gordana Dodig-Crnkovic and Marcin Schroeder, refer to the disjunction above in their call for a new synthesis of scientific and philosophical knowledge. Whatever else may be true about it, such a synthesis, re-integration or rejunction of knowledge with its origins must provide for a grounding of human value systems in that knowledge. This is a minimum necessity for its use in support of the common good.

A new synthesis should, among other things, go beyond the familiar analytic/synthetic distinction. One can envisage the appearance of a new Synthetic Philosophy that will be a better natural partner, in both senses, of Analytical Philosophy than is the diffuse and not very useful concept of Continental Philosophy. I propose this paper as a contribution to such a new synthesis.

2. Philosophy and Natural Philosophy

2.1. What Is Philosophy?

It seems essential to first outline my position as to what philosophy and Natural Philosophy are and how they differ. Before addressing the status of contemporary Natural Philosophy, let us therefore try to answer the question posed in 1991 by Deleuze and Guattari: "What is philosophy?", "*Qu'est-ce que la philosophie?*" [11]. In their view, philosophy is neither contemplation, reflection nor communication. It is the cognitive activity of creating concepts in a domain of pure immanence, in contrast to science and logic which involve functions and observers, and to art which operates with percepts and affects. Most importantly, philosophy does not operate with propositions: the relations that compose the concept are not those of comprehension or extension but of ordered variation, processual and modular, pure events, real without being actual, ideal without being abstract. I can agree with these authors that standard logic has an 'infantile' conception of philosophy.

Concepts, hence philosophy, should not be confused with the energetic cognitive states-of-affairs in which they are found. "There is no energy; only intensities" in philosophy, whereas energy involves intensity in an extensive context. Taking this line of reasoning one step, the level of immanence itself is pre-philosophic, becomes philosophic under the influence of the concept and then evolves is a philosophic relation with non-philosophy. Finally, while the two domains—of immanence and event—are inseparable, philosophic concepts do not 'intervene' in scientific functions or functionalities and vice versa. I will introduce a similar demarcation, to use a term familiar to philosophers of science, to distinguish between philosophy and Natural Philosophy.

The philosophy of Deleuze illustrates the results of applying the concepts of immanence and transcendence without defining and including any dynamic dialectical relation between them. It constitutes a domain, governed by a binary logic of undetermined, idealized entities, Humean in its lack of effective interactions. In the domain of reality to which LIR applies, the existence of all beings depends and is defined by that of others. Infinities and infinitesimals do not exist, but are replaced by transfinite values, and immanent and transcendent aspects of phenomena are mutually and alternately actualized and potentialized. Thus, LIR can discuss philosophical issues in physical, dynamical terms that do not require recourse to any imaginary, abstract structures which to separate aspects of reality. The aspects that are considered 'virtual' or 'possible' in Deleuze are so 'in philosophy' but 'in reality' are instantiated as potentialities.

The answer to the question posed in 2.2 below by the contemporary philosopher of information and information ethics Rafael Capurro [12] is the following: philosophy deals with the question about reality as a whole stated by beings (ourselves) that finds ourselves in reality without having the possibility of a holistic view of being ourselves in reality and not beyond it. The fact that we are able to ask this question means that we have some kind of pre-knowledge about reality as a whole while at the same time this pre-knowledge is problematic, otherwise we would not ask the question and would not be able to become philosophers.

2.2. What Is Natural Philosophy? The Ontological Turn

I continue with Capurro's response in the same format as above: Natural Philosophy deals with the question about nature as a whole stated by beings (ourselves) that finds themselves in nature without having the possibility of a holistic view of being ourselves in nature and not beyond it. The fact that we are able to ask this question means that we some kind of pre-knowledge about nature as a whole while at the same time this pre-knowledge is problematic, otherwise we would not ask the question and would not be able to become natural philosophers.

The question then changes to the difference between nature and reality as a whole, including fictions, non-verifiable beliefs and intangible objects of thought. Since the idea that classical Natural Philosophy evolved into science seems correct, we are left, for the domain of Natural Philosophy, a speculative interpretation of nature viewed in its entirety. This interpretation is, *ipso facto*, at a lower ontological level than the science which has largely replaced it. Much of the 20th Century linguistic turn, expressed in both analytical and phenomenological and residual transcendental traditions, is still visible in contemporary philosophy.

The reaction to this unsatisfactory state of affairs has been the reinstatement of realisms and materialisms of various kinds, associated today with the names of Derrida, Badiou, Zizek, and others. The 'ontological turn' in philosophy is a term of art that designates dissatisfaction with descriptions of reality based on analytical, semantic criteria of truth. Starting with Heidegger's critique of hermeneutics and the basing of philosophy on human life, the ontological turn is a challenge to neo-Kantian epistemologies, and looks to what the structure of the world might be like to enable scientific, that is, non-absolute knowledge. Unfortunately, ontological theories have been hobbled by the retention of static terms whose characteristics are determined by bivalent logic.

In 2002 [13], Priest suggested that an ontological turn in philosophy was taking place, away from language in the direction of a contradictory nature of reality. However, Priest proposed paraconsistent logic as appropriate to this turn. Lupasco anticipated this ontological turn by some 60 years, but his logical system lacks the epistemological limitations of paraconsistency.

We may thus say that contemporary philosophy is largely natural and realist: I note the landmark date of July 2012 and the Summer School in German Philosophy at the University of Bonn: "The Contemporary Turn in German Philosophy". I have no difficulty in associating this group of thinkers with the term 'natural philosophers', but I do not believe that the issue of what is natural has been exhausted by them.

The most important point for me is that Natural Philosophy tells us something real about the world that is consistent with our best science, physical, biological and cognitive. Speculative philosophy can always re-illuminate 'eternal' questions such as what it means to be a thinking being in a non-thinking environment, but it cannot in itself be other than part of philosophy *tout court*. This non-Natural Philosophy, to repeat, exists for 'natural' reasons: it is a natural necessity for human beings to create it, by a natural process, but it is not part of nature *qua* content.

2.3. Nature and Non-Nature: Belief

Capurro suggests that we humans are the *tertium datur*, the included third (see below), living the paradox of a being who is able to ask questions about the whole of reality (of nature, the soul, god) from a perspective that is the negation of such an 'absolute' perspective. The kind of 'relative' transcendence (going 'beyond' but remaining 'inside') that is characteristic of philosophy (as different from theology and myth) is that this philosophical perspective on the whole of reality (or nature, the soul, god) is the one of indeterminateness or 'nothingness'. This paradox, our own way of existence, might 'explain' while we, humans, asking some kind of true and permanent knowledge about what is at stake concerning what is, was, will/can be, have looked and still look for answers in myths and religions.

The result is not an answer but a dead end. It is a fact that people who believe in a transcendental deity, outside and/or including nature believe that it is the true reality and all else is illusion. Realists such as the writer think that the believing of such believers is real but its objects are illusions. Neither side can accept that the other is even partly correct without invalidating their respective theses. Since such absolute polarization is not a part of nature, it cannot be part of any Natural Philosophy. The demarcation problem is simpler than that between science and non-science.

2.4. A New Role for a New Logic

This sub-Section outlines my core thesis: I take the Logic in Reality mentioned above and see how it might provide a criterion for distinguishing between Natural Philosophy and philosophy in general. Obviously, if one takes 'nature' to be all of 'reality', there is no difference between them. I think it is more useful to define the following three domains and their respective theories and logics:

- Philosophy
  - The non-natural domain: fictions[1], beliefs, especially, transcendental beliefs, computational programs
  - Epistemology
  - Classical bivalent/multivalent propositional logic, present or 'projected' (Sherlock Holmes behaves logically)
  - Being (abstract: the being of Being)
- Natural Philosophy
  - The natural domain of physical and mental reality
  - Ontology

[1] A discussion of fictionalism is outside the scope of this paper.

- ○ Dynamic logic of processes (Logic in Reality—LIR)
- ○ Becoming (real; the link to 'Being')

There is no sharp cut between these domains: in some one perceives that epistemology is dominant, but there is also a longing for ontology, while propositional/predicate logic is largely retained.

I will refer below to aspects of Natural Philosophy in the work of some contemporary thinkers coming from biological and social scientific fields, such as Terrence Deacon [14] and Wolfgang Hofkirchner [15], who almost by definition work at the interface of Natural Philosophy and philosophy. It is not by accident that these people, as well as myself, are involved in the development of the science and philosophy of information and their naturalization.

It is now time to present the basic principles and formalisms of Logic in Reality, as described in detail in my 2008 book, *Logic in Reality* (Dordrecht, Springer) [9]. We will see among other things that the boundaries between the indicated domains should not be considered absolute, and why the word 'pure' should be banished from discussion.

3. Logic and Logic in Reality (LIR)

3.1. The Logical Line. Change

Part of the difficulty for the Lupasco concepts and LIR to gain acceptance is that it requires changes in perspective not only in the content of logic and logical analyses and the process of using it, but in our common-sense views of parts and wholes, sets, categories, truth, determinism, causality and time and space, all based on a more complex view of the principles underlying thought [16]. What is gained is a better perception of the dynamics of first-person experience, consciousness and other complex psychological and socio-economical processes, creativity and art.

The discussion of Logic in Reality, as it has emerged from the pioneering work of Lupasco, is formulated in this paper in language I have used previously, as it remains the best I have found to make this unfamiliar approach understandable. I am encouraged to note that at least two of the contributions to this Special Issue include references to LIR.

3.2. The Principle of Dynamic Opposition: The T-State

The antagonistic dualities of our world can be formalized as a structural, logical, and metaphysical principle of opposition or contradiction instantiated in complex higher-level phenomena (Principle of Dynamic Opposition—PDO). The fundamental postulate of LIR is that for all energetic phenomena (all phenomena) alternate between degrees of actualization and of potentialization of themselves and their opposites or 'contradictions' but without either going to the absolute limits of 0% or 100%. The point at which a logical element and its opposite are equally, 50% actualized and potentialized is one of maximum interaction from which new entities can emerge. It is designated by Lupasco and Basarab Nicolescu, the physicist colleague and major continuator of Lupasco [17], as a 'T'-state, T for included middle or third (*Tiers-inclus*). I use the concept of T-states to evaluate both philosophical and scientific theories, including patterns of human individual and social behavior. A dynamic systems view can be used to focus on the feedback in all natural processes.

3.3. Philosophy and the Philosophy of Mind

Regarding philosophy as such and the vast subject of the philosophy of mind, I will restate my criticism [18] of philosophical arguments. They often depend on some form of absolute separability of opposing or dichotomous terms, which use, in one way or another, the principles of binary logic which exclude the functionality of complex interaction.

For a philosophy of mind, the central problem is to show how physical tokens, the neuro-physiological processes occurring in the brain, can give rise to mental tokens that retain the properties of intentionality, 'aboutness', individuality and some level of causal powers or functionality. I have discussed the Lupasco conception of the operation of the human mind on which these capacities may be based in an article forthcoming in an *APA Newsletter* [19].

3.4. Insights from Chemistry

For clarity, I should explain that my ideas of process and change have been influenced by my training as a chemist. In chemical reactions one has, at the same time, reactants; an environment, for example a solvent in a reaction vessel; energy being added as heat or light; and some of the reactant atoms or molecules absorbing that energy to move toward a transition state from which, given favorable thermodynamic criteria, most of them will become products. However, also at the same time, some products are absorbing sufficient energy to move in the opposite direction and re-become reactants. I claim that not only is this a picture of what happens in other physical and biological sciences, but also in real cognitive and social situations. No description of processes, not relations as such but changes in relations or ideas, theories, etc. can be less complex, in a thermodynamic world, than this one from chemistry.

In more logical-philosophical terms—those of Lupasco—the movement described is from potentiality to actuality, from the point of view, say, of reactants to products, but this movement, to repeat, is not total and is always accompanied, even to a minor degree, by the opposite movement from actuality to potentiality, the 'regeneration' of reactants. We can always change our mind—twice. We do it from a point, a T-state in Lupasco or a transition state in chemistry—where the driving forces for change in direction are approximately equal.

I claim that the LIR approach can redefine the domains of philosophy: theories of reality which follow a bivalent or multivalent logic of propositions are satisfactory for philosophy, idealist or reductionist-materialist. The domain of Natural Philosophy can only be described by a logic of real processes that shows the origin and evolution of change.

3.5. Scientific Structural Realism (SSR)

I have positioned LIR as a theory of reality by comparing it to formulations of other realist theories. The conception of structures in LIR as real processes permits an alternate to Scientific Realism which I defined in [9] as a kind of scientific structural realism (SSR). The ontological structure of reality of LIR supports a non-naïve and above all non-absolute scientific realism, so that a theory of scientific structural realism is possible that includes the best of both worlds.

Details of this approach, including the relation to Ontic Structural Realism (OSR) are provided in my book. Basically, the answer to the question asked by Lupasco—"What is a structure?" [20]—is that structures also must be looked at as processes-in-change, dynamic entities (cf. [21,22]).

The metaphysics of LIR provides for a fundamental vagueness in nature. Any semantic conception, such as that of Kuhn, according to which the most basic laws in a theory or paradigm are true in some absolute sense is excluded as anti-realist.

3.6. A New Synthetic Philosophy

LIR statements look like what are termed synthetic statements, that is, ones whose truth depends on matters—in particular, contingent facts about the world—to which I have ascribed a certain dialectic structure. Such statements are to be distinguished from analytic statements that are true by virtue of the meaning of their constituent terms alone.

LIR thus provides support to a naturalistic, causal-role theory of mental content and a naturalistic means of drawing the analytic/synthetic distinction. This can be part of Natural Philosophy, even if a 'pure' analytic theory cannot be. LIR always defines a real relation between the intensional notions or aspects of a phenomenon and the extensional ones. Analytic claims can provide insight into external reality, but only if coupled with a non-semantic theory that provides some basis for explanation of the coincidence between our concepts and the properties or real phenomena of the world. By starting from the side of the phenomena, LIR permits progress toward a new 'synthetic' philosophy that if not entirely is more within the domain of Natural Philosophy[2].

4. Conceptual Precursors of LIR in Relation to Natural Philosophy

To support my new approach to and content of Natural Philosophy, reference needs to be made to its precursors to see where the LIR Principle of Dynamic Opposition might apply. Precursors include both non-contemporary and contemporary thinkers, and both philosophers and scientists. I will not attempt to review the entire history of knowledge from 'Heraclitus to Hegel to Heidegger', recognizing that significant elements of Logic in Reality are to be found in all of them. To repeat my thesis, to the extent that a component in these theories is present explicitly or implicitly equivalent to Logic in Reality, the relevant doctrine is *ipso facto* in the domain of a Natural Philosophy.

4.1. An Historical Line: Gare on Fichte, Schelling, and Engels

The contribution of Arran Gare to this special issue [24] suggests a dialectic line of development of Natural Philosophy from Hegel through Fichte, Schelling, and Engels to Whitehead. He has set himself the objective of specifying the difference between natural philosophy and science in order to give the former a more functional role for making progress in knowledge. My approach in this paper can be summarized as specifying the difference between philosophy and natural philosophy in order to give the latter a more functional role for making progress in knowledge. In my approach, what is emphasized is the similarity or overlap between natural philosophy and the non-experimental sciences.

I refer the reader to Gare's article, but I will cite here some highly suggestive passages in the work of these authors that foreshadow the basic principles of Logic in Reality. Despite the 'bad press' which contradiction usually receives, Fichte said quite clearly [25] that the "thing-in-itself ... is a contradiction though as the object of a necessary idea it must be set at the foundation of all of our philosophizing, and has always lain at the root of all philosophy and all acts of the finite mind, save only that no one has been clearly aware of it, or of the contradiction contained therein. This relation of the thing-in-itself to the self forms the basis for the entire mechanism of the human and all other finite minds. Any attempt to change this would entail the elimination of all consciousness, and with it of all existence." It is this positioning of the concept of active, ontological contradiction, in Fichte and Lupasco that defines its place in Natural Philosophy.

As Gare points out, it was dialectics as developed by Schelling that "provided the forms of thinking required to develop natural philosophy". Schelling developed Fichte's notions of the appreciation of subjects as activities (JEB: processes) rather than objects and of cognition as the process by which nature has come to comprehend itself. The notion of synthesis rather than analysis is central, and so, as in Lupasco, is opposition. "Thought is inherently synthetic, Schelling argued, and begins with a genuine opposition between thought and something opposing it, or between other factors within thought." As in Lupasco, the dynamic basis is provided for emergence from a state of contradiction of a "new synthetic moment that can be treated as a product or factor in the next level of development". I only suggest, based on the principles of LIR, "product and factor". Emergent entities, as 'products', enter into oppositional relations as 'factors'. Lupasco specifically refers to his method as a 'dialectomethodology' which he saw as requiring the identification of the dialectically opposing forces operating in a process, their reciprocal degree of actualization and potentialization and the direction of the trend toward predominantly one or the other, as noted in Section 3 above.

It is equally relevant for this study to note the central place Gare gives to the unfinished 1883 work of Friedrich Engels, *Dialektik der Natur*. It can be described both as a philosophy of the natural sciences and a Natural Philosophy, demonstrating not the identity but the overlap of these concepts. As summarized by a Soviet writer, Boniface Kedrov (in a curious work found in an East German

2 Let us not forget, at this point, from Schroeder's charter for *Philosophies*: "Synthesis through Diversity" [23].

bookstore in the 1980s [26]), Engels gives ample justification for considering dialectics as a fundamental natural as well as epistemological process: "What is called objective dialectics is found throughout nature, and subjective dialectics, dialectical thought, only reflects the dominance, again throughout nature, of movement by opposition of contraries." This statement could be considered a philosophical foundation for the Natural Computation of Dodig-Crnkovic [27] (see below). Engels said that a dialectical method was the only one that could enable an understanding of reality. Engels made dialectics the basis of his and Lenin's materialism, but we do not need to follow him here. It is ironic that Lupasco adopted and developed the logic of this dialectics coming from a bourgeois background of *petite noblesse.* His rehabilitation of dialectics, however, was routinely attacked and denigrated (as well as plagiarized) by some of the armchair Marxists of the French *intelligentsia* such as Yves Barel. As for Lupasco, the point of departure for knowledge for Engels was the "qualitative aspect of things and phenomena and not their quantitative side".

In his further citations from the *Dialektik der Natur*, Gare suggests a relation to Lupasco with which I agree: "Dialectics is the science of universal interconnection, of which the main laws are the transformation of quality and quantity—mutual penetration of polar opposites and transformation into each other when carried to extremes—developments through contradiction or negation of negation—spiral form of development." Logic in Reality is a way of avoiding the dogmatism of Engels' thesis when it is stated this rapidly: the transformation of the polar opposites operating in complex systems is never complete; extremes of 0 and 1 are never reached except in trivial cases. Contradiction inheres in physical processes, and negation of negation remains at the level of linguistic logic. The concept of spiral form of development is an absolutely essential one which I have described in detail as a consequence of Deacon's concepts of "incomplete nature" [28]. I will discuss the work of both Whitehead and Deacon below.

4.2. A Scientific Line: Gödel, the Philosophy of Physics and LIR

Contemporary Natural Philosophy cannot be discussed without reference to the most important developments in 20th Century physical science: quantum physics, including the Pauli Exclusion Principle; the uncertainty principle of Heisenberg; and the Gödel principle of the reciprocity of completeness and consistency in mathematics. I call attention in particular to the work of Sklar on the Philosophy of Physics [29]. Let me state the relation between quantum mechanics and Logic in Reality apodictically: the superposition of quantum states is isomorphic to the T-state in LIR at macroscopic levels of reality. Together with uncertainty, a physical basis is provided for the Lupasco physical-logical Principle of Dynamic Opposition. As I have shown in [9], LIR can be usefully compared with quantum logics, but further conceptual changes are necessary to make quantum-type logics applicable to macroscopic change. It should be clear that an explanation of the experimentally demonstrable quantum features of the world will (still) require a radical rethinking of our metaphysical picture of it. At the latter level, the one of greatest generality, the definition of some principle that is missing or has been ignored would have major consequences for the future of 'reason' in the broadest possible sense. As indicated above, there may exist aspects of physics, expressed in the PDO, that are already accessible and could fit this description. In a recent paper [30], Bishop and I have discussed how Heisenberg's conception of potentiality, his *res potentiae*, should apply at a macroscopic level.

In has ontological approach to modern physics with regard to the development of field theories, Cao [21] sees the synergy—'mutual penetration'—between physics and metaphysics, considering that physics has also provided us with a direct access to metaphysical reality. Cao describes a debate, over the nature of energy suggest: "What if energy is taken as substance *with the new feature of being always active, always changing its form while keeping its quantity constant* (emphasis mine)? Then energeticism would seem to be a precursor of James's functionalism and Whitehead's ontology of process." This doctrine is close to LIR and perhaps should be how a philosopher could appreciate the first law of thermodynamics.

My interim conclusion is that a philosophy of physics embodying these principles lies comfortably within Natural Philosophy. The links to nature are extensively described in a crucial 2012 compendium by Kuhlmann and Pietsch: "What Is and Why Do We Need Philosophy of Physics?" [31]. Very much in the spirit of my analysis is the authors' thesis (ii): the boundary between physics and philosophy of physics is blurry, particularly with regard to foundational questions (e.g., the physical 'ground' of existence).

Nature's Metaphysics?

As an anti-thesis to the concepts developed in this paper, I cite a recent book by Alexander Bird which has the title of this section [32]. Bird defines the only fundamental natural properties as 'potencies' which, linguistically at least, are akin to potentialities. This dispositional monism gives him the foundation for the—necessary—laws of nature. As I stated in [9], the contradictorial relation between actuality and potentiality in LIR thus provides arguments against attacks on the reality of 'potencies', defined as dispositional properties that include potential manifestations. My demonstration that what is potential as well as what is actual is real answers the critique that only the actual is real. The modal argument (*possibilia* are not things that exist in other worlds but not in this one) against the objection that potencies involve unrealized manifestations of possibilities that, accordingly, violate naturalism is supported by a view of unrealized possibilities as real potentialities, but ones whose reality does not depend on their manifestation if this is prevented by an actuality.

Bird sees the elimination of invariance as a desirable feature, part of a general strategy of eliminativism: symmetry principles and conservation laws may be eliminated as being "features of our form of representation rather than features of our world requiring to be accommodated within our metaphysics". I do not contest—here—Bird's argument. I consider it an example of the Lupascian standpoint possible, namely, that a total separation of the world and our representations of it is neither necessary nor desirable. However, I would exclude his overall thesis from the domain of Natural Philosophy.

With this scientific–philosophical background, let us now look at one of the areas of major interest to contemporary philosophy, that of process.

4.3. The Philosophy of Process

An area to which it is natural to apply the logical system outlined above is that of process. To the extent that it refers to real, physical and mental phenomena, placing the philosophy of process in the domain of Natural Philosophy should be self-evident. That it is not entirely so is a measure of the problem which this paper addresses. I analyze here the work of two contemporary philosophers.

4.3.1. A. N. Whitehead: Consistency, Coherence, and Concrescence

Curiously, the criteria proposed in this paper place Whitehead's concepts of consistency and coherence both outside and inside the domain of Natural Philosophy. As summarized by Soelch [33], Whitehead supplements James's notion of an empirical, rational but subjective domain by a logic, but this logic is based on not more than standard rules of inference and the law of non-contradiction. I consider that this doctrine remains here at the level of epistemology, that "the fundamental ideas in terms of which a scheme is developed presuppose each other, so that in isolation they are meaningless". I note a reference to propositional truth. However, Whitehead's focus, anticipating phenomenology, is on the "texture of human experience". Coherence is also defined as the body (*sic*) of our theoretical knowledge, but at the same time it is "a basic inventory of concepts", an inert Peircean classification.

Much closer to NP in my view, which I discussed in [10], is Whitehead's concept of 'concrescence', extended in his *Process and Reality* [4] toward real systems: "The coherence, which the system (organism) seeks to preserve, is the discovery that the process, or concrescence, of any one actual entity involves the other actual entities among its components. In this way the obvious solidarity of the world receives its explanation."

4.3.2. Nicolas Rescher

The foundational work of Rescher on process metaphysics and process semantics is well known [5], and I have summarized my views of it elsewhere [9]. Rescher's mission for process philosophy is "enabling us to characterize, describe, clarify and explain the most general features of the real." Further, he relates his view of the processual structure of reality to energy, the entities of quantum mechanics entering into more and more complex arrangements.

In an Appendix to his [5], Rescher proposes a Process Semantics as an alternative to standard predicate logic as the conceptually most versatile and philosophically most fundamental tool for reasoning and understanding reality. His semantical (*sic*) strategy dispenses with object/subject terms and replaces them with verbs and adverbs indicative of processes. According to Rescher, these are capable of accomplishing what a semantics of individuals can do with properties and relations. His process semantics is thus at the basis of his ideas of process philosophy and process metaphysics. What he called the mainstream logical theory of the West, which takes an approach to truth that is committed to its static fixity, was and is unable to meet this challenge.

I can agree here with Gare's suggestion [34] that the resulting process doctrine looks like a logic whose terms are those of processes, including living processes. From an LIR standpoint, the notion of logic can be extended to include Gare's construction, which goes beyond Rescher's. The latter states that "dispositional processes accomplish exactly the needed job of rendering predicational terms of the form G[the-x(Fx)] contingently true or false". We are thus clearly in a truth-functional, linguistic domain. Logic in Reality of course is about nothing but properties and relations and their dynamics, but it is in a non-truth-functional, non-linguistic domain. Rescher does call attention to the lack of fixity of his conception of truth and the fluidity and analogue character of natural processes. On the other hand, he suggests their "kinship" to the continuities captured by differential equations, which is not adequate, as no reference is made to the continuity-discontinuity dualism.

Going now from Process Semantics to his major theme of Process Metaphysics, Rescher correctly states that matters of cognition and communication cannot be substance-like 'things', but are processual phenomena. These are described, we would now say, by the science and philosophy of information (see for example one of my papers with Wu Kun [35] and the discussion below). His processual view of scientific inquiry is equally important for the break it makes with the standard philosophy of science. As a process metaphysics which includes all these ideas, Rescher's philosophical 'system' does provide a distinctive and illuminating window on the world. He himself seems to have had an intuition of the transitional character of his doctrine and this is where I would position him, somewhere 'between' philosophy and natural philosophy. LIR describes change in terms of dynamic opposition and captures some of the features of process described by Rescher. In the absence of any other formal logical system that does so, LIR can be seen as the preferred logic of, in and for process. With this addition, we may consider the philosophy of process as being in the domain of Natural Philosophy.

4.3.3. Johanna Seibt

Among contemporary philosophers, Johanna Seibt, a student of Rescher, has extended the work of Whitehead and provides a basis for its potential naturalization into Natural Philosophy. I say 'potential' because I do not believe Seibt has fully achieved a naturalization in the terms of this paper. Her standard categorial entities in this formal ontology are theoretical entities with only axiomatic characterization. The only things to which she says we are ontologically committed by the use of abstract singular terms are linguistic entities, without explanatory force. In Lupasco, the term 'explanatory force' of non-linguistic entities (items) is not only a metaphor.

In correcting the 'The Myth of the Given', Sellars says [36] that non-propositional items cannot serve as what is given, but inferential relations are always between items with propositional form. However, even Sellars, I would like to believe against his will, is forced into making 'distinguos'—yes or no positions due to the absence of a principled manner in which they can be seen as operating jointly, synchronically, or diachronically as the case may be.

I have suggested that the exclusion of contradiction from logic has overly constrained its applicability. Similarly, Seibt has shown how characteristic Aristotelian presuppositions have constrained ontology to a substance paradigm. From her standpoint, Seibt sees a trend in ontological theories that leads from traditional substance-ontological schemes operating with concrete, particular, static, and 'causally separate' entities (including abstract and general entities) to schemes whose basic entities are concrete but non-particular, dynamic, and 'causally interlaced' or 'overlapping'. LIR implies a dynamics for moving from the first group of entities to the second and a physical meaning to 'interlaced or overlapping'. This founds a metaphysical to and accordingly to a further new ontology, one of which the physical dynamics are an explicit part. Only such an ontology would meet my criteria for a role in Natural Philosophy.

4.4. Information Ethics and Digital Ontology

Rafael Capurro has made pioneering contributions to the fields of the science, philosophy, and ethics of information based on his unique philosophical perspective of the position of humankind in the world. For Capurro, the field of information ethics defines the essentially social nature of meaningful information. In his formulation of a digital ontology [37], Capurro emphasizes that our ways of understanding ourselves and the world cannot be separated from the effects of the world on us but are radically grounded in them. He is in effect saying "ontology is not a discipline distinct from ethics; it is ethics in its original sense". In today's world, ethics and information ethics cannot be considered independently of one another.

From my dynamic logical perspective, Capurro's critical Heideggerian concepts of human existence have been naturalized, brought into a non-reductionist relation to science, and can be considered part of Natural Philosophy. They can be seen as part of a convergence of science and philosophy directed toward a revitalization of the concepts of the commons and of the common good.

4.5. Philosophy in the Flesh

In their major 1999 study [2], George Lakoff and Mark Johnson make a devastating indictment of standard philosophy and—analytical and formalist philosophy in general, and they give full ontological value to the constructs of cognitive science. "The results of second-generation cognitive science stand squarely opposed to the analytic and formalist philosophical traditions . . . on (1) the embodiment of concepts and of mind in general; (2) the cognitive unconscious; (3) metaphorical thought; and (4) the dependence of philosophy on the empirical study of mind and language." Their position on the relationship between science and philosophy is similar to the one taken in this paper: empirical scientific results, especially through an informational perspective, take precedence over *a priori* philosophical theories.

In their conclusion, the authors make a trenchant case for the importance of metaphor in philosophy, to ensure that "philosophical theories work". Metaphorical metaphysics "is not some quaint product of antiquated and naïve philosophical views. Rather, it is a characteristic of all philosophies, because it is a characteristic of all human thought." "Metaphors are the very means by which we can understand abstract domains and extend our knowledge into new areas."

I can agree with basically all of the critique of Lakoff and Johnson—their embodied realism—as an absolutely necessary part of a philosophy that is, as they say, creative and synthetic. I have some questions about the role assigned to metaphor. By saying that the logical structure of Aristotle's reasoning is metaphorical, and that his ontological commitments come out of the metaphors, our authors seem to have inversed ontological priority. They make metaphors—metaphorically—do more philosophical work to bind thought, knowledge, and imagination into an organic whole than I think they are capable of. I will refer again to their work in the Section 5 on Naturalization and Merleau-Ponty.

4.6. Dé-Coïncidence (Decoincidence)

The French philosopher and sinologist François Jullien has recently coined the term '*dé-coïncidence*' (decoherence/incoherence) to describe the dynamics of the evolution of cognitive and social processes [38]. Currently discredited theories of mind postulated quantum phenomena occurring in microtubules in the brain as the physical basis of thought. In fact, these would be 'washed out' by thermal noise, that is, they would no longer be coherent.

Jullien associates, very much in the spirit of Lupasco, decoincidence with temporality, emergence, symmetry breaking, and the foundations of ethics in opposition to the coherent inhuman world of quantum phenomena, timeless, changeless, and ethically neutral. One must follow the advice of von Bertalanffy and avoid pushing analogies to far, but in the context of Jullien's deep knowledge of Chinese philosophy and logic, the coincidences (*sic*) between the principles of LIR and his concept are striking.

5. Phenomenology and the Naturalization of Phenomenology

The reworking of some additional subjects within Philosophy seems necessary to eliminate what amount to category errors, ascribing to natural phenomena logical properties which are essentially fictions. These subjects are thus the main targets for the naturalization proposed in this paper. I will now discuss how this grid might apply to them, in other words, 'move' them to Natural Philosophy where possible. The precursor to naturalization as a process [39] was 'scientization', defined as the incursion of empirical science into areas of knowing previously the purview of theology and philosophy. An example of this is the attempted naturalization of intentionality [40], which has been only partially successful. If one looks explicitly for precedents to naturalization in philosophy, one finds that the term is generally used to describe a kind of grafting of philosophy onto science studies. This conceptual dead end suggests that the entire domain requires reconceptualization.

5.1. Husserl and the Naturalization of Phenomenology

In contemporary philosophy, phenomenology occupies a strange position: on the one hand, it seems to place major ontological value on appearance while at the same time denying access to it by science. Perhaps it is best seen from an historical standpoint as a reaction, perfectly understandable in the 20th Century, to the hegemony of reductionist scientific views of a universe in which a transcendental deity no longer had a place.

The 'naturalization of phenomenology' might however be considered an oxymoron to the extent that phenomenology was designed by Husserl to exclude physical reality. My view of physical reality is simply the world independent of our thought processes which are nevertheless part of it and without which it would not have meaning), as in the weak objectivity of D'Espagnat. Hussserl's approach of focusing on the unique lived character of experience available to individuals has led to the familiar definition of phenomenology. Familiar, also, is Husserl's later bracketing of the question of the existence of the natural world and its relation to experience vs. a realist ontology. As discussed below, the informational approach leads to alternate, and from an LIR standpoint preferable, descriptions of the co-existence of meaning and non-meaning in the world.

In the *Naturalizing Phenomenology* compendium of 1999, Roy [43] confirms that Husserl's phenomenological theory of intentionality is based entirely on the assumption that "truly adequate characterization of intentional phenomena can only be achieved by renouncing all forms of naturalism, both ontological and epistemological." I obviously agree with Roy that this is too high a philosophical price to pay. Although in Husserl every intentional state is conceived as one entity mediated by another, his relation of interpretation resembles that of Peirce with an ontological 'cut' between the interpretation and its intentional correlate. There is 'identity within difference', but not semantic, in my terms real, interaction between them.

5.2. Semiotics: Peirce and Brier

The semiotician Sören Brier has claimed that the semiotics of Charles S. Peirce can deliver the missing philosophical framework for phenomenology through his semiotic conception of a fundamental triadic structure of the universe. Semiotics is a transdisciplinary doctrine that studies how signs in general—including codes, media, and language, plus the sign systems used in parallel with language—work to produce interpretation and meaning in human and nonhuman living systems such as prelinguistic communication systems. For Peirce, a sign is anything that stands for something or somebody in some respect or context.

Sören Brier has pointed out the weaknesses in much of standard philosophical and sociological thought in general and phenomenology in particular. He thus writes [44] that Husserl, Heidegger, Merleau-Ponty, and Luhmann were unsuccessful in developing a proper philosophical framework for phenomenology. They did not offer any adequately deep picture of things in themselves in relation to appearance. Thus both Wu Kun (see below, Section 8) and Brier state that Husserl's transcendental idealism makes no contact with the world or the natural sciences. In particular, Wu has provided a unique analysis of Husserl from an informational standpoint [45]. I will simply reiterate here his key conclusion, namely, the complexity of human individual and social existence and experience cannot be captured by reference to a "life-world" and "intersubjectivity" that exclude the detailed functional role of information, information processing and the operation of the physiological and psychological structures necessary for that processing.

Peirce's introspectional method leads him to ascribe a foundational role to chance and spontaneity as causal factors. The subsequent classification of reality into "Firstness, Secondness and Thirdness" follows. I have argued that Peirce's system remains one of classification of phenomena in terms of representation by signs and symbols. It adds nothing that helps us understand the ontological basis of the way the world evolves. Signs obviously refer to existing therefore natural objects, but they are abstractions from them, and the corresponding relationship is not natural-philosophical as no dynamic, ontological relations obtain between the entities involved.

The above considerations are the basis of Brier's thesis outlined in his major book *Cybersemiotics* [44] whose sub-title is "*Why Information is not Enough?*". My reply is that semiotics is not enough since it does not incorporate in its 'flesh', to use the Merleau-Ponty and Lakoff concept, the dynamic, energetic changes from actual to potential, present, and absent that the term 'information' refers to.

5.3. The 'Flesh': Merleau-Ponty and Lakoff and Johnson

The contribution of Merleau-Ponty and his existentialist followers can be seen as a necessary reaction to the transcendentalism of Husserl. In his *Phenomenology of Perception*, Merleau-Ponty emphasized the role of the body in human experience. In the terms of Logic in Reality, his body-image is a kind of "included middle" between the mental and mechanical-physical domains. The human subject is inseparable from both his body and the world. Arran Gare has provided recent [47] authoritative discussion of Merleau-Ponty's trajectory which led him ultimately to embrace natural philosophy as the framework for his thought.

Unfortunately, by focusing on the human body (the 'flesh') as the primary philosophical entity, Merleau-Ponty effectively eliminated any foundational role for the properties of the underlying physical components of the 'flesh'. In my view, these properties that are not only consistent with consciousness and life but underlie their emergence as real and not epiphenomenal.

It is perhaps more than anecdotal to note that in a competition for a key position in the *Collège de France* in the 1950s, Merleau-Ponty was chosen over his contemporary rival—Lupasco. The marginalization of Lupasco can be dated to this event. As I have suggested in a paper in French [48], it is high time for this 'noble' marginalization to end. Finally, as I have discussed in another reference to Capurro's work [49], phenomenology should never, *pace* Husserl, have been conceived of as being a science in the first place.

5.4. Speculative Realism: 'Ends'

The basic concept of this paper is that the natural philosophical stance is augmented by inclusion of the logic of Lupasco outlined above. One of the consequences of my interpretation it that it becomes otiose to talk about the 'end' of phenomenology, like Sparrow, as in Sparrow's Speculative Realism [50] or even of the end of philosophy, as Heidegger famously did. If there is an 'end' to something, it is the splendid isolation of philosophy from science that amounts to a simplistic idealistic position. Philosophy, as opposed to phenomenology retains some transcendental aspects as essential to its existence as a domain of knowledge, even if concessions to satisfactory aspects of the scientific paradigm may have to be made. Philosophy and Natural Philosophy retain their specificities as disciplines within a transdisciplinary framework of which science and LIR are a part. The LIR categorical feature of non-separability denies the traditional philosophical division between theory and practice and looks for ways in which they overlap and inform one another. This process, and the mental movements it entails, are those which take place when a logic—LIR—is and should be considered as part of knowledge as a whole, including science, in what I have called the 'logical rejunction' of logic with knowledge initiated by Lupasco [51].

Let us now see, therefore, what a Philosophy of Information in relation to phenomenology and Natural Philosophy might bring to the table.

6. Luciano Floridi: Information Philosophy and Informational Structural Realism (ISR)

The concept of a specific Philosophy of Information was introduced by Luciano Floridi in Europe in order to bring some order into the many theories of and approaches to information. The debate went back to Wiener's "proto-physical" view of the nature of information—information is information, not matter or energy. LIR approaches the realist/anti-realist debate from a logical and scientific standpoint in which information as data or propositions are not primitive. From my perspective, Wiener's statement can no longer be accepted without some additional qualification. If the important properties of non-digital information are processual, causal, and value-bearing, in the LIR ontology, it is also energetic in nature.

I have discussed Floridi's Informational Structural Realism (ISR) [52], which I consider is supported by LIR at several points, in detail in my book, *Logic in Reality* [9] and in [53] and I will not repeat them here. I believe ISR is a useful tool to block radical anti-realist and anti-scientific scepticism. ISR, however, lacks the ontological dimension of LIR and cannot be included in the domain of Natural Philosophy. This position is supported by Beni in [54].

In the next section, I will show why I believe the Philosophy and Metaphilosophy of Information developed by Wu Kun in China can so be included.

7. Wu Kun and the Philosophy of Information

Working for over thirty-five years on a Philosophy of Information (PI) that includes an informational theory for all major fields of knowledge [7], Wu recovers dialectics as an appropriate strategy for philosophy and science, including social and political science. The basic insight of his Philosophy of Information is that the concept of objective reality = objective existence is too poor to describe the informational world. A proper new ontology and worldview is needed to describe the phenomenological characteristics of that existence. The development of Wu's thought, in and of itself, is equivalent to an 'emergence' from the ideological dialectical materialism of standard Marxism-Leninism. A more appropriate designation for Wu's doctrine is 'dialectical realism', a concept associated with the work of Theodor Adorno.

Wu's new informational view of the need for unification of critical disciplines and their formulation as a metaphilosophy constitute a major contribution, as yet little recognized outside China, to any general theory of information [55,56]. His theories constitute part of a new transdisciplinary paradigm, in which information has a central role in the transformation of the society and its approach to knowledge and the classical separation of the academic disciplines. In fact, Wu's approach constitutes and new, original and in my view necessary critique of the bases of modern philosophy as a whole.

In [57], Wu repeats his conviction that an informational ontological doctrine would provide the foundation for change in all other areas of philosophy, including epistemology. This statement of a new "open problem" has been addressed by Wu and the writer in a compendium relating information and the 'quest' for transdisciplinarity [58]. Our paper suggests convergence of science and philosophy in the area of information, and we propose reasons why this could be a phenomenon defining the contours of the Philosophy of Science and Philosophy in general.

Wu's picture confers an ontological dimension to the categorial discussions of information theory that have been largely epistemological, for example, the Philosophy of Information of Luciano Floridi (see above). In the perspective of this paper, the complex physical and non-physical real properties of information place the philosophy applicable to them within a generalized Natural Philosophy. This approach is consistent with my view of 'information-as-process' set out in my 2014 paper [10].

7.1. Information as Process

In the LIR view, real informational entities are processes, binary and non-binary, that are not independent of and cannot be discussed without reference to the *a priori* non-binary transfers of energy that are their source, in some real situation, at all levels of reality. The LIR approach thus incorporates and provides for a relation between information as well-formed, meaningful and truthful data (Floridi) and information as real energetic processes. Information-as-processes can function as higher-level operators, capable of causing change on information-as-data and higher level entities.

The approach of the sociologist and systems theorist Wolfgang Hofkirchner approach to a Unified Theory of Information (UTI) [59] is to eliminate the absolute and in my view artificial separation between critical concepts of information in favor of a dialectical relationship similar to the ancient intuition of 'unity-in-diversity'. Specifically, his "UTI seeks a concrete-universal concept of information rather than an abstract one". Hofkirchner considers information as a "superconcept", which includes a group of overlapping concepts—such as message, signal, etc.—as they apply to communication, cognition and cooperation between human and non-human organisms. Hofkirchner asks how matter and idea, mind, information, etc. can be grasped as complements and with them information as a thing (a structure, a flow) or as a human construction. Hofkirchner gives a dialectical answer to the implied division between subject and object, suggesting that mind, and with it information, is of a different 'materiality' than 'non-emergent' states of matter.

From the LIR standpoint, mind and information can be seen as "complements" if one sees them as processes. Structure, flow and "human processing activity" all follow the same real, physical dialectics. If matter and information are differentiated in a "common genus", for LIR, that genus is simply energy, and within it both follow its logical patterns of evolution, avoiding the problems of the term "different materiality". Logic in Reality is, also, a logic of emergence or "emergent materialism". In this view, information is, *pace* Wiener, an energetic phenomenon that instantiates real contradictions.

My conception of information as process should not be taken to exclude other perspectives. Marcin Schroeder seeks [60] the structural characteristics of information—syllogisms—using a combination of philosophical and mathematical perspectives (one/many; Boolean algebra; lattices of closed sub-sets). Such structures can be carriers of some new qualitative properties of information, for example the level of information integration which reflects the mutual interdependence of the elements of a variety. Schroeder has called the lattices involved the logic of the information system, by loose analogy to quantum logic.

However, the basic logic of this approach is in my opinion still a logic of propositions or their mathematical equivalents. The qualitative properties of information which are described are formal; these structural characteristics have no meaningful implications for real phenomena beyond their (clear) formulation. Accordingly, they are not within Natural Philosophy in the sense of this paper.

It is, rather, non-Boolean algebras together with non-Kolmogorovian probabilities that are appropriate systems for analysis.

7.2. Wu Contra Husserl

Wu expressed his views of the critical role of information in 2011 [61]. As noted above, in the light of information theory, the weaknesses of modern philosophy, from Kant through Husserl become apparent. It is the existence of information, even more than, but in concordance with, the logic of and in reality (LIR), that breaks the traditional absolute separation of subject and object. As noted above, although Husserl found a way of beginning to describe the reality of consciousness, his one-dimensional phenomenological reduction maintains, in another form, the disastrous (for human society) polarization of standard bivalent logics. As a hermeneutic process, Husserl's bracketing is thus fundamentally flawed. My conclusion from this discussion of phenomenology is that in the informational terms of Wu Kun, it can be included in Natural Philosophy. In its initial formulation by Husserl it cannot.

In the work of both philosophers and neuroscientists such as Searle and Deacon as well as Wu Kun, the basic worldview of natural science, namely, that consciousness is part of nature is upheld. As is discussed below, the advantage of an informational standpoint, or 'stance', is that information serves as the unifying concept between the fields of physics, biology, neuroscience and mind. In this sense, the philosophy of information is a more scientific and reasonable explanation of the mechanism of human understanding than in phenomenology.

Following Wu, I propose an informational ontology in which we as humans have (self-evidently) access to "things-in-themselves" as a 'natural phenomenology' that is objective or better objective and subjective in its interpretation of the structure of the world. We live, also as indicated in the dialectics of Lupasco, by adhering to route on which "the natural noumenon's own movement explains the world".

Thus, functional and operational definitions of information have their role to play in practical applications. However, they fail to capture both the intrinsic dynamics of complex processes and the nature of information itself which is instantiated in them. For the understanding of knowledge and knowledge propagation, drastic modifications of points in standard epistemology, also foreseen in LIR, have to be made.

7.3. The Science-Philosophy of Information

The insights gained in the study of the unique scientific and philosophical characteristics of information are summarized in [58]. Wu's original idea is that what is taking place in philosophy is a 'scientification' of philosophy and a 'philosophization' of science, his terms for the convergence of the disciplines under the influence of the unique properties of information processes. The term Unified Science of Information has been applied to characterize the convergence, but this is not strictly accurate, as the convergent theory includes the Philosophy of Information as a proper part, without conflation. We therefore proposed the term Unified Science-Philosophy of Information (USPI) as the best possible description of this field.

The philosophical stance of USPI may be usefully compared to Hofkirchner's proposal [15] of a praxio-onto-epistemology (POE) as "a response to the current developmental requirements of humanity". According to Hofkirchner, (I invert his order of points) we need to (1) reflect the unity of the physical world by the unity of the world of knowledge; (2) the unity of the social world presupposes the unity of the physical world; (3) the survival of civilization itself depends on establishing a new world order, a unity of the social world. Traditional approaches are apparently stuck in the three disciplines of epistemology, ontology, and praxiology as alternatives. POE offers a transdisciplinary response for going beyond them. It is a synthesis, and a concept for inclusion in a new Synthetic Philosophy that resembles that of LIR and the USPI in this respect.

Wu and I concluded that what has been defined is both new content of the philosophy of science and new dynamics of the relations between a science and its philosophy. The dynamics of the processes can be captured in the concept of a trend toward an Informational Metaphilosophy of Science as the most appropriate model of knowing and reasoning. This Philosophy-Science justifies a new non-reductionist view of the world in which it is ethically impossible to maintain any scientific basis for economic, social or ethical exclusion. The use of this doctrine to promote the development of an information commons and the common good is thus a moral as well as a methodological imperative.

From the point of view of this paper, everything that could be considered part of such a Unified Science-Philosophy of Information, or which could be described as a science-philosophy in general would be part of Natural Philosophy. The Philosophy of Science itself could thus also be segmented based on the same criterion.

7.4. The Philosophy of Natural Computation

Computational approaches are currently at the center of developments in the theory and philosophy of information; what form of computationalism is most adequate is a metaphilosophical issue. The theory comes in two major forms, (1) pan-computationalism or strong computationalism, which includes statements that the universe operates like a computer; and (2) a weaker form, developed by Gordana Dodig-Crnkovic [27], informational or info-computationalism (ICON) which reflects Floridi's view of the universe as an informational structure (see above), in which natural computation governs the dynamics of information.

Natural computation represents implementation of physical laws on an informational structure within a living system. Her work thus presents a synthesis of two paradigms within contemporary philosophy—computationalism and informationalism - into a new dual-aspect info-computationalist framework. The dualism itself does not mean that the phenomena are separated, and exclude each other. On the contrary, they are mutually determining, constraining, and completely indissoluble. Structures and the processes are inseparably interwoven by physical laws, as described by Dodig-Crnkovic, and LIR gives logical underpinning to the dynamics of "interwoven". ICON, as a naturalized epistemological approach, it conceptualizes information as both here (intelligence), there (world) and on the interface, as information constitutes the basic 'stuff' of existence. It grasps many features of natural processes.

In the context of this study, computationalism as natural computation thus appears as an acceptable, natural philosophical component of a Metaphilosophy of Information as I have defined Natural Philosophy.

7.5. The Logic of the Third

In his approach to a Unified Theory of Information (UTI), Hofkirchner does not refer to the fields of philosophy or the philosophy of information as such. However, many of his concepts and formulations illuminate core philosophical, logical and ethical problems, in the context of the 'informational turn' and with a clearly stated objective of furthering a Global Sustainable Information Society (GSIS).

As Hofkirchner writes [15], a UTI should be a logical as well as an historical thesis, explaining not only the historical appearance (emergence) of new information processes and structures but how these processes and structures are logically linked. Hofkirchner explicitly excludes standard deduction as incapable of accomplishing this task, but LIR would appear to be an acceptable candidate for doing so.

His combination of critical thinking and systems thinking—of Critical Theory and Systems Theory—includes what he calls the Logic of the Third [63]. The (informal) Logic of the Third is the foundation of a critical social systems theory, in which "criticism is a method oriented toward recognising and sublating contradictions". Hofkirchner is an adept of Hegel; I will only remind readers here that real contradictions have a positive valence in Lupasco and LIR. 'Management' rather than elimination of them is my preferred strategy.

Hofkirchner states that given a society characterized by agonisms, legitimate agonistic differences can and do degenerate into antagonistic denials of the 'other' when social actors try to impose their own interests exclusively. This phenomenon can be considered as one principle of this Logic of the Third:

only the social relations that reinforce one's own position enter into consideration as a 'mechanism' that operates for the transformation of agonisms into antagonisms. The most important question is if and how a needed 'mechanism' of turning antagonisms into agonisms can work, how it can take the edge off them, how it can sustainably de-escalate them—a question to be answered according to the same Logic of the Third. A conjunction between Hofkirchner's approach and Logic in Reality is easily found: Lupasco's central 1951 book is entitled, in English, "The Principle of Antagonism and the Logic of Energy" [16]. LIR is, also, a logic of an emergent 'third' element in real processes and included without difficulty the real antagonism between human beings as logical in this sense.

Another classical philosophical problem, with which both LIR and Hofkirchner are concerned, is the relation between the 'one' and the 'many'; identity and diversity; and identity and difference. This is a key concept in Lupasco's dynamic logic of/in reality in which movement from primarily diversity or heterogeneity to unity or homogeneity was as fundamental as that between actuality and potentiality in the basic structure of the universe.

Hofkirchner proposes the relation between identity and difference as describing four ways of thinking: reductionism, projectivism, disjunctivism, and integrativism. The first two yield unity without diversity, the third diversity without unity. The fourth, as also expressed by the contemporary philosophers Edgar Morin, yields the necessary unity-in-diversity and diversity-in-unity. Hofkirchner applies these concepts to information in a doctrine of emergent materialism (EM) that goes beyond materialistic and idealistic monism and (even) interactive dualism. The dialectics of EM recognizes, like the theory of Wu Kun, the identity and difference of matter and information. EM is a philosophy of mind, "overarching all manifestations of information and not only mind."

Logic in Reality is compatible with part but not all of this approach. LIR provides a realistic interpretation of the physical, dialectical relation, a grounded 'interactive dualism' between identity and diversity, a unity-in-diversity and a diversity-in-unity as well as between the terms of other critical physical and philosophical dualities. As stated above LIR, in contrast to standard bivalent or multivalent propositional logics, it provides the basis for an ethics as the finality for the intellectual process, a principle which also pervades the work of Hofkirchner. It thus satisfies both my formal and moral criteria for a Natural Philosophy.

7.6. The 'Incomplete Nature' of Terrence Deacon

The currently prevailing assumptions about the nature of information are still based largely on computational extensions of Shannon's original ideas, sufficient to explicate its minimal physical characteristics but insufficient to define its representational character or its functional, qualitative, and normative value. The biologist Terrence Deacon has proposed a new approach to information as a process instantiating a complex dynamics that starts with thermodynamics and continues throughout higher ontological levels of form (morphodynamics) and intentionality (teleodynamics). In his *Incomplete Nature* [14], Deacon extends a thermodynamic concept of energy derived from statistical mechanics to yield a complete and cohesive description of complex processes, in which absence, the fact of being not or not completely present, plays a critical role in the emergence of living systems, mind, and information.

Deacon shows the central role of negative relationships defined with respect to absence. The concepts of information, function, purpose, meaning, intention, significance, consciousness, change and human value are intrinsically defined by their fundamental incompleteness.

This is similar to the LIR picture of energy as an energy-matter duality, with a critical role of potential as well as actual properties of processes. My own presentation of a concept of information focused on its dynamic characteristics—information as a process constituted by energy but carrying meaning [65]. Deacon shows how the operation of both Shannon entropy and Boltzmann entropy must be taken into account in information, and Logic in Reality (LIR) further suggests that information involves non-Markovian processes.

In my 2012 paper [28], I demonstrated the complementarity of the LIR and Deacon approaches to what is not, or not fully, present—not "there"—in gaining an understanding of the dynamics of complex phenomena, especially, of intentionality, information and ethics. My own presentation of a concept of information focused on its dynamic characteristics—information as a process constituted by energy but carrying meaning.

Deacon showed that the key feature of information is its absent content, a resultant function of the necessary physicality of information processes. LIR shows that presence (actuality) and absence (potentiality) in such processes must be related dynamically. While the importance of a concept of absence for information was indicated by Marijuan 10 years ago, it is Deacon's detailed current development that now calls for our attention.

LIR provides a necessary further *validation* of the role of absence as defined by Deacon, in relation to presence, and prepares its *valuation*. Valuation of absence and negation in general is logically equivalent to the valuation of the other, immanently. Thus in addition to explicating the evolution of complex processes, Logic in Reality, unlike all standard logics, founds an ethics and this implies, today, an ethics of information.

The work of Deacon and Logic in Reality share the ontological feature of being firmly grounded in physical processual reality. The latter enables a critique of the former such that principles of the combined theories offer a new platform for progress in the science and philosophy of life. Meaning, morality, emergence have their own logic and real dynamics and do not need to import natural philosophical principles from outside of physics. In more recent work [66], Deacon and Cashman explored further the philosophical implications of absence as incompleteness, emphasizing that it is a necessary component for the description of a real world that includes meaning and human values. I thus see his work as a major contribution to a new Natural Philosophy.

8. Conclusions

The theory outlined in this paper starts from a logic grounded in science and applied to philosophy. This non-standard logic of processes in/of reality, LIR, is a rigorous alternative to bivalent or multivalent propositional logic as a requirement for a valid system.

LIR can be a method of distinguishing between Natural Philosophy and philosophy *tout court.* It is based on the assumption that energy deploys itself in all existence, in particular in human existence and complex cognitive and social processes, in a movement from actuality to potentiality and vice versa, alternately and reciprocally, without either totally disappearing, except in trivial static cases. This logic, which I call Logic in Reality, supports and is supported by parts of doctrines from many different and disparate sources, including some of the informal perspectives of Eastern, in particular Chinese world-views. This logical approach establishes non-separability as a basic ontological principle and, among other things, supports the role of 'the other' in society, an argument in favor of social-economic justice and the common good.

The domain of philosophy-as-such, 'just' philosophy, as a separate discipline is best directed toward the study of general principles, such as the unity of knowledge and speculative, 'fundamental' questions such as "why is there something rather than nothing?" A characteristic feature of such questions is that they do not change, although an individual's interpretation of them will obviously be a function of his or her context. In this domain I include apparently dynamic theories such as category theory, semiotics and quantum-type logics applicable to macroscopic phenomena which in fact retain the principles of standard propositional and mathematical logics. Their capability of describing the 'interesting', that is, interactive, changing and moral aspects of phenomena is accordingly limited.

The phenomenon of human and animal consciousness is placed squarely in the domain of Natural Philosophy. Representations and beliefs are natural *qua* the mental processes from which they develop; they are only pure philosophy with regard to content, even if they refer to real objects and can be verified *a posteriori*. As in the case of organism evolution, it is only by examining the dynamics of lower-level emergent processes that we will be able to adequately explain the sentience, representation, perspective, and agency that are the hallmarks of mental experience as a dynamic proces. Rather than being the ultimate "hard problem" of philosophy and neuroscience, the subjective features of neural dynamics are the expected consequences of its emergent hierarchy, as discussed by Deacon [66]. The so-called mystery of consciousness may be a false dilemma, created by our failure to understand the causal efficacy of emergent constraints.

I have addressed two major errors that have been made in the discussion of lived experience: one is to 'bracket' it, following Husserl; the other is to deny that it has a scientific or at least regular, partly reproducible properties, structure and dynamics. The anti-scientific approach had perhaps the laudable intention of avoiding reductionism, but it lacks the necessary coherence to function as a guide to ethical behavior. Transcendental intuition is not a concept within Natural Philosophy as discussed in this paper.

The formulation of LIR does not preclude and welcomes the development of alternative, opposing logical systems, in which some logic is explicit or implied. I have suggested elsewhere the work of Derrida [67] on "grammatology as a positive science" and the process philosophy of Seibt as examples. However, I cannot accept as candidates for any such newer, expanded theory those which aim at some absolute truth or certainty. My 'philosopher's stone' tests for the absence of pure concepts, conceptions of pure 'things'—identities, static concepts, and unstructured diversities without a minimum of self- and hetero-organization. LIR seeks the presence of physical processes-in-progress, all of which are meaningful and capable of being re-cognized as such.

If one accepts that Natural Philosophy should be a coherent but dynamic doctrine with the above properties, capable of integrating science without falling into 'scientism', Logic in Reality is a tool for achieving this 'naturalization'. Accordingly, I look forward with great interest to reading the other papers in this special issue and the revisions and additions to Logic in Reality, as well as other ideas that they may suggest.

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philosophies

Article

MES: A Mathematical Model for the Revival of Natural Philosophy

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Abstract: The different kinds of knowledge which were connected in Natural Philosophy (NP) have been later separated. The real separation came when Physics took its individuality and developed specific mathematical models, such as dynamic systems. These models are not adapted to an integral study of *living systems*, by which we mean evolutionary multi-level, multi-agent, and multi-temporality self-organized systems, such as biological, social, or cognitive systems. For them, the physical models can only be applied to the local dynamic of each co-regulator agent, but not to the global dynamic intertwining these partial dynamics. To 'revive' NP, we present the Memory Evolutive Systems (MES) methodology which is based on a 'dynamic' Category Theory; it proposes an info-computational model for living systems. Among the main results: (i) a mathematical translation of the part–whole problem (using the categorical operation colimit) which shows how the different interpretations of the problem support diverging philosophical positions, from reductionism to emergentism and holism; (ii) an explanation of the emergence, over time, of structures and processes of increasing complexity order, through successive 'complexification processes'. We conclude that MES provides an emergentist-reductionism model and we discuss the different meanings of the concept of *emergence* depending on the context and the observer, as well as its relations with anticipation and creativity.

Keywords: category theory; memory evolutive system; emergence; emergentist reductionism; anticipation; creativity; info-computational model

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1. Introduction

For Aristotle, "Natural Philosophy" (NP) is a branch of Philosophy which examines the phenomena of the natural world; it includes fields that are now classified as physics, biology, and other 'natural' sciences. This division of Science into specific disciplines came later. In particular Physics only took its more restrictive modern sense around 1690, with Galileo, Descartes, and Newton.

Today, the aim is to search for connected knowledge able to re-unify sciences and revive NP, for instance in Complexity Theory and Network Science. For Truesdell [1]: "The first aim of modern natural philosophy is to describe and study natural phenomena by the *most fit* mathematical concepts. The most fit need not be the most modern, but < . . . > we neither seek nor avoid the most abstract mathematics".

1.1. Mathematical Models in Physics

Among the usual mathematical models in Physics figure dynamic systems (generally employing differential or difference equations), nonlinearity and chaotic dynamics. They are based on the concept of *phase space* which was developed in the late 19th century by Ludwig Boltzman, Henri Poincaré, and Willard Gibbs. In dynamical system theory, a *phase space* is a space in which all possible states of a system are represented, with each possible state corresponding to one unique point in the phase space. For mechanical systems, the phase space usually consists of all possible values of position and momentum variables. In quantum physics, it is a little more difficult to describe this space, but there exists an analog.

The phase space model cannot lead to an integral model for complex dynamic living systems. By *living system*, we always mean evolutionary multi-level, multi-agent and multi-temporality self-organized systems, such as biological, social, or cognitive systems. The reason is that these systems are submitted to frequent environmental constraints which would necessitate incessant changes of phase space; thus we cannot find a unique phase space in which to proceed (cf. Longo et al. [2]). In these cases, the phase space model can only be applied locally and on a short duration; for instance, in multi-agent systems, the dynamic of a co-regulator agent is computable on its specific landscape, during one of its steps (Section 3.2); the global dynamic, which results from complex interactions between these local dynamics, is generally non-computable and unpredictable on the long term.

The problem is to develop new methods for studying the system in its integrality, for instance Plamen Simeonov [3] has proposed an *Integral Biomathics* for studying biological systems. In complexity theory, a complex system is represented as a network (or directed graph) having for objects the components of the system and for arrows the links between them through which they can interact.

1.2. Composed Objects: The Part–Whole Problem

Reductionism dates back to the 1600s when Aristotle's Laws of Thought were used by Descartes and Newton to explain their theories. The general idea is to deduce the properties of a 'whole' complex system from those of (some of) its better known 'parts', for instance some of its subsystems justifiable of computational methods. It is related to the philosophical part–whole problem: to determine the new set of integrative properties that acquires the single 'composed' object obtained by aggregation of a pattern of interacting objects when these objects are joined together. The problem was already raised by Aristotle in his Metaphysics [4]: "What is composed of something so that the whole be one is similar not to a pure juxtaposition, but to the syllabus. The syllabus is not the same as its component letters: ba is not identical to b and to a, it is still something else". This sentence has led to different non-equivalent interpretations:

- "The whole is nothing more than the sum of its parts";
- "The whole is something else than the sum of its parts";
- "The whole is more than the sum of its parts".

These interpretations lead to different philosophical positions, from 'pure' reductionism, to emergentism (and even holism when conjugated with "the whole must of necessity be prior to the parts").

In Section 2, we will show how the categorical concept of *colimit* of a diagram (or pattern) gives a precise mathematical translation of the part–whole correspondence that makes clear the above distinctions. In fact, it allows for a formal definition of a composed object as an aggregate of a pattern of interacting objects, which is at the basis of the concept of a multi-level system.

1.3. Compositional Hierarchy

A multi-level system, such as a living system, can be modeled by a *compositional hierarchy* (in the sense of Salthe [5], that is a system, in which the components are distributed in different complexity levels (from 0 to m), with the following property: a component C of a higher complexity level is a composed object acting as a 'whole' aggregating a pattern of interacting components of lower levels.

This part-whole correspondence can be one-to-one or not, in which case C is the aggregate of several structurally non-isomorphic lower-level patterns P_i. In this case, we say that C is *multifaceted* and that the P_i's represent its lower-level *multiple realization* (compare with Kim [6]). Over time, new multifaceted components of increasing complexity may 'emerge', generally due to non-linear phenomena or chaotic dynamics.

A compositional hierarchy is a *holarchy*, meaning that a component of level other than 0 acts as a *holon* (Koestler [7]): it is a 'whole' with respect to (each of) its lower-level decompositions, and a 'part' for a higher component to which it is connected. The different levels are intertwined, with intra-level interactions from lower to higher levels, and vice-versa. A component can simultaneously receive information from objects of any level, and in response send messages to any level, as long as the necessary material (e.g., energy) constraints are satisfied. For instance, an enterprise has such a hierarchical organization with several levels: individuals, departments, from small producing units to higher directorial levels. The links between different components represent channels through which they exchange information and can collaborate to achieve a common goal.

A pure methodological reductionism to the lowest level 0 (e.g., molecular level for biological systems) would mean that each object of a higher level is the simple aggregate of a pattern of interacting objects of level 0. A main result (Section 2.4) asserts that such 'pure' reductionism is not possible if there are multifaceted objects, in which case we have an "*emergentist reductionism*" (in the sense of Mario Bunge [8]). This result is obtained in the frame of the following methodology.

1.4. The MES Methodology for Reviving NP

Reviving NP requires to design pervasive models adjustable to different kinds of systems, from physical systems to multi-level living systems, able to adapt to changing conditions through learning and to account for the development of emergent properties over time. At this end, in the sequel, we propose the mathematical methodology named *Memory Evolutive Systems* (MES), introduced by Ehresmann and Vanbremeersch [9,10], to study evolutionary multi-level, self-organized complex systems such as living systems, with the following properties:

- they have a tangled hierarchy of components which vary over time, with possible loss of components as well as emergence of more and more complex components and processes;
- through learning, they develop a robust but flexible memory allowing for better adaptation;
- the global dynamic is modulated by the interplay between the local dynamics of a net of specialized agents, called *co-regulators*, each operating stepwise with the help of the memory.

MES is a kind of info-computational model (in the sense of G. Dodig-Crnkovic [11]) which interweaves two mathematical domains: a Category Theory incorporating time to model the organization of the system and its changes over time; and hybrid Dynamic Systems to study the local dynamics of its co-regulators. While the local dynamics of the co-regulators might be computable via usual physical models, the global dynamic is generally not computable and even unpredictable on the long term (cf. Section 3).

MES have developed applications in different domains: (i) Biology (Integral Biomathics [12], Immune system, Aging theory [10]); (ii) Cognition (integrative model MENS of the neuro-cognitive system, up to the emergence of higher cognitive processes [13], and even neuro-phenomenology [14]); (iii) Collective Intelligence and Design Studies (D-MES [15]); (iv) Anticipation and Future Studies (FL-MES [16]).

For a complete theory of MES, we refer to the book [10] and, for more recent applications, to papers on the site [17].

1.5. Outline of the Article

In Section 2, we briefly recall the categorical notions of a colimit (Kan [18]) and of a hierarchical category [9] and discuss their philosophical implications with respect to the part–whole problem and to the categorical modeling of a compositional hierarchy. Defining the notion of a multifaceted object in a hierarchical category, we prove that the existence of such components is at the basis of emergent properties. The Reduction Theorem asserts that the absence of multifaceted objects is necessary for pure reductionism. A main construction is the *Complexification Process* (CP) that explains how *complex* links are at the basis of the emergence of objects of higher complexity orders (*Emergence Theorem*).

In Section 3, we recall the local and global dynamics of a MES. In particular, we explain how iterated CPs may lead to unpredictable emergent behaviors. We deduce from these results that MES propose an 'emergentist reductionism' [8] model for living systems, and so could be a valid candidate to 'revive' Natural Philosophy. Section 4 discusses how the meaning of emergence depends on the observer and the context, and studies the relations of emergence with anticipation and creativity.

2. Categories for Modeling Multi-Level Systems

Category theory is a domain of Mathematics introduced by Eilenberg and Mac Lane [19] in 1945. It is a 'relational' theory, in which the structure of objects is deduced from the morphisms which connect them. It has a foundational role in mathematics by analyzing the main operations of the "working mathematician" [20], thus reflecting some of the prototypical operations that man does for making sense of his world: distinguishing objects and their interrelations; synthesis of complex objects from more elementary ones (colimit operation) leading to the emergence of more complex objects and processes (complexification process); optimization processes (as solutions of 'universal problems' [20]); classification of objects into invariance classes (formation of concepts).

2.1. Categories for Modeling Complex Systems

Networks of any nature are often represented by (oriented multi-)graphs. Such a *graph* is a set of objects and a set of directed arrows between them. A *category* is a graph on which there is given an associative and unitary composition law which associates to each path (=sequel of adjacent arrows) of the graph a unique arrow, called its *composite*, connecting its extremities; an arrow of the category is also called a *morphism*.

Examples of categories:

- *Small categories*: A monoid is a category with a unique object. A group is a category with a unique object and in which each morphism has an inverse. A category K with at most one morphism between two objects 'is' (associated to) a p(artially)o(rdered)set (K_0, <), where K_0 is the set of objects of K and where the order < on it is defined by: k < k′ if and only if there is a morphism from k to k′ in K.
- *Categories of paths:* To a graph G is associated the category of paths of G, denoted by L(G): the objects are the vertices of G, a morphism from x to x′ is a path from x to x′ and the composition of paths is given by concatenation.
- *Large categories: Sets* denotes the category having for objects the (small) sets and for morphisms from A to B the maps from A to B; the composition is the usual composition of maps. Similarly we define categories of structured sets, for instance the category of groups, with homomorphisms of groups as morphisms; the category *Top* of topological spaces, with continuous maps as morphisms. *Cat* denotes the category having for objects the (small) categories H and for morphisms the functors between them, where a functor F from H to H′ is a map which associates to an object A of H an object F(A) of H′ and to a morphism f: A → B of H a morphism F(f): F(A) → F′(B) of H′, and which preserves the identities and the composition.

In applications to evolutionary systems whose components vary over time (for instance in MES), the configuration of the system at a given time t will be modeled by a category H. Its objects model the (state at t of the) components of the system which exist at t; its morphisms model their interactions, via channels through which they can exchange information of any nature. More precisely, if C is an object, the morphisms arriving at C transmit information, constraints, or commands sent to C, those issued from C transmit information allowing for actions of C toward other objects. Thus if f: A → C is a morphism (or arrow) from A to C, we think of A as an active transmitter of information and C as a receiver.

The composition law defines an equivalence relation on the set of paths of the category H: two paths are equivalent if they have the same composite; then the category H is the quotient category of the category L(H) of paths of H by this equivalence. In concrete applications, objects and morphisms can represent elements which have specific 'physical' properties (measured by real observables, e.g., activity at t, strength, propagation delay, . . .); and paths which have the same composite correspond to paths which are functionally equivalent. A *diagram* (or pattern) P in the category H defines a sub-graph of H. The diagram is commutative if, for each pair of objects P_i and P_j, the paths in P from P_i to P_j have the same composite. In category theory, commutative diagrams lead to a kind of calculus in which they play the same role as equations in algebra.

2.2. Interpreting the Part–Whole Problem via the Categorical Notion of Colimit

To interpret a sentence such as: "the whole is nothing more than the sum of its parts", we need to specify what we mean by 'parts', by 'sum' and by 'whole'. In a general network, there is no natural way to do this because we cannot compare parallel paths. The situation is different in a category where the composition law allows distinguishing paths which have the same composite, meaning, in concrete applications, that they are 'functionally equivalent'.

2.2.1. The Categorical Notion of Sum

The sum of a family of objects can be modeled using an important categorical operation, namely the coproduct operation, which is a particular case of the colimit operation introduced by Kan in 1958 [18]). Formally:

Definition 1. *In a category H, the* coproduct *(or* sum*) of a family of objects P_i, if it exists, is an object S of H such that there exists a family of morphisms s_i: $P_i \to S$ satisfying the 'universal' condition:*

> *if (a_i) is a family of morphisms a_i: $P_i \to A$ toward any object A, then there is a unique morphism a from S to A 'binding' this family, meaning that a: $S \to A$ satisfies the equations $a_i = s_i a$ for each i (cf. Figure 1).*

(Let us note that these equations, which mean that for each i the composite $s_i a$ is equal to a, would have no meaning in a network where composites are not defined).

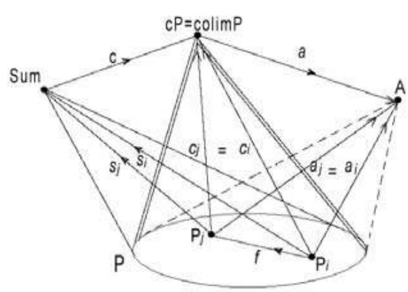

Figure 1. A pattern P, the colimit cP of P and the sum S of the family of objects of P. The colimit cone (c_i) from P to cP binds into the comparison morphism c from S to cP.

With this notion, the sentence "the whole is nothing more than the sum of its parts" becomes: "The whole is modeled by the coproduct S of the family of objects P_i modeling its parts". It corresponds to a 'structural' reductionism (in a non-relational context).

2.2.2. The Categorical Notion of *colimit*

Let us consider the sentence: "the whole is something other than the sum of its parts" which corresponds to the Aristotle's example of the syllabus ([4], cf. Section 1.2): In this case, the data are not only the family of parts P_i but also 'something else', namely some given relations between them.

In a category H, these data are represented by a *diagram* (also called *pattern*) P whose objects represent the objects P_i and whose morphisms represent the given relations between them, so that the entire P models the parts and their organization.

To characterize the 'whole' associated to a pattern P, the idea is to represent it by the colimit of P in H (if it exists). For that, let us first define what is a *collective link* from P to an object A; in concrete applications, it corresponds to an 'action' (emission of a message, constraint, command, . . .) performed by the pattern acting collectively (whence the name) in the respect of its organization, and which could not be realized by its objects acting separately Translated in categorical terms, a collective link from P to A in H is modeled by a *cone with basis* P and vertex A, that is a family (a_i) of morphisms a_i from P_i to A such that, for each morphism f: $P_i \to P_j$ in P we have $a_j = a_i f$ (cf. Figure 1).

Definition 2. *Let P be a diagram in the category H. The colimit of P, if it exists, is an object cP such that there exists a cone (c_i) from P to cP (called a colimit-cone) satisfying the 'universal' condition:*

> *For each cone (a_i) from P to any object A there is a unique morphism a from cP to A such that we have: $a_i = c_i a$ for each i; this a is called the binding of the cone (a_i).*

For instance, if H models a chemical system, a molecule is the colimit of the pattern formed by its atoms with the chemical bonds which determine its spatial configuration. A pattern P in H may have at most one colimit cP (up to an isomorphism of H). Conversely, different non-structurally isomorphic patterns of H may have the same object C as their colimit; in this case we say that C is *multifaceted*; we come back to this case in Section 2.3.

By modeling the 'whole' as the colimit cP of the pattern P modeling its 'parts' and their organization, the sentence "the whole is something other than the sum of its parts" becomes: "the colimit of P is different from the sum of the objects of P". In a category where there exist both a colimit cP of a pattern P and a sum S of the family of its objects, this sentence takes a precise meaning, allowing to 'measure' the difference between S and cP by a well-defined morphism c (Cf. Figure 1).

Proposition 1. *Let P be a pattern in a category H; if there exist both the colimit cP of P and the sum S of its family of objects, then there exists a 'comparison' morphism c from S to cP.*

Proof. By the universal property of the sum, the family (c_i) of morphisms forming the colimit-cone from P to cP binds into the comparison morphism c from S to cP. □

Thus in the relational context H, we have a *reduction* of the 'whole' cP to the pattern P representing its parts and their organization, but not to (the sum S of) its parts. In the other way, to model the 'whole' as the colimit of P imparts to it an *emergent property* in H, namely that any cone with basis P uniquely factors through the colimit cone; we come back to this in Section 4.1.

2.3. Categorification of A Compositional Hierarchy

Using the preceding representation of a 'whole' as the colimit of the pattern of its 'interacting parts', and thinking of the whole as something more complex than its parts, we can model the notion of a 'compositional *hierarchy* given in Section 1.3 as follows.

Definition 3 [9]**.** *A hierarchical category is the data of a category H and a partition of the set of its objects into a finite number of levels of complexity, numbered from 0 to m, verifying the condition: Each object C of the level n+1 is the colimit of at least one pattern P of interacting objects P_i of levels less or equal to n. Then we call P a lower-level decomposition of C. A morphism of level n is a morphism between objects of level n.*

By definition of the colimit, it means that C admits at least one lower-level decomposition in a pattern P verifying: for any object A of H there is a one-to-one correspondence between the cones from P to A and the morphisms from C to A. Roughly, each object C of a level > 0 'aggregates' at least one lower-level decomposition P, so that C alone has the same operational role that the pattern P acting collectively. It follows that, in a hierarchical category, an object C of level > 0 acts as a *holon* playing as a Janus (Koestler [7]): It is a 'whole' more complex than the objects of one of its lower-level decompositions P, while accounting for the constraints imposed by their interactions in P. At the same time C acts as a 'part' of a more complex object C′ if C is an object of a pattern admitting C′ for colimit. For instance, in the hierarchical category representing a society, a group of interacting people is 'more complex' than its members, but 'less complex' than a society to which it belongs.

Going down the levels, we can construct at least one *ramification* of C down to level 0 (cf. Figure 2), obtained by taking a lower-level decomposition P of C, then a lower-level decomposition Π_i of each object P_i of P, and so on, down, till we reach a set of patterns of level 0 which form the *base* of the ramification.

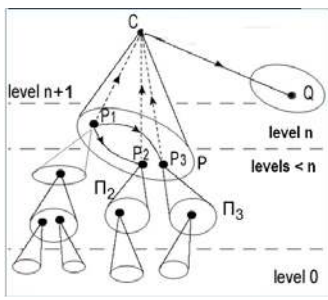

Figure 2. A hierarchical category with a ramification of an object C.

Definition 4. *In a hierarchical category H, the complexity order of an object C of H is the smallest length of a ramification of C down to level 0. This order is less than or equal to the level of C.*

While the complexity level of an object is specified in the definition of the hierarchical category H, its order of complexity (to be compared to the Kolmogorov–Chaitin complexity of a string of bits) is the result of a computation accounting for the whole structure of the category. For instance, if C is an object of complexity order 2, there is no pattern of level 0 of which C is the colimit (otherwise C would be of order 1), but C has a ramification (P, (Π_i)) where P is a pattern of level < 2 having C as its colimit, and Π_i for each object P_i of P is a pattern of level 0 with P_i as its colimit. The patterns Π_i (some of which can possibly be reduced to an object of level 0) form the *base* of the ramification. This base is not sufficient to re-construct C from level 0 up since we need supplementary data expressing the constraints imposed by the morphisms of P.

2.4. Simple and Complex Morphisms: The Reduction Theorem

The (methodological) reductionism problem in a compositional hierarchy consists in a 'reduction' of the system to one of its levels (say the lowest one): can we deduce the properties of the whole system from the properties of its objects of level 0 and their relations? This problem will be analyzed in the categorical setting. Let H be a hierarchical category. We know that all its objects are connected to patterns of level 0 through the unfolding (possibly in several steps) of a ramification of C. Is there something analog for the morphisms? This problem necessitates to characterize different kinds of morphisms.

2.4.1. Morphisms between Complex Objects Deducible from Lower Levels

Let C be an object which is the colimit of a pattern P and C′ an object which is the colimit of a pattern P′. A *cluster* from P to P′ is generated by a family of 'individual' morphisms connecting each object P_i of P to objects P'_j of P′, well correlated by a zig-zag of morphisms of P′ (Cf. Figure 3).

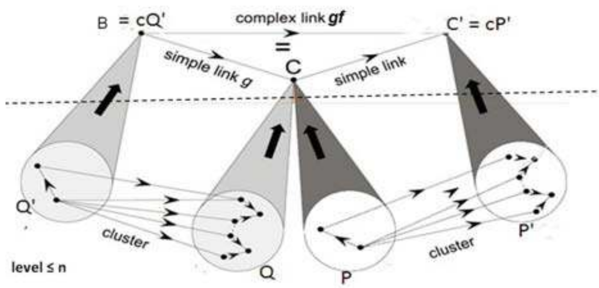

Figure 3. C is an n-multifaceted object which is the colimit of P and of Q. Then the composite of the n-simple morphism from B to C with the n-simple morphism from C to C′ is a complex morphism.

From the universal property of the colimit, it follows that such a cluster *binds* into a unique morphism f from C to C′, called a (P, P′)-*simple morphism* or just an n-*simple morphism* if the objects of P and P′ are of levels ≤ n. If C and C′ are of level > n, such an n-simple morphism represents a morphism of level > n which transmits only information mediated through individual objects of the patterns, hence entirely accessible at level ≤ n; we can say that g is *reducible* to (the cluster) of level ≤ n. Let us note that any morphism f of level ≤ n is n-simple, as well as a morphism connecting an object of level n+1 to an object of a level ≤ n. An n-simple morphism is also n′-simple for n′ > n, A composite of n-simple morphisms binding adjacent clusters is still an n- simple morphism.

2.4.2. Multifaceted Objects

Multifaceted objects [21]. Let C be a complex object of level n+1. Two decompositions P and Q of C are said to be structurally isomorphic if the identity of C is both a (P, Q)-simple morphism and a (Q, P)-simple morphism, meaning that there exista cluster G connecting P and Q whose binding is the identity of C and a cluster from Q to P whose binding is the identity of C. [Formally it means that G defines an isomorphism in the category Ind(H) having for objects the patterns in H and for morphisms the clusters between them.] However C may also have structurally non-isomorphic decompositions.

Definition 5. *Let C be an object of level > n of the hierarchical category H. We say that C is n-*multifaceted *if C admits at least two structurally non-isomorphic decompositions P and Q of levels ≤ n; the passage from P to Q is called a switch. The category H is said to satisfy the Multiplicity Principle (MP) if, for each n > 0 it has n-multifaceted objects.*

If C is multifaceted, it also implies that C has several structurally non-isomorphic ramifications down to level 0.

The notion of multifaceted objects (initially called multiform objects in Ehresmann and Vanbremeersch [21]) and the MP have been introduced to formalize the concept of degeneracy of the neural code introduced by Edelman [22], that he later generalized to all biological systems "Degeneracy, the ability of elements that are structurally different to perform the same function or yield the same output, is a ubiquitous biological property < . . . .> a feature of complexity." (Edelman and Gally [23]). For instance, different codons of the same amino acid remain unrelated at the atomic level, though they give rise to the same molecule at the molecular level. Or the two possible images in an ambiguous figure gain their 'symmetry' only when they are interpreted in relation to the complete figure, not when they are apprehended separately. The word degeneracy reflects a *flexible redundancy of function* (from bottom to top). We prefer to look from top to bottom and call this property the *Multiplicity Principle* (MP) to insist on the fact that C admits *multiple realization* [6] in structurally non-isomorphic lower-level patterns. It follows that C has also multiple structurally non-isomorphic ramifications down to level 0.

2.4.3. Complex Morphisms

Let H be a hierarchical category which satisfies the Multiplicity Principle. In a category each path of morphisms must have a composite; it follows that the composite of a path of two (or more) n-simple morphisms binding non-adjacent clusters must exist; however, it is not always n-simple; in this case it is called an n-*complex morphism* (Ehresmann and Vanbremeersch [21]).

Definition 6. *An n-complex morphism is a composite of n-simple morphisms which is not n-simple, so that its factors bind non-adjacent clusters. (cf. Figure 3)*

More precisely, let C be an n-multifaceted object. The composite of an n-simple morphism g from B to C with an n-simple morphism f from C to C′ must exist by definition of a category. However, since C is n-multifaceted, it admits structurally non-isomorphic decompositions P and Q of levels $\leq n$, so that g may bind a cluster from a decomposition Q′ of B to the decomposition Q of C, while f binds a cluster from the structurally non-isomorphic decomposition P of C to a decomposition P′ of C′. In this case, the composite gf of f and g is generally an n-complex morphism (though in some cases it can be n-simple). For instance, the morphism from the group of authors of a Journal to the group of its subscribers is a complex morphism, mediated by the journal as such, considered as a multifaceted object representing both its editorial staff and its administration.

An n-complex morphism gf of level n+1 has properties which 'emerge' at this level. Indeed, its properties depend on the lower-level properties of the clusters that f and g bind, but also on the existence of a switch between P and Q which stands for a *global* property of the lower-levels, not locally recognizable at these levels, namely that P and Q have the same operational role with respect to all objects A. Thus there is no 'reduction' of the complex morphism to lower levels.

A composite of n-complex morphisms is generally an n-complex morphism (though it might be an n-simple morphism). In the dynamic case (Section 3), we'll see that complex morphisms are at the basis of the emergence of new properties corresponding to "change in the conditions of change" (Popper [24]) which make the systems unpredictable.

2.4.4. The Reduction Problem

For a natural system, the *reduction problem* (under different kinds) searches to 'reduce' its higher-level properties to lower-level properties so that methods already developed for these lower levels could be extended; for instance reduction of a biological system to its molecular level to apply and extend methods used in physics or chemistry. As explained above, in a hierarchical category, such a reduction is only possible for a simple morphism whose properties depend on those of the cluster which it binds; but the situation is different for a complex morphism which has emergent properties at its level.

From the following theorem we deduce that a pure reductionism necessitates that the system has only simple morphisms.

Theorem 1 (Reduction Theorem [10,21]). *Let H be a hierarchical category. Let C be an object of level n+1 and P a pattern of level n of which C is the colimit. If all the morphisms of P are $(n-1)$-simple morphisms, then there exists a pattern V of levels $n-1$ of which C is also the colimit. Whence the complexity order of C is strictly less than n. The result is generally not true if P has a complex morphism.*

Proof. Let us explain this in the case of an object C of level 2, with a ramification (P, (Π_i)). If all the morphisms f_{ij}: $P_i \rightarrow P_j$ of P are simple morphisms, they bind clusters F_{ij} of morphisms of level 0 from Π_i to Π_j. We can define a pattern V of level 0 as follows: it contains the Π_i as sub-patterns and has also for morphisms the union of the clusters F_{ij}. It is proved [10] that the pattern V has also C for its colimit. Since C is colimit of such a pattern of level 0, its complexity order is 1. □

Corollary 1 [pure (methodological) reductionism]. *In a hierarchical category in which there are no complex morphisms, all the objects are of complexity order 0 or 1.*

In the more general case where the category H admits multifaceted objects of complexity order strictly more than 1. we have no pure reduction to the level 0. Each object can still be related to the level 0, but the reduction cannot be done directly in one step: it necessitates the unfolding of a ramification in several steps, with emergent properties at each different step (through complex morphisms). In Section 4.1, we describe this situation as an *'emergentist reductionism'* [8].

2.5. The Complexification Process. Main Theorems

The configuration of a natural system such as a living system varies over time. Its structural changes correspond to the four "standard transformations: Birth, Death, Scission, Confluence" characterized by R. Thom [25].

If the system is modeled by a hierarchical category H, these structural changes will correspond to the realization of a procedure Pr = (A, E, U) with objectives (O) of the following kinds:

- 'adding' to H a given external graph A,
- 'suppressing' a set E of objects and morphisms of H, eventually thus dissociating a complex object by suppressing its colimit;
- 'binding' patterns P of a set U of finite patterns in H so that each P acquires a colimit cP or, if P has a colimit in H, preserves this colimit.

The realization of such a procedure Pr imposes a number of other operations. For instance to 'bind' a pattern P which has no colimit in H necessitates to add to the system a cone from P to a new object cP and to 'force' this cone to satisfy the universal condition of a colimit-cone; and this will eventually lead to the emergence of complex morphisms in the category H' modeling the system after these modifications.

The interest of the categorical approach is that it gives an explicit construction (by recurrence) of the category H'obtained after application of the procedure Pr to H (including the above-mentioned operations). This category H', called the *complexification of* H *for* Pr, provides a 'conceptual' anticipation of the result of Pr, and so allows a 'virtual' evaluation of this procedure. However, when H models a natural system, the complexification H' might not respect some material or temporal constraints (cf. Section 3.1.2), and anticipation raises other problems (cf. Section 4.2).

2.5.1. The Complexification Process

The Complexification Process [9,10]. Given a (hierarchical) category H and a procedure Pr = (A, E, U) on H with objectives of the above kinds (O), the complexification process (CP) for Pr consists in constructing a 'universal solution' to the problem:

> To construct a (hierarchical) category H' and a partial functor F from H to H' satisfying the objectives (O); in particular, it means that, for each P in U, the image of P by F will have a colimit cP in H'.

To say that F is a 'universal solution' to the problem means that, if there is another partial functor F' from H to a category H" in which the objectives of Pr are realized, this F' factors through F via a *comparison functor* from H' to H".

Remark 1. *In recent publications (e.g., [16], Chapter 3) we use the term* de/complexification *of H for Pr instead of 'complexification' to emphasize that the construction can lead both to a kind of 'de-complexification' by loss or dissociation of some complex objects in E, and to a real 'complexification' by formation of more complex objects cP becoming the colimit in H′ of patterns P which have no colimit in H.*

Theorem 2 (Complexification Theorem [9,10]). *Let Pr = (A, E, U) be a procedure on a hierarchical category H satisfying MP. The complexification process for Pr has a universal solution F: H → H′ where H′ is a hierarchical category which is explicitly constructed (by recurrence).*

2.5.2. Construction of the Complexification

Construction of the Complexification (cf. Figure 4). For an explicit construction of the complexification H', we refer to ([10], Chapter 4). Let us just indicate the following points:

- The partial functor F from H to H' is defined on the greatest sub-category of H not meeting E.
- The objects of H' are: the vertices of A, the (image by F of the) objects of H not in E and, for each pattern P in U, a new object cP which becomes the colimit of F(P) in H'. This cP is selected as follows: (i) if P in U has already a colimit C in H, we take for cP the image of C by F; (ii) If two patterns P and Q in U have the same functional role in H, we take cP = cQ, so that, if P and Q are structurally non-isomorphic, cP will be a multifaceted object in H'.
- The morphisms of H' are the arrows of A, the (images by F of the) morphisms not in E and new morphisms which are constructed by recurrence to 'force' cP to become the colimit of F(P) in H' for each P in U: At each step of the recurrence, for each P in U we add morphisms from cP to B to bind cones from P to an object B, then we add composites of all the so obtained morphisms; this operation can lead to the emergence of *complex morphisms*. Then, repetition of such a step on the category so obtained, and so on.

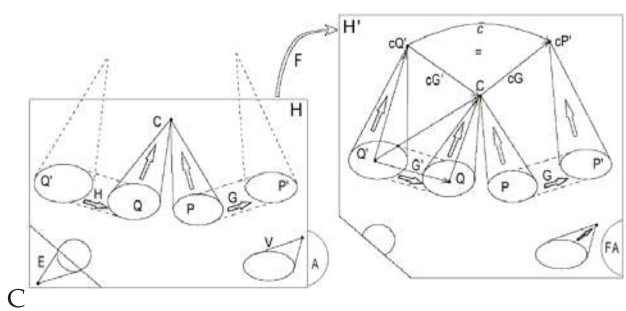

Figure 4. Construction of the complexification H' of H for the procedure Pr = (A, E, U).

If H is hierarchical, H' is also hierarchical: the level of a 'preserved' object is the same as in H; the level of an emerging object cP is n+1 if P is in levels $\leq$ n; if P has a complex morphism, the *complexity order* of cP is more than that of the objects of P (Reduction Theorem, Section 2.4). In particular the complexification process may add a new highest-level m+1 to the hierarchy. It can also add new morphisms between objects in the image of F, and even complex morphisms (the image of F is not a full subcategory of H').

2.5.3. Main Theorems

From the construction of the complexification, we deduce the theorems.

Theorem 3 (Emergence Theorem [10]). *Let Pr = (A, E, U) be a procedure on a hierarchical category H satisfying MP. The CP for Pr may lead to the emergence of complex morphisms; in particular, if some pattern P* *in U has a complex morphism, the emerging object cP is of a higher complexity order than (the objects of) P. A sequence of CPs may lead to the emergence of multifaceted objects of increasing complexity orders.*

Theorem 4 (Iterated complexification Theorem [10]). *Let Pr = (A, E, U) be a procedure on a hierarchical category H and let Pr′ = (A′, E′, U′) be a procedure on the complexification H′ of H for Pr. If some patterns in U′ have a complex morphism, then there is no procedure Pr″ on H such that the complexification H″ of H′ for Pr′ be the complexification of H for Pr′.*

In Section 4, we will draw the consequences of these theorems in terms of emergence, creativity, anticipation, and unpredictability. Roughly, the formation of a complex morphism can be interpreted as a "change in the conditions of change" (in Popper's sense [24]), that makes the long term result unpredictable.

3. The MES Methodology

In the preceding Section 2, we have considered the 'static' structure of a living system at a time t of its life, modeled by a hierarchical category, and its structural changes over time, generated by successive complexification processes. Here we propose the Memory Evolutive Systems (MES) methodology as a model, not of the invariant structure of the system (as for instance in Rosen's (M-R)-systems [26]), but as an integral dynamic model sizing up the system 'in its becoming' during its life.

A MES consists of:

- a *Hierarchical Evolutive System* (HES) which describes the components of the system and their variation over time through structural changes, leading to
- a developing *flexible long-term memory* with emergent properties;
- a network of agents, called *co-regulators*, which self-organize the system through their cooperation/competition; each co-regulator operating at its own rhythm on its own landscape.

3.1. The Hierarchical Evolutive System underlying a MES

As we have already said the configuration of an evolutionary system at a time t is modeled by a category, say H_t having for objects the states C_t of its components C existing at t and for morphisms the state at t of the links (or communication channels) between these components. The state at t reflects the static and dynamical properties at t, measured by observables depending of the specific system. Among the observables (represented by real functions), we suppose that, at each time, a component has an activity, and a link between components has a propagation delay, a strength and a coefficient of activity. Over time, the components and the links between them vary, with possible addition or suppression, due to structural changes of the kinds indicated in Section 2.5.

3.1.1. Evolutive Systems (ES)

To account for time and the changes it so produces, an evolutionary system cannot be modeled by a unique category: it is modeled by an Evolutive System H which consists of:

- the timeline of the system, modeled by an interval T of the real line **R**;
- for each t in T, a category H_t called the *configuration* of **H** at t which represents the state of the system at t;
- for t′ > t in T, a partial functor from H_t to $H_{t'}$ called 'transition' from t to t′, which models the changes of configuration; it is defined on the sub-category of H_t consisting of the (states of the) objects and morphisms which exist at t and will still exist at t′. These transitions satisfy a transitivity condition.

The transitivity condition implies that a *component* C of the system, identified to the 'dynamic' trajectory consisting of its successive states C_t from its initial apparition in the system to its 'death', is modeled by a maximal family of objects C_t of successive configurations connected by transitions. Similarly, a *link* f from a component C to a component C′ is modeled by a maximal family of morphisms f_t: $C_t \to C'_t$ of successive configurations, connected by transitions, namely the family of its successive states for each t at which both C and C′ exist. At each time t of its existence, a link has a *coefficient of activity* 1 or 0, to model if it is active (information transfer at t) or not. To sum up more formally:

Definition 7. *An Evolutive System (ES) is defined by a functor **H** from the category associated to the order on an interval T of **R** to the category of partial functors between categories; it maps t in T to the configuration category H_t, and the morphism from t to t′ to the transition from t to t′.*

3.1.2. Hierarchical Evolutive Systems

In the sequel the aim is to study multi-level ES in which the successive configurations have a compositional hierarchy (for instance, in a biological organism: atoms, molecules, cells, tissues, ...). For that, we suppose that the successive configuration categories of the ES are hierarchical categories (cf. Section 2.3), and we define:

Definition 8. *A Hierarchical Evolutive System (HES) is an ES in which the configuration categories are hierarchical and the transitions preserve the complexity levels (Cf. Figure 5).*

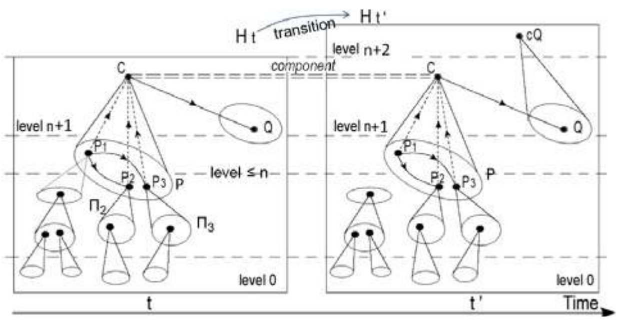

Figure 5. Two configurations H_t and $H_{t'}$ of a HES and the transition from t to t′.

Over time in a living system, there are both dynamic changes affecting the observables and structural changes of configurations of the forms indicated in Section 2.5, and both kinds of changes must be compatible. From the results of Section 2.5 we know that the structural changes can be modeled by sequences of complexification processes (CP); however, these CPs must also be compatible with the dynamic changes. In the HES frame, it means that the transitions are generated by CPs for procedures Pr which must be compatible with the dynamic constraints.

Now if we give a procedure Pr = (A, E, U) on the configuration H_t of the HES at a time t, we can always 'categorically' construct the complexification H′ of H_t for Pr. However, H′ might become a configuration of the system at a later time t′ (dependent on the material change duration) only if the observables defining the states of components and links (e.g., propagation delays for the links) are extendable to H′ through the partial functor from H_t to H′. This is not always possible because these observables might impose some dynamic constraints which cannot be extended to H′. For instance, if one constraint is that the propagation delay of a composite morphism be the sum of the propagation delays of its factors, we have proved [27] that this constraint can only be extended to H′ if the patterns P in U are polychronous in the sense of Izhikevich [28].

By definition, the complexification H′ for Pr is the *universal solution* to the problem of realizing Pr. If it is not compatible with some dynamic constraints, there can exist another solution H″ of the problem which is compatible with them; in this case, the weight of these constraints can be measured by the comparison functor from H' to H" (cf. Section 2.5.1).

The HES theory does not propose methods for the selection of adequate procedures. We come back to this selection problem in Section 3.2 in the more specific frame of a MES which is a HES with a multi-agent self-organization modulating the dynamic of the system.

3.1.3. Complex Identity of a Component

Let C be a component of the HES. At each time t of its life, C (or more precisely its state C_t in H_t) is the colimit of a lower-level pattern P in H_t. We say that C is activated by P at t if all the morphisms of the colimit-cone from P to C_t are active at t; roughly, it means that C receives collective information from P itself at t. For instance, the information can be a constraint, or a command imposed on C by lower levels; it can also be an energy supply allowing C to perform a specific action.

At a later time t', the component C has a new state $C_{t'}$ in the configuration at t' and the pattern P is transformed in a pattern $P_{t'}$ via the transition from t to t'. However, this pattern $P_{t'}$ may not admit C as its colimit in the configuration at t'. Indeed, some objects or morphisms of P may have been suppressed from t to t' (we recall that the transitions are only partial functors) and it is not supposed that they preserve all colimits. For instance, at a time t a cell is the colimit of the pattern of its molecules existing at that time, but there is a progressive renewal of these molecules and, after some time, the initial molecules will all have disappeared while the cell as such persists

We call the *stability span of* P at t the largest period (from t to t+d) such that, for each t' between t and t+d. the image $P_{t'}$ of P still admits $C_{t'}$ as its colimit, while this is no more the case at t+d. However, if C persists at t+d, it admits at least one other lower-level decomposition Q in the configuration at t+d; this Q can have been progressively deduced from P, or not. In this way, C takes its own *complex identity* independent from its lower-level constituents; this situation corresponds to the Class-Identity of Matsuno [29].

The complex identity of a component C can be multiple, making it more flexible. It is the case for multifaceted components. We say that a component C *is multifaceted on an interval* J if its state at each instant t of J is a multifaceted object in the configuration at t. Let us recall that it means that, for each t of J, the state at t of C is the colimit of at least two lower-level patterns which are structurally non-isomorphic; thus at that time C can be activated by either of them, or by both concurrently, and even switch between them. In this way, C takes its own individuation (in the sense of Simondon [30]) allowing for a kind of 'flexible redundancy'.

From now on, we suppose that the HES satisfies the Multiplicity Principle (MP), meaning that it has such multifaceted components. It follows that there are two kinds of links between components:

Definition 9. *In a HES, a link between components C and C' on an interval J is called an n-simple link if its state at t is an n-simple morphism in the configuration at t for each t in J. Similarly, we define an n-complex link on J as a link whose successive states on J are n-complex morphisms.*

3.1.4. Development of a Memory

Multifaceted components and complex links between them play an important role in the development of a memory of the system. A living system (such as a biological, social, or cognitive system) develops a robust though flexible long-term memory, able to adapt it to changing conditions. This memory consists in interconnected internal representations of knowledge of any kind, such as items (external objects, signals, past events), internal states (conscious or non-conscious and non-volutional, affects, emotions) that the system can recognize, and different procedures that the system can activate. A component of the memory takes its own complex identity in time and can later be 'recalled' under its different lower-level decompositions, providing plasticity in time to adapt to environmental changes. For instance, we recognize a person independently from the way (s)he is clothed, and even, on the longer term, independently from his (her) age.

In the HES modeling the system, this memory is modeled by a hierarchical evolutive subsystem Mem, whose components (called 'records') and links are obtained through successive complexification processes for adequate procedures. It follows from the Emergence Theorem (Section 2.5), that the number of complexity levels of this memory will increase over time, with formation of more and more complex multifaceted records C, connected by complex links. Such a C can be later 'recalled' by activating any of its multiple ramifications to recognize the item it memorizes under different forms and it adapts to changing situations by acquiring new decompositions and suppressing those which are no more valid. The system can also develop 'resilience': in an adverse situation or a crisis, some decompositions of multifaceted records can be temporally disactivated (but not suppressed), making it possible to quickly reactivate them after the crisis and so return to pre-crisis status.

3.2. A Memory Evolutive System and Its Multi-Agent, Multi-Temporality Organization

Formally a MES is a HES equipped with:

- a sub-HES which models a flexible long-term memory Mem, still called 'memory', developing through the emergence of multifaceted components connected by complex links;
- a multi-agent organization consisting of a network of evolutive subsystems, called *co-regulators*, each operating stepwise at its own rhythm, which self-organize the system through their interactions.

3.2.1. The Coregulators and Their Landscapes

Living systems have an internal modular organization, with modules of different sizes; for instance, in the neural system we have a variety of such modules, from more or less large specialized areas of the brain to a hierarchy of smaller treatment units (in the sense of Crick [31]). At a given time, each module has only access to a part of the system (its 'landscape') on which it operates at its own rhythm, with the help of the memory. The global dynamic results from an 'interplay' among the local dynamics of the different modules.

A MES has such a modular organization, in which a module is modeled by an evolutive subsystem CR called a *co-regulator*. A co-regulator has its own function, complexity, rhythm and differential access to the memory. It acts *as a hybrid system*, meaning that it has both a discrete timeline delineating its successive steps in the continuous timeline of the system, and, during a step, it follows the continuous dynamic of the system.

At each step, CR only receives partial information from the system via the active links b, c, . . . arriving to it during the step. This information is processed in the *landscape* of CR at t which is an Evolutive System L_t having those links for components; in particular the CR is itself included in the landscape. Using the differential access of CR to the memory Mem, an adapted procedure Pr is selected on this landscape (via pr), and the corresponding commands are sent to effectors E of Pr (Cf. Figure 6).

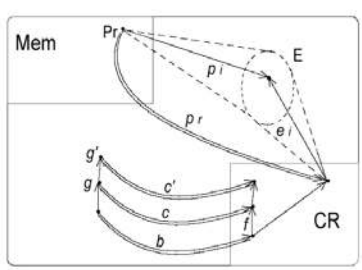

Figure 6. The landscape of CR is an evolutive system whose components b, c, c', pr, . . . are representede by the curved arrows (their links being the rectangles between them).

The effectuation of these commands starts a dynamic process whose result will be evaluated at the beginning t′ of the next step; this process can often be studied with usual physical models (e.g., ODE on its specific phase space) making it computable.

If the objectives are not attained at t′, we have a *fracture* for CR. An important cause of fractures is the non-respect of the dynamic temporal constraints of CR expressed by the *synchronicity equations*:

$$p(t) << d(t) << z(t),$$

where

- p(t)= mean propagation delay of the links in the landscape,
- d(t) = *period* of CR at t = mean length of its preceding steps,
- z(t) = least *remaining life* of the effectors of Pr.

3.2.2. The Global Dynamic

In a modular system, there is an "ability of agents to autonomously plan and pursue their actions and goals, to cooperate, to coordinate, and negotiate with others" (Wooldridge & Jennings [32]). Similarly, in a MES, the cooperation and/or competition between the co-regulators modulates the global dynamic which weaves the different internal local dynamics of the co-regulators.

At a given time, the various co-regulators may send conflicting commands to effectors. The global dynamic results from an *interplay* among them, and it may cause a fracture to some of them. While the local dynamics can be computable, the interplay between co-regulators renders the global dynamic generally non-computable, partly because of the flexibility of multifaceted components (e.g., in the memory) which can be activated through anyone of their lower-level ramifications. The various periods of the co-regulators lead to a *dialectic* between co-regulators with different rhythms, with a risk of a *cascade of fractures and re-synchronizations* at increasing levels. It leads to ubiquitous complex events processing, as in the *Aging Theory* for an organism developed by the authors [10].

MES give a model for a kind of 'competing local reductionisms'. The whole system cannot be 'reduced' to a given subsystem of it, but some 'parts', namely the dynamics of the co-regulators during one of their steps, can be modeled by usual Physics' models (related to different phase-spaces). However, these partial models are incompatible and there is need of an 'interplay' among co-regulators to select which ones will be finally retained in the overall dynamic.

4. Discussion

Applied to a living system S, the MES methodology does not lead to a methodological reductionism to a given level; in fact it characterizes the obstacle to such a reductionism, namely the existence of multifaceted components (MP). It is only the local dynamics of the co-regulators which are susceptible of reduction to computable models (eventually nonlinear or chaotic). The global dynamic is not so reducible, and it allows for the emergence of more and more complex phenomena through successive complexification processes.

4.1. Emergentist Reductionism

In philosophy, the concept of emergence is itself multifaceted: it is given different meanings depending on the authors. For the Standard Encyclopedia of Philosophy [33]: "Emergent properties are systemic features of complex systems which could not be predicted (practically speaking; or for any finite knower; or for even an ideal knower) from the standpoint of a pre-emergent stage, despite a thorough knowledge of the features of, and laws governing, their parts". There is a distinction between what is called 'synchronic' and 'diachronic' emergence. As we are not philosophers, we are not qualified for a general study of emergence. Hereafter, we successively study these two kinds of emergence in living systems, in connection with the categorical notion of a colimit and its applications to the MES methodology.

4.1.1. Emergence in Terms of Levels

In Section 2.2.2, the part–whole relation has been modeled in a category H by using the notion of a colimit: the whole is represented as the colimit cP of the pattern P of interacting objects in H representing its parts and their organization. To say that a pattern P in a category H admits a colimit if, and only if, there exists a cone from P to cP, called colimit-cone, satisfying the 'universal property':

(E) *any* cone with basis P uniquely factors through the colimit cone from P to cP.

If H is a hierarchical category modeling a complex system S and if we think of a 'whole' as an object of a higher complexity level than its 'parts', we can say that (E) is an *emergent property in* H *in terms of levels*. The word 'emergent' is justified for an 'external' observer of the system S (be it a human or even a computer) who 'retrospectively' has a global vision of H, including the cone from P to cP, independently from the time and circumstances in which cP has appeared (e.g., 'birth' of a new object, addition of a new cone or complexification process). Indeed, while (E) is conceptually a well-defined categorical property, its practical verification by the observer would raise a 'physical' problem, due to the number of cones to consider: this number can be very large and to observe the behavior of each of them would require too much time.

For similar reasons, the property for an object C of level n+1 to be a *multifaceted object* (Section 2.4), exemplified by a 'switch' between two of its structurally non-isomorphic lower-level decompositions P and Q, is also a well-defined categorical property which is only an *emergent property* for an observer retrospectively looking at the system. As a consequence, a complex morphism (Section 2.4) also represents such an emergent property in terms of levels.

Let us note that, in all these cases, the physical problem relates to the time necessary to handle large numbers, though we can quickly conceptualize them.

4.1.2. A Hierarchical Category Resorts to An Emergentist-Reductionism

From the Reduction Theorem (Section 2.4) it follows that a hierarchical category H without multifaceted objects is reducible to its level 0. Now let us suppose that H has n-multifaceted objects for each n. An object C of level n+1 has at least one ramification down to level 0, consisting of a lower-level decomposition P of C, then a lower-level decomposition Π_i of each object P_i of P, and so on down to level 0 patterns forming the basis of the ramification (cf. Figure 2). In this way, C is reducible to P, each object P_i of P is reducible to Π_i, and so on top-down through to level 0. This defines a kind of step-by-step reductionism for the objects, with emergent properties related to the bottom to top formation of the different colimits at each step. This situation corresponds to what M. Bunge [8] has called an 'emergentist-reductionism'.

4.2. Diachronic Emergence in a MES

In the preceding section we have not explicitly considered the dynamic of the system, so that 'emergence' relates to a retrospective comparison between complexity levels rather than to a temporal change. Here we consider the dynamic of a living system S modeled by a MES. Its hierarchical configuration categories have emergent properties in terms of levels of the kind considered above, and the transitions are generated by complexification processes for adapted procedures (Section 3.2).

4.2.1. Emergent Properties of Complex Links between Components

As we have already said, the MES methodology aims to model a living system S in its 'becoming': knowing the system up to a time t, we study the change of configuration from t to a later time t'. Here we consider a transition from t to t' consisting in a unique complexification process for an adapted procedure Pr. The categorical construction of the complexification (by recurrence, cf. Section 2.5) gives a 'conceptual' anticipation of the resulting category', but it does not account for its 'physical' implementation nor for the duration of the process because of physical temporal constraints similar to those studied above.

In particular, let us suppose that the construction leads to the formation of a complex link c from B to C′ obtained as the composite of an n-simple link g from B to C and an n-simple link f from C to C′ which bind non adjacent clusters separated by a switch between lower-level decompositions P and Q of C (cf. Figure 3). The successive states of c are complex morphisms which represent emergent properties in their respective configuration categories. Can an external observer of S 'physically' anticipate the emergent properties of the link c when it is activated?

For c to become active at t, the link g must be active at t and the information it transfers will arrive at C at t+p(t), where p(t) is the propagation delay of g at t. The activation of C at t+p(t) then activates the morphism f from C to C′, thus imposing a switch between (the states of) P and Q in the configuration category. As said above, this 'instantaneous' switch, which plays the role of 'change in the conditions of change', is at the root of diachronic emergent properties of the complex link c for an external observer, since it would require the simultaneous treatment of a large number of operations, and this is not 'physically' possible for the observer.

This situation agrees with Brian Johnson's explanation of emergence [34]: "Given that emergence is often the result of many interactions occurring simultaneously in time and space, an ability to intuitively grasp it would require the ability to consciously think in parallel"; and he proposes a "simple exercise < . . . > used to demonstrate that we do not possess this ability".

4.2.2. Emergence at the Basis of Unpredictability, Creativity, and Anticipation

The Emergence Theorem (Section 2.5) shows that the formation of complex morphisms in a complexification process is at the basis of the emergence of objects of increasing complexity orders, themselves connected by complex morphisms. The "changes in the conditions of changes" due to these complex morphisms are responsible for the unpredictability of the result of iterated complexifications (Section 2.5). As the long-term evolution of a MES depends on iterated complexification processes, it follows that the long-term evolution of the living system modeled by the MES is also unpredictable.

Emergence has consequences for creativity. Boden [35] has distinguished three forms of *creativity*: combinatory, exploratory, and transformational. In a living system modeled by a MES, these three forms can exist and be distinguished:

- the complexification process *combines* the specified patterns into more complex objects;
- the selection of procedures via the co-regulators leads to an *exploration* of different possibilities;
- *transformational creativity* is characterized by iterated complexification processes leading to successive changes in the conditions of change which make the result unpredictable, allowing for surprising results.

The role of emergence is also important for anticipation and futures thinking. While the complexification process allows to 'virtually' evaluate different procedures in the purely categorical setting, the situation is different when applied to natural systems. Indeed, because of emergent properties, the construction of the complexification for an adequate procedure Pr is not physically implementable. However, a step by step analysis of this construction may suggest new *anticipatory assumptions* (AA). This is helpful in the *Futures Literacy Framework* where the aim is to identify and deploy AAs "to 'use-the-future' for specific ends in particular contexts" (Miller [16], Chapter 1).

5. Conclusions

Let us mention that the MES methodology can be enriched in a variety of ways, by adding more structures on their configurations, for example by defining:

- K-MES, where K is a category of structures (for instance, *topological MES* if K =Top, *multifold MES* if K = Cat) in which the configuration categories are internal categories in K and the transitions partial functors in K [36];
- *relational MES* in which the transitions are replaced by relations, so that a given object at t is related to different objects at t′, the repartition being assigned a specific probability (not yet published).

To conclude, we propose that the MES methodology could help for a revival of Natural Philosophy, by itself and through some of its possible variants.

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philosophies

Article

Natural Philosophy and the Sciences: Challenging Science's Tunnel Vision

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Abstract: Prior to the nineteenth century, those who are now regarded as scientists were referred to as natural philosophers. With empiricism, science was claimed to be a superior form of knowledge to philosophy, and natural philosophy was marginalized. This claim for science was challenged by defenders of natural philosophy, and this debate has continued up to the present. The vast majority of mainstream scientists are comfortable in the belief that through applying the scientific method, knowledge will continue to accumulate, and that claims to knowledge outside science apart from practical affairs should not be taken seriously. This is referred to as scientism. It is incumbent on those who defend natural philosophy against scientism not only to expose the illusions and incoherence of scientism, but to show that natural philosophers can make justifiable claims to advancing knowledge. By focusing on a recent characterization and defense of natural philosophy along with a reconstruction of the history of natural philosophy, showing the nature and role of Schelling's conception of dialectical thinking, I will attempt to identify natural philosophy as a coherent tradition of thought and defend it as something different from science and as essential to it, and essential to the broader culture and to civilization.

Keywords: natural philosophy; R.M. Unger; L. Smolin; Aristotle; F.W.J. Schelling; *Naturphilosophie*; A.N. Whitehead; Ivor Leclerc; dialectics

1. Introduction: The Marginalization of Natural Philosophy

In a recent book, *The Singular Universe and the Reality of Time* [1], the legal theorist Roberto Mangabeira Unger and the theoretical physicist Lee Smolin set out to defend the reality of temporal becoming, to incorporate into physics the notion of coevolution, to redefine the nature and role in science of mathematics, and thereby replace basic assumptions deriving from Newton's physics about the nature and role of scientific explanation. However, to do so, they first had to defend natural philosophy, without which, they argued, philosophical assumptions are confused with empirical observations, damaging efforts to advance science in new directions. Natural philosophy no longer exists as a recognized genre, they argued, and '[i]n the absence of an established discourse of natural philosophy, scientists have often used the presentation of ideas to a general educated public as a device by which to address one another with regard to the foundational matters that they cannot readily explore in their technical writings' (p. xvii). They noted that natural philosophy plays a greater role in biology than physics, but even in biology those who engage in natural philosophy are marginalized. Also marginalized are philosophers who have focused on natural philosophy. Instead of masking their arguments as popularizations, Unger and Smolin presented their work explicitly as a contribution to natural philosophy. They then equated natural philosophy to natural history. In the absence of an established discourse of natural philosophy, they had to define what it is, and what is its relation to science. They proclaimed:

'The discourse of this book is also to be distinguished from the philosophy of science as that discipline is now ordinarily practiced. The work of the philosophy of science is to argue about the meaning, implications, and assumptions of present or past scientific ideas. It offers a view of part of science, from outside or above it, not an intervention within science that seeks to criticize and redirect it. . . . The proximate matter of the philosophy of science is science. The proximate subject matter of natural philosophy is nature. Unlike the philosophy of science, natural philosophy shares its subject matter with science' (p. xvii).

While Unger and Smolin do provide a good starting point for characterizing natural philosophy and for equating it to natural history, without an established discourse of natural philosophy it is difficult to defend their definition of it and further extend their work. To do this and develop it further, it is necessary to identify what works in the past could be characterized as natural philosophy. Without an established discourse on this, however, it is difficult to even identify which thinkers in the past should be characterized as natural philosophers. What we are faced with is such a disintegration of intellectual traditions that it is necessary to reconstruct the history of natural philosophy and its relation to both philosophy and science in order to judge whether or not Unger and Smolin have correctly specified their subject matter, whether they are making a real contribution to its development, and to characterize and then defend natural philosophy as a valid form of knowledge.

This is more difficult than it might seem because despite the work of philosophically oriented historians of science, most histories of what is taken to be science have ignored natural philosophy as such and thereby distorted these histories. This is evident even in the classification of who was a philosopher and who a scientist. Newton is regarded as a major figure in science and Leibniz a major figure in philosophy, but both were natural philosophers who debated with each other, mostly indirectly in the Leibniz–Clarke Correspondence. Among philosophers, the most important natural philosophers are frequently characterized, and sometimes have characterized themselves, as metaphysicians. This is problematic because when the notion of metaphysics was coined in collecting a number of Aristotle's works together and labelling them as the work which followed writings on physics, that is, *Metaphysics*, the subject matter of this was confused [2] (ch. vi). Studies of this book have shown that early in his career when Aristotle was still aligned with Plato, the subject of this work was the study of what exists and is unchanging, the Unmoved Movers conceived of as divine beings, and metaphysics came to be identified with theology. On this basis, metaphysics was taken to be a subject dealing with a reality beyond the physical world, that is, nature. Later, Aristotle rejected this as his focus and redefined his goal as the study of being. As he put it:

'There is a science which takes up the theory of being as being and of what 'to be' means, taken by itself. It is identical with none of the sciences whose subjects are defined as special aspects of being. For none of them looks upon being on the whole or generally; but each, isolating some part, gets a view of the whole only incidentally, as do the mathematical sciences. Since we are searching for the first principles and most general factors of being, these must clearly be distinctive traits of some nature.' [3] (p. 61, 1003a21-28).

As John Herman Randall interpreted him, metaphysics so conceived is the study of 'What properties are involved in "being" anything, in any subject matter that can be investigated, in "being as being"?' [2] (p. 110). This is what has come to be called ontology.

Aristotle himself noted that this sense of metaphysics has two aspects [2] (p. 110). One is that 'to be means to be something that can be stated in discourse' [2] (p. 111). This sense of metaphysics has been taken up exclusively in so-called 'analytic metaphysics' in which discourse is identified with symbolic logic and its interpretation [4]. Exemplifying such analytic metaphysics, Willard van Orman Quine wrote, 'To be is to be the value of a variable' [4] (p. 5). This does not have a place for natural philosophy as such, even when as in the case of Quine and his followers, they defend naturalism. In fact, while the work of these analytic metaphysicians can be important for natural philosophy, more commonly, it has crippled it [5] (ch. 2). The second aspect of Aristotle's metaphysics in this sense is the examination of what comes into being and passes away, with the 'essence' of any such entity being what is knowable and stateable about it. This is natural philosophy. Later, Aristotle modified this characterization of metaphysics as natural philosophy to incorporate the eternal features of the celestial realm. Such an investigation requires an account of the stuff of which everything is made, the growth process, and the internal organizational principle, thereby showing what is it to explain anything, the place of principles and consideration of the status and role of mathematics in this. Natural philosophy also includes the quest to specify the main kinds of beings that are possible and that exist and their relation to each other; most importantly, physical beings as such, including those that are not alive, living beings and the different kinds of these, including humans, and then abstract entities such as mathematical relations. Living beings were investigated by Aristotle in *De Anima*, and this should be seen, along with *Metaphysics*, *On Generation and Corruption* and several other works, as a major contribution to natural philosophy. A number of philosophers characterized as metaphysicians, along with philosophical biologists and philosophical anthropologists, are centrally engaged in natural philosophy in this sense, and their work is central to the tradition of natural philosophy, but none of these are not identified as natural philosophers by simply being labelled as metaphysicians.

Understanding the history of metaphysics as natural philosophy, ignoring other forms of metaphysics, does identify natural philosophy as a tradition of thought, however. As Aristotle himself argued, this tradition began with philosophy itself. As he put it, 'the question that has always been asked and is still being asked today, the ever-puzzling question "What is being?" amounts to this, "What is primary being (*ousia*)?' [3] (p. 131, 1028b). He characterized efforts to answer this question as first philosophy because this is basic to all particular sciences. These deal with particular kinds of being and the primary principles and factors basic to them, but first philosophy deals with what is basic to all sciences [3] (p. 63, 1004a). It is also the prime focus of the philosopher since the task of the philosopher is to view things in a total way, and this is achieved by characterizing what is primary being [3] (p. 64, 1004b).

What Aristotle understood this question to mean and how it could be answered is clarified by the first book of his *Metaphysics* where he discusses his predecessors. For naturalists such as the first philosophers, Thales, Anaximander, and Anaximenes, natural philosophy was identical with metaphysics, with Thales claiming that primary being is water, Anaximander that it is the limiting of the unlimited, and Anaximenes that it is air. The atomists argued that it is atoms and the void. Their treatises were, according to Aristotle, *peri physeōs* 'concerning nature'. They were concerned with the nature of physical existence, or *physis*, the term that the Latins translated as *natura*. In examining these philosophers, Aristotle recounted what they claimed primary being to be, and then how the principles of this were used to explain all else. That is, the task of philosophy for naturalists is not only to define what nature (or *physis*) is as primary being, but to show how everything else can be explained as an aspect or manifestation or as having been generated by this primary being. If this is to be carried through, it must include nature before the existence of life or humans (Anaximander had offered a theory of evolution in which the unlimited engendered all particular entities, and life evolved in the oceans and then colonized land), and also humans with their philosophical discourse about nature, and along with this, discourse about philosophical discourse.

Aristotle also showed the importance of identifying the tradition of metaphysics as natural philosophy and writing its history, since the conclusions he reached and the defense of these conclusions involved identifying his predecessors, and then criticizing and claiming to overcome what he then claimed to have shown were the limitations of their philosophies.

Such philosophical discourse can include the claims about and avowed beliefs of philosophers in non-natural entities, along with abstract thoughts and non-existent imaginary beings. This means that naturalists can accept that natural philosophy also includes a place for questioning naturalism and claiming that there is more to philosophy than natural philosophy. For naturalists, such questioning and such claims will also be seen as products of nature, that is, products of beings which have been generated by and are part of nature.

For those who reject naturalism, there is still a place for natural philosophy, although such philosophers claim there are realities, entities, or possibly non-entities that are beyond nature. These can be mathematical forms, relations or truths, other Platonic forms, immortal souls or transcendent divine beings who can be conceived of as having created nature or as the beings from which nature emanated, as in Plotinus. Philosophy for non-naturalists is broader than it is for naturalists, but should include natural philosophy as one of its major domains of inquiry, unless as extreme Idealists they completely deny the reality of nature; but then even this is a form of natural philosophy.

Subsequently, almost all work in natural philosophy has taken Aristotle's third characterization of metaphysics as the quest to characterize primary being, through which everything else can be understood, as a reference point for defining and advancing such work. Usually, but not always, this goes along with utilizing Aristotle's arguments and ideas in his own philosophy of nature. This is true not only of those who embraced Aristotle's own characterization of metaphysics and natural philosophy along with his work in natural philosophy, but also those who have rejected both these and developed alternatives, often attempting to revive the philosophies of nature criticized by Aristotle. This was the case with the Stoics and Neoplatonists, medieval Christian philosophers and the natural philosophers of the fourteenth century. It was also the case with natural philosophers associated with the scientific revolution of the seventeenth century, where atomism was revived and entelechies excluded from the physical world. Aristotle's own work was not entirely rejected by those claiming to be scientists, however, as is evident from efforts to revive aspects of it, such as the notion of final causes by Hans Driesch, theoretical biologists developing the concept of biofields and chreods, the mathematician René Thom (who coined the term 'attractor' for precisely this reason), Robert Rosen, Stanley Salthe, biosemioticians, Terrence Deacon and Robert Ulanowicz, among others. The living presence of Aristotle's philosophy is also evident in efforts to revive aspects of his notion of mathematics as a realm of abstractions rather than primary beings, in opposition to the widespread assumption by physicists and mathematicians of Pythagorean Platonism.

The importance of natural philosophy as the whole or major part of metaphysics was revealed in the twentieth century by historians of science, beginning with their study of the seventeenth century scientific revolution. Émile Meyerson, Ernst Cassirer, Gaston Bachelard, Edwin A. Burtt, Alexandre Koyré, Karl Popper, Michael Polanyi, Norwood Russell Hanson, Stephen Toulmin, Thomas Kuhn, Imré Lakatos, and Paul Feyerabend were only the most prominent of the historians of science and historical-oriented philosophers of science involved in refuting the claims of the empiricists, positivists, and logical positivists who had defined science in opposition to metaphysics. Their work demonstrated the essential role of natural philosophy to science (although usually characterized as metaphysics rather than as natural philosophy), and the central importance of work in natural philosophy when major new directions in science have been taken, as opposed to the claims of the logical positivists who dismissed natural philosophy as metaphysics, a speculative discourse that they claimed should be superseded by science and the rigorous application of the scientific method based on empirical work.

These historians–philosophers also exposed the characterizations of subsequent science by empiricists, positivists, and logical positivists, essentially, the bucket image of science (as Karl Popper called it) according to which science accumulates certain knowledge by engaging in empirical investigation rather than speculation, to be fallacious. Most of what are now recognized as the most important advances in science have been shown to be the result of theoretical work and, more fundamentally, work in natural philosophy struggling with theoretical and philosophical problems, using imaginative thought experiments rather than empirical work. Far from science leaving metaphysics behind, what defines genuine science is the effort to advance our comprehension of the world in terms of some well worked-out philosophy of nature; that is, a metaphysical doctrine. For instance, Newton's greatest achievement was to have shown that Johannes Kepler's explanation of the observations by Tycho Brahe of the movement of the planets, that they were in elliptical orbits around the sun, could in turn be explained (at least in the case of Mars) through the postulation of a gravitational force decreasing with the square of distance, along with his three laws of motion. This required the development of a new form of mathematics, calculus, and its defense. However, this theory required a fundamental revision and a new synthesis of the notions of space, time, motion, acceleration, and matter, that is, a philosophy of nature. This synthesis was strongly influenced by the Cambridge Neoplatonists as well as Bruno, Gassendi, Descartes, and Boyle. However, his philosophy of nature was a new synthesis and was defended in opposition to not only Aristotelian natural philosophy but also to the philosophies of his immediate predecessors. [6] Newton's success entrenched his natural philosophy as the basis for most of what came to be identified as science for more than a century. As Kant pointed out, working in the shadow of Newton, we do not simply receive experience but make observational judgements on the basis of questions we formulate using concepts. In Newtonian science, these questions are formulated through the categories or conceptual framework of Newtonian natural philosophy.

Newton did engage in empirical work in his effort to convert base metals into gold using mercury. Here he worked with the poorly worked-out natural philosophy of the alchemists without questioning it, asking questions of nature that could not be answered, and achieved nothing, apart from suffering the effects of mercury poisoning.

2. The Failure to Revivify Natural Philosophy in the Late Twentieth Century

Such historical work should have been expected to and did stimulate some new work in natural philosophy, with Meyerson, Bachelard, Polanyi, Popper, and Feyerabend making contributions to this. Some of this work also helped stimulate the revival of interest in the work of late Nineteenth and early twentieth century philosophers such as C.S. Peirce, Henri Bergson, and Alfred North Whitehead, who, as natural philosophers, had been marginalized and often misrepresented after the rise of analytic philosophy. Such work also helped inspire efforts to combat the influence of logical positivism in science itself and to make sense of and advance the revolutions in thought that had taken place or were taking place over the last century in the way nature was understood. It became very clear that the opposition between Albert Einstein and Niels Bohr was not over empirical work, or even theory, but their fundamentally different philosophies of nature. However, even in the philosophy of science, natural philosophy was very marginal to the direction of research subsequently taken by most philosophers, and science itself has been and continues to be damaged through the influence of the false view of science promulgated by empiricists, positivists, and logical positivists. This is evident in the current crisis in physics with its preoccupation with mathematics unrelated to any coherent natural philosophy [7].

Work on the history of science did create a supportive environment for physicists and theoretical biologists to openly proclaim their ideas on natural philosophy, but as Unger and Smolin observed, almost always these were in popularizations of their work rather than being part of mainstream academic discourse. Or they were in anthologies which were generally ignored. It also influenced some philosophers, although these were rare.

For instance, it helped revive philosophical biology and philosophy anthropology, stimulating interest in earlier work on these topics by phenomenologists such as Max Scheler. These philosophers had opposed not only the mechanistic world-view and the Hobbesian conception of humans based on this, but the Idealist turn taken by Edmund Husserl. Marjorie Grene, who aligned herself with Polanyi, played a leading role in the temporary revival of these subjects [8]. As suggested, philosophical biology and philosophical anthropology should be seen as important components of natural philosophy. The quest to revive philosophical biology has been associated with efforts to support more radical developments within science challenging the usual epistemological and ontological reductionism [9]. In France, where logical positivism had little influence and phenomenology had a major impact, the historical work of Bachelard and Koyré helped stimulate Maurice Merleau-Ponty's redirection of his phenomenological philosophy in the 1950s to build on his work in philosophical anthropology and philosophical biology to embrace and advance natural philosophy generally. Merleau-Ponty returned to the whole tradition of natural philosophy, examining the work of Friedrich Schelling, Bergson, and Whitehead, and recent advances in physics along with theoretical biology. Unfortunately, he died before developing these ideas, and the contents of his lectures were only published in 1995 in French (and 2003 in English translation [10]). French philosophy took a very different path and abandoned the trajectory of Merleau-Ponty's thought. However, his work inspired later efforts by Francisco Varela, Evan Thompson and others to 'naturalize' phenomenology [11–13], and this has become a major movement of thought that is advancing natural philosophy, but again still as a marginal philosophical and scientific movement.

In Britain, beginning in the 1970s, Rom Harré embraced the rejection of logical positivism but criticized the anti-realist tendencies in Kuhn's characterization of science and defended a form of metaphorical realism that made natural philosophy central to his work [14]. Focusing on chemistry rather than physics to begin with, his argument against logical positivism and neo-Kantianism was that the regularities expressed in scientific laws must be explained as manifestations of the essential properties of entities, their powers and liabilities, the dormitive powers of opium for instance, which in turn must be explained through the powers and liabilities of their components. In doing so, he drew a distinction between logical necessity associated with deduction and natural necessity associated with causal processes. Reviving interest in the work of Roger Boscovich who in *A theory of Natural Philosophy* had attempted to reconcile Leibniz and Newton by proposing and developing a dynamic theory of matter, Harré, along with E.H. Madden, developed ideas on causal powers and fields as fields of possibilities. This work had a significant influence on some scientists, and building on this work, Harré attempted to provide new foundations for psychology which was essentially work in philosophical anthropology [15–17]. Although aspects of Harré's naturalism were defended and developed by Roy Bhaskar, this work was largely ignored by philosophers, although it did have some influence on psychologists.

More success was achieved in developing natural philosophy by philosophers who aligned themselves explicitly with specific natural philosophers of the past who had been marginalized by the development of analytic philosophy, although this had the effect of creating intellectual ghettoes of their work, ignored by mainstream philosophers. Those aligned with Alfred North Whitehead, mostly in the USA but also in Belgium and elsewhere, formed the biggest group in this regard, and in so doing, succeeded in attracting and offering support for radical scientists, including David Bohm, Ilya Prigogine, Joseph Early and later, the quantum physicist Henry Stapp and the theoretical ecologist Robert Ulanowicz. Gilles Deleuze (who was strongly influenced by Leibniz and Bergson) in his later years also embraced aspects of Whitehead's philosophy. This Whiteheadian movement also provided support for philosophers striving to keep alive and further develop the contributions to natural philosophy of Henri Bergson and C.S. Peirce and this led to further efforts to revive natural philosophy. Milič Čapek defended and further developed Bergson's philosophy as a major contribution to the theory of time and space, showing its relevance for interpreting recent work in physics and, more broadly, defending the value of such philosophical work [18]. His work has been ignored even by later Bergsonian philosophers.

Other natural philosophers influenced by these thinkers such as Suzanne Langer, Dorothy Emmet, Ivor Leclerc, Frederick Ferré, John A. Jungerman, and Michel Weber have attempted to advance natural philosophy in new directions. From the perspective of these attempting to revive natural philosophy, the most important of these is Ivor Leclerc.

Leclerc began as an interpreter of the philosophy of Whitehead. Arguing that Whitehead should be seen as part of the tradition of natural philosophy rather than merely an interpreter and philosopher of science, re-examining the philosophies of nature that had been put in place in the seventeenth century, his work should be interpreted as an argument that these had been rendered obsolete and were now hindering the advance of science [19]. His work should then be understood as an effort to supply a new philosophy of nature. On this assumption, Leclerc attempted to overcome not only what he took to be the limitations of the natural philosophy inherited from the seventeenth century, but also of Whitehead's philosophy of nature. Leclerc later concluded that Aristotle and Leibniz were just as important for natural philosophy as Whitehead, and from this perspective revisited the problems they had addressed. In doing so, he provided a history of natural philosophy up to the seventeenth century, revealing its achievements and failures and offering a thorough critique of the seventeenth century natural philosophers, including both Descartes and Newton. He also went on to criticize Kant's natural philosophy. Leclerc then offered his own work as a revival of natural philosophy and a further contribution to the tradition of natural philosophy [20,21]. He concluded his major work, *The Nature of Physical Existence*, published in 1972 with the proclamation:

> ' . . . as in the seventeenth century, 'the philosophy of nature' must not only be brought into the forefront, but the recognition of its intrinsic relevance to and need by the scientific enterprise must be restored. Then it will be seen that there are not two independent enterprises, science and philosophy, but one, the inquiry into nature, having two complementary and mutually dependent aspects' [20] (p. 351).

Leclerc found great resistance to this proposal, and offered an explanation for it very similar to that of Unger and Smolin. As he put it in his later book *The Philosophy of Nature* published in 1986,

> 'Until about two centuries ago, there had been a main field of inquiry known as *philosophia naturalis*, the philosophy of nature. Then this field of inquiry fairly abruptly ceased being pursued. It is interesting, and as I shall show, important for us today to determine how and why this happened. . . . After Newton the success of the new natural science had become overwhelming . . . [T]he universe was divided into two, one part consisting of matter, constituting nature, and the other part consisting of mind or spirit. The fields of inquiry were divided accordingly: natural science ruled in the realm of nature, and philosophy in the realm of mind. Thenceforth these two, science and philosophy, each went their own way, in separation from the other. In this division, there was no place for the philosophy of nature. Its object had been nature, and this was now assigned to natural science. What remained of philosophy was only epistemological and logical inquiry, which has natural science, but not nature, as its object–today, usually called the philosophy of science. Philosophy of nature as a field of inquiry ceased to exist' [21] (p. 3f.).

Leclerc argued that the advances in the sciences beyond the philosophy of nature promulgated and adopted in the seventeenth century had left modern civilization without any philosophy of nature, a condition that must be overcome not only in the interests of advancing science, but more importantly, for the broader culture.

His efforts to revive natural philosophy also failed, although he did have an influence on the Nobel Laureate in chemistry, Ilya Prigogine, and other eminent scientists, who also made significant contributions to natural philosophy [22–24].

A later effort to extend and defend process metaphysics by the prominent analytic philosopher, Nicholas Rescher [25], who had been influenced by Peirce, also had little influence other than on philosophers who had already aligned themselves with natural philosophy [26].

As Unger and Smolin noted, natural philosophy had more success in biology where theoretical biologists set out to challenge the reductionism of mainstream biology and evolutionary theory. There is no sharp dividing line between theoretical biology and philosophical biology and works devoted to theoretical biology were clearly significant contributions to philosophical biology and natural philosophy generally. This was the case with Ludwig von Bertalanffy who founded general systems theory which had a major influence on a whole range of disciplines, although largely ignored in philosophy. The conferences on theoretical biology in Switzerland organized by the British biologist C.H. Waddington in the late 1960s and early 1970s, issuing in the four-volume work *Toward a Theoretical Biology* [27], contained strong defenses of metaphysics as natural philosophy by Waddington and David

Bohm, with further developments in natural philosophy emerging from discussions. Participants in these conferences, which included David Bohm, Brian Goodwin, Richard Lewontin, Richard Levins, Stuart Kauffman, and Howard Pattee, subsequently wrote major works which contributed further to natural philosophy, much of it associated with interpreting and developing complexity theory. Pattee was particularly important in this regard, having developed a theory of hierarchical order and emergence through new constraints, an idea that was further developed by the theoretical ecologist, Timothy Allen, and the theoretical biologist, Stan Salthe [28–30], and was later taken up by the biosemioticians [31].

Whitehead was the natural philosopher most commonly invoked at these conferences on theoretical biology. Independently of these theoretical biologists, the Whiteheadian philosophers John Cobb Jr. and David Ray Griffin organized another conference on the philosophy of biology in USA, which was published in 1978 as *Mind in Nature* [32]. This was followed by a series of conferences organized by the *Center for Process Studies* in USA, issuing in several books on natural philosophy [33–35]. All such work, along with the work of the Whitehead-inspired natural philosophers Langer, Emmet, Ferré, Jungerman, and Weber, is ignored by all but a minority of philosophers who hold academic positions in philosophy departments, particularly in Anglophone countries, and has been taken more seriously by theology departments and by scientists.

Largely independently of this Whiteheadian movement, biosemioticians took up the work of Peirce and embraced his radical ideas on natural philosophy. In doing so, they helped bring into prominence the few interpreters of Peirce who had taken seriously and argued for the importance of this aspect of Peirce's work. The biosemioticians are still striving to develop their alternative approach to biology and to draw out the broader implications of Peircian semiotics [36]. Their views have been strengthened by building on systems theory and interpreting biosemiotics through hierarchy theory as put forward by Pattee (who was developing ideas from Michael Polanyi), originally by Stanley Salthe [28–30] who has been a strong supporter of natural philosophy. Inspired by biosemiotics, Søren Brier has set out to construct a whole philosophy of nature based on the notion of cybersemiotics [37]. Largely through the efforts of the biologists Jesper Hoffmeyer and Kalevi Kull, biosemioticians have established strongholds in Denmark and Estonia, but globally they are still a marginalized group and all but ignored in philosophy, at least outside Denmark.

Within the discipline of philosophy itself, proponents of natural philosophy have been scattered and isolated, usually occupying positions in lower-ranked universities or working as private scholars with little influence and often having to deal with hostile intellectual, institutional, and political environments. Denmark appears to be an exception. Apart from important works in biosemiotics, three major works in natural philosophy were published in Denmark around the turn of the millennium, *Nature and Lifeworld* [38] edited by Bengt-Pedersen and Thomassen, *Downward Causation* [39] edited by Andersen, Emmeche, Finnemann, and Christensen, and *Process Theories* [40] edited by Johanna Seibt. However, this is unusual. Generally, academic philosophers do not recognize natural philosophy or the philosophy of nature as part of contemporary philosophy.

So, it appears from this survey that Unger and Smolin are right to claim that there is no widely accepted discourse on natural philosophy at present, and they are right in their suggestion that the most influential work in natural philosophy has been developed and presented in popularizations of science by scientists; however, this survey shows that there are a number of marginalized and thereby fragmentary discourses on natural philosophy that have kept the subject alive. The problem is that they are so marginalized and fragmentary at present that they fail to cohere as an established discourse based on a coherent tradition. While scientists engaging in natural philosophy, as with Unger and Smolin, acknowledge predecessors, generally they do not really engage with their work, and so there is no way in which what is presented can be judged to be real progress in natural philosophy itself. Furthermore, popularizations by scientists are directed to an intelligent general audience which appears to be disappearing with the eclipse of print media. Young people read far less books, and such works are seldom studied in universities. Failing to constitute a coherent tradition, the proponents of natural philosophy have failed to uproot the deep assumptions about nature and what counts as science put in place by the seventeenth century scientific revolution. However, identifying these fragments and putting them together in an historical narrative could have the potential to reconstitute natural philosophy as a coherent tradition and provide a context and discourse in which there could be real progress. Here I will defend this claim, constructing such a narrative both using and defending a dialectical form of reasoning, and in so doing, identifying and integrating a Schellingian tradition of natural philosophy through which the work of Unger and Smolin can be interpreted and evaluated as a contribution to this Schellingian tradition.

3. The Challenge of Advancing Natural Philosophy

As Unger and Smolin suggest, without natural philosophy to bring into question current manifestly defective assumptions, major advances in science are blocked by deficiencies in entrenched assumptions. As I have noted, this has been well demonstrated by historians of science, historically oriented philosophers of science, and a number of radical scientists. This is likely to be even more the case when the natural philosophy assumed within mainstream science has entrenched itself not only in science, but in the broader culture which then controls how science is funded and developed. What we have at present is funding bodies identifying science with nothing but empirical research and valuing it only insofar as it facilitates the development of profitable technology. Such efforts to control science by governments can be even more problematic to the broader culture. It can block efforts of societies to face up to their problems and deal with them, which is clearly the case with the inadequate response of societies today to deal adequately with ecological destruction. If this is the case, then it is vital to the future of civilization that proponents of natural philosophy work out how to identify the causes of past failures to revive natural philosophy and overcome these failures [41].

The most important reason for the failure by proponents of natural philosophy to revive it is their failure to adequately specify the difference between natural philosophy and science, and then to justify natural philosophy as a form of knowledge different from science, although essential to it, with a form of reasoning whereby it can be advanced. This is not to say that efforts have not been made in this regard. The problem is to show why these efforts failed, before offering something new.

Since Whitehead is the most influential of the modern natural philosophers of the last century, his efforts to defend speculative philosophy (which for him was essentially 'natural philosophy') can be taken as a point of departure. Whitehead briefly distinguished speculative philosophy from science (and from analytic philosophy) in the epilogue to *Modes of Thought*. This is very succinct, and bears quoting:

> Philosophy is an attitude of mind towards doctrines ignorantly entertained.... The philosophical attempt takes every word, and every phrase, in the verbal expression of thought, and asks, What does it mean? ... Of course you have to start somewhere for the purpose of discourse. But the philosopher, as he argues from his premises, has already marked down every word and phrase in them as topics for future enquiry. No philosopher is satisfied with the concurrence of sensible people, whether they be his colleagues, or even his own previous self. He is always assaulting the boundaries of finitude...
>
> The scientist is also enlarging knowledge. He starts with a group of primitive notions and of primitive relations between these notions, which defines the scope of his science. . . . [T]he scientist and the philosopher face in opposite directions. The scientist asks for the consequences, and seeks to observe the realization of such consequences in the universe. The philosopher asks for the meaning of these ideas in terms of the welter of characterizations which infest the world [42] (p. 171f.).

Here Whitehead made the crucial point that the philosopher and the scientist face in opposite directions even when dealing with the same subject matter. Their interests are different. Scientists as scientists (that is, when not reflecting philosophically on their research) work with assumptions, usually unexamined, which direct their research and define their goals, with their focus being on particular, very specific objects, situations, or problems. This is not necessarily empirical research; it is very often theoretical research provoked by contradictions between different branches of science, as when Einstein struggled to deal with the incompatibility between Newtonian physics and Maxwell's theory of electro-magnetic fields. It can also be mathematical problems, and the problem of developing and utilizing appropriate forms of mathematics, as was the case with Newton, Maxwell, and Einstein. The concern of scientists is to achieve as much certainty as possible in their conclusions by the rigor with which they apply their methods, reconcile inconsistencies or spell the implications of their theories, devise experiments where predictions can be validated, or make the required observations. While Einstein did not engage in empirical work, he was concerned to make precise predictions from his theories which could be observed. Within science there is therefore a tendency to increasing specialization to achieve such certainty, resulting in the multiplication of disciplines and subdisciplines, often without much concern for their relationship to each other. Consequently, scientific knowledge tends to become compartmentalized. This can marginalize theoretical scientists whose main interest is in overcoming inconsistencies between different branches of science. This tendency has become so extreme over the last fifty years that, as Bruce Charlton argued in *Not even trying … The Corruption of Real Science*, disciplines no longer check each other, making defective assumptions invisible and ineradicable. We no longer have 'Science' as such, but 'an arbitrary collection, a *loose heap* of micro-specialties each yielding autonomous micro-knowledge of unknowable applicability' [43] (p. 121).

The natural philosopher on the other hand has a global focus and must be prepared to question every assumption, and when investigating any particular object or subject matter, is concerned to understand how these relate to everything else that could be investigated. The assumption that they are so related, that no entity can be conceived in complete abstraction from everything else, Whitehead suggested is the great preservative of rationalistic sanity. It is equivalent to C.S. Peirce's notion of synechism, that the universe exists as a continuous whole of all its parts, with no part being fully separate. Consequently, natural philosophers are concerned with how all the different disciplines and arts are related to each other and must engage not only with the assumptions underpinning scientific disciplines, but the assumptions dominating other forms of inquiry and the broader culture while continuously questioning their own assumptions. They are less focused on consistency between sharply defined concepts than with inclusivity, being prepared to work with relatively vague concepts to achieve this. As with theoretical science, this involves considering whether knowledge claims made in diverse fields of practice or inquiry are consistent with or contradict each other, and then how to overcome these contradictions, but over a much broader range of scientific and cultural domains. Einstein as a theoretical scientist, for instance, paid little attention to whether his theories were compatible with the existence of conscious beings capable of taking responsibility for their actions, creating civilizations and developing scientific theories, while this was the central concern of Whitehead as a natural philosopher.

Whitehead seemed to assume that the philosopher and the scientist are different people, but this need not be the case, and prior to the eighteenth century, seldom was the case. Those studying nature were usually both philosophers and scientists as these were characterized by Whitehead. Natural philosophy is broader than theoretical work in science, having to consider and give a place to nature in all the diverse ways that nature is experienced. While this includes what is experienced in everyday practical life, in history and in the arts: sculpture, painting, architecture, and poetry as well as the sciences, advances of science cannot be ignored. It is for this reason, as Unger and Smolin pointed out, that most of the most important work in natural philosophy in recent years has been undertaken by investigators who could also be called scientists, although only a few scientists now are also natural philosophers. Whitehead and Peirce exemplified this duality, each being natural philosophers after having advanced mathematics and participated in scientific work. Generally, it is those scientists involved in what Thomas Kuhn called revolutionary science who tend to be natural philosophers as well as being scientists. That is, they are not prepared to accept received assumptions and are oriented to achieving a comprehensive understanding of the world, including themselves as part of the world, while being engaged in one or more specialized areas of scientific research.

There is also an asymmetry in natural philosophy and science as characterized by Whitehead because science as it has developed since the seventeenth century would not have been possible without the work of natural philosophers, while natural philosophy existed before science. This does not mean that there are not people who think they can ignore theory and make observations and measurements and look for correlations using usually crude forms of statistics, and then call their work science. This often happens in psychology, sociology, and medicine. This is widely recognized as pseudo-science. However, it is still assumed by most philosophers and scientists who are doing genuine science that once science is established, it can leave philosophy behind. Even Kuhn was more sympathetic to what he called normal science, where philosophical questions have been settled, than revolutionary science. This view was neatly summarized by the editors of *After Philosophy: End or Transformation* when they wrote: 'The rise of the modern sciences of nature removed–forever, it seems–vast domains from the authority of philosophical reflection', and '[t]he ensuing turn to the subject, appears now to have been only a temporary stopgap, which could remain effective only until the human sciences and the arts grew strong enough to claim their proper domains from philosophy as well' [44] (p. 1).

This view had already been challenged by Whitehead. As he argued:

> 'The Certainties of Science are a delusion. They are hedged around with unexplored limitations. Our handling of scientific doctrines is controlled by the diffused metaphysical concepts of our epoch. Even so, we are continually led into errors of expectation. Also, whenever some new mode of observational experience is obtained the old doctrines crumble into a fog of inaccuracies' [45] (p. 154).

If science is not to stagnate, he went on to argue, its assumptions must be open to question by philosophers concerned to spell out the implications of ideas in each domain of enquiry for every other domain. As he put it:

> '[O]ne aim of philosophy is to challenge the half-truths constituting the scientific first principles. The systematization of knowledge cannot be conducted in watertight compartments. All general truths condition each other; and the limits of their application cannot be adequately defined apart from their correlation by yet wider generalities. The criticism of principles must chiefly take the form of determining the proper meanings of the notions of the various sciences, when these notions are considered in respect to their status relatively to each other. The determination of this status requires a generality transcending any special subject-matter' [46] (p. 10).

This very much accords with the arguments of Unger and Smolin for natural philosophy.

There has to be more than this, though. Normal scientists take for granted the conditions for their operation, including language, institutions, traditions, and cultural fields with their long histories. All of these must be acknowledged by natural philosophers who, in their commitment to comprehensiveness, must acknowledge that their work is being undertaken in a world of which they are part, and which is already underway. Normal scientists applying their methods can ignore the ultimate incoherencies of the natural philosophy they assume. This is clearly the case with those working with various forms of reductionism, most of which have their roots in the seventeenth century scientific revolution. The natural philosophies which came to prevail at this time, whether Cartesian or Newtonian, provided strong support for the experimental methods associated with methodological reductionism developed by Francis Bacon and refined by Galileo, where boundary conditions were set up to enable variables to be correlated to make measurable and testable predictions. However, their conceptions of nature made it impossible to understand how there could be conscious, self-reflective beings with their culture, institutions, and capacity to ask questions and act according to plans who could investigate, set up experiments and comprehend nature so conceived. Natural philosophy, being obliged to deal with every subject matter, must be able to account for the possibility of there being natural philosophers and scientists as subjects, along with their institutions, being able to gain such knowledge. For this reason, the scientific achievements generated by the seventeenth century scientific revolution have always been problematic from the perspective of subsequent natural philosophy and this has been the central problem for natural philosophers from Spinoza and Leibniz onward.

Even if natural philosophy can be shown to be essential to science and culture generally, there is a problem of how to evaluate rational progress in its development. While normal science can proceed with relatively clear criteria of what counts as advances in knowledge, natural philosophy brings all criteria into question. This means that radically new developments in natural philosophy, along with the new forms of science they inspire, are left without criteria to evaluate them. This is the problem that Kuhn had to confront in accounting for claims to progress with revolutionary science. Whitehead did attempt to provide general criteria for evaluating philosophies. As he put it in *Process and Reality*:

> 'Speculative Philosophy is the endeavour to frame a coherent, logical, necessary system of general ideas in terms of which every element of our experience can be interpreted. By this notion of 'interpretation' I mean that everything of which we are conscious, as enjoyed, perceived, willed, or thought, shall have the character of a particular instance of the general scheme. Thus the philosophical scheme should be coherent, logical, and in respect of interpretation, applicable and adequate. Here 'applicable' means that some items of experience are thus interpretable, and 'adequate' means that there are no items incapable of such interpretation' [46] (p. 3).

These notions are vague when it comes to utilizing them in practice, however, and Whitehead at one stage claimed that when it comes to speculative philosophy, there is no method. As he put it:

> 'The speculative Reason is in its essence untrammeled by method. Its function is to pierce into the general reasons beyond limited reasons, to understand all methods as coordinated in a nature of things only to be grasped by transcending all method. This infinite ideal is never to be attained by the bounded intelligence of mankind' [47] (p. 51).

Consequently, there can be no absolute criteria of success, and no philosophical system can ever be entirely successful.

However, Whitehead qualified this conclusion, arguing that there is a method of sorts involved in reaching beyond set bounds, including all existing methods. It was this 'method' which was discovered by the Greeks, and why we now talk of speculative reason rather than inspiration. Essentially, speculative reason is, in the terminology of Peirce, abduction, the development of a working hypothesis through the free play of imagination to elucidate experience. Working hypotheses are arrived at through the generalization of patterns experienced in particular domains. This procedure is referred to by Whitehead as the method of 'descriptive generalization', meaning 'the utilization of specific notions, applying to a restricted group of facts, for the divination of the generic notions which apply to all facts' [46] (pp. 5 & 10). Although Whitehead seldom used the terms, this is a matter of elaborating analogies or metaphors.

Whitehead concluded that what is required to reveal the limitations of each speculative scheme of ideas is a plurality of such schemes, each revealing the limitations of each other [45] (145). But how could these rival systems, each with their own criteria of success, be evaluated in relation to each other? Only by revealing and transcending the limitations of earlier thinkers, while appreciating their achievements. As Christoph Kann in a recent anthology on Whitehead's late work interpreted Whitehead's views on this:

> Any cosmology must be capable of interpreting its predecessors and of expressing their explanatory limitations. In their historical interdependence cosmological conceptions reveal a continuity that protects them from arbitrariness and supports their mutual relevance and their capability of illuminating one another [48] (p. 33).

Alasdair MacIntyre's argument that it is through narratives that judgements can be made in these circumstances provides support for this claim and explains the role of narrative in achieving this. He illustrated this using the work of Galileo as an example:

> Wherein lies the superiority of Galileo to his predecessors? The answer is that he, for the first time, enables the work of all his predecessors to be evaluated by a common set of standards. The contributions of Plato, Aristotle, the scholars at Merton College, Oxford and Padua, the work of Copernicus himself at last all fall into place. Or to put matters in another and equivalent way: the history of late medieval science can finally be cast into a coherent narrative.... What the scientific genius, such as Galileo, achieves in his transitions, then, is not only a new way of understanding nature, but also and inseparably a new way of understanding the old sciences way of understanding... It is from the stand-point of the new science that the continuities of narrative history are re-established [49], (pp. 459–460 & 467).

While it is impossible for any intellectual endeavor to proceed without such a narrative, this must be central to natural philosophy. Aristotle's *Metaphysics* began with such an historical narrative, the source of most of our knowledge of the early Greek philosophers, and Whitehead in *Science and the Modern World* [50] provided a brilliant history of modern thought. Even Descartes, who claimed to be starting afresh and beginning his philosophy from supposedly indubitable foundations, could only defend what he was doing through an historical narrative. And it is for this reason that much of the work in natural philosophy since the 1950s, after analytic philosophy and logical positivism had produced a collective amnesia about the history of natural philosophy, has been devoted to history, recovering this lost narrative. But then it is necessary for natural philosophy to characterize and account for narratives and the beings that can produce and understand narratives and be oriented by them.

There is also thinking even more primordial than narratives. To be able to tell stories and have them understood, let alone deploy abstract concepts to particular cases or situations, people need to be able to make discriminations and put the topics they are focusing on in context. It is for this reason that various thinkers have suggested the need for a non-propositional logic of context-dependent discrimination and association. This is the case with Chris Clarke, a theoretical physicist who has also become a natural philosopher. Clarke [51] (p. 83ff.) has invoked the logic of Ignacio Matte Blanco. Another natural philosopher, Joseph Brenner, has attempted to revive the non-Aristotelian ontological logic of the Franco-Romanian thinker, Stéphane Lupasco, based on the inherent dialectics of energy which could serve this function in a more profound way [52]. It is through the implicit utilization of a logic of context and discrimination, allowing for the possibility that entities are inseparable yet essentially opposed to each other, that not only natural philosophy generally, but philosophical biology and philosophical anthropology are able to make contributions to knowledge over and above what is offered by theoretical biology and theoretical psychology or anthropology. These domains of inquiry can and do consider far more than science of what is experienced in recognizing something as alive as opposed to all that is not alive, or in recognizing the distinctive features of humans as opposed to all other living beings. It is for this reason that ultimately, theoretical biology and theoretical anthropology must defer to philosophical biology and philosophical anthropology [53].

4. Reviving Dialectics

Considering all this together, it should be evident that the reasoning associated with natural philosophy cannot be reduced to induction and deduction which, logical positivists claimed, were the only valid forms of reasoning and the ultimate foundations of scientific knowledge. And as Paul Livingston showed, a great deal of modern analytic philosophy is devoted to dealing with the paradoxes generated by efforts to define reason in these terms, ultimately, unsuccessfully [54] (p. 20ff.). Russell's paradox and Gödel's two incompleteness theorems were just the beginning of these paradoxes, but the most fundamental and insoluble paradox is the incoherence of the claim that deduction and induction exhaust what is involved in reasoning. If this were the case, there would be no way to validate this claim, since it clearly cannot be defended by either induction or deduction or any combination of the two, and so cannot be judged to be true. It is self-refuting. This paradox also highlights the core problem of dealing with reflexivity when attempting to achieve absolute certainty by claiming absolute foundations for reasoning and knowledge.

Natural philosophy is advanced through dialectical reasoning (which at the very minimum includes abduction as well as induction and deduction) and such reasoning must be recognized as more primordial than the demonstrative logic of Aristotle, and even more primordial than modern symbolic logic. These should be seen as adjuncts to dialectical reasoning, which is required to judge when these latter forms of logic are applicable, what are their boundaries of validity, and how to deploy them. The problem here is to characterize dialectical reasoning and thereby to situate, interpret, and defend Whitehead's defense of speculative philosophy as a contribution to dialectical thought. What stands in the way of this is that dialectics tends to be identified either with the geometrized dialectic of Hegel's *Science of Logic*, or with dialectic as characterized by Friedrich Engels and the Marxists who followed Engels. What has been lost is a broader and more adequate history of dialectics, and the absence of this is largely responsible for the lack of appreciation of natural philosophy and how it has developed.

To begin with it is necessary to appreciate dialectics as it was developed in Ancient Greece, particularly by Plato. Aristotle also utilized a form of dialectical thinking to reason from reputable opinions on any subject matter to reach what he claimed were the first principles for their study. This is too limited. Plato, on the other hand, developed dialectic as a way of questioning to discover the meaning of words, thereby revealing the relationship of these words and their meanings to each other, while giving a place to new conjectures or speculations and the development of radically new ideas and ways of thinking. He is known primarily for the claim that knowledge can only be of the Forms (*eidos*), although whether these are separate, transcendent entities or omni-temporal aspects of what exists (as Jaakko Hintikka, [55] (p. 67f.) among others, argued) is open to dispute. If the latter, Plato could be regarded as a naturalist as well as a natural philosopher. Heidegger [56] (p. 104) claimed that Plato upheld an older notion of truth as disclosing or revealing, while at the same time elaborating a coherence theory of truth according to which, as Gail Fine summarized,

> ' ... one knows more to the extent that one can explain more: knowledge requires, not a vision, and not some special sort of certainty or infallibility, but sufficiently rich, mutually supporting, explanatory accounts. Knowledge, for Plato, does not proceed piecemeal; to know, one must master a whole field, by interrelating and explaining its diverse elements' [57] (p. 114).

So, dialectics in Plato was a form of reasoning based on asking questions, beginning with discriminating and appreciating relationships between items identified in this way, and then contrasting different perspectives, thereby enabling people to overcome the one-sided thinking that leads to disasters [58]. In the process, new perspectives could be offered to overcome the limitations of those perspectives revealed to be defective. Achieving this required narratives to allow arguments to be 'viewed together' (that is, they are 'synopses'), always situated in contexts, and Plato's dialogues were, as Nietzsche characterized them in *The Birth of Tragedy,* philosophical novels [59] (xiv, p. 88).

Subsequently, decontextualized propositional thinking came more and more to dominate philosophical thinking, associated with a more domineering orientation to the world. Aristotle was at the starting point of this trend. While Plato placed dialectics above all other studies, denying the possibility of placing any other study, including mathematics, above it, Aristotle distinguished demonstrative reasoning from true premises, utilizing syllogisms, from dialectical reasoning and took demonstrative reasoning to be the more important form of reasoning. It should be noted though that even Aristotle's development of formal logic as a logic of classes and class membership was still closely tied to drawing distinctions and to characterizing the essential differences between diverse kinds of beings, and this itself was a contextual, relational form of thinking. Classes are not merely sets, and they can also be implicitly evaluative. To characterize humans as *zoon politikon* is not only to distinguish humans from other organisms by virtue of all the capacities that are formed by being educated and then participating in a self-governing community, but to distinguish humans who have developed their potential from those who have not, and to evaluate them as superior by virtue of this.

Aristotle did not identify causation with logical necessity, but such an identification resulted from the trajectory of thought begun by the focus on demonstrative reasoning. Formal logic was about reducing reasoning to following explicit rules, and the further development of this conception of reasoning continued through the centuries, culminating in the seventeenth century. Leibniz claimed that since much of human reasoning is just combinatorial operations on characters it can be substantially improved with the help of a mechanical procedure to guide our judgements. To this end, he proposed an algebra of logic that would specify the rules for manipulating logic concepts. This is the project later embraced by Frege, Bertrand Russell and the logical positivists who, with the development of symbolic logic, also attempted to reduce mathematics to logic and set theory. This project, which led to the development of computers and information technology, became so entrenched that until Jaakko Hintikka pointed it out, most analytic philosophers were unaware of what they were assuming or the possibility of according a different status to demonstrative reasoning [60]. It is this form of demonstrative reasoning that came to dominate science, locking in place Newtonian philosophy of nature and assumptions about science and choking off efforts to develop alternative philosophies of nature, fostering both epistemological and ontological reductionism. As Unger and Smolin pointed out, the Newtonian paradigm extrapolates to the whole universe an explanatory strategy which involves distinguishing 'between initial conditions and timeless laws applying within a configuration space demarcated by stipulated initial conditions' [1] (p. 43), with an implicit ambition to provide mathematical equations through which the state of the universe at each instant could be deduced from any earlier or later state [61]. From this perspective, time as temporal becoming is unreal, and it is assumed that apparent diversity such as the existence of sentient organisms can be explained away as appearances generated by the laws characterizing the fundamental components of nature, whether these be particles, fields or strings. Smolin pointed out just how pervasive this paradigm is:

> 'To use this paradigm, one inputs the space of states, the law, and the initial state, and gets as output the state at any later time. This method is extremely powerful and general, as can be seen from the fact that it characterizes not just Newtonian mechanics, but general relativity, quantum mechanics and field theories, both classical and quantum. It is also the basic framework of computer science and has been used to model biological and social systems' [1] (p. 373).

In the Middle Ages, the words logic and dialectic were treated as synonymous. This did not really change until Kant used the term 'dialectics' and it was taken up by the post-Kantian philosophers. Kant is usually interpreted from the perspective of neo-Kantianism, which developed (initially by Hermann von Helmholtz) to oppose the influence of post-Kantian philosophy, and for this reason, Kant is usually left out of histories of natural philosophy. This is not surprising because Kant, following interpretations by neo-Kantian philosophers, is usually identified with his critical philosophy grappling primarily with epistemological issues, used to deny the possibility of characterizing the world as it is in itself, the noumenal realm. His vastly superior characterization of mind to Descartes or Locke, the role he ascribed to asking questions as necessary for judgements, and his claim to be laying the foundations for superior knowledge in metaphysics, have been almost completely ignored. Also, largely ignored until recently for similar reasons have been his defense of a dynamism, the characterization of matter as forces of repulsion and attraction rather than bits of inert matter occupying space, in his *Metaphysical Foundations of Natural Science*, and his contributions to philosophical biology in his *Critique of Judgment* [62] (§65). Recognizing Kant's broader ambitions, what is important for the history of the idea of natural philosophy is the role he accorded to imagination and to 'concepts', and his defense of a constructivist theory of mathematics according to which we know mathematical truths as synthetic a priori because we have constructed our mathematics. On this basis, he argued that we only know what in some sense we have created. It is also important to recognize his efforts to develop a different kind of reasoning, transcendental deductions, to justify synthetic a priori knowledge about the sensible world. Through these he attempted (unsuccessfully) to demonstrate that we have to accept a particular set of concepts if the sensible manifold we experience is to be made intelligible. In conjunction with these supposed transcendental deductions, Kant reintroduced the term dialectics, although following Aristotle rather than Kant, he did not accord dialecticsa central place. What is more important is that, in attempting to give a place to transcendental deductions, synthetic a priori knowledge, and dialectics he highlighted the need for a different kind of reasoning and different kind of knowledge than had come to dominate and still dominates mainstream science.

The post-Kantian tradition of philosophy emerged with those philosophers who embraced Kant's notion of forms of intuition and categories of the understanding as conceptual frameworks, and developed Kant's concept of synthesis, but went beyond Kant to treat synthesis not as the basis for synthetic a priori knowledge but as central to speculation and speculative knowledge. In some cases, they not only accepted but amplified the place accorded by Kant to imagination. However, they claimed that Kant's notion of the noumenal realm was incoherent in terms of what he claimed could be known and, more importantly, they claimed that Kant failed to specify what transcendental deductions are, or to show that the concepts currently dominating science are the only possible coherent concepts. Speculation, by which old concepts could be brought into question and new concepts and conceptual frameworks elaborated, that is, a more creative form of 'synthetic' thinking, was given a central place. The notion of dialectics was taken up to characterize this, interpreted through Plato's philosophy rather than Aristotle's, and then deployed to show how conceptual frameworks emerge, are or can be criticized, improved upon and replaced by better conceptual frameworks. The figures involved in this revival and development of dialectics were J.G. Fichte, Friedrich Schelling, G.W.F. Hegel, and Friedrich Schleiermacher. As far as natural philosophy is concerned, the most important figure is Schelling, a philosopher who, despite being commonly classified as an Idealist, defended natural philosophy (*Naturphilosophie*) as more fundamental than transcendental philosophy [63] (p. 5), [64]. It is also important to appreciate that Kant himself in his very last unpublished writings appears to have been developing his ideas in precisely the same direction as Schelling, as I have argued elsewhere [65]. Hegel also attempted to advance natural philosophy as part of his Absolute Idealism, but the focus on his work had the effect of discrediting the contributions to natural philosophy of post-Kantian philosophers.

Fichte began the tradition of post-Kantian philosophy and the revival and development of dialectical thinking, although this is not how he characterized it. Criticizing both the notion of the noumenal realm and Kant's supposed transcendental deductions, he was the first philosopher to embrace and defend the notion of 'intellectual intuition', a notion coined by Kant to describe immediate knowledge of oneself as a thing-in-itself in order to reject it as a possibility. Fichte characterized it as experience of reflection on the nature and development of experience and on the generation of concepts, and on the adequacy of concepts used to interpret experience, anticipating both the genetic phenomenology of Husserl's later work, and the genetic epistemology of Jean Piaget. He accorded extended powers of synthesis to intellectual intuition, claiming that Kant's notion of construction could be extended from mathematics to all cognitive development. For Fichte, intellectual intuition is not a faculty of the subject, but is the subject positing itself and its other, coming to know itself and thereby constituting itself in a non-objective manner through mediation of what can be known objectively. He argued for the priority of action in the formation of concepts, taking theoretical knowledge of concepts as derivative [66] (pp. 61 & 256). It is through action that experience, which is first and foremost 'feeling', including feelings of resistance to striving rather than discrete sensations, is constituted as objects, and it is only on reflection that we develop concepts of these objects. However, Fichte later concluded that self-consciousness and free agency are further dependent upon being recognized by and recognizing other finite rational beings as free and ascribing efficacy to them. 'No Thou, no I: no I, no Thou' he proclaimed [66] (p. 172f.).

Kant had argued that some debates in philosophy are irresolvable. These are the antinomies of pure reason, practical reason and taste; for instance, the claim that all composite substances are made of simple parts (thesis) and no composite thing consists of mere simple parts (antithesis), and that to explain appearances there must be a causality through freedom (thesis) and all that happens is determined by the laws of nature (antithesis). Fichte set out to show that through such synthetic thinking it is possible to reconcile these antinomies, and in doing so, achieve higher syntheses. There is no algorithm for solving such problems. Every problem must be dealt with in its own terms, requiring a fresh exercise of imagination in problem solving. This form of synthetic thinking provided him with a way to construct the concepts required to organize experience, achieving self-comprehension in the process. All of this is made possible, Fichte argued, by 'the wonderful power of productive imagination in ourselves' [66] (pp. 112, 185 & 187). Unlike conceptual analysis, logical inference, or syllogistic reasoning, this 'dialectical' method of derivation is thoroughly synthetic, always involving imagination. Through such thinking, Fichte attempted to establish and justify the forms of intuition and the categories of the understanding without postulating an unknowable thing-in-itself.

5. Schelling's Dialectics

It is dialectics as developed by Schelling that provided the forms of thinking required to revive and develop natural philosophy. Schelling took Fichte's work as his point of departure and focused on and developed the notions of synthesis and construction to forge a synthesis of natural philosophy, art, and history. He took over from Fichte the view that the subject is activity that can be appreciated as such through intellectual intuition, that objects of the sensible world can only be understood in relation to the activity of this subject, that conceptual knowledge originates in practical engagement in the sensible world, that there can be and is also an appreciation of other subjects as activities rather than objects, and that the formation of the self-conscious self is the outcome of the limiting of its activity by the world and other subjects. Schelling also took over and further developed Fichte's defense of construction and his genetic, dialectical approach to construction, but instead of seeing the development of cognition only as humans achieving consciousness of their own self-formation, saw it as the process by which nature has come to comprehend itself and its evolution through humanity. He defended an even stronger thesis against Kant's effort in 'The Discipline of Pure Reason' in the *Critique of Pure Reason* to limit construction to mathematics [67] (A725/B753ff., p. 677ff.), arguing that 'the philosopher looks solely to the act of construction itself, which is an absolutely internal thing' [66] (§4, p. 13). Thought is inherently synthetic, Schelling argued, and begins with genuine opposition either between thought and something opposing it, or other factors within thought. This necessitates a new synthetic moment that can be treated as a product or factor in the next level of development.

Building on Kant's and Fichte's ascription of a central place to imagination in such synthesis and developing Kant's concept of construction and extending Fichte's genetic approach from the development of cognition to the development of the whole of nature, Schelling characterized 'intellectual intuition' as a form of knowledge gained through a reflective and imaginative experimentation and construction by the productive imagination of the sequence of forms produced by the 'Absolute'; that is, the unconditioned totality, the self-organizing universe. Intellectual intuition reproduces in imagination the process by which nature, through limiting its activity, has constructed itself as a diversity of productivities and products, a process of self-construction in which the philosopher in his or her particular situation is participating. In this way, Schelling embraced and further radicalized Kant's more radical conjectures: his dynamism, according to which matter is defined by forces of attraction and repulsion and his conception of living organisms put forward in the *Critique of Judgment* as unities in which the parts are both causes and effects of their forms [62] (p.252), and in doing so, anticipated not only the notion of autopoiesis but hierarchy theory as developed by Pattee, Allen, and Salthe. Referring to this dialectic as the 'standpoint of production' in contrast to the Kantian 'standpoint of reflection', Schelling was concerned not only to show the social conditions for objective knowledge, but the nature of the world that enables it to be known objectively and explained at least partially through Newtonian physics, while questioning the assumptions of Newtonian physics. At the same time, he was concerned to show how the world has produced subjects able to achieve knowledge of it and of themselves, and who could question current assumptions and ways of conceiving the world, and go beyond received knowledge. This was seen to require the development of a new physics which he claimed would reveal the relationship between magnetism, electricity, and light, provide the theoretical foundations for chemistry, justify and advance Kant's conception of life, and provide a new way of understanding human existence. This, in essence, is the whole project of Schelling's *Naturphilosophie* [68].

As opposed to Hegel's geometrized dialectic of his *Science of Logic*, Schelling's version of dialectics requires creative imagination and is infused with willing. The production of truth goes beyond abstract logic and is guided by volition. The advance of the dialectic adds something new; it does not simply sublate earlier phases of the dialectic as in Hegel. This notion of dialectics embraces and extends Kant's constructivist account of mathematics to knowledge generally. Dialectical construction assumes a generative order of nature that is ontologically prior to this dialectical production of truth, and is reproduced by this dialectical construction. Such reconstruction enables the universal and the particular, the ideal and the real, to be grasped together.

Through such construction, Schelling characterized the whole of nature as a self-organizing process, showing how it had successively generated opposing forces, apparently inert matter (in which stability is achieved through a balance of opposing forces), organisms which actively maintain their form, inner sense, and sensory objects, intelligence, self-consciousness and human institutions with their history. Nature on this view is the activity of opposing forces of attraction and repulsion, generating one form after another. He argued that 'The *whole* of Nature, not just *part* of it, should be equivalent to an ever-*becoming* product. Nature as a whole must be conceived in constant formation, and everything must engage in that universal process of formation' [68] (p. 28). Inverting Kant's characterization of causality, Schelling argued that mechanical cause–effect relations are abstractions from the reciprocal causation of self-organizing processes. Matter is itself a self-organizing process. While 'matter' emerges through a static balance of opposing forces, living organisms were characterized by Schelling as responding to changes in their environments to maintain their internal equilibrium by forming and reforming themselves, a process in which they resist the dynamics of the rest of nature and impose their own organization. In doing so, they constitute their environments as their worlds and react to these accordingly. While Schelling was centrally concerned with explaining the emergence and evolution of humans, in the end he abandoned the notion that the telos of the entire universe is humanity and its development, allowing the possibility that in the future humans could become extinct.

Like Unger and Smolin, Schelling defended the philosophy of nature as natural history, the study of how matter, time, space, structures, organisms, and human life have emerged and evolved, in doing so, rejecting Kant's denigration of natural history as not a genuine form of knowledge. A rigorously developed history of the cosmos, Earth and life on Earth within which human history can then be situated, Schelling argued, will provide the ultimate framework for understanding nature. 'From now on," Schelling proclaimed, "Science [*Wissenschaft*], according to the very meaning of the word, is history [*Historie*]. . . . From now on, science will present the development of an actual, living essence' [69] (p. 13).

Schelling did not believe that this dialectical reconstruction of nature by itself would guarantee the truth of his philosophy of nature, however. Philosophers should develop their own systems, knowing that no system could be final. Dialectics extends from thoughts of individuals to the thoughts of others and to the relationship between philosophies and philosophical systems, and also the findings of empirical and experimental research guided by these systems. Philosophy advances as less perfect forms of philosophy are discarded and their valuable contents assimilated to more perfect forms. A philosophical system should be judged according to its coherence and comprehensiveness, and its capacity to surpass by including more limited philosophical stances. This is revealed by constructing histories of philosophy, and Schelling wrote a history of modern philosophy to this end. These are the ideas revived by Peirce and Whitehead, and then later, by the post-logical positivist philosophers of science, although they were not identified as part of the tradition of dialectical logic.

Recognizing them as such provides the basis for a better appreciation of their contribution to characterizing dialectical reasoning. Peirce's concept of abduction and his characterization of the relationship between abduction, which is a creative interpretant of received signs of objects being studied, deduction where the necessary implications of these interpretants are spelt out and elucidated, and induction which involves posing questions based on such elucidations that can be answered by experience, paving the way for further abduction, is a significant contribution to and clarifies the nature of dialectical thinking. So also is the reciprocal relationship identified by Whitehead between philosophy's quest for global comprehension, and science's quest for certain knowledge through rigorous methods, with each serving as an impetus for revising and developing the other. Whitehead's insight into the importance of co-existing philosophies to illuminate the deficiencies of each and the importance to traditions of inquiry of acknowledging ideas that had been transcended, appreciated by Schelling and cogently argued for by post-positivist philosophers of science, should also be seen as important aspects of dialectical thinking.

Once this tradition of Schellingian dialectics is recognized, it becomes possible to appreciate which were the real contributions of these later thinkers to the tradition of dialectics and natural philosophy, and also to see where forgotten insights and achievements of earlier thinkers need to be recovered.

6. Phenomenology, Philosophical Biology, and Philosophical Anthropology

My claim for the continuity of the tradition of natural philosophy, once the crucial role and influence of Schelling is understood, might not seem to fit philosophical biology and philosophical anthropology as major components of natural philosophy. Explicitly formulated as such, these were influenced by Husserl's phenomenology, although disowned by him, and Husserl was mainly influenced by Brentano and Frege. Brentano was highly critical of Kant and called for a return to Aristotle in place of the neo-Kantian call for a return to Kant, and dismissed Fichte, Schelling, and Hegel as 'lacking all value from a scientific point of view' [70] (p. 21). His core concept of intentionality originated in the Aristotelian tradition of philosophy as Aristotle had been interpreted by Aquinas. Frege is often seen as the originator of analytic philosophy and is usually seen as an anti-Kantian philosopher, and certainly anti-post-Kantian. However, Husserl was also influenced by William James and Henri Bergson [71]. James' radical empiricism was partly influenced by Peirce's phenomenology, but really was a revival of Goethe's call for a proper appreciation of all experience [72] (p. 91f.). Peirce characterized himself as a Schellingian of some stripe. Goethe was Schelling's mentor, and had a strong influence on the development of his philosophy of nature. Bergson corresponded with James, and also belonged to a French tradition of thought influenced by Schelling led by Félix Ravaisson (who attended Schelling's lectures) and Émile Boutroux.

The importance of phenomenology was not that it achieved what Husserl aimed at, a rigorous, science based on a presuppositionless method for examining experience providing apodictic knowledge more fundamental than the natural sciences, a goal that Husserl himself acknowledged had failed [73] (p. 389), but that it freed philosophers from the assumptions about experience (and associated conception of humans) foisted on them by philosophers and scientists influenced by

Descartes, Thomas Hobbes, John Locke, and Isaac Newton. Phenomenology enabled them to appreciate the complexity of experience, of what they experienced and what they are as experiencing beings. It could deal with the temporality of lived experience, with unreflective, pre-predicative experience as well as the way in which concrete and abstract objects are constituted as a temporal process, the experience of being embodied in the life-world and the highest levels of self-conscious reflection. It freed philosophers (most notably, Merleau-Ponty) to appreciate the original global experience of the world that is the background to discriminating and identifying any item of experience, to examine the discriminations that are made and the bases of these discriminations, that is, the essences of any item of experience, and to see these in their various contexts and in relation to each other. It also enabled philosophers to examine why these discriminations were made. In doing so, it forced philosophers to recognize the temporality of all experience and the complexity of this temporality, and to give a place to the experience of subjects as well as of objects, along with other items of experience that could not be objectified.

Phenomenology gained much of its impetus by offering a rigorous approach to studying topics and issues raised by Schelling in his *Essay on Freedom* and his late Berlin lectures from 1842 onwards. This was the origin of the existentialist movement. Heidegger's hermeneutic phenomenology was closely associated with existentialism, and such hermeneutics was really a revival of themes developed by Herder, Schleiermacher, and Schelling as well as Wilhelm Dilthey. Phenomenology was providing a logic of context and discrimination, despite Husserl's intentions. Husserl's later genetic form of phenomenology, showing how more complex forms of experiencing and thinking develop out of more basic forms of experience, echoed Fichte's study of cognitive development on the basis of which he developed his notion of dialectics. As Merleau-Ponty [74] suggested and put into practice, genetic phenomenology was a significant contribution to and expansion of dialectics, incorporating into it pre-predicative lived experience while facilitating engagement with various specialized inquiries, scientific and nonscientific, while being irreducible to these specialized inquiries.

It was in this way that phenomenology provided the way to develop philosophical biology and philosophical anthropology as contributions to natural philosophy, beginning with the work of Max Scheler [75] and developed by Helmuth Plessner, Arnold Gehlen, Hans Jonas and others, including most recently, Andreas Weber [76]. This in turn engendered a revival of interest in the work on philosophical biology and philosophical anthropology by Kant, Herder, Hegel, Marx, Engels, and George Herbert Mead [53], and more distantly, Aristotle. It enabled philosophers to examine what were the essential features of any living being as these were experienced in the context of other experiences, ultimately the global experience of the being of the world, differentiating such beings from and relating them to nonliving beings in the context of the world. And it enabled them to examine the essential features of humans as opposed to other living beings, giving a place to the various dimensions of human experience associated with subjectivity that cannot be understood through the objectifying approach of science. It is this which differentiates philosophical biology and philosophical anthropology from developments in theoretical biology and the human sciences committed to doing full justice to the distinctive characteristics of life and of humans, and requires that even these more radical forms of science be judged by their capacity to do justice to the insights of philosophical biologists and philosophical anthropologists [9,53]. Philosophical biology and philosophical anthropology also reveal the need for a broader natural philosophy challenging mainstream science, a natural philosophy that privileges temporal becoming and accords a place to self-organizing processes, as with process philosophy, as Merleau-Ponty came to appreciate [10].

7. Contemporary Natural Philosophy as a Coherent Tradition

Acknowledging the central place of Schelling in the history of natural philosophy, in characterizing natural philosophy, developing a form of reasoning by which it could be advanced, and offering a particular philosophy of nature, provides the basis for recognizing natural philosophy as a discourse which is a coherent tradition, although not properly recognizing itself or being recognized by others as such and therefore somewhat fragmented. This enables us to see natural philosophy as something different from science and mathematics with a different kind of rationality and different and more inclusive criteria for judging progress, and that natural philosophy, while being distinct from science, is essential to the progress of science. It also provides the basis for a better understanding of the history of science and, thereby, much of the confusion in how current science is understood where advances based on the influence of Schelling continue to be interpreted through Newtonian assumptions that Schelling rejected.

Despite the marginalization of natural philosophy and dialectics in philosophy, most of the major advances in science over the last century and a half have been inspired directly or indirectly by the Schellingian tradition of *Naturphilosophie* [29,64,77,78]. Even many of the most important advances in mathematics on which current science is based were inspired by Schelling's call for new developments in mathematics adequate to a dynamic nature, mainly through his influence on Justus and then Hermann Grassmann [79,80]. In developing his extension theory which he offered as a keystone to the entire structure of mathematics, Hermann Grassmann invented linear and multilinear algebra and multidimensional space and foreshadowed the development of vector calculus, vector algebra, exterior algebra, and Clifford algebra. He also anticipated to some extent the development of category theory, which, through the work of Robert Rosen and Andrée Ehresmann, has led to new efforts to provide mathematical models adequate to life [80,81]. Schelling was the first to suggest that electricity, magnetism, and light were associated [82] and could be understood through the dynamism he embraced and developed. Schelling was then a direct influence on Hans Christian Oersted, the first scientist to show a direct relationship between electricity and magnetism. This tradition of dynamism, and especially the contribution to it of Schelling, was embraced in Britain by Coleridge and his circle, which included the mathematician William Hamilton and Humphrey Davey. Faraday's work and his notion of fields were enthusiastically supported by this circle, along with the Oxford philosopher William Whewell who coined many of the terms utilized and incorporated by Faraday into physics (for instance, 'anode', 'cathode', 'ion', and 'dialectric'). Faraday's work, including his development of field theory, was hailed by Schelling himself as the fulfilment of his philosophy of nature, and this was reported to Faraday by Whewell [83] (p. 296f.). *Naturphilosophie* inspired the first law of thermodynamics, that energy is conserved, leading to claims by some natural philosophers, the energeticists, that energy should replace matter as the basic concept of science [84] (p. 301). This included Aleksandr Bogdanov whose work on tektology, the study of organization, was a major influence on the development of general systems theory [85]. Insofar as chemistry is based on the notion of chemicals existing as balances of opposing forces (valence), it also manifests the influence of Schelling's *Naturphilosophie* [84] (p. 321). Darwin's evolutionary theory was strongly influenced by Alexander von Humboldt, a friend of Schelling and an admirer of his natural philosophy [86] (ch. 14). Building on Kant's conception of living organisms, Schelling anticipated Jacob von Uexküll's characterization of organisms as defining their environments as their worlds and the more recent notion of autopoiesis.

More broadly, the whole tradition of process philosophy as developed through Peirce, James, Bergson, and Whitehead and those they influenced, by virtue of the philosophers and mathematicians who influenced these thinkers, should be seen as part of the tradition inspired by Schelling, despite Whitehead being influenced only indirectly by Schelling and claiming that he was returning to pre-Kantian forms of philosophizing [65]. Most natural philosophy since Whitehead can be seen as developing the tradition of process philosophy or in some way aligned with it, and Unger and Smolin's work, defending temporality and creative emergence, accords with and is really a contribution to process philosophy.

As Unger and Smolin noted, most scientists put forward their ideas on natural philosophy in books written to popularize their work. They are very often influenced by this tradition of natural philosophy, and a few have engaged with the work of natural philosophers and made significant contributions to natural philosophy. David Bohm and Ilya Prigogine are obvious examples. The biosemioticians have revived Peirce's natural philosophy, a form of process philosophy strongly influenced by Schelling [64], and Jesper Hoffmeyer's popularization of biosemiotics in his book *Signs of Meaning in the Universe* [87] was a significant contribution to natural philosophy entirely in the tradition of Schellingian philosophy of nature. This work has had a significant influence on some biologists and also on other disciplines. Biosemiotics has provided a rigorous foundation for reviving, defending, and further developing both philosophical biology and philosophical anthropology [53,76], which, in turn, challenges and calls for a redirection of biology and human sciences generally.

Other work in philosophical biology and philosophical anthropology is less directly influenced by Schelling and the tradition of *Naturphilosophie.* The more immediate influence was Husserlian phenomenology. However, once developed, earlier and often more profound work in philosophical biology and philosophical anthropology could be recovered and integrated with this later work, most importantly, Kant's and Schelling's efforts to characterize life and the characterization of humans by Hegel. Merleau-Ponty's philosophy exemplifies such efforts. However, there were other developments in philosophical biology and philosophical anthropology not labelled as such that have advanced these areas of study. This includes more recent efforts to naturalize phenomenology inspired by Merleau-Ponty and Francesco Varela [61], and the work of the earlier philosophical anthropologists such as Herder and Hegel. Harré's work on providing new foundations for psychology, work associated with hierarchy theory and Peircian and non-Peircian biosemiotics, and the work of various cross disciplinary thinkers such as Terrence Deacon and Andreas Weber, are also contributions to philosophical biology and philosophical anthropology.

Complexity theory, insofar as it is genuinely opposed to reductionism, as developed by Prigogine, Howard Pattee, Brian Goodwin, Stuart Kauffman, and Robert Ulanowicz, should also be seen as another triumph of the tradition of *Naturphilosophie,* although only very indirectly influenced by it [80]. This includes Alicia Juarrero's work, *Dynamics in Action: Intentional Behaviour as a Complex System* [88], and work on anticipatory systems, most importantly, the work of Robert Rosen and those he influenced. Rosen's work, grappling with the problem of modelling life itself and developing new forms of mathematics adequate to this, and his claim that biology rather than physics should become the reference point for defining science and its goals, is a major contribution to natural philosophy providing further support for Schelling's efforts to overcome the Newtonian tradition of science [80,89–91].

All such work is now being brought to bear on what is claimed by more conventional philosophers to be the hard problem of accounting for consciousness, much of it associated with the development of neuroscience. This has attracted a number of radical scientists who have written popularizations of their work and in doing so have contributed to natural philosophy [92–94]. Here more than anywhere else the fragmentation of ideas in this area is damaging not only the advance of science, but of society more generally by allowing fundamentally defective characterizations of humans in the human sciences, particularly in economics and psychology, to dominate the cultures of nations. Seeing the effort to understand the place of sentient organisms and humans capable of understanding themselves and their place within nature as the core problem uniting the whole tradition of natural philosophy since Schelling, and seeing the rationality underpinning and required to further develop this tradition as dialectical reason, should provide the means to overcome this fragmentation.

8. Conclusions: Creating the Future

It should now be evident that Unger and Smolin are continuing the modern tradition of natural philosophy that goes back to Schelling, grappling with the problem of how sentience can have emerged in the evolution of nature [1] (p. 480ff.). It is of major significance because the views defended are responses to the failures of advanced theoretical physics where assumptions deriving from Newtonian science are most deeply entrenched, and what they defended is an important contribution to advancing the Schellingian tradition of thought. They are reconceiving the very nature of science and its place in culture and society, and this has great relevance for confronting the cultural deficiencies of our present civilization. Their work can thus be evaluated in relation to this tradition.

To begin with, in their defense of the reasoning and claims to knowledge of natural philosophy and the significance of this knowledge, they have contributed to dialectical thinking [1] (p. 76ff.). The new form of science influenced by a revived natural philosophy would have several features:

> '[A] more ample dialectic among theories, instruments, observations, and experiments than is ordinarily practiced. Another is the investigation of problems that require crossing boundaries among fields as well as among the methods around which each field is organized. Yet another is the deliberate and explicit mixing of higher-order and first-order discourse. Viewed in this light, natural philosophy works to overcome the contrast between normal and revolutionary science' [1] (p. 82).

Natural philosophy was defended by them as a broad discourse which could engage with science, criticize it, and open new directions for research, changing the agenda of scientific research. With the revival of natural philosophy, it would be a recognized part of everyday science to identify presuppositions and consider replacing these one by one. This would involve maintaining a distinction between what science has discovered and interpretations of these discoveries, so that these discoveries could be reinterpreted. This largely accords with the discourse on natural philosophy defended by Schelling as natural philosophy, speculative physics, and natural history, and defended by Whitehead as speculative philosophy [26], but puts the ideas developed by these earlier thinkers in focus in relation to very recent science.

The most important component of the natural philosophy defended by Unger and Smolin involves reconceiving the role of mathematics in science, downgrading it and subordinating it to natural history. There have been several precursors to this, beginning with Schelling himself in opposing Kant's claim that there is only as much science as there is mathematics and in defending natural history against Kant. Grassmann accepted that, in the quest to understand nature, mathematics and the reasoning associated with it has its limits, as did Peirce and Whitehead. This was the basis of Peirce's natural philosophy privileging habits and semiosis, giving a place to the creativity that has generated diversity and Whitehead's natural philosophy giving a central place to process and creativity. More recently, theoretical scientists have pointed to the inevitable limitations of mathematics, including Prigogine, Robert Rosen, Salthe, Hoffmeyer, and Kauffman. However, most of these have been theoretical biologists, and even radical physicists such as Roger Penrose have been loath to countenance rejecting the Pythagoreanism of the Newtonian tradition of science. For a leading theoretical physicist to contribute to this debate on the side of those questioning the defining role of mathematics in science is itself a major event. Furthermore, Smolin offers an original way of characterizing the nature and role of mathematics in science that can be seen to accord with Schelling's natural philosophy [1] (p. 422ff.).

Smolin argues that new structures that can be characterized mathematically emerge into existence, and that mathematics itself is evoked in this way. Just as chess was an invention that, once evoked with its rules of play, made possible the exploration of a vast landscape of possibilities, mathematical structures are evoked, creating vast landscapes of possibilities that can be explored. These possibilities are not arbitrary but are objective properties of these mathematical structures. The bulk of mathematics consists in the elaboration of four concepts: number, geometry, algebra, and logic. Our knowledge of number and geometry apply to the world because they were developed through studying the world, that itself evolved by generating new structures. Number captures the fact that the world consists of denumerable objects that can be counted, while geometry captures the fact that these objects take up space and form shapes. Algebra captures the fact that these numbers can be transformed. Logic captures the fact that we can reason and draw conclusions about the first three concepts. According to current physics and cosmology, there was a stage in the universe where there were vacuum states of quantum fields without space and without elementary particles, and so no denumerable objects. We ourselves are part of a world where space and denumerable objects do exist, and our arithmetic and geometry, which are the foundation for evoking further developments in mathematics, were elaborated because the relations of geometry and number had emerged in nature. Later developments in mathematics, for instance through axiomatization of geometry, making possible new kinds of geometry, are evoked through the invention of novel ways of thinking. New forms of mathematics have been evoked through the invention of algebra, then through the formalization of logic, and then through the development of group theory and topology facilitating the study of symmetries. Although Smolin does not allude to this, at present, category theory is evoking new developments in mathematics more adequate to life and consciousness [81,91]. However, possibilities evoked through further developments of mathematics might never be realized, and there are structures and possibilities that cannot be grasped through mathematics. There is a potential infinity of formal axiomatic systems that can be evoked, but only a very small subset of these provide partial mirrors or models of nature, and the elaboration and exploration of these systems is no substitute for empirical research and must recognize structures and possibilities that cannot be modelled mathematically. This view of mathematics, Smolin claims, transcends the opposition between constructionism and Platonism, since there is a constructive component and such construction can go on indefinitely, but the possibilities are objectively there, and in the case of number and geometry and a small subset of the axiomatic systems that have been evoked, these possibilities have emerged in nature.

This view of mathematics involves abandoning the quest for the discovery of a timeless realm of mathematical truths modelling the entire universe. Just as geometrical possibilities only emerged with the emergence of space and arithmetic possibilities only emerged with denumerable particles, the applicability of mathematics is dependent on which stable structures have emerged with the evolution of the universe. Unger and Smolin have embraced this notion of evolution from biology and, along with it, the notion of co-evolution from ecology. The mathematical described laws of nature and the possibilities that can be pre-stated through them co-evolved with these structures which exist in the process of realizing these possibilities. However, in doing so, these structures can be transformed, and new structures created, creating new possibilities that did not pre-exist these new structures. This can be seen in biology and the human sciences, where the structures clearly have emerged and are clearly mutable. The laws of economics formulated by economic theory could only be evoked when there were people able to make monetary exchanges. But the nature of these exchanges has changed with new institutions and, as Unger pointed out, economic theory in its quest for timeless truths which do not consider the mutability of institutions has distorted our understanding of the economy and its possibilities [1] (p. 339ff.). Associated with this co-evolution, the so-called constants of physics along with physical laws and symmetries should be seen as only relatively enduring and could be changing with the evolution of the universe. This claim is central to Smolin's efforts to advance cosmological theory in new directions.

All this accords with the Schellingian tradition of natural philosophy and the science that it has engendered, including taking comprehension of the self-organization of life as characterized by Kant in the *Critique of Judgment* as the reference point for defining science rather than physics, and then characterizing his natural philosophy as a speculative physics designed to replace Newtonian physics [68] (p. 195). The idea of space and then denumerable objects emerging is entirely consistent with Schelling's philosophy where his notion of intellectual intuition was characterized as effectively the reconstruction in thought of the necessary stages in the creative construction of the universe leading up to the development of humanity and individuals through whom the universe is becoming conscious of itself as constructive activity. On this view, instead of treating human consciousness as outside the world it is studying, life and humanity, mathematics and science must be seen as having in some sense co-evolved with the structures of the universe, and it is for this reason that the development of arithmetic and geometry, and then later forms of mathematics that have modelled these structures, is possible. Humans are part of the universe, and so their development of mathematics and science is part of the development of the universe and influences which possibilities will be identified and realized. In the case of the natural sciences, this facilitates the development of new technologies. In the case of the human sciences, this facilitates new relations between people and between humans and the rest of nature, and new social structures based on these relations facilitating exploration of their possibilities. Defective science does not merely limit what possibilities can be realized but can be destructive of structures and their possibilities. Unger points this out in his analysis of economic theory and its failures brought about by its quest for eternally true mathematical models and its blindness to institutions and their transformations.

By invoking co-evolution, Unger and Smolin are not only aligning their work with that of post-reductionist biologists, but with ecology. The notion of co-evolution was developed in the process of taking ecology seriously in evolutionary theory and acknowledging the importance of symbiosis and the creativity generated through the balancing of opposing forces. Robert Ulanowicz has argued that it is ecology rather than just biology that should be taken as the reference point for defining science and charting new directions for it, not only in biology but even in physics, overcoming the conceptual logjams that are presently afflicting science generally [95] (p. 6), [96]. These claims are supported by Andreas Weber [76] and Gare [5]. Ecology provides a focus for integrating all the diverse developments in the Schellingian tradition of natural philosophy and science, including energetics, the theory of fields, hierarchy theory, and biosemiotics (as ecosemiotics), and it could be argued that ecology provides the best basis for evoking new advances in Schellingian philosophy of nature and Schellingian science. Ecology is being embraced in biology where organisms are now being characterized as highly integrated ecosystems and Unger and Smolin's work vindicates Ulanowicz's claim that ideas being developed in ecology could facilitate overcoming the roadblocks in physics.

When the whole tradition of natural philosophy is revealed, it becomes clear that it has been more than just guiding and facilitating the development of science. Reflecting on and questioning the place of science in culture, society, and civilization, natural philosophy is central to the dynamics of culture and civilization [97]. It is through natural philosophy that we define our place in the cosmos, and this underpins all other human endeavors. Baconian, Galilean, Cartesian, and Newtonian assumptions dominating science associated with their philosophies of nature are largely responsible for seeing science primarily as a means of achieving control over the world, including other people insofar as the human sciences embrace these assumptions. As Heidegger argued, nature and then people are enframed as standing reserves to be controlled and exploited [98] (p. 21). The quest for control is responsible for astonishing technological achievements that are why in one form another European civilization came to dominate the world. However, these very achievements have created a nihilistic culture and a global ecological crisis which threatens the future of civilization, and possibly humanity itself [41]. It is necessary to evoke a new kind of science and to reformulate all old science to understand this in all its dimensions and to open up different possibilities for the future, elevating ecology to a dominant position in science, replacing mainstream economics by ecological economics and mainstream sociology by human ecology, defending the humanities and reformulating history so that it takes into account geography and ecology, and then embodying this new conception of the world in our culture and institutions. This is required to create an ecologically sustainable civilization, or as radical Chinese environmentalists have argued for, an ecological civilization [5]. At present, this provides the most important reason for promoting natural philosophy [5] (97). Unger and Smolin's work, by defending the importance of natural philosophy, redefining the goal of science, challenging the pre-eminence of mathematics over history in cosmology to accord a place to temporality, creativity and qualia in nature, is a significant contribution to realizing this goal.

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philosophies

Article

Sciences of Observation

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Abstract: Multiple sciences have converged, in the past two decades, on a hitherto mostly unremarked question: what is observation? Here, I examine this evolution, focusing on three sciences: physics, especially quantum information theory, developmental biology, especially its molecular and "evo-devo" branches, and cognitive science, especially perceptual psychology and robotics. I trace the history of this question to the late 19th century, and through the conceptual revolutions of the 20th century. I show how the increasing interdisciplinary focus on the process of extracting information from an environment provides an opportunity for conceptual unification, and sketch an outline of what such a unification might look like.

Keywords: awareness; cognition; computation; cybernetics; differentiation; fitness; holographic encoding; memory; perception; quantum information; signal transduction; spatial representation; thermodynamics; unitarity

1. Introduction

Science is distinguished from speculation by its grounding in observation. What "observation" is, however, has been largely neglected. What does it mean to "ask a question of Nature" and receive a reply? How are the sought-after observational outcomes actually obtained? Even in quantum theory, where the "measurement problem" has occupied philosophers and physicists alike for nearly a century, the question of *how observations are made* is largely replaced by far more metaphysical-sounding questions of "wavefunction collapse" or the "quantum-to-classical transition" (see [1,2] for recent reviews). Once the world has been rendered "effectively classical", the thinking goes, observation becomes completely straightforward: one just has to look.

Here, I will advance two claims: (1) that substantial scientific effort is currently being devoted, across multiple disciplines, to understanding observation as a process, though seldom in these terms; and (2) that making this cross-disciplinary effort explicit offers an opportunity for conceptual cross-fertilization that leaves entirely aside troublesome issues of reductionism and disciplinary imperialism. Viewing a substantial fraction of current science as being fundamentally about observation, as opposed to some specialized domain or other, allows us to collapse a large amount of disparate ontology into a few very general concepts, and to see how these concepts inform science across the board. While suggestions along these lines have been made previously within the cybernetic and interdisciplinary traditions (e.g., [3–9]), developments in the past two decades in quantum information, cognitive science and the biology of signal transduction, among other areas, render them ever more compelling and productive. This multi-disciplinary conceptual landscape has recently been explored with somewhat different goals by Dodig Crnkovic [10,11]. As in [10,11], the focus here is on the formalized sciences, working "upwards" from the precise but relatively simple formal description of observation employed in physics toward the higher complexity needed for the life sciences. The alternative interdisciplinary tactic of working "downward" in complexity from studies of human language or culture toward the formalized sciences, as attempted in, e.g., cultural structuralism or general semiotics, is not considered here, though some points of contact are briefly mentioned.

Observation per se became a topic for investigation by physicists only in the late 19th century, with Boltzmann's realization that observers are characterized by uncertainty and must pay, in energetic currency, to reduce their uncertainty [12]. Energy, therefore, is an essential *resource* for observation. Any physically-implemented observer is limited to a finite quantity of this resource, so any such observer is limited to finite observations at finite resolution. Shannon, some 50 years later, recognized that while observational outcomes could be encoded in myriad ways, any finite sequence of finite-resolution outcomes could be encoded as a finite string of bits [13]. The third foundation of the classical, thermodynamic theory of observation was laid by Landauer, who emphasized that observational outcomes can be accessed and used for some further purpose only if they have been written in a thermodynamically-irreversible way on some physical medium [14,15]. This triad of energy, encoding and memory can be summarized by the claim that each bit of an irreversibly-recorded observational outcome costs ck_BT, where k_B is Boltzmann's constant, $T > 0$ is temperature, and $c > \ln 2$ is a measure of the observer's thermodynamic efficiency. Less formally, this classical theory defines "observation" as the exchange of energy for information.

As recognized by many and proved explicitly by Moore ([16] Theorem 2) in 1956, *finite* observations are necessarily ambiguous: no finite observation or sequence of observations can establish with certainty what system is being observed (see [17] for review). Hence any thermodynamically-allowed theory of observation is a theory of ontologically-ambiguous observation. Real observers are not "god's-eye" observers [18]. Bearing this in mind, we can ask several questions about observation:

- What kinds of systems exchange energy for information?
- How does this exchange work?
- What kinds of information do such systems exchange energy for?
- How is this information stored?
- What is it used for?

The sections that follow examine these questions in turn, from the perspectives of sciences from physics to psychology. We start with physics, both because physics defines observation precisely, albeit perhaps incompletely, and because it has historically been most concerned with how observation *works*, as opposed to the more philosophically- or linguistically-motivated question of what individual observations (or observations in general) *mean*. This latter question, which is related in at least its pragmatic sense to the final one above, is deferred to Section 6 below. How the answers to these various questions, however tentative, might be integrated into a theoretically-productive framework is then briefly considered.

2. What Is an Observer?

An "observer" as a perspective on the unfolding of events has been part of the lexicon of theoretical physics since Galileo's *Dialogue* of 1632. This Galilean observer is effectively a coordinate system; it has no active role in events and no effect on what transpires. An observer with an active role first appears in the mid-19th century, in the guise of Maxwell's demon. Macroscopic observers, in particular human scientists, gain an active role with the development of quantum theory, with Bohr's acknowledgement of the "free choice of experimental arrangement for which the mathematical structure of the quantum mechanical formalism offers the appropriate latitude" ([19] p. 71) and von Neumann's suggestion that a *conscious* observer is needed to collapse the wave function [20]. While observer-induced collapse has been largely superceded by the theory of decoherence [21–25], the observer's active role in freely choosing which observations to make remains a critical assumption of quantum theory [26,27].

In classical physics, the observer simply records information already present in the observed environment. This essentially passive view of observation is carried over into realist interpretations of quantum theory, in which collapse, branching, and/or decoherence are viewed as in some sense objective. Gell-Mann and Hartle [28], for example, describe the observer as an "information gathering and using system" (IGUS) that collects objective classical information generated by decoherence.

The decoherence-based quantum Darwinism of Zurek and colleagues [29–31] similarly requires an objectively redundant encoding of classical information in an environment shared by multiple observers. This realist assumption that classical information is objectively available to be "gathered" by observation was already challenged by Bohr in 1928: "an independent reality in the ordinary physical sense can neither be ascribed to the phenomena nor to the agencies of observation" ([32] p. 580). Bohr's and Heisenberg's view that observation was an active process, and that observational outcomes are well-defined only in the context of this process, finds recent expression in the "observer as participant" of Wheeler [33], Rovelli's [34] relational formulation of quantum theory, and Fuchs' [35] quantum Bayesianism (more recently, "QBism"). It is supported by the absence, within the quantum formalism, of any principled reason to decompose a state space into one collection of factors rather than another [36–44]. As loopholes in experimental demonstrations of Bell-inequality violations are progressively closed [45–47], physicists are increasingly forced to choose between giving up the objectivity of unobserved outcomes (i.e., "counterfactual definiteness" or just "realism") or giving up locality, including the idea that an experiment is a local operation on the world [48,49].

Describing an observer either as an IGUS or an outcome-generating participant raises an obvious question: what kinds of systems can play these roles? What, in other words, *counts as* an observer within a given interpretation or formulation of quantum theory? There are three common responses to this question. One is that any physical system can be an observer (e.g., [2,33,34]), a response difficult to reconcile with the assumption that observers can freely choose which observations to make. Another is to explicitly set the question outside of physics and possibly outside all of science (e.g., [35,50]), rendering a "theory of observation" impossible to construct. By far the most common response, however, is to ignore the question altogether. Prior to the development of quantum information theory, this reticence could be attributed to the general distaste for informal concepts memorably expressed by Bell ([51] p. 33):

> *Here are some words which, however legitimate and necessary in application, have no place in a formulation with any pretension to physical precision: system, apparatus, environment, microscopic, macroscopic, reversible, irreversible, observable, information, measurement.*

Since roughly 2000, however, quantum theory has increasingly been formulated in purely-informational terms [52–60]; see [61] for an informal review. In these formulations, quantum theory is itself a theory of observation. A physical interaction between A and B, represented by a Hamiltonian operator H_{AB}, is an information channel. If only quantum information passes through the channel, then A and B are entangled, i.e., are nominal components of a larger system $AB = A \otimes B$ in an entangled state $|AB\rangle$, by definition a state that cannot be factored into a product $|A\rangle|B\rangle$ of states of A and B individually (kets $|\cdot\rangle$ will be used to denote states, whether quantum or classical). In this case, no observation has occurred. If classical information flows through the channel, A and B must be separable, i.e., $|AB\rangle$ can be factored into $|A\rangle|B\rangle$, $|A\rangle$ encodes information about $|B\rangle$ and vice-versa, and observation can be considered to have occurred [17]. The only classical information associated with H_{AB} are its eigenvalues, so these are the only possible observational outcomes [62]. This picture, however, places no constraints at all on what counts as an observer. It does not, in particular, tell us the conditions under which an interaction transfers classical information. What more can be said? The next four sections pursue an indirect approach to this question, focusing first on the question of what is observed.

3. What Is Observed?

It is when the question, "what is observed?" is asked that one encounters the first serious disconnect between physics and the life sciences. At least in theoretical and foundational discussions, physicists describe observers interacting with *systems*, typically systems that have been defined a priori by specifying their state spaces. Biologists and psychologists, on the other hand, describe observers—organisms—interacting with the *world*. This world does not have an a priori specified state space, at least not one known to or even knowable by any organism. It is the organism's job to figure out, by interacting with the world, what in it might be useful for the task of continuing to live.

The reliance of physics on predefined systems is sometimes explicitly acknowledged. Zurek, for example, remarks that "a compelling explanation of what the systems are - how to define them given, say, the overall Hamiltonian in some suitably large Hilbert space - would undoubtedly be most useful" ([63] p. 1818). Lacking such an explanation, however, he makes their existence axiomatic, assuming as "axiom(o)" of quantum mechanics that "(quantum) systems exist" ([50] p. 746; [64] p. 2) as objective entities. It is, as noted above, the objective, observer-independent existence of systems that allows the eigenvalues of their objective, observer-independent interactions with an objective, observer-independent environment to be encoded with objective, observer-independent redundancy in the theory of quantum Darwinism [29–31]. An even more extreme example of this assumption of given, a priori systems can be found in Tegmark's [65,66] description of decoherence (Figure 1). Here, the "system" S is defined as comprising *only* the "pointer" degrees of freedom of interest to the observer O, and O is defined as comprising *only* the degrees of freedom that record the observed pointer values. Everything else is considered part of the "environment" E and is traced over, i.e., treated as classical noise. The only information channel in this picture is the Hamiltonian H_{OS}, which is given a priori.

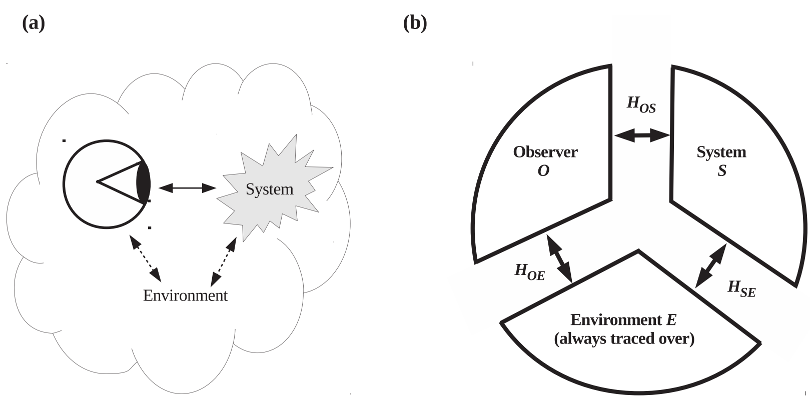

Figure 1. (**a**) The classical conception of observation, standardly carried over into quantum theory. The observer interacts with a system of interest; both are embedded in a surrounding environment. (**b**) Interactions between observer (O), system of interest (S) and environment (E) enabling environmental decoherence [1,2]. The Hamiltonian H_{OS} transfers outcome information from S to O; H_{SE} and H_{OE} decohere S and O respectively. Adapted from [66] Figure 1.

It is useful to examine this assumption of a priori systems in a practical setting. Suppose you have a new graduate student, Alice, who has never set foot in your laboratory. You ask Alice to go to the laboratory and read the pointer value for some instrument S. What does Alice have to do when she enters the laboratory? The assumption that S is given a priori is, in this case, the assumption that S is given *to Alice* a priori. All she has to do is read the pointer value. *In practice*, however, Alice has to do much more than this. Before reading the pointer value, she has to *identify* S: she has to *find* S amongst the clutter of the laboratory, and *distinguish* S from the other stuff surrounding it. Doing this, obviously, requires observation. It requires observing not just S, but other things besides S—for example, the tables and chairs that she has to navigate around before she gets to S. These other things are part of the "world" W in which S is embedded; in the notation of Figure 1, $W = S \oplus E$. It is W that Alice has to interact with to identify S, which she must do before she can read its pointer value (Figure 2). This W is, it bears emphasizing, *Alice's* world: it comprises everything in the universe except Alice.

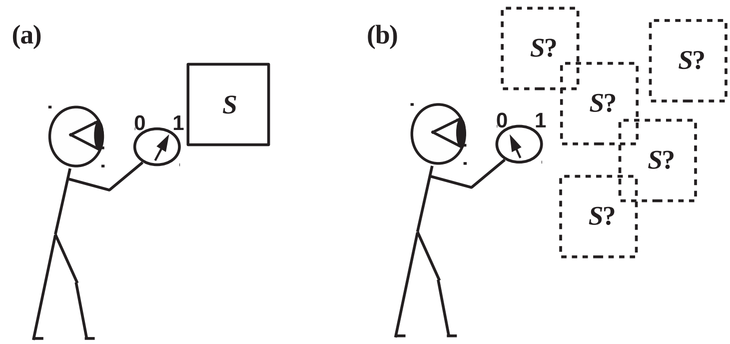

Figure 2. (**a**) Observers are standardly assumed to interact with a priori given systems, as in Figure 1. Here, the observer is equipped with an observable (e.g., a meter reading) with which to interact with the system S. Adapted from [35] Figure 1. (**b**) In practice, observers must *look for* the system of interest S by probing the "world" W in which it is embedded.

Classically, if I want Alice to observe the pointer of S, I need to give her a description of S that is good enough to pick it out from among the other objects in the laboratory. Such a description might specify the kind of instrument S is (e.g., a voltmeter), its size, shape, color, brand name, and possibly what it is sitting on or connected to. In quantum theory, these classical criteria are replaced with specified outcome values for some finite set of observables, which given Shannon's insight can be regarded as binary. It is important to emphasize that quantum theoretic observables are *operators* with which an observer *acts on the world*; the world then *acts on the observer* to deliver an outcome (e.g., [35]). This key idea of observation as *physical interaction*, formulated initially by Boltzmann and emphasized by Bohr and Heisenberg, is what is lost when systems are considered "given" and observation is regarded as a passive "gathering" of already-existing, observer-independent information. Recognizing that observers must *search for* systems of interest in the environments in which they are embedded brings this idea of observation as an activity to the fore.

Let us call the observables that identify some system S *reference observables* and their specified, criterial outcomes *reference outcomes* and denote them $\{M_i^{(R)}, x_i^{(R)}\}$. Given a set of reference observables and outcomes, Alice can then go into the laboratory, and measure everything she sees with the reference observables $\{M_i^{(R)}\}$. If every measurement yields its specified reference outcome $\{x_i^{(R)}\}$, Alice has found S; if not, she must keep searching. By giving Alice $\{M_i^{(R)}, x_i^{(R)}\}$, I am giving her what she needs, in practice, to identify S in the context of my laboratory. It is what she needs *in practice*, or as Bell [51] would have it "FAAP" due to Moore's [16] theorem noted above: such information is insufficient for objective, ontological precision. This set $\{M_i^{(R)}, x_i^{(R)}\}$ can be specified only because it is finite; hence, Alice needs only finite thermodynamic resources to employ it.

To read the pointer value of S, Alice also needs a finite set $\{M_j^{(P)}\}$ of *pointer* observables. These include not just the usual "meter readings" but also whatever is indicated by any adjustable control settings that serve to "prepare" the state of S. The outcome values $\{x_j^{(P)}\}$ of these observables are to be discovered, and in the case of control settings perhaps adjusted, so they are not specified in advance. For macroscopic systems, in practice, there are many more reference observables for any system than pointer observables: *identifying* a system against the inevitably cluttered background of the world requires more measurements, and hence more energy, than checking the variable parts of the state of the system once it has been identified (Figure 3).

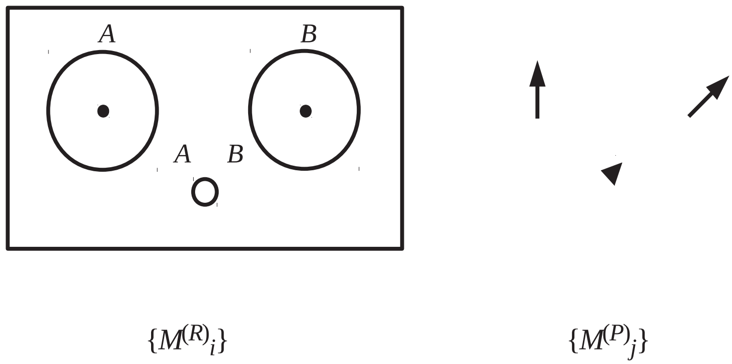

Figure 3. Identifying a system requires many more observables than are required to measure its pointer state, including the positions indicated by control knobs or other "preparation" settings. Adapted from [67] Figure 3.

The set $\{M_i^{(R)}, M_j^{(P)}, x_i^{(R)}\}$ of operators and expected values constitutes *semantic* information; it specifies a referent in W. It specifies, in particular, the desired system S. Moore's theorem [16], however, renders this referent intrinsically ambiguous. It can be thought of as the time-varying equivalence class of all components of W that satisfy $\{M_i^{(R)}, x_i^{(R)}\}$, i.e., all components of W that yield $\{x_i^{(R)}\}$ when measured with $\{M_i^{(R)}\}$, for all i, and can also be acted upon by $\{M_j^{(P)}\}$. This class can be represented, from the perspective of an observer deploying $\{M_i^{(R)}, M_j^{(P)}, x_i^{(R)}\}$, as a superposition of "systems" having dimension at least the cardinality of full set $\{M_i^{(R)}, M_j^{(P)}\}$ of operators [17]. Identifying S is, in fact, identifying such a superposition, as opposed to an observer- and observation-independent "thing" as assumed in classical physics.

As noted, the life sciences have treated observers as interacting not with pre-defined systems but with their worlds throughout their history; the continuing emphasis on understanding such interactions as methods shifted, over the 20th century, from strictly observational to experimental is reflected in continuing calls for "naturalism" and "ecological validity" (e.g., [68]). From a cognitive-science perspective, when Alice explores the laboratory in search of S, she is just doing what organisms do when exploring a novel environment. It is, moreover, clear from this perspective what the observables and values $\{M_i^{(R)}, M_j^{(P)}, x_i^{(R)}\}$ are: they specify a collection of semantically-coherent *categories* and a (partial) instance of this collection. The reference observables together specify what *type* of system S is, and their fixed values identify a particular instance or *token* of this type as S (for a general review of types and tokens, see [69]). These token-specifying values cannot change, or can change only very slowly and gradually, so long as S remains S. For Alice to search for a voltmeter with a specific size, shape, color and brand name, for example, she must know, in some sense to be determined empirically, what a voltmeter is, and that anything qualifying as a voltmeter has a specific size, shape, color and brand name, as well as some specific mass, surface texture, and layout of knobs or buttons, dials or digital displays, connectors, and so forth. She must, moreover, understand what voltmeters are used for, and that the pointer observables $\{M_j^{(P)}\}$ return the values of such properties as selector-switch positions and meter readings. Sets of observables and specified outcome values are therefore, from this perspective, *structured knowledge*; observers are systems—in this case, cognitive systems—capable of deploying such knowledge. Philosophers and, more recently, psychologists have expended considerable effort characterizing this categorical knowledge, investigating its implementation, and determining how it is used to identify and then re-identify objects over time (for reviews, see [70–74]); we will return to the question of implementation in Section 5 below.

Cognitive science, therefore, tells us something important about the *physics* of observers: an observer needs sufficient degrees of freedom to represent both the category and the category-instance distinctions that are required to both identify and measure the pointer states of any systems that it can be regarded as observing [67]. Observers also need access to, and a means of acquiring and incorporating, the energy resources needed to register the outcome values of their observations, and they need a means of dissipating the waste heat. Finally, observers need a control structure that deploys their observables in an appropriate order. Observers cannot, in other words, be mere abstractions: they have physical, i.e., energetic, structure, and they must process energy to process information. Coordinate systems cannot be observers. The degrees of freedom that register the pointer state of a given meter on a given instrument cannot, by themselves, constitute an observer; additional degrees of freedom that encode categorical knowledge and others that manage control and energy input and output are mandatory. The former can be considered *memory* degrees of freedom; they are further characterized in Section 5.

Cognitive science also allows us to reformulate Zurek's question of where the systems come from to the question of where the categories that allow system identification and pointer-state measurements come from. This latter question has answers: evolutionary and developmental biology for observers that are organisms, and stipulation by organisms for observers that are artifacts. In the case of human observers, some of these categories (e.g., [face]) are apparently innate [75]; others (e.g., [chair]) are learned early in infancy [76], while still others (e.g., [voltmeter]) require formal education. For observers that are neither organisms nor artifacts, and ultimately for organisms and artifacts as well, the "where from" question demands an account of cosmogony. The relationship between physics and the life sciences is, in this case, not one of reduction but rather one of setting boundary conditions, as recognized by Polanyi [77] among others. It is, in other words, a historical as opposed to axiomatic relationship. The ontological consequences of this reformulation for a theory of observation are considered in Section 8 below.

4. What Information Is Collected?

The goal of observation is to get information about the *state* of what is observed. State changes are the "differences that make a difference" [78] for observers. In the traditional picture of Figure 1, the goal is to discover the pre-existing, observer-independent pointer state $|P\rangle$ of a given, pre-existing system S. We have seen above, however, that to measure $|P\rangle$, one must first measure the time-invariant reference state $|R\rangle = |x_1^{(R)}, x_2^{(R)}, ..., x_n^{(R)}\rangle$ by deploying the n reference observables $\{M_i^{(R)}\}$; hence measuring $|P\rangle$ requires measuring the entire state $|S\rangle = |R \oplus P\rangle$. As this identifying measurement is made *by the observer*, S cannot be considered given. The state $|S\rangle$ is, therefore, observation- and hence observer-dependent. To paraphrase Peres' [48] well-known aphorism, "unidentified systems have no states".

As in the case of Alice searching the laboratory, measuring $|S\rangle$ requires trying the $\{M_i^{(R)}\}$ out on many things besides S, some of which will yield some of the specified reference outcomes $\{x_i^{(R)}\}$ but not all of them. These extra measurements are *overhead*; they cost energy and time. As the complexity of W increases, this overhead expense increases with it.

This notion of overhead allows us to distinguish between two types of observers:

- "Context-free" observers that *waste* their observational overhead.
- "Context-sensitive" observers that *use* (at least some of) their observational overhead.

As an example context-free observer, consider an industrial robot that visually identifies a part to pick up and perform some operation on. The robot must identify the part regardless of, e.g., its orientation on a conveyor, but has no use for any "background" information that its sensors detect. Except for its assigned part, everything about its environment is noise. It can afford to be context-free because it only has to deal with one, completely well-defined context: that of identifying a particular part on a conveyor and picking it up. Its control system is, in a sense, trivial: it needs to do only one thing, which it can do in the same way, up to minor variations, every time. It does not, in particular, have to worry about the frame problem [79], the problem of predicting what does *not* change as a consequence of an action or, in its more generalized (and controversial) form, the problem of relevance [80]. Nothing that happens outside of its context matters for *how* it performs its task; however, as we will see in Section 6 below, outside happenings do matter for *whether* it performs its task.

Alice, walking around the laboratory, has different requirements and a different experience. She encounters many things roughly the right size and shape to be S, but that are not voltmeters, and perhaps some other voltmeters, but not the right brand or not connected to anything. Hence Alice, even before finding S, knows much more about the laboratory than when she entered. Her next pointer-value reporting task will be much easier to accomplish after this initial foray in search of S. For Alice, the search overhead is valuable. It is valuable in part because Alice *does* have to worry about the frame problem; every action she takes may have unintended and possibly unpredictable side effects relevant to her [81].

What is the difference between these two cases? Let us assume, for the sake of argument, that Alice and the robot have exactly the same input bandwidth: both record the same number of visual bits. The robot subjects these bit strings to a single analysis that returns 'yes' or 'no' for the presence of the target part. This analysis has multiple components, e.g., specification of a three-dimensional shape together with rotations and projections that accomplish "inverse optics" from the visual image (see e.g., [82] for an implementation of recognition of not one but several objects). These constitute the robot's reference measurements $\{M_i^{(R)}\}_{Robot}$; the pointer measurements then specify the position for grasping the part. Identifying the part requires all of the reference measurements to agree; all other scenes or scene components are "negatives" and are ignored. For this robot, objects of the "wrong" shape or size are task irrelevant and so effectively invisible.

Alice's analysis of her visual bits is superficially similar: she also employs a set of reference measurements $\{M_i^{(R)}\}_{Alice}$, agreement among all of which constitutes identifying S. Alice does not, however, ignore the negatives. They are not invisible to her; she has to see them to navigate around the room. This requirement for autonomous navigation already distinguishes Alice from the robot; Alice must deal with a different context, filled with different objects, every time she moves. She must, moreover, devote some of her observational overhead to observing *herself* in order to update her control system on where she is relative to whatever else she sees and how she is moving. The robot has no need for such self-observation (though again see [82] for a robot that must distinguish its own motions from those of another actor).

Alice can, moreover, classify some of the "negatives" she encounters as things that share some but not all of their characteristics with S. These similar-to-S things are not vague or undefined in whatever characteristics they do not share with S; Alice is not limited, as the robot is, to the "right" size, shape, or color and "other". Alice, unlike the robot, is capable of recognizing many different objects not just as "other" but as individuals; this tells us that she has a much larger set of deployable measurement operators, of which the $\{M_i^{(R)}\}_{Alice}$ that identify S are a tiny fraction. Her ability to group similar objects, e.g., to group voltmeters of different sizes, shapes and brands, tells us that her measurement operators are organized at least quasi-hierarchically. Whereas the robot needs only a single category, [my-target-part], Alice has an entire category network incorporating a large number of types, in many cases associated with one or more tokens. These types and tokens are, moreover, characterized by both abstraction and mereological relations (see e.g., [83,84] for reviews).

For human observers, categories are closely linked to, and commonly expressed in, language. Visual category learning is by far the best investigated; here, it is known that human infants can identify faces from birth [75], track moving objects by three months [85], and learn hundreds of initially-novel object categories by the onset of language use, approximately one year [76]. "Entry-level" categories such as [dog], [person], [chair], or [house] are learned first and processed fastest [86]. Category learning accelerates with language use [87] and later, formal education, resulting in word repertoires in the tens of thousands (up to 100,000 in rich languages like English [88]) in adulthood and category repertoires somewhat smaller due to word redundancy. Multiple, quasi-independent systems contribute to learning distinct kinds of categories, e.g., perceptible objects versus abstrata [89]. New categories, like new words, can be constructed combinatorially, with no apparent in-principle limits beyond finite encoding. Human observers can, therefore, be viewed as encoding tens of thousands of distinct "observables" with sets of specified outcome values that identify subcategory members or individuals. The deployment of these categories on both input (i.e., recognition) and output (language production, bodily motion, etc.) sides is highly automated and hence fast [90] except for novel objects that must be categorized by examination or experimentation. While the categorization systems of non-human animals are not well studied and their lack of language suggests far smaller, niche-specific repetoires, their evident practical intelligence suggests robust and highly-automated categorization systems.

The ability to deploy a large number of different measurement operators, the results from which can contribute combinatorially to behavior is also ubiquitous in "simple" biological systems. Archaea and bacteria, for example, employ from a handful to well over a hundred different sensing and regulation systems, generally comprising just one [91] or two [92] proteins; the numbers of such systems roughly correlate with environmental niche complexity. These systems primarily regulate gene expression and hence metabolism, but also regulate motility [93] and aggregative and communal behaviors [94]. Eukaryotic signal transduction pathways are more complex and cross-modulating (e.g., Wnt [95] or MAPK [96]), typically forming "small-world" or "rich-club" patterns of connectivity [97,98] (Figure 4). Large numbers of distinct sensors—typically transmembrane proteins—are expressed constituitively, so the expressing cell is "looking" for signals that these sensors detect all the time. Especially in eukaryotic cells, the result of detecting one signal is in some cases to express other sensors for related signals, the cell-biology equivalent of "looking more closely" or "listening for what comes next".

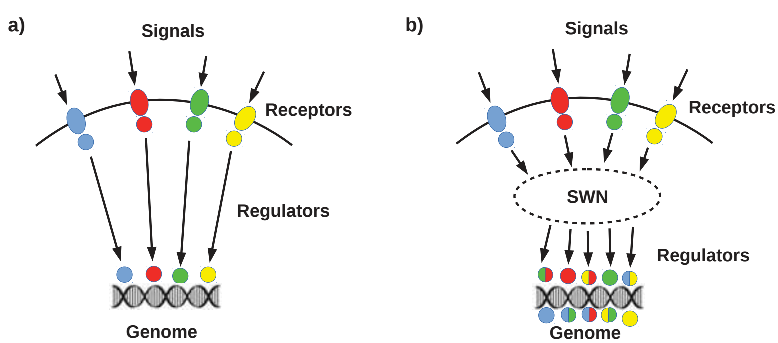

Figure 4. Simplified cartoon of sensing and regulation systems in (**a**) prokaryotes (archaea and bacteria) and (**b**) eukaryotes. Regulatory signals can interact and cross-modulate in eukaryotes more than in prokaryotes. Colors indicate communicated information. SWN = small-world network [99].

Context-sensitivity allows the response to one signal to be modulated by the response to another signal. Sets of signals identify systems; hence, context-sensitivity allows the response to one system to be modulated by responses to other systems. If Alice sees smoke coming out of a system to which S is connected, it will affect her report on the pointer state of S. To return to the language of physics, it will affect the probability distribution over her possible reports, by assigning high probabilities to reports that had low or zero probability before. Dzhafarov has termed this ubiquitous effect of context on response probabilities "contextuality by default" [100,101]. Within this framework, the ideal of a fixed probability distribution on outcomes, impervious to the modulatory effects of other observations, becomes a minor special case. Contextuality is a hallmark of quantum systems, and the experimental recognition of ubiquitous contextuality in human cognition has motivated the adoption of quantum theoretic methods to psychological data (see [102–104] for reviews).

Most mammals, many birds [105] and at least some cephalopods [106] are not, however, just sensitive to context in real time; they are also able to notice and store currently task-irrelevant information that may be relevant to a different task at some time in the future. The combined use of landmarks, cognitive maps, and proprioception in wayfinding is a well-studied example [107,108]. Humans are particularly good at storing task-irrelevant information—for Alice, the other contents of the laboratory and their general layout—for possible future use. This ability underlies the human ability to discover Y while searching for X and is thus a key enabler of scientific practice.

5. What Is Memory?

As pointed out earlier, observers must, in general, devote some of their degrees of freedom to encoding the observables that they are able to deploy, as well as the reference outcomes used to identify systems. They must, moreover, devote degrees of freedom to the implementation of their control systems and to energy acquisition and management systems. Such dedicated degrees of freedom can be considered *memory* in the broadest sense of the term (but see [109] for an argument that this usage is too broad). Adventitious information, e.g., pointer-state outcomes not directly relevant now, collected by context-sensitive observers is also clearly of no use unless it can be remembered. Memory is often listed as an attribute of observers by physicists (e.g., [28,35,50]); clearly, any observer that prepares a system before observing it, or that re-identifies the same system for a repeat observation requires a memory [67].

Remembering a system S requires remembering the set $\{M_i^{(R)}, M_j^{(P)}, x_i^{(R)}\}$ that identifies it and enables measuring its pointer state. The $\{M_i^{(R)}, M_j^{(P)}\}$ are descriptors or, in quantum theory, operations: tests to which the world W is subjected. The $\{x_i^{(R)}\}$ are expectations about the outcomes of the reference tests that enable system identification. As noted earlier, the $\{M_i^{(R)}, M_j^{(P)}\}$ are effectively categories, specified by specifying their membership criteria.

The question of *how* such remembered information is encoded leads naturally to the ontological question of what kinds of "encodings" exist. Is there, for example, such a thing as a memory engram [110]? Newell [111] postulated that cognitive agents are "physical symbol systems": but are there such things as symbols? Most approaches to cognitive science postulate some form of representation [112]: do such things exist? The semiotic tradition postulates the existence of signs: are they real? Ecological realists postulate affordances encoded by an animal's environment [113]: do these exist? Is, indeed, *information* real in any sense? It is important to distinguish at least three formulations of these questions. One can ask whether the "existence" or "reality" of signs, symbols, representations or affordances is meant to be: (1) "objective" in the sense of observer- and observation-independent; (2) observer- and observation-relative; or (3) a convenience for the theorist, a "stance" [114] that aids description and prediction while making no ontological commitments. We defer the first of these questions to Section 8 below, here only noting its similarity to the question of whether "states" are observer- and observation-independent discussed above, and the second and third questions to Sections 6 and 7, respectively. Here, we focus on the initial "how" question, which is more tractable experimentally.

Influenced in part by J. J. Gibson's [113] idea of "direct uptake" of information from the environment, some theorists within the embodied/enactive tradition have concluded that "memories" can be stored entirely within the world; organisms, on this view, simply have to look to find out what they need to know (see [115–117] for reviews). Taken literally, this is another version of the hypothesis that systems and their states are "given" a priori. An observer required to identify systems of interest must remember *how* to identify them. It must, in other words, remember the $\{M_i^{(R)}, M_j^{(P)}, x_i^{(R)}\}$. It cannot, on pain of circularity, store this "how" memory in W.

The alternative, "good old-fashioned AI" (GOFAI) view that cognitive systems store their memories as a collection of "beliefs" or as "knowledge" encoded in a "language of thought" (LoT) [118], including storing category networks as networks of connected "concepts" represented by either natural language or LoT words, has increasingly given way to a more implicit view of memory as a collection of *ways of processing* incoming signals. This shift to a "procedural" view of even "declarative" memories has been driven mainly by cognitive neuroscience, and comports well with "global workspace" models of neurocognitive architecture as comprising networks of networks, with small-world structure at every scale [119–124]. Functional imaging studies of pre- and perinatal human infants show that this architectural organization develops prenatally and is already functional at birth [125–127]. "Representations" in such models are network-scale activity patterns, which are reproducibly observable, specifically manipulable experimentally, and in some cases specifically disrupted either genetically or by pathology (for a review of such models and manipulations in the specific case of autism, see [128]). The only "symbolic" content, on this newer view, are the experienced outcomes themselves [129]. The best-supported current candidates for the implementation of such an implicit memory are multi-layer Bayesian predictive-coding networks, in which categories are effectively collections of revisable expectations about the perceptible structure of W [130–134]. Such models can be directly related to small- as well as large-scale neural architecture [135,136] and have achieved considerable predictive success in such areas as vision [137], motor control [138] and self-monitoring [139]. Cognitive systems powered by such networks are intrinsically exploratory observers, trading off category revision and hence learning to recognize new kinds of systems or states against behavioral changes that enable continuing interactions with familiar kinds of systems and states.

The gradual rejection of explicit-memory models of cognition has been paralleled at the cellular and organismal levels by an increasing recognition that explicitly-encoded genetic memory is only one of many layers of biological memory [140–143] (Figure 5). This expanded view of memory is broadly consistent with thinking in the biosemiotic tradition, e.g., with the idea that "any biological system is a web of linked recognition processes" at multiple scales ([144] p. 15), particularly within the "physical" and "code" approaches to biosemiotics identified by Barbieri [145]. It frees the genome from the task of "remembering" how receptors are organized in the cell membrane or how pathways are organized in the cytoplasm; such information is maintained in the membrane and cytoplasm themselves, and is automatically passed on to offspring when these compartments are distributed between daughter cells by the process of cell division. Preliminary work suggests that this extended, supra-genomic biological memory can be productively modelled as implementing Bayesian predictive coding [146].

From this perspective, to *recall* a memory is simply to use it again: one recalls how to identify S when one identifies S. System identification and measurement are competences remembered as "know-how". Human observers can also formulate *descriptions* of these competences; in our running thought-experiment, the identification criteria for S given to Alice are such a description, as is the notation $\{M_i^{(R)}, M_j^{(P)}, x_i^{(R)}\}$. From the present perspective, these descriptions are themselves observational outcomes, and the process of generating them is a process of observation, implemented in humans by "metacognitive" measurement operators. This view accords well with the reconstructive nature and recall-context dependence of even episodic memories (see [147] for review) and with Chater's "flat" conception of the mind as a representation of outcomes only [129]. "Knowing-that" is knowing how to retrieve "that" by observation—by querying some memory, external or internal [148]—when needed.

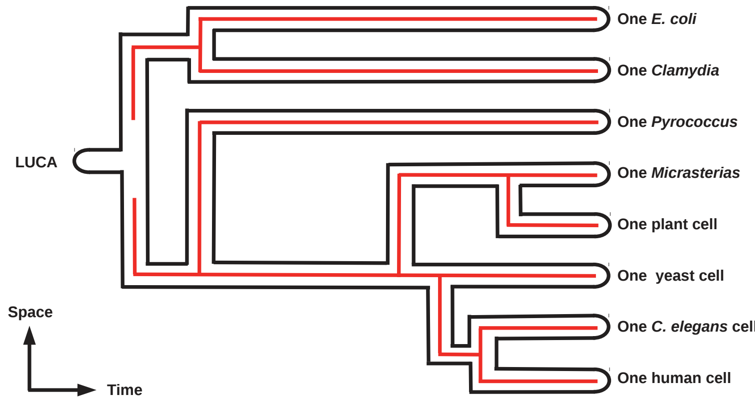

Figure 5. A phylogenetic tree showing the cell membrane (solid black lines) and cytoplasm (enclosed space) as well as the genome (red lines) from the last universal common ancestor (LUCA) to the present. Whether LUCA has a well-defined genome is left open. All compartments of the cell are continuous from LUCA to the present across all of phylogeny; hence, all cellular compartments can serve as memories.

6. What Is Observation for?

Evolutionary theory suggests that organisms make observations for one purpose: to survive and reproduce. The requirements of survival—obtaining and incorporating resources, self-maintenance and repair, an ability to detect and escape from threats—are seen by many as the key to making information "for" its recipient or user [116,149]. Roederer [150,151] similarly restricts "pragmatic information"—information that is *useful* for something, and hence can be considered to have causal effects—to organisms. This would suggest that outcomes can only be "for" organisms, and indeed that it only makes sense to consider organisms observers; writing from a biosemiotic perspective, Kull at al. make this explicit: "the semiosic/non-semiosic distinction is co-extensive with life/non-life distinction, i.e., with the domain of general biology" ([149] p. 27), here identifying observerhood with sign-use. It was this conclusion, in large part, that motivated Bell's rejection of observation and measurement, and hence information, as fundamental concepts in physics ([51] p. 34):

> *What exactly qualifies some physical systems to play the role of 'measurer'? Was the wavefunction of the world waiting to jump for thousands of millions of years until a single-celled living creature appeared? Or did it have to wait a little longer, for some better qualified system ... with a PhD?*

Wheeler famously took the opposite tack, making "observer-participancy" the bottom-level foundation of physics [33]; Wheeler's insistence on information and *active* observation ("participancy") as the sole ontological primitives of physics motivated not only the quantum-information revolution described in Section 2 above, but also the more recent drive to derive spacetime itself from processes of information exchange [152–158]. Observation, it is worth re-emphasizing, implies recordable observational outcomes and hence *classical* information. In practice, most physicists do not worry about where to put the "von Neumann cut" at which information is rendered classical, and hence regard ordinary laboratory apparatus as "registering outcomes". But are these outcomes *for* the apparatus? Should the apparatus be considered an observing "agent"? Do they have an effect on what the apparatus does next?

For organisms like *E. coli*, all observational outcomes are directly relevant to survival and reproduction. How its observational outcomes affect its behavior have, in many cases, e.g., flagellar motility [93] or lactose metabolism [159], been worked out in exquisite detail. These functions have, however, been worked out by *us* from our perspective, using our capabilities as observers and theorists. *E. coli* itself has no ability to determine by observation how it changes direction or digests lactose; it has, as Dennett [160] puts it, competence without comprehension. It has no knowledge that its actions are "for survival and reproduction", though we can infer, using our understanding of the world in which both we and it live, that they are. Its observations and its current state together determine its actions, but it is the *world* that determines whether it will survive and reproduce. It has no ability to do the experiments that could reveal this causal connection. Saying that *E. coli*'s observational outcomes are "for" it is using a purely third-person sense of "for"; we could as well say that its observational outcomes have consequences, imposed by the world, that affect it.

Setting suicide and voluntary sterilization or celibacy aside, whether human observers survive and reproduce is also determined by the world. Our cognitive organization permits us to regard our observational outcomes as for us, but this ability can be lost, e.g., in psychosis [161], insular-cortex seizures [162], or Cotard's syndrome [163], and losing it does not prevent their consequences being "for" us in the third-person sense above. Unlike *E. coli*, we have some ability to explicitly associate observational outcomes with their consequences either pre- or postdictively, but this ability is limited and often prohibitively expensive. We are competent in many observational feats, from understanding natural languages to recognizing individual people decades after last seeing them, with little understanding of how we achieved or how we implement that competence [90,129,164,165]. Indeed, our understanding of *how* we do things tends to vary inversely with our competence; we can often explain cognitive abilities learned slowly and painfully through extensive practice, e.g., computer programming, but cannot explain abilities learned easily and automatically, e.g., grammatical sentence production in our native language. We are sometimes aware of our competence only by testing it, i.e., by performing further observations to determine whether our previous performances were competent. We often have *feelings* of competence, but they are unreliable and often spectacularly wrong (see [164] for various examples).

If an observational outcome is *for* an observer, it is natural to regard that observer as an *agent* that acts intentionally on the world to obtain an outcome. Here, again, Kull et al. make this explicit: a semiotic agent is "a unit system with the capacity to generate end-directed behaviors" ([149] p. 36), including the acquisition of information. It is, however, useful to ask whether a system is an agent from its own, first-person perspective—whether it is able to self-monitor its goals and agentive activity—or whether it is only an agent from our third-person theoretical perspective. Human observers have an essentially irresistible (i.e., highly automated) tendency to attribute agency to anything, animate or inanimate, exhibiting any but the simplest of motions, a tendency that develops in infancy and appears in every culture examined [166–169]. Humans self-monitor and hence experience their own agentive activity as agentive, but tend to over-attribute agency, in the sense of having reasons for actions, to themselves as well as to others (see [129] for examples). Hence, our third-person attributions of agency to other systems, whether Heider and Simmel's animated circles and triangles [166], *E. coli*, or each other, are of questionable reliability. Given our lack of access to the first-person perspective of other systems, however, we are left only with third-person attribution as a basis for theory construction. It is not, therefore, clear that characterizing something as an "agent" adds anything to its description beyond the claim that its observational outcomes have consequences for it, with "for" used in the third-person sense above.

Let us now consider the role of observational outcomes in influencing the survival and reproduction of artifacts like voltmeters or context-free industrial robots. When a voltmeter obtains an observational outcome, it "registers" it *for us* by displaying it on some output device, typically a meter or a digital display. If the voltmeter's behavior is erratic, we may attempt calibration or repair; if it remains erratic, we may discard or recycle it. These are consequences *for the voltmeter*; *it* ceases to exist as an organized entity, not something else. If we or fate destroy it, it has not survived. If, on the other hand, the voltmeter proves extremely reliable, we may buy another one like it. The voltmeter is a “meme” in the broad sense defined by Blackmore [170]: a cultural artifact that can be reproduced, particularly one that can be reproduced by the accurate and efficient process of reproduction from recorded instructions, as opposed to by direct copying. The voltmeter’s world, that which determines whether it will survive and reproduce, i.e., be reproduced, includes not just us but also numerous non-human actors, from curious housepets to earthquakes. As with any meme, the consequences of the voltmeter’s actions for it (third-person “for”) are different from the consequences of its actions for us (first- or third-person “for”). In this, the voltmeter is like *E. coli*, whose actions may be beneficial to it but detrimental to us or vice-versa, and indeed like most organisms.

For any observer, non-survival is not an observational outcome, but is rather the cessation of observational outcomes [62]. Survival is, therefore, the continuing of observational outcomes. Hence, we can reformulate the standard evolutionary goal of survival and reproduction as the general statement:

For any observer, the goal of observation is to continue to observe.

This goal is a third-person theoretical attribution for almost all observers, including any humans who have never thought of it or do not believe it. If observer-participancy is the foundation of physics as Wheeler proposed, however, the goal of continuing to observe is the fundamental principle of cosmogony [33,171].

7. A Spectrum of Observers

What, then, is an observer? The physics of observation, as pointed out in Section 2, places no limits; any physical interaction can be considered observation. A proton moving through an accelerator samples the electromagnetic field at every point and behaves accordingly. Its observational outcomes—the field values, as detected by it—have consequences for its behavior. Indeed, they have consequences, in the context of human culture, for the production of more (unbound) protons and more accelerators; for us, the proton is a meme. The proton has no choice but to observe, and no choice beyond the freedom from local determinism granted by the Conway–Kochen “free will” theorem [172] of how to respond, but in this it differs little from *E. coli* observing and responding to an osmolarity gradient. Thinking of the proton as “computing” its trajectory is unhelpful [173], but is no more anthropomorphic than thinking of it as “obeying” a physical law. Thinking of the proton as observing and responding to its environment—as physicists naturally do when they describe it as “seeing” the electromagnetic field—is perhaps the least anthropomorphic approach.

Voltmeters and many other artifacts are designed by us to be observers. Their observations are far more fine-grained and accurate than we could achieve directly, and in many cases they probe phenomena to which we are otherwise insensitive. Such artifacts are context-free by design, and are likely to be discarded if they become irreparably context-sensitive. Like the proton, they have no choice beyond the Conway–Kochen prohibition of local determinism in what they do, but unlike the proton, it is often helpful (to us) to think of them as computing. It is worth noting, here, that while all artifacts are at least potentially and approximately reproducible and are hence memes, not all memes are observers. Abstract memes like coordinate systems, in particular, are not observers as noted earlier. Neither are words, symbols, representations, or other abstracta.

Some artifacts we want to be context-sensitive observers, and we expend considerable effort trying to equip them to be context-sensitive. We want them to recognize novelty unpredicted and possibly unpredictable by us, and to respond in ways unpredicted and possibly unpredictable by us. We want autonomous planetary-exploration rovers, for example, to take advantage of whatever circumstances they encounter, without the need for time-consuming communication with Earth. Explicitly evolutionary, developmental, and psychological thinking appears essential to the development of such artifacts [174–177].

While it has yet to become commonplace, treating cells, whether prokaryotic or eukaryotic and whether free-living or components of multicellular systems, not just as observers and actors but as cognitive agents has become progressively more widespread and productive [178–181]. The risky and quite-literally shocking experience of action-potential generation by neurons has been proposed as the basis of awareness in organisms with brains [182]; this idea is easily extensible to the risky experiences of sudden osmolarity, membrane-voltage, or metabolic changes common in the unicellular world, or to the massively-risky experience of cell division. Canonical cognitive processes including learning [183], communication [184,185], memory and anticipation (priming) [186] are now often, though not yet routinely, used to characterize plants. They are, once again, used by *us* to make this characterization; we have no evidence that plants regard themselves, metacognitively, as learning, communicating, or remembering. It is interesting to note that less than 20 years ago, the idea that other mammals [187] and even human infants [188] were cognitive agents aware of their environments—observers, in other words—required vigorous defence. Not just human- or primate- but even animalocentrism about observation is fading, as is the notion that metacognitive awareness is required for awareness.

Multicellularity forcefully raises the question of how observers cooperate, compete, and possibly even coerce each other to form a larger-scale observer with its own capabilities, interests and boundary conditions [189–191]. Similar processes operate at every scale thus-far investigated, up to interactions between human population-culture combinations. A central finding of evolutionary developmental ("evo-devo") biology is that successful large-scale evolutionary transitions, e.g., from invertebrate to vertebrate body plans, involve the duplication and modification of modular packages of genetic instructions, typically instructions specifying where and when to express large sets of other genes [192,193]. While evo-devo thinking has entered psychology [194], what counts as a "module" and how they can be identified across species is considerably less clear. Whether duplication-with-modification mechanisms acting on knowledge "modules" can be demonstrated in, e.g., category learning, remains to be determined. The common use of analogy in abstract category learning [195–197] suggests that this may be common. The ubiquity of duplication-with-modification of instruction modules as a mechanism for producing progressively more complex memes is well recognized [160,170].

What happens above the scale of terrestrial populations and their cultures? Blackmore has argued that we are far more likely to encounter supra-terrestrial memes than organisms [170]; indeed, all SETI searches are searches for memes. Beyond familiar measures of non-randomness, however, we have few resources for meme-identification. If the Crab nebula were an artwork, could we identify it as such?

8. An Observer-Based Ontology

Every observer inhabits a perceived world, what Sellers [198] termed the "manifest image" for that observer (cf. [160]). The identifiable components of this world constitute the observer's "naive" ontology. This ontology contains everything that the particular observer it characterizes can detect, including objects, other organisms, environmental features, signs, words, affordances, memes, etc. It also contains whatever the particular observer can detect by self-monitoring, e.g., pains, pleasures, emotions, and feelings of believing, knowing, representing, owning, agency, or passivity. With this definition, the manifest image of any observer is clearly "personal" to it; it encompasses its possible first-person experiences. As described in Section 3 above, the observer identifies the components of its manifest image with finite sets $\{M_i^{(R)}, M_j^{(P)}, x_i^{(R)}\}$ of operators and expected values. Hence, specifying an observer O and the complete set $\{M_i^{(R)}, M_j^{(P)}, x_i^{(R)}\}$ of operators O can deploy and outcome values O can register specifies a (observer, world) pair.

As emphasized by von Foerster [5] among others, observation is an intrinsically symmetrical process. We can, therefore, ask how some observer O's world identifies O. As O's world can be considered an observer, it can be considered to deploy operators and expected values $\{Q_i^{(R)}, Q_j^{(P)}, q_i^{(R)}\}$ to identify O and characterize O's components and behavior. Specifying $\{M_i^{(R)}, M_j^{(P)}, x_i^{(R)}\}$ and $\{Q_i^{(R)}, Q_j^{(P)}, q_i^{(R)}\}$ thus specifies the "universe" comprising O and O's world entirely in terms of observations and outcomes, with no additional "systems" or "representations" of any kind needed.

The operators $\{M_i^{(R)}, M_j^{(P)}\}$ and $\{Q_i^{(R)}, Q_j^{(P)}\}$ specify the interaction between O and O's world, an interaction conceptually localizable to the "boundary" between them. The outcomes $\{x_i^{(R)}, x_j^{(P)}\}$ and $\{q_i^{(R)}, q_j^{(P)}\}$ obtained by O and O's world, respectively, are "written on" O's and O's world's, respectively, sides of this boundary [62]. Locating a *boundary on which outcomes are written* is, therefore, locating an observer; indeed, it is locating two interacting observers, each complementary to the other.

An observer may also be identified as a "system" by another observer, e.g., Alice may be identified by Bob. The outcomes of Bob's observation of Alice are, in this case, encoded on Bob's boundary with Bob's world, in which Bob sees Alice as embedded. Moore's theorem, as always, renders Bob's identification ambiguous: "apparent Alice" for Bob may be a different collection of degrees of freedom than "apparent Alice" for Charlie. Bob and Charlie cannot determine that they are observing the same Alice by increasing their measurement resolution [199]; to obtain reliable evidence of a shared system, they must contrive to violate a Bell inequality.

Conceptualizing observation in terms of operations *at* a boundary with outcomes encoded *on* that boundary makes explicit the fundamental epistemic position of any observer: observers can have no information about the *internal* structures of their worlds. This statement is familiar as the holographic principle, first stated by 't Hooft for black holes: "given any closed surface, we can represent all that happens inside it by degrees of freedom on this surface itself" ([200] p. 289). Hence, holography joins the principles of Boltzmann, Shannon, and Landauer as a fundamental principle of any theory of observation. The holographic principle reformulates and strengthens the ambiguity of system identification proved by Moore. As 't Hooft emphasizes, even *metric* information is inaccessible to observers outside of a closed system: "The inside metric could be so much curved that an entire universe could be squeezed inside our closed surface, regardless how small it is. Now we see that this possibility will not add to the number of allowed states at all." A boundary may encode *apparent* metric information, e.g., distances between systems "inside" the boundary, but both the apparent distances and the apparent systems are only observational outcomes encoded on the boundary itself.

A general account of perception explicitly compliant with the holographic principle has been developed by Hoffman and colleagues [201,202]. This "interface theory" of perception (ITP) postulates that percepts are compressed, iconic encodings of fitness information that are not homologous to, and encode no information about, structures in the world other than fitness. It assumes, in other words, that all information an observer is capable of obtaining is relevant to survival and reproduction, an assumption consonant with the significance of the frame problem for context-sensitive observers discussed in Section 4 above. The interface—the particular set of available icons and their behaviors—is species- and even individual-specific. ITP is supported by extensive evolutionary game theory simulations showing that agents sensitive only to fitness outcompete agents sensitive to world structures other than fitness [203] and by theorems showing that perception–action symmetries will induce apparent geometric and causal structures on worlds that lack such structures intrinsically [201,204].

As ITP implicitly assumes that perceiving agents are aware of what they perceive, Hoffman and Prakash [205] have proposed an ontology of "conscious agents" (CAs) that implement ITP. CAs comprise an interface through which they perceive and act on their world, together with a "decision" operator, modelled as a Markov kernel, that links perceptions to actions. The world with which any CA interacts is itself a CA or, equivalently, an arbitrarily-complex network of CAs; hence, the CA ontology comprises interfaces, each with an "internal" decision operator, linked bidirectionally by perception and action operators. It is, therefore, an ontology of boundaries and interactions as described above. Finite networks of CAs have the computational power of finite Turing machines, and networks of sufficient size can straightforwardly implement canonical cognitive processes including memory, categorization, attention, and planning [206].

The most fundamental problem that any theory of observation consistent with quantum theory faces is that of *unitarity*: the unitary dynamics required by quantum theory conserves net information, just as it conserves net energy. Any *net* information present in the universe at any time must, therefore, be present as a boundary condition on the universe's initial state, and must be equally present as a boundary condition on its final state. This is the notorious "fine-tuning" problem typically addressed with some form of anthropic principle (e.g., [207]). Postulating observer-independent systems (as in Zurek's "axiom(o)"; Section 3), categories, or even observers themselves falls afoul of this problem; whatever information is required to specify the assumed entities, data structures, or operations must be included in past and future boundary conditions. The simplest solution to this problem, clearly, is for the universe to contain zero net information. Boundary or interface ontologies that comply with the holographic principle escape this problem provided two conditions are met: (1) information encoding on boundaries must be both signed and symmetric, so that the total information / entropy and energy transfers across any boundary are zero, and (2) every possible boundary must be allowed. The latter condition is consistent with Wheeler's postulate of observer-participancy: *every* characterizable system is an observer; the former enforces unitarity locally at every boundary. Both the formal and conceptual consequences of these conditions remain to be investigated; some initial considerations are discussed in [62].

9. Conclusions

When physical interaction is reconceptualized in informational terms, it becomes observation. The conflicts between this reconceptualization and both physical and psychological intuitions became obvious with the advent of quantum theory in the early 20th century, with the measurement problem and the explosion of competing interpretations of quantum theory as the result. Since the 1960s, the life sciences have investigated the implementation of observation by organisms at multiple scales with ever-increasing precision. Examining organisms tells us not only how observation works, but what it is for. Moreover, it reveals that observation is ubiquitous in nature and strongly linked to fitness. Its greatest contribution, however, is to emphasize and make obvious that observers must actively distinguish "systems" from the environments in which they are embedded. It is systems and their state changes that carry meaning for observers. Requiring that observers be capable of identifying systems removes the possibility of treating "the observer" as a mere abstraction or as a system of irrelevant structure. Indeed, the structure of any observer determines the measurement operators it can deploy, and the observational outcomes it can register.

As Dodig Crnkovic [11] also emphasizes, recognizing observation as a *relation* between observer and observed leads naturally to an observer-relative and observation-dependent "observed reality": an individual-specific *Umwelt* [208], "image" or interface. Moore's theorem renders this interface a boundary that cannot be looked behind. If interaction is observation, observational outcomes are holographically encoded on this boundary. An ontology of boundaries supporting interactions naturally emerges. "Systems" and "representations" are no longer necessary as ontological entities, though their utility in practice remains.

Little has been said, in the foregoing, about awareness or consciousness, terms I regard as synonyms. It is, however, difficult to conceive a meaning for "observation" that does not entail awareness. Strawson [209] has argued that any self-consistent physicalism entails panpsychism; it seems simpler to follow Wheeler [33] and treat awareness as an irreducible primitive characterizing the dynamics of the universe, whatever these may be. If this threatens the meaning of "physicalism," perhaps that meaning should be abandoned. "Materialism" in any strict sense has, after all, been dead for a century. Weiner famously insisted that "information is information, not matter or energy" ([210] p. 132), but this was in a vastly different cultural context, four decades before "it from bit" and the quantum-information revolution it provoked. Perhaps it is time to consider the possibility that our traditional distinctions between information, energy, and awareness no longer have value.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial intelligence
CA	Conscious agent
FAAP	For all practical purposes
GOFAI	Good old fashioned AI
IGUS	Information gathering and using system
ITP	Interface theory of perception
LoT	Language of Thought
QBism	Quantum Bayesianism
SETI	Search for extra-terrestrial intelligence

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Time and Life in the Relational Universe: Prolegomena to an Integral Paradigm of Natural Philosophy

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Abstract: Relational ideas for our description of the natural world can be traced to the concept of Anaxagoras on the multiplicity of basic particles, later called "*homoiomeroi*" by Aristotle, that constitute the Universe and have the same nature as the whole world. Leibniz viewed the Universe as an infinite set of embodied logical essences called monads, which possess inner view, compute their own programs and perform mathematical transformations of their qualities, independently of all other monads. In this paradigm, space appears as a relational order of co-existences and time as a relational order of sequences. The relational paradigm was recognized in physics as a dependence of the spatiotemporal structure and its actualization on the observer. In the foundations of mathematics, the basic logical principles are united with the basic geometrical principles that are generic to the unfolding of internal logic. These principles appear as universal topological structures ("geometric atoms") shaping the world. The decision-making system performs internal quantum reduction which is described by external observers via the probability function. In biology, individual systems operate as separate relational domains. The wave function superposition is restricted within a single domain and does not expand outside it, which corresponds to the statement of Leibniz that "monads have no windows".

Keywords: Leibniz; monad; internal quantum state; relational biology; reflexive psychology; self

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1. Introduction: Relational Ideas in Philosophy and Science

After Thales (c. 624-546 BC), who formulated the concept of substance and is recognized as the first philosopher, Anaximander (c. 610-546 BC) became the founder of scientific thinking [1]. His definition of the primary substance as *apeiron* introduced the idea of potentiality in philosophical thought. According to Anaximander, "things are transformed one into another according to necessity and render justice to one another according to the order of time" [1]. Time orders things by separating them in a way that the simultaneous contradiction is avoided. While Pythagoras (c. 570-495 BC) is regarded as the founder of mathematics, and Parmenides (c. 540-470 BC) was the founder of logic, Anaxagoras (c. 510-428 BC) can be considered as the founder of the relational science. Anaxagoras claimed the multiplicity of "seeds" called later by Aristotle *homoiomeroi*—the particles having same nature as the whole [2]. *Nous* (mind) in the philosophy of Anaxagoras orders all homoiomeroi and can be related to the philosophical idea of pre-established harmony. Later, the relational concept of knowledge was developed in detail by Aristotle (384-322 BC) who, in his tractate *De Anima (On the Soul)*, attributed the notion of self to the internal determination within living systems [3], and introduced two types of time in *Physica*, one which is measured and one by which we measure, suggesting that our visible world is generated by a reflexive loop that involves these two types of time [4]. This loop assumes the minimum action that cannot be further divisible, which provides a possibility of the physical movement and establishes the quantum nature of the physical space and time. The idea of indivisible quantum arises to Democritus (460-370 BC) who, by accepting the atomic structure of the world, escaped the paradoxes of movement formulated by Zeno of Elea (c. 490–430 BC). The idea of external time was later relationally elaborated in the special and general theory of relativity, while the concept of internal time, appearing as a reduction of potentialities, became the basis of quantum mechanics. The contradiction between the foundations of the general relativity and quantum mechanics arises to the incongruity of the external and internal times in the Aristotelian sense.

The temporality as a bridge between the ideal mathematical world and the real physical world represents the central point of the philosophy of Aristotle. We can say that the actual existence resides at the crossing point of the two types of time defined by Aristotle. The logic of life, according to Aristotle, involves a profound component that is referred to the temporal transformations. While Plato (427-347 BC) analyzed the forms beyond time, Aristotle observed them also in the temporal world, and for this observation he developed a complex conceptual apparatus that describes the phenomenon of actualization. It is important to emphasize that the space-time of Aristotelian physics is clearly relational. He considered time as the measure of movement which, when viewed as external, can itself be the subject of measurement. Aristotle developed the concept of *res potentia* (if we use Latin terms), which has relevance to Anaximader's *apeiron* and through which the worlds of *res cogitans* and *res extensa* are interconnected and mutually arranged. He called it *entelechy* which can be either in the form of knowledge (as referred to the noumenal world of *res cogitans*) or as *energeia* (as linked to the phenomenal world of *res extensa*). The theory of actualization is represented in Aristotle's philosophy in great detail, while further philosophers often misinterpreted or ignored it, with the most radical view (in some positivist theories) claiming that *res potentia* does not really exist.

The modern concept of thinking arose from the understanding of the dual nature of the world by René Descartes (1596–1650). To resolve the duality of *res cogitans* and *res extensa*, Baruch Spinoza (1632–1677) considered these two perceivable properties, among an infinite number of others that we do not perceive, as the qualities of the ultimate *causa sui* substance. Gottfried Wilhelm Leibniz (1646–1716) challenged this solution and, in fact, revitalized Plato's concept that the "existing one" is actualized as "many" in the real world (the dialogue "Parmenides" [5]). The actual *res cogitans* represents the pluralism of monads [6], where coexistence is expressed as a "pre-established harmony", while the *res extensa* appears as the relational space-time of interacting monads being their intersubjective pattern. The exposition of *res cogitans* into the world of *res extensa* takes place via the common potential field which corresponds to the *existing one* of Plato's philosophy [5]. Each monad possesses a kind of subjective being, spanning from the subatomic levels with the pilot-wave duality to the sophisticated living beings having free will and consciousness. The internal time of monad is arranged by the reflections of the monad on itself, while the space comes as a set of reflections on the whole. The parameters of space-time satisfy the condition of coexistence of monads and correspond to the observability of the world. Such a representation of the world replaces its objectivity by an intersubjective pattern arising from the relativity of a single picture represented by the monad's point of view and having the characteristics common to all individual beings. The temporal evolution of the world is a process aiming to overcome the limits of its individual representation; it has no external frames and opens into infinity (for details see [7–12]).

The relational physics that appeared two centuries after Leibniz, is based on the relational nature of space-time. This space-time comprehension in the special theory of relativity was later substituted by the quasi-substantial space-time of the general theory of relativity and its recent developments. The unification theories of modern physics often abandon the relational nature of space-time, which is particularly noticeable in the models of the Universe evolution assuming the uniform time flowing from the Big Bang to the future phases of its expansion.

Living organisms, viewed in the frames of the relational concept, are characterized by an internal cause of their dynamics in the Aristotelian sense which was defined by Rosen [13] as a "closure to efficient causation". For Immanuel Kant [14] it was certain "that we can never adequately come to know the organized beings and their internal possibility in accordance with merely mechanical principles of nature". Vladimir Lefebvre [15] defined living system as a body that has at least one point in which its movement is not determined physically. This determination corresponds to the internal efficient cause in the sense of Robert Rosen [13]. By introducing the concept of relational biology, Rosen followed Leibniz's paradigm in which individual biological systems appear as separate relational domains. According to Rosen, living systems "rescue and organize their natural autonomy by internalizing and thus isolating entailments from external information" [16]. Living systems correspond to Leibniz monads as the "multiple complementarity, decomposable into generative (intrinsic) and interactive (extrinsic) relations comprising causal entailments in contextually related categories" [16]. While the concept of relational biology was outlined by Rosen, the appearance of conscious systems corresponds to a new level of reflexive structure where the subject reflects and estimates itself. The reflexive structure of a subject, anticipated by Freud [17] and Lacan [18], was formally described by Lefebvre [19]. This structure was defined as a double homunculus [20] and its role in the dynamics and evolution of social systems was further analyzed in detail [21].

2. Relational Logic and Mathematics

Plato's dialogue "Timaeus" [22] has a special relevance to the relational structure of the physical world from the point of view of the foundations of mathematics. According to this dialogue, the structure of the world is based on the principle of optimality and follows the paradigm that was later presented by Leibniz as "the best of possible worlds". In "Timaeus" Plato described a distinction between the physical world and the eternal world. The physical world changes and perishes, while the eternal world never changes and can be apprehended by reason. According to Plato, the origin of the Universe is based on the eternal and perfect world of "forms" (*eidoi*) as a template. Plato assumed that the minimal particle of each element has a special geometric shape corresponding to ideal Platonic forms. Tetrahedron is the constituent of fire, octahedron represents air, icosahedrons are constituents of water, and cube represents earth. Each of these perfect polyhedra would be, in turn, composed of triangles of certain triangular shapes. If we consider triangles not only as spatial shapes but as basic structures of reflexive systems, we can understand a profound importance of the views developed in Timaeus [23]. Different essences can transform between each other—they are disassembled to triangles and then assembled again. Only cube (earth) is not transformable. This 3D world is disassembled to 2D and then assembled back. The world, according to Plato, consists of the two types of triangles: equilateral and rectangular isosceles. When disassembled into triangles, the essences cease to be bodies, and the 2D triangles exist in the ideal space. Therefore, the basis of the world is the mathematical structure, which, in its transformation, forms first ideal bodies and then material bodies. Plato perceived the world geometrically; from triangles he developed the plastics of the ideal.

For the real logic of *eidoi* (forms) becoming the templates for the physical world, the most important is Plato's dialogue "Parmenides" [5]. It represents pure dialectics and avoids speculations that are apparent in "Timaeus". The most important here, from the point of view of generation of the physical world, is how the pure logical being becomes the "existing one". The action in the physical world is presented here as "*exaiphnes*" (instant, sudden): "Then the one, if it is at rest and in motion, must change in each direction; for that is the only way in which it can do both. But in changing, it changes instantaneously, and when it changes it can be in no time; and at that instant it will be neither in motion nor at rest". Thus, the movement is always signified (we can call it "*semiokinesis*" [24]), it is initiated by the action of signification being its real cause, which precedes movement and is absent at the time present in the point occupied by the moving object. In another place of the dialogue "Parmenides", Plato states: "Then let us say that, and we may add, as it appears, that whether the one is or is not, the one and the others in relation to themselves and to each other all in every way are and are not and appear and do not appear". In Plato's dialogue "Parmenides", the multiplicity originates from the logic imposed by the existence of one via the self-referential process of generating numbers. The objective counting becomes a consequence of this self-referential process which is perceived by the mind in reverse: it perceives the complexity of the composition but not the entity that generates complexity, which can be comprehended only in the philosophical thought.

In Leibniz's philosophy, the actualization represents an ordered revelation of the entity taking place outside the temporal order, bringing the idea of the relational nature of objectivity of the space-time. The space-time is also relational in the philosophy of Kant, where the '*Ding an sich*' can be viewed as a sum of possible histories, which in the course of perception is reduced to the actual thing existing in the 3D space. Objectivity of the space-time appears as a fixed intersubjective precondition of perception that generates the phenomenal reality of the observed world. Following Parmenides, Plato, and Leibniz, it can be stated that the primary substance is rather not a Pythagorean number but mere the *apeiron* in the sense of Anaximander that precedes the process of counting and is actualized via generation of numbers.

The existence is equivalent to the embodied number that comes as a realization of the computational activity, and this activity is attributed to the single substance (monad) that observes itself in the world. Bertrand Russell [25] in his "*History of Western Philosophy*" states: "the relations of essences are among eternal truths, and it is a problem in pure logic to construct that world which contains the greatest number of coexisting essences". In modern interpretations of quantum mechanics, the approach to see the world as a set of consistent histories [26] can be traced to Leibniz and to his unpublished at his time logic: the existence is formed by the events that are consistent with more events than other possible events. Observability means a possibility to perform multiple quantum measurements in such a way that their results are compatible and can form the pattern that corresponds to our trivial sense of the absolute space-time common to all beings.

The logic of the dynamical process unfolding in the reality rather than describing the formal change determines the state of three dynamic elements, which are the opposites A and non-A, and the middle state T ("included middle"). The predecessor of this logic was Nicolai Vasiliev [27] and in the advanced form it was introduced by Stéphane Lupasco in 1930s [28] and further developed by Joseph Brenner [29,30]. Aristotle described the process of actualization through the introduction of a non-classical logical scheme [3], which differs from the well-known Aristotelian logic operating in the actualized world. In the actualized world, the middle state T is excluded, but it is always present in the dynamical process that holds the energy of actualization of A or non-A, and uses it for switching from A to non-A, which become separated by time interval and diverged spatially. This evolutionary process forms new entities, generates new events through the separation and synthesis of the particulars of oppositions, and incorporates new spatiotemporal solutions in the course of this dynamics.

While every possible world exists as an infinite set of monads, not every set of monads represents a possible world, since it must be coordinated (symphonic). In the actual Universe some programs cannot be implemented into bodies, and some bodies cannot coexist with others. The relational foundations of mathematics consist in the origin of numbers from the counting activity as developed in Plato's dialogue "Parmenides". The universal principles representing foundations of mathematics were sought in logic by many authors, and the tradition arising to Parmenides was revived in early XX century by such different authors as Frege and Russell, Gilbert, and Wittgenstein. To bring mathematics to the phenomenal world, the geometrical constituent needs to be included in its foundations. The idea arising to Pythagoras, Plato, and Anaxagoras was further developed by Leibniz in his Universal Program [6] and revived in a new approach to mathematical foundations called the theory of homotopic types developed by Vladimir Voevodsky [31]. The idea of form incorporated to the foundations of mathematics is based on the supposition that they should include geometry. The intrinsic logic that is revealed in the foundations of mathematics corresponds in this approach to the spatiotemporal structure that is generated internally on the basis of this logic. When geometry is introduced to the foundations of mathematics, the world becomes shaped in a certain particular way fitting to its inhabitability, which resembles the anthropic principle in physics. The limits of geometry become associated with the limits of computation of the particular world, and in the theory of homotopic types the basic foundations of mathematics can be verified via using a computer [31].

The geometric form appears to be computable and possesses certain laws of its computability. The concept of geometrization of foundations of mathematics approaches us to the anthropic principle in mathematics. In Greek philosophy, Pythagoras initially introduced geometry in the mathematical pattern of the world. The *musica universalis* (harmony of the spheres) maintaining the movement of planets and stars according to mathematical equations and producing an inaudible symphony, has the fundamental geometrical constituent. Music is a reflexive mathematics according to Leibniz [6]. Geometric atoms appeared in the foundation of world's structure in the philosophy of Anaxagoras who called them "seeds", then these atoms were named as *homoeomeria* by Aristotle. Actualization of the ideal essences in the physical world was metaphorically associated with the process of seed germination, which occurs via the imposition of temporality.

3. Relational Physical Universe

The transition from the mathematical world to the physical world occurs via the imposition of limits of computation that appear as the set of fundamental constants. These limits shape the spatiotemporal physical world and determine its dimensionality and curvature. The idea that the physical world is shaped by the limits of computation arises to Parmenides and Plato and then to Leibniz, it is introduced in modern science [32] and represented, in particular, as the existence of limits of computing in the Universe [33]. The parameter, which is intrinsic to the action introducing computation, is time which separates contradictory statements [8] and defines the velocity of observation propagation [34]. The physical complementarity corresponds to the non-simultaneous existence of contradictory statements and properties, which, in turn, generates recursion and flow resulting in complexification [35]. In the dialogue "Parmenides", Plato introduced multiplicity via the process of assignment of the being by the existence. This assignment takes place via temporality, and the existing being appears in its multiplicity. The existing models of the Universe should explain the existence of multiple particles of the same properties such as electrons etc. The idea of retrocausality which is outlined by Matsuno [36] and needs to be further developed, helps to understand the origin of multiplicity via what can be described as the directions forward and backward in time. From the only few retrocausal loops corresponding to the basic elementary particles appearing as antiparticles in the reverse direction, the whole Universe is unfolded in correspondence to the one electron model of the Universe [37]. In the flow of time, the contradictory statements appear as the retention-protention relations according to Husserl [38]. Memorization of retention leads to certain basic values of the actualized structures such as the golden section [23]. Only few geometric atoms are needed if they are implemented in the physical world moving back and forth in time. The physical world emerges when time is introduced into the mathematical world [9], in other words, when the numbering comes into being as a result of measurement. Measurement as the basic underlying process in physics corresponds to the relation in which time and space become connected via the certain values that are the physical fundamental constants.

While both the special and general theory of relativity deal with the external time which is measured, the quantum mechanics in the concept of quantum reduction or decoherence is associated with the internal time by which we measure and which itself can be measured provided that quantum measurements are performed in a regular way, with low dissipation of energy [12]. In this case the quantum system becomes an internal autonomous clock that distinguishes the past (memory), the present (life), and the future (anticipation based on the reproducible model). Both the theory of relativity and the quantum mechanics are the relational theories but they use different concepts of time. Their synthesis can be also only relational and it can be based on the development of the concept unifying both types of time. The internal time (by which we measure, according to Aristotle) separates contradictory statements while in the external time (which is measured) they appear as separated and sequentially ordered. The agency of time traffic-controls the contradictions sequentially. For the unification of physics in a general theory integrating the general relativity and quantum mechanics, the question of the relation between the external, and the internal time has to be rethought and further developed. In the frames of the external time envisioned in special and general relativity, the generative aspect of contradictions is not anticipated, however, the generative aspect is latently present in the internal time grounded upon the quantum phenomena. The mitigation of the gap between the external and internal time has been a hard problem since Aristotle, and only the resolution of this problem can open the way for the unification of physics and for its constructive integration with the other fields of knowledge including biology.

When time is viewed as the engine separating contradictory statements, we face the necessity of reconsideration of the evolution of the Universe from the Big Bang, which in the relational world will appear in a different way than usually depicted in handbooks. In the relational Universe the Big Bang remains real but not in a local way. The "delocalized" Big Bang represents a knot being a kind of fixed point for all reflexive loops of observation of the physical Universe from which everything emerges. The generation of the Universe is a process in which the unique set of fundamental constants is defined via quantization of the elementary action. Evolution of such Universe is dependent on the observation propagation velocity which differs in the different systems of observation. Time may go fast or slow depending on the observation or even be absent like in some relational models of the physical world [39]. The action of separation of contradictory statements is quantized, so the Planck's constant represents the constant of action, which also quantizes information by determining the number of events in the Universe. The minimal quanta are the units of action representing the loops of quantum gravity while the macroscopic quanta correspond to hypercycles, cells, self, and finally conscious beings. The process of avoiding infinity is the basis of quantized physical world. It is introduced as the quantum of action, which was understood by Democritus as a necessary operation to escape from Zeno paradoxes. The operation of renormalization is always applied in quantum mechanics to avoid infinities. It relates to the internal measurement where the minimum quantum of action is applied. Renormalization corresponds to the process of putting finite limits to make the system computable. The physical world emerges as divided into the computable and non-computable parts [40]. The computable part is shaped by the fundamental constants while the non-computable part represents the set of actions that introduce computation in the real world.

The highest velocity of observation propagation corresponds to the speed of light. This universal constant determines the synchronization of signals between the observers communicating via a vacuum. The observation propagation velocity can be slowed down significantly in the coherent media. A shielded state with very low temperature is characterized by long relaxation times corresponding to the macroscopic scales. This is explained via the Heisenberg's uncertainty relation between time and energy, where very low dissipation corresponds to the extended times of relaxation. In these coherent states, the speed of light is slowed down to very low values. Several years ago, the lowest registered speed of light was recorded as 17 m s^{-1} via the vapors of sodium at 1 K [41]. However, later much lower speed of light of 0.2 mm s^{-1} was reached in the Bose–Einstein condensate of cold rubidium atoms [42]. Light speed reduction realized the transition of the system to the macroscopic time scale, which is observed in living systems. It has been hypothesized that the slow relaxation of biological macromolecules is explained by the reduction of observation propagation in the coherent medium of the shielded internal quantum states [7–9]. Thus, the molecules such as enzymes can function as precise measuring devices that recognize the substrate and transform it into the product with high precision or generate a precise signal transduction event in the case of receptor molecule.

In the relational world, the external space-time appears as the medium ('environment') suitable for the coexistence of individual units having their own substantiality; i.e., monads. These units are "seeds" realizing a small part of potentially possible actualizations, and their own actualization cannot afford coexistence of everything possible. The simplest monads correspond to the quantum loops in the concept of loop quantum gravity. Space, according to modern views, represents a fine network of finite loops called spin network. Its evolution over time is called a spin foam. Quantum cells of space are connected with each other via their internal field and can be referred to geometric atoms. The value of this field is a certain "internal time". The transition from the weak field to a strong field appears as there was a "past", which affects the "future" (causality). In a big universe these cells merge forming the common space-time [43]. The basic process that underlies complexification and expansion is the quantum measurement. It establishes the spatiotemporality and determines its growth via continuous measurement of the system plus environment [12]. This special non-Newtonian causality corresponds to the expansion of the Universe viewed as a consequence of quantum measurement. The *ceteris paribus* principle is not generally working in the real Universe, it rather follows the principle of *pratitya-samutpada* (dependent-arising) of Buddhist philosophy [44].

The solution of realization of monads' programs in the actualized world is a difficult philosophical problem. It had different ways of being solved in biology and recently the same challenge appeared in the implementation of the multiverse idea in physics. The principle that is beyond simple logic was introduced in biology as the principle of natural selection. It still dominates in biology and can be applied in cosmology as the natural selection of universes [45]. In physics it brings the final cause for observability, i.e., it is based on the anthropic principle, while in biology it is based on the survival of the fittest, which has also the teleonomic nature in the Aristotelian sense. This principle was introduced explicitly by Lucretius, who borrowed it from Epicurus and probably from earlier philosophers. The principle of natural selection can be considered as the consequence of spatiotemporality generated by multiplicity of monads but it cannot directly explain complexification and the necessity of evolutionary growth unless it is viewed as a consequence of the more general process of actualization.

The relational space-time for the observability condition should meet the criteria of universality for all observers defined by the set of fundamental physical constants. These constants correspond to observability of the world and represent the natural limits of computation that generate the observable physical Universe [8]. It is possible that their values may evolve in the meta-evolutionary process [46]. In the physical world, monads can be viewed as active units that perform quantum measurements. In certain conditions, when the measurements are held for prolonged times with precise outputs within the organized structures (bodies) where a higher monad rules other simpler monads, the cognitive phenomena and consciousness arise. None of the monads act on any other but the patterns of their spatiotemporal representation physically interact in the external actualized world [47].

Physics of the XX century generally evolved in the direction to the substantial understanding of the space-time. It incorporated such concepts as the age of the Universe, its inflation and expansion, and raised the question what was before the Big Bang. The alternative to the general theory of relativity model suggested by Edward Arthur Milne [48] excluded the gravitational interaction from the model of the Universe expansion. In fact, the internal measurement takes place in the gravitational field. All other fields have entropy, and the complexity of structures is relational to the basic field, which is gravitational. That is why Roger Penrose [49] links measurement to reaching the Planck's gravitational mass. Any complexity is relational, it is not the property of the system but the property of its observation, according to Robert Rosen [13]. The relational complexity means also the relational entropy which acquires exact value only in relation to the primary non-entropic field appearing to us as the gravitational field.

This actually means that the property of the Universe expansion follows from the development and complexification of patterns generated in the individual quantum measurements performed by monads. John J. Kineman proposed the sketch of theory that he called the "relational self-similar space-time cosmology" [50,51] where the individual substances form the spatial relations to each other, which logically refers to the fundamental features of windowless monads. The temporal relations in a similar way logically arise to the timeless characteristics of individual monads. This understanding can be seen in the statement of Heraclitus: "An invisible harmony is better than a visible one" [52]. The realization of computation could be possible only at certain preconditions expressed in the basic symmetries and corresponding to the fundamental physical laws.

The existing physical parameters may strictly conform to the observability of the world and represent a unique solution for free will and consciousness, as suggested by the anthropic principle.

The free will theorem of Conway and Kochen [53] states that, if we have a certain amount of "free will", then, subject to certain assumptions, so must some elementary particles. The minimum action defined by the Planck's constant already has certain freedom of will. It generates the loop of space and can be the basis of retrocausality, so a particle can be multiplied via the reversal of time. The existing values of fundamental constants may represent the only solution for the shielded coherent states of living beings. This unique solution may appear beyond mathematics and can be substantiated only by the sets of empirical data revealing that it perfectly fits to the observability of real world. Like the reduction of uncertainty during decision-making occurs in the unconscious prior to its awareness [54], the proof of validity of the fundamental constants comes in a way like Diogenes proved the existence of movement by walking; i.e., via establishing the limits of computation that shape the physical world.

Leibniz, being the proponent of the relational space-time, kept only *cogito* and not extension as the basic property of the substance. He observed the Universe as the pattern of self-maintaining units—monads having "no windows". Such representation has certain interpretational difficulties in physics, therefore, it was mainly ignored in science. However, the understanding of a fundamental relational nature of the space-time requires the interpretation of Leibniz paradigm that is compatible with foundations of physics. In this interpretation, the internal observers, acting as measuring agents, constitute a network of mutual interactions, in which the refinement of the wave function generates intersubjective patterns having universal characteristics and corresponding to perception of the reality of external world [55,56]. This understanding leads to the idea of the relational quantum mechanics in which all its particular interpretations remain correct [57]. The many-world interpretation of Everett is valid in the area of the mind while the Copenhagen interpretation of Bohr relates to the matter, both being the ultimate representations of the same reality. The relational interpretation of quantum mechanics may not be exactly isomorphic to the monadological approach of Leibniz [58] but it corresponds to it in its conceptual basis.

4. Relational Biology

For understanding the nature of living beings, the problem of self has to be analyzed in detail. The "self" is characterized by a spontaneous activity that introduces computation into the real world, which itself represents a non-computable decision attributed to the living system. Erwin Schrödinger [59] was the first who suggested that the nature of self is quantum mechanical and placed it beyond quantum reduction. It corresponds to the internal quantum state (IQS, the term introduced in [8,9]) that holds the potentiality that directs possible actualizations, is delocalized and pre-programs the *a priori* forms of space and time, generating the spatiotemporal frame in which the world is observed. The Universe, according to Kineman [50], consists of the units called "holons" that possess self and correspond to Leibniz's monads. The Everett's multi-world interpretation of quantum mechanics is valid in these isolated domains but not between the domains as noted by Matsuno [60]. The wave function superposition is limited by the single domain and does not expand outside it which corresponds to the statement of Leibniz that monads have no windows. The principle of "closure to efficient causation" introduced by Rosen for living systems [13], can be seen as the application of Leibniz's "no windows" principle in biology. In the quantum mechanical concept of self, the growth of complexity results from living activity as a necessary consequence of the embedding measurement in which the reduction of uncertainty takes place. Evolution is a process that aims to overcome the physical limits of computability in which the incomplete identification appearing as an uncertainty in the measurement process is read and interpreted as a cause for new realizations. In such a process, the environment continuously changes in the course of adaptation, and evolution becomes a generic phenomenon having its own cause.

The relational biology was introduced by Nicholas Rashevsky [61] and further developed by Robert Rosen [13]. It describes life as ontologically independent generic phenomenon. The generic property of living systems can be analyzed as possessing self, which is related to internal determination (Aristotle's "*di aytoy*") or "closure to efficient causation" [13]. Life corresponds to a certain relation between elements, and its physical structure can possibly be substitutable. In the system closed to efficient causation, the internal determinant, defined by Lefebvre [15] as "eidos-navigator", ultimately appears. A living system has at least one point of determination by the eidos-navigator, so any living body has a point in which its movement is not determined physically. This movement unfolds into a structure that reflects the internal choice. The navigator in its choice does not use energy but it can operate only in the state within the system where energy does not disturb its bipolar choice; i.e., near the absolute zero. In fact, macroprocesses can be described by quantum mechanics only near the absolute zero [49]. The navigator is a fabric realizing the probability distributions and the infinitely small pushes that direct the evolution of body's state. When smaller systems unite into bigger systems, e.g., in the symbiogenesis corresponding to the origin of eukaryotic cell and then of multicellular organisms, the unification of individual eidos-navigators under the governing one in a bigger system takes place. The temperatures corresponding to the areas where the eidos-navigator can operate are realized in the shielded states and have the values of the millikelvin range or lower [9,50,62] forming Bose–Einstein condensates. These temperatures are much lower than the background radiation of the Universe (2.725 K) and can be found in the internal quantum states of living organisms shielded in the macromolecular complexes [9] and also in the inner worlds of black holes [63]. The shielded proteinaceous macromolecules may realize millikelvin temperatures in some particular folding configurations which stretch beyond the overall macromolecule size in such structures as cytoskeleton. The latter can be viewed as a macroscopic enzymatic system that generates long-range coherent states percolating between cells.

The latter states cannot be discussed at the present time in detail in relation to potential biological consequences, however, the possibilities of reflexive activities in them have been mentioned in the literature [64]. It is possible to speculate that reflective loops corresponding to Rosen's (M,R) systems can be established in Bose–Einstein condensates separated by the horizon from other area of the Universe; i.e., within black holes. For small black holes, the black body radiation emission corresponds to the temperature of about 100 nanokelvin, while larger black holes would be even colder because they let less radiation escape [63], which means that black holes are colder than space itself. The Bose–Einstein graviton condensate in a Schwarzschild black hole has been postulated [63]. A black hole is not purely a perfect Bose–Einstein condensate of gravitons but there could be bosons in a black hole which exist in that state.

While the eidos-navigator in Lefebvre's concept operates in the states with extremely low temperatures, its bipolar choice should be fixed within the thermodynamic machine of living body which operates in a steady non-equilibrium state that supports the shielded state and is capable of evolving. The argument against Bose–Einstein condensates in living beings refers to the thermal movement of molecules which occurs at the temperatures of ca. 300 K. However, as shown by Matsuno and Paton [62], the effective temperature of shielded states within macromolecules corresponds to millikelvin values. Biological protein bodies can be viewed as "refrigerators" in which very low temperature is achieved *inside* macromolecules. Macromolecules by themselves are involved in the thermal dissipative processes [65] in which the condition of stable non-equilibrium [66] supports metabolic closure and the maintenance of the internal coherent state. While the maintenance of the system in a homeostatic state occurs via the conservative type of stable non-equilibrium that tends to keep the initial state, the generic capacity of biosystem in their individual development and evolution is related to the special type of closure which is called hyper-restoration [67] and corresponds to the stable non-equilibrium of the second type that leads to the increased external work, according to Ervin Bauer [66]. The complexification of biological systems at corresponding stages of evolution generates different levels of organization such as prokaryotes, eukaryotes, multicellularity, and finally reflexive consciousness.

In the metabolically closed stable non-equilibrium systems, the precision of information transfer is achieved via the self-reflexive loops of autocatalysis. The autocatalytic systems appear at a certain level of complexity [68] and can be realized even within sufficiently complex polypeptide sets.

The probability that the set of polypeptides up to the length M contains a reflexively autocatalytic subset can be calculated and graphically presented [68]. At higher level of complexity, proteins can reproduce themselves via encoding in nucleic acids which represent the complex versions of coenzymes. Encoding formally corresponds to the generation of Gödel numbers appearing in sufficiently complex formal systems, and as a result an internal logic emerges in these systems. It leads to the appearance of precise self-reproduction [69]. The level of complexity corresponding to (M,R) systems [13] is homologous to a self-maintained internal model and advanced generic properties. The structure of (M,R) system is an example how the internal logic generates the topological structure and the abstracting capacity of the system [70]. At the very high level of complexity the double homunculus structures appear having an internal reflexive model of themselves and corresponding to the conscious beings [20].

5. Relational Psychology

While physics and even biology developed for a long time within non-relational paradigms, the understanding of psychology remains very limited if we do not consider the problem of self and its relation to other self. This means that psychology by definition is a relational field of knowledge. In the tractate of Aristotle "*De Anima*" [3] the basic principles of psychology have been formulated. While the living system is characterized by internal determination, which was later defined as a closure to efficient causation, the internal efficient determinant can be called "eidos-navigator" in the terms of Lefebvre. In "*De Anima*" Aristotle defined the structure of soul that includes the constituent of possession of knowledge and the constituent of the actual exercise of knowledge operating in the field of potentialities defined as matter. In fact, Aristotle formulated the triadic model of soul in which the actual exercise of knowledge operates in the potential field being determined by the constituent of possession of knowledge associated with an imposed determinism.

In unconscious living beings the actual exercise of knowledge corresponds to metabolism, while the possession of knowledge is fixed in the genetic system, and the field of potentialities is formed by the available chemical resources. This model became explicitly present at a new level in reflexive systems where it corresponds to the Freudian triad of *Ego* as an exercise of knowledge operating over the potential field of the Unconscious (*Id*) being directed by the imposed determinism of the *Super-Ego* (the possession of knowledge) [17]. While the triadic structure of soul was formulated by Freud in mythological terms as the Oedipus complex and further expressed by Lacan [18] in semiotic terms, the strict mathematical formulation was introduced by Lefebvre [19], who developed the concept of reflexive psychology and formulated two main opposite types of reflection that are realized in social evolution.

Self-reflection was attributed by Lacan [18] to the mirror stage of development, which he defined as a possibility of a subject to recognize himself in a mirror. This stage corresponds to the development of self-agency. Based on the recent studies of self-recognition of representatives of several species of animals in mirror, which may be related to the development of the system of mirror neurons that can fire through the observation of behavior of the other, as though the observer were itself acting [71], we can suggest that the ability to self-recognition appears at a certain level of brain complexity. Self-reflexive properties arise in cognitive systems upon their complexification like autocatalytic properties. They can be attributed to the development of the "double homunculus" system [20] where the image of the self appears inside the self [15,19]. The field of reflexive psychology established by Lefebvre is, in fact, the field of relational psychology studying how the individual reflexive systems interact with each other using their reflexive structures as reference systems. We can hypothesize that in the Universe the reflexive subject structures can be realized not only via the biological protein-based organisms and that intelligent beings at certain level of civilization may acquire a capability of changing the physical nature of their bodies.

6. Conclusions

In the framework of the upcoming synthetic natural philosophical paradigm that is discussed here, the observed structure of the world is a result of a perpetual solving activity rather than given *a priori*. This framework corresponds to the philosophical synthesis of ideas of integral biomathics developed by Plamen Simeonov in recent publications and special issues, see, e.g., [72]. The new paradigm of natural philosophy should ultimately be based on relational principles. The reality in this framework can be represented as a set of self-maintaining reflective systems capable for the continuous process of complexification. The solutions appearing in the evolutionary process of growing complexity are based on the most optimal realizations for the physical embodiment of the computing process which corresponds to the well-known Leibniz's notion of the most perfect world among all possible worlds as well as to the contemporary formulations of the anthropic principle [73].

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Induction and Epistemological Naturalism

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Abstract: Epistemological naturalists reject the demand for a priori justification of empirical knowledge; no such thing is possible. Observation reports, being the foundation of empirical knowledge, are neither justified by other sentences, nor certain; but they may be agreed upon as starting points for inductive reasoning and they function as implicit definitions of predicates used. Making inductive generalisations from observations is a basic habit among humans. We do that without justification, but we have strong intuitions that some inductive generalisations will fail, while for some other we have better hopes. Why? This is the induction problem according to Goodman. He suggested that some predicates are projectible when becoming entrenched in language. This is a step forward, but not entirely correct. Inductions result in universally generalised conditionals and these contain two predicates, one in the antecedent, one in the consequent. Counterexamples to preliminary inductive generalisations can be dismissed by refining the criteria of application for these predicates. This process can be repeated until the criteria for application of the predicate in the antecedent includes the criteria for the predicate in the consequent, in which case no further counterexample is possible. If that is the case we have arrived at a law. Such laws are implicit definitions of theoretical predicates. An accidental generalisation has not this feature, its predicates are unrelated. Laws are said to be necessary, which may be interpreted as ' "Laws" are necessarily true'. 'Necessarily true' is thus a semantic predicate, not a modal operator. In addition, laws, being definitions, are necessarily true in the sense of being necessary assumptions for further use of the predicates implicitly defined by such laws. Induction, when used in science, is thus our way of inventing useful scientific predicates; it is a heuristic, not an inference principle.

Keywords: induction; naturalism; evidence and justification; epistemic norms; induction and concept formation; induction and discovery of laws

1. The Induction Problem in the Naturalistic Perspective

Inductive, i.e., non-deductive, reasoning is a core feature of both everyday reasoning and empirical science. Can it be justified? Hume famously answered NO. There are two possible ways for justifying a statement, i.e., to give arguments for its truth; either to point out that it follows logically from other statements held true, or that it is supported by experience. Neither can be used in a general justification of using induction: if we argue that past experiences show us that inductive reasoning quite often is successful and therefore continued use of induction is justified, our reasoning is circular. Neither can logic provide any justification, and since there are no other options, inductive reasoning cannot be given any general justification at all.

Many philosophers have tried to rebut Hume's conclusion, without success in my view. So, for example, several philosophers have entertained the hope that probability theory could be used to overcome Hume's skeptical argument; but one may easily recognise that Hume's original argument still applies for the simple reason that probabilities are based on previous experiences.

Reliabilists have tried to evade the circularity critique by suggesting that meta-beliefs about first-level reliably produced beliefs can be reliably produced in part by the very processes that formed the first-level beliefs. However, how do we know that a certain belief forming process is reliable?

Normally we use induction when obtaining knowledge about probabilities, thus still using circular reasoning. The alternative is to rely on a priori knowledge about some probabilities, but that is not acceptable for any empiricist.

The induction problem is still with us; we use a form of inference, which we see no way of defending. Quine once characterised our situation with his characteristic wittiness: "The Humean predicament is the human predicament." ([1], p. 72).

As with many other predicaments the solution is, I believe, to reconsider the tacit presuppositions at work when formulating the problem. The most basic presupposition when stating the induction problem is that we need an independent foundation for knowledge and science and that, I think, is wrong.

Many people believe a general justification of induction is required because they assume it is the business of epistemology to provide a foundation for the sciences. Science is that kind of human activity that should fulfil the highest standards of rationality, which means that we, ideally, should be able to justify our scientific methods. A lot of specific methods are species of induction, hence we need a general justification of induction.

However, this train of thought is, I think, erroneous. It is based on a rationalistic outlook, the notion that we humans are able to know, a priori, something about the relations between human minds and the external world. However, I cannot see how such a priori knowledge is possible; no good reason can be given for the assumption that we humans have a non-sensoric faculty by which we can obtain knowledge about nature. Hence no purely a priori principle with empirical content is in our reach. Epistemological naturalists like myself thus reject the presupposition that epistemology is, or could be, a non-empirical inquiry into the foundations of knowledge and science, a first philosophy.

Should we then stop doing epistemology? I think not. Instead we should reconsider our picture of the relation between philosophy and empirical science. Like many present day epistemologists, I suggest that we adopt a naturalistic stance, which means, as I interpret the term 'naturalism', to view epistemology as part of our scientific and empirical study of the world; epistemology is the study of how the cognitive apparatus of humans works and under what conditions the resulting cognitive states represent real states of affairs. In such an endeavour no a priori knowledge with empirical content is needed.

Traditional epistemology results in epistemic norms. The critic might now claim that, as an empirical study, naturalised epistemology cannot entail any norms and so it cannot do its work. My reply is that it can result in statements of normative form, but that does not entail the existence of a kind of entities, Norms. We may well accept a declarative sentence as true without accepting that that sentence refers to a Fact and similarly, we may well accept the validity of a normative statement without accepting the existence of any Norms.[1]

Epistemic principles have the form 'do so and so in order to obtain knowledge', or maybe 'do so and so in order to minimise the risk of drawing false conclusions'. Such statements can be reformulated as conditionals, such as 'if you want to get knowledge, do so and so'. Such a sentence could be the conclusion (an inductive one!) of empirical investigations of our cognitive faculties and earlier failures. Now, our goal of obtaining knowledge are often left unsaid as a tacit condition, since in many contexts it is obvious and we follow Grice' rule of not saying obvious things. Hence we just utter the consequent, which is a sentence of normative form. Thus, the normative form of epistemic principles can be explained as ellipsis, the tacit presupposition being 'We want to know'.

Many norms have this character. For example the social norm 'Do not play music loudly if you live in a flat' could be interpreted as tacitly presupposing that people normally want to have good relations with their neighbours and in order not to jeopardise that goal, they should avoid disturbing

[1] I endorse the deflationary view on truth; saying that $\ulcorner p \urcorner$ is true, is the same as asserting $\ulcorner p \urcorner$ and by that one is only forced to say that the singular term(s) of $\ulcorner p \urcorner$ refer to object(s): it does not follow from the truth of a sentence that it refers to a *fact*, nor that its general term refers to a universal. Hence no further commitments about the truth-predicate is called for.

them. In addition, the conditional is based on an inductive inference from ones own and others' experiences.

In the naturalistic view epistemology is fallible and revisable as all our knowledge. There is no vantage point of view from which to judge whether a particular method is bad or good; such a judgement must be made from within the sciences. The conditionals we believe and express as sentences of normative form, leaving the condition tacit, are the results of empirical investigations and every day experiences.

2. Justification in the Naturalistic Perspective

Propositional knowledge consists of true, justified beliefs according to the standard definition. Justification is a relation between beliefs and statements expressing these beliefs; one statement can contribute to the justification of another statement. No matter how we analyse the relation, it is obvious that a general demand for justification will result in an endless regress; if B justifies A, one will immediately ask for a justification of B etc. In practice we must stop somewhere and epistemological foundationalists have thought that the endpoints must be some kind of a priori and self-justifying statements.

As already pointed out, epistemological naturalists do not believe that there are any *a priori* grounds for empirical knowledge; no set of basic and self-evident statements with empirical content can be found. Hence, any statement can be doubted; even the simplest observation or the most obvious logical principle can be and has been doubted. Now the sceptic attacks; from the statement 'Any particular statement can be doubted', it follows, he claims, 'All statements can be doubted'. However, this is an invalid inference. The premise can be paraphrased as 'For all x, if x is a statement, it is possible that x is false' and the conclusion as 'It is possible that for all x, if x is a statement, x is false'. This is an invalid inference, no matter which modal logic you adopt. The same point has been made, in a different context, by Davidson:

> Yet, it has seemed obvious to many philosophers that if each of our beliefs about the world, taken alone, may be false, there is no reason all such beliefs might not be false. The reason is fallacious. It does not follow, from the fact that any one of the bills in my pocket may have the highest serial number, that all the bills in my pocket may have the highest serial number, or from the fact that anyone may be elected president, that everyone may be elected president.[2] ([2], p. 192)

So it is perfectly consistent to say that none of my beliefs are beyond doubt, that anyone might be false, and at the same time hold that most of my beliefs are true. Furthermore, doubts about a particular belief are based on other beliefs not in doubt.

However, how can there be starting points in chains of justification, which are not justified? This is, certainly, a problem for traditional epistemology. But in the naturalistic perspective we do not ask for ultimate *justification*; instead we look for intersubjective agreement of observation reports. Such agreements make up the empirical basis in the empirical sciences, the endpoints where chains of justification begin. In addition, this fact is the reason I prefer to talk about statements/sentences instead of beliefs.

Rationalistists follow Descartes' search for ultimate justification in terms of subjective certainty. That is a big mistake in my view; as basis for knowledge we need *intersubjective agreement* about statements, both in science and in our everyday interactions with the environment, including other persons.

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2 Davidson's premise can be formalised in quantified modal logic as 'For all x, if x is a bill in my pocket, it is possible that x has the highest serial number.' and the conclusion 'It is possible that for all x, if x is a bill in my pocket, x has the highest serial number.' Hence, it has the same logical form as the sceptical argument.

We humans are normally able to agree about shared observations. When several people at the same spot and talking the same language observe an event, they normally agree on at least some descriptions of it, so long as no intentional notions are used. Since any observed situation may be described in many different ways, they may disagree about what should be called the most salient description of what happens, but that is another thing. Some descriptions of observed events are agreed to be true.

The agreement is about the utterance, not about what it means; two persons may agree to assent to an utterance while interpreting it differently. In other worlds, they may have different beliefs. What they agree on is that the predicate in the uttered sentence is true of the object referred to by the singular term in the utterance (or the ordered set of objects, if the predicate is many-placed); but beliefs about the meaning of the predicate may differ.

Agreement is not a guarantee for the truth of the sentences agreed upon. However, it is a basis for empirical knowledge in the sense of a starting point in an ongoing discourse. Rejection of a previously agreed sentence is possible, if coherence arguments, emanating from our background knowledge, against it are strong enough. However, this in turn depends on agreement about the truth of other observation sentences.

We ask for justification when we doubt a certain statement made. In cases when two or more people at the same spot are able to observe something and agree on the observation, the demand for justification has come to an end. If several people standing in front of, say, an elephant, none would ask for any justification if someone uttered: Look, an elephant! Others would simply agree. If someone disagrees, he would not ask for reasons for the statement made, but simply reject it.

Such intersubjective agreements function as implicit determinations of the extensions of the predicates used in observation reports. This fact is most clearly recognised when we reflect on how infants learn language. For example, we learn a little child words for colours by pointing; we point to several hues of e.g., blue and say ‘ This is blue’ (if we speak English). Learning to use ’blue’ correctly requires repetition, situations where we point at blue things and say ‘blue’. After some time the child agrees with competent language users about which things to classify as blue and which not. In other words, we have learnt it the (approximate) extension of this predicate. As with all learning, it is an inductive process. No one will ask for reasons.

The extension of the predicate ‘blue’ is somewhat vague. How would a child classify a hue between blue and green, if it has only learnt the words ’blue’ and ’green’? It depends on its internal dispositions for similarity among colour hues. If the unclear case by the child is perceived as more similar to blue than to green, it will call it ’blue’, otherwise ’green’. Thus classifications of perceived objects is determined by spontaneous perceptions of similarities. This is a point made by Quine [3].

This is the way we begin to learn predicates in our mother tongue. Wittgenstein argued this point at least at two places in his oeuvre. The first is in §§143–202 of *Philosophical Investigations*, [4] where we find his famous discussion about the notion ‘to follow a rule’. He discussed a simple rule of arithmetic, addition, and considered the possibility of explicitly stating rules for its application in particular cases. When so doing we get another rule and the application of this in turn requires another rule. Very soon we find that we just do things without any justification. Wittgenstein arrives at the conclusion in §202: ‘In addition, hence also “obeying a rule” is a practice’. The point with this remark is, I believe, that the request for general justification cannot be met and the search for it is a misconception of the task of philosophy.[3]

The second place is remark 150 in [5]:

[3] There is an enormous debate about this famous passage in *Philosophical Investigations*. To me it is obvious that Wittgenstein’s point is that language usage is open-ended and based on habits. The demand for ultimate definitions of meanings of linguistic expressions is a modern version of the rationalists’ demand for fundamental justification of knowledge, a demand that Wittgenstein totally rejects. In addition, we empiricists agree.

> 150. How does someone judge which is his right and which his left hand? How do I know that my judgment will agree with someone else? How do I know that this colour is blue? If I do not trust myself here, why should I trust anyone else's judgment? Is there a why? Must I not begin to trust somewhere? That is to say: somewhere I must begin with not-doubting; and that is not, so to speak, hasty but excusable: it is part of judging.

To judge, to express one's beliefs, is to apply predicates. I interpret Wittgenstein as saying that those beliefs/statements which we hold true without justification, such as the observation report 'This is my right hand.', function as criteria for use of the predicates occurring in such statements, i.e., as partial implicit definitions of those predicates. Asking for justification of such sentences is to misunderstand their function. The same is true of some theoretical sentences, the fundamental laws; the predicates occurring in such laws are implicitly defined by us accepting those laws as true, as will be exemplified in a moment.

Every chain of justification ends in implicit definitions; at every moment we unreflectively hold some beliefs while doubting others. This holds true even in logic; if we for example try to justify modus ponens we find ourselves using modus ponens, as is nicely shown by Lewis Carroll in the famous dialogue 'What the tortoise said to Achilles' [6]. The discussion is about a certain inference in Euclidian geometry. Achilles asks the Tortoise to accept the conclusion Z upon the premises A and B:

A: Things that are equal to the same are equal to each other.
B: The two sides of this Triangle are things that are equal to the same.
Z: The two sides of this Triangle are equal to each other.

The tortoise accepts A and B but do not yet accept the conclusion Z. Achilles and the Tortoise agree that in order to accept Z one need to accept A, B and the hypothetical,

C: If A and B are true, then Z must be true.

So they agree to make this completely explicit by writing in a notebook:

A: Things that are equal to the same are equal to each other.
B: The two sides of this Triangle are things that are equal to the same.
C: If A and B are true, then Z must be true.
Z: The two sides of this Triangle are equal to each other.

Achilles now maintains that logic tells us that Z is true. However, Tortoise still expresses doubts about Z and Achilles then repeats the move. He asks the Tortoise to accept:

D: if A, B and C are true, then Z must be true.

Tortoise now accepts A, B, C and D, but he still expresses some doubts about Z. Achilles once more repeats his move and the dialogue continues infinitely.

The point Lewis Carroll wanted to make, was, I think, that we cannot really say that the general rule modus ponens *justifies* its instances. Rather, the inference rule modus ponens must be seen as a *description* of how we in fact use the if-then-construction. The naturalist has only to add that this is our way of thinking and talking. If someone would fail to use the if-then-construction correctly the only thing one can do is to give examples of its use; fundamental rules cannot be proved. Hence, explicitly accepting modus ponens as a valid inference is the same as accepting it as part of an implicit definition of the sentence operator 'if...... then.......'.[4] Similarly, many basic beliefs, when expressed as sentences held true, function as implicit definitions of predicates occurring in these sentences.

[4] This is explicit in natural deduction, where the logical constants, for example 'if....then...', each are defined by two rules, on for its introduction into discourse, one for its elimination.

In science we introduce many new predicates, i.e., scientific terms, in this way. One early example is the introduction of the predicate 'mass'. In *Principia* [7] Newton explicitly introduced the word 'mass' as short for 'quantity of matter'. This expression in turn was 'defined' in the very first sentence of *Principia*: 'The quantity of matter is the measure of the same, arising from its density and bulk conjointly.' However, this formulation is, I believe, a rhetorical move against Descartes, who held that quantity of matter is volume, for one is immediately prone to ask how Newton defined 'density'; obviously he cannot, on pain of circularity, define density as mass per volume unit.

The empirical basis for the introduction of the term 'mass' is the discovery of conservation of momentum made by John Wallis, Christopher Wren and Christiaan Huygens some 20 years before the publication of *Principia*. Newton extensively rehearses their findings in the first *Scholium* (after Corollarium VI) in *Principia* and it is clear that this is the empirical basis for the introduction of the predicate 'mass'.

Wallis, Wren and Huygens had, independently of each other, found that two colliding bodies change their velocities in constant proportions, i.e., $\Delta v_1/\Delta v_2 = constant$, which can be written as $k_1\Delta v_1 = -k_2\Delta v_2$. (Their velocity changes have opposite directions.) One only needs to chose a body as the mass unit in order to attribute a definite mass to each body. Consequently, Newton introduced the quantity of mass as a constant attributable to each body. So our formulation and acceptance of the law of momentum conservation applied to two colliding bodies, i.e., $d/dt(m_1v_1 + m_2v_2) = 0$ is at the same time a generalisation of observations and an implicit definition of mass. One may say that mass is that quantitative attribute m being such that when two bodies collide, the equation $m_1\Delta v_1 = -m_2\Delta v_2$ is true.

I see a resemblance between Carroll's and Wittgenstein's stance on ultimate justification. And, of course, the idea traces back to Hume's position in *Treatise* when he discussed the sceptic's doubts about the veracity of our immediate experiences of external objects. Hume concluded that a convincing argument cannot be given, but it does not lead to doubts about the existence of external objects:

> Thus the sceptic still continues to reason and believe, even tho' he asserts that he cannot defend his reason by reason; and by the same rule he must assent to the principle concerning the existence of body, tho' he cannot pretend by any arguments of philosophy to maintain its veracity. ....We may well ask 'What causes induce us to believe in the existence of body?' but 'tis in vain to ask Whether there be body or not? That is a point, which we must take for granted in all our reasonings.' ([8], p. 238)

Thus Hume did not aspire to justify that our experiences are caused by external objects. Instead he stated that it is an empirical fact about us that we do believe that our perceptions are perceptions of external physical objects and we do believe that these objects may cause each other's motions. It belongs to our nature to assume that external objects exist and cause our impressions. One may say that, in Hume's view, someone who claims to be sceptical concerning the existence of external objects and other mundane things is not serious; he professes scepticism, but that is just empty talk. Hume's stance is the first exposition of epistemological naturalism.[5]

The most explicit proponent of naturalism is Quine [1] (p. 82). The common trait in Hume's and Quine's position is the stance that justification of beliefs from a vantage point outside the realm of empirical knowledge is impossible. The difference between Hume and Quine is that Quine thinks it possible to give a scientific explanation of the interaction between our mind and the external world, whereas Hume is satisfied without such an explanation, he just notes that certain ways of thinking belong to our nature. For my own part I would say that naturalism is the natural development of empiricism.

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[5] There are other passages in Hume's writings that not so easily fit into a naturalist stance. However, I, and other naturalists, do not claim to give a coherent interpretation of all Hume's writings; we only point out that he is the first suggesting a naturalist position.

3. Epistemology without Foundation

Epistemological foundationalists argue that there must be endpoints in chains of justification, statements that we accept as certain without them being justified by something else. In older times some such statements were called 'self-evident', but this label has come into disrepute; there is, for example in the history of mathematics examples where we now dismiss as false statements once held to be self-evident. (One example is Euclid's axiom that the whole is greater than any of its parts.)

It is obvious that there must be endpoints of justification, but foundationalists' mistake is to conceive these endpoints as certain *knowledge*, i.e., a true *justified* beliefs. It seems to me wrong to say that a sentence we accept as true without asking for further reasons is justified, and still worse, to say that it is self-justifying. (This is perhaps a reason to doubt the correctness of the classical definition of propositional knowledge, but I leave this topic for another occasion.)

Hume did not argue that our of bodies were evident or justified; rather, he pointed out that we accept the existence of external objects without justification. Using modern semantics, we may describe his position as: when we accept an observation sentence as true, it follows that the referent of a singular term in that sentence refers to an existing object and this object satisfies the predicate in the statement made.

There is a class of sentences we legitimately accept as true without asking for justification, viz., explicit, stipulative definitions. An observation sentence is of course not an explicit definition, but it may reasonably be viewed as an *implicit* definition, more precisely, a partial and implicit definition of the predicate occurring in that sentence. In addition, explicit and implicit definitions alike are held true without justification.

In our vernacular it should be rather obvious that no predicates have predetermined and strict criteria of application; language use is an ongoing negotiation. When we accept a sentence, which lacks any kind of justification, as true, we in fact treat it as a partial implicit definition of the predicate in that sentence.[6] This is the core point of remark 150 in *On Certainty*.

This is true also in scientific language. However, we should not assume that these endpoints of justification forever will be conceived as such. It is possible to change what we treat as definitions and what we treat as empirical statements. This was, I think, one of the points Kuhn wanted to make in his [10].

By viewing certain statements as implicit definitions of terms used in these statements we also shift focus from the individual to the communal perspective. I think it has been a big mistake to focus the epistemological discussion about reasons for *beliefs*, i.e., whether an *individual* has, or may have, reason for his/her beliefs. Both in science and in ordinary life we interact by talking to each other. What we may discuss is whether intersubjectively available things, viz., *utterances*, are true or not; how people interpret utterances, what they believe, is not public. However, epistemology is fundamentally a social endeavour. The question is which *sentences* we may agree upon and take as basis for further discussions; talking about beliefs is a side issue. Davidson expressed a somewhat similar criticism of much of epistemology in his *Epistemology Externalized*.

When we decide to accept a certain statement, or an entire theory, as true, we do that after considering what other people say about the matter. The ultimate evidence for any theory consists of its empirical consequences found true after comparisons with observation reports. Such observation reports are neither self-evident, nor justified by other sentences. However, they are agreed upon by several observers.

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6 The same is true of axioms in mathematics. A well rehearsed example is Euclid's axioms, which nowadays are understood as implicitly defining 'point', 'line', 'circle' etc. Euclid had 'defined' a point as an object having no parts, but this 'definition' is irrelevant in Euclid's geometry viewed as pure mathematics. Points were in fact implicitly defined by those axioms talking about points. This view was first clearly defended by Hilbert, see e.g., [9] (pp. 64–66).

Some might claim that naturalism leads to a vicious circle in epistemology: we gain knowledge about our own knowledge process through precisely that very knowledge process we are describing. I agree that it is a circle, but it is not a vicious one. It is more like the hermeneutic circle: by an ever-increasing inquiry we constantly widen the circle in order to make it as vulnerable as possible to empirical constraints.

4. Induction in the Naturalistic Perspective

In the naturalistic view the problem of induction is thus *not* that of justifying induction in general. We do inductive reasoning all the time, it is a natural habit. However, it is obvious that we do not consider all instances of inductive thinking equally good; we have strong intuitions that some conclusions are much more reliable than others. Hence, we should reformulate the induction problem as the task of describing more thoroughly our inductive practices and to give an account of the methodological role of induction in our scientific work. We should try to explain why we think that certain inductions are more trustworthy than others.

This is roughly Goodman's way of viewing the matter in his [11]. More precisely, he asked what kind of predicates are used in (normal) inductive reasoning. To illustrate the problem he construed the artificial predicate 'grue', defined as true of things examined before some time in the future, AD 3000 say, and found to be green, or examined after AD 3000 and found blue. All emeralds so far examined are thus both green and grue. Without further constraints simple induction tells us that we have equal reason to assume that the first emerald to be examined after the year 3000 will be green as well as grue, i.e., blue. One prediction, at least, will ultimately fail and we all believe that emeralds will continue to be green. But why? This is the induction problem in the new key.

Goodman's formulation of the problem is that some predicates are projectible and some other not. Obviously, we need to know the conditions for a predicate being projectible and Goodman suggested that the notion of entrenchment could be used in order to distinguish between projectible and non-projectible predicates; in [12] (ch. 4), he suggested that a predicate is entrenched when we have used it in successful predictions in the past. On this account I completely agree, it is a naturalistic stance.

Goodman analysis is a step forward, but stating the problem in terms of the distinction between projectible and non-projectible predicates, taken one at a time, is not satisfying. Goodman overlooked a crucial component in describing the situation, viz. the identification of the referents of the singular terms used in our observation statements.[7] When we for example ask which predicate to use in generalisations about emeralds, green or grue, we should also consider the rules we follow in the identification of emeralds. The question is thus not which single predicate, green or grue, to use in a particular case of inductive reasoning, but the correct *pairing* of predicates. In the sentence 'This emerald is green' we have two predicates, 'emerald' and 'green'. Obviously, we use a predicate, 'emerald', in the identification of the referent of the noun phrase in the sentence.

In general, any inductive conclusion has the form 'For all x, if Ax, then Bx', hence the real question concerns the relation between the predicates 'A' and 'B'. The induction problem can now be reformulated as: for which pair of predicates A and B is it reasonable to expect that if an object satisfies A, it also satisfies B?

In the case of grue or green emeralds it is rather simple. We know that emeralds consist of the mineral beryl contaminated with chromium. This metal makes the mineral green, according to physical laws. The necessary and sufficient condition for something to be an emerald is that it is a gem made up of beryl containing chromium. The same condition entails, via physical laws, that it is

[7] In the appendix 'Emeroses by Other Names' to his paper 'Mental Events', Davidson brought up this point, see [13] (p. 225).

green, independent of time.[8] Hence if something satisfies the predicate 'emerald', it satisfies also the predicate 'green'.

I rely here on the predicate 'physical law' and on the fact that laws are supported by empirical findings, by being generalisations of observations. (I'll discuss the distinction between laws and accidental generalisations in the next section.) Hence the argument depends on previous inductions. This is no vicious circle, as already pointed out.

Suppose we have observed a regularity in nature: So far, all observed objects are such that if they satisfy a predicate A, they also satisfy another predicate B. Let us assume that both predicates are expressions taken from our vernacular without using scientific theory. We thus have two options: either to assume that the regularity so far observed is a mere coincidence, i.e., an accidental generalisation, or else to assume that in fact no counter instances ever will be found. Taking the first option is to guess that sooner or later will we hit upon a counterexample. The second option is to guess that the generality 'for all x, if Ax, then Bx' is true. If this is correct, we have found a strict regularity, which we are inclined to call a natural law.

Suppose we have found a strict regularity, thus calling it 'a natural law', by inductive reasoning. Isn't the existence of such regularities a bit astonishing: Why is it the case that an indefinite number of objects satisfy two logically unrelated predicates? Is not the most reasonable assumption that the probability for such a state of affairs is zero?

History of science suggests two ways of explaining such regularities. The first possibility is to derive the regularity, or some version close to it, from a set of more fundamental and independently acceptable principles. A telling example is the general law of gases. This law began life as Boyle's observation that the product of pressure and volume of a portion of gas is constant. Later, Jacques Charles in 1787 and Joseph Lois Gay-Lussac in 1808, found that this constant depends on temperature and still later the complete general law of gases was formulated when the concept of mole was available. For some time this law appeared to be merely an empirical regularity, a brute fact. However we now know that it can be derived from the principle of energy conservation, given the identification of absolute temperature as mean translational kinetic energy among the particles making up the gas. So it is not just an empirical fact that the two open sentences 'x is a gas' and 'the pressure, volume and temperature of x satisfies the equation $pV = nRT$' are both satisfied by the same objects. It follows from a basic principle, given some auxiliary assumptions.

This brings us to the second way explaining the remarkable fact that an indefinite number of objects all satisfy two unconnected predicates. Many scientific predicates start their lives as part of our vernacular, 'energy' and 'force' are two obvious examples. As science advances vague notions are sharpened and changed into scientific predicates with explicitly defined criteria of application. And, of course, many new predicates, such as 'mass', are introduced by implicit or explicit definitions. The crucial point is that in this process of conceptual development a well-established regularity is normally not given up. Suppose we have such a well-established generality, 'for all x, if Ax, then Bx', and hit upon a putative counter example, an object which satisfies A but not B. Logically we have two options; either to drop the regularity and accept it being falsified, or to change the criteria of application of the predicate A so that the putative counter example can be excluded.

A simple example of the latter is the history of the concept of fish. Aristotle had observed that dolphins have lungs, that mothers gave birth to living offspring and fed them with milk, hence he clearly recognised that they were not fishes. (He classified dolphins, porpoises and whales in the genus *cetacea*.) However, his insights were forgotten and for a long time these mammals were classified as fishes. However, fishes have gills, while cetaceans have no gills, so how to resolve this conflict? It was John Ray (1627–1705) who in his [14] finally recognised that dolphins, porpoises and whales are not

8 A physical body looks green when it reflects electromagnetic radiation of wavelengths around 400–500 nm, and absorbs radiation of longer wavelengths in the visible part of the electromagnetic spectrum. This is determined by the available excitation levels in the molecules at the surface of the body, which in turn is determined by quantum mechanical laws.

fishes. Thus our predecessors did not give up the generality 'all fishes have gills', instead dolphins were reclassified as not being fishes. The intuitive criteria for being a fish, 'animal swimming in the seas with mouth, fins and eyes', or something of the kind, were sharpened by additional clauses.

Another example is provided by the atomic theory and in particular the law of definite proportions. This law says that all elements have atomic weights which are integer multiples of the atomic unit, equivalent to the weight of a hydrogen atom. However, soon after the formulation (beginning of 19th century) of this law it was found that the atomic weight of chlorine is 35.5, indicating that chlorine in fact do not consist of a certain number of atomic units. However, the law of definite proportions was not given up; instead one guessed, correctly, that chlorine samples extracted from naturally existing compounds is a mixture of two isotopes with different masses, Cl-35 and Cl-37, hence naturally existing chlorine is not really one single substance but two and the average weight of chlorine in naturally occurring mixtures is the weighted mean of Cl-35 and Cl-37. Thus, identification of substances were improved.

These are two examples of a possible and sometimes reasonable strategy, viz., to keep the regularity and redefine the criteria of application of the predicate in the antecedent or for that in the consequent. New counter examples might trigger new adjustments and the logical endpoint of this process is reached when the set of necessary conditions for satisfaction of the predicate in the consequent is a subset of those for the predicate in the antecedent; in such a case no further counter example is possible; we have arrived at a *epistemically fundamental* law.

One example of such a law is momentum conservation, as shown in Section 2. Another example is provided by Maxwell's equations+ Lorentz' law, which are the fundamental laws of electromagnetism. These jointly define the quantities *charge, current, electric field* and *magnetic field*. (I have argued this in detail in 'An empiricist view on laws, quantities and physical necessity' submitted to *Theoria*.) Since the predicates occurring in such laws are the result of successive adjustments, these laws function as (partial) implicit definitions of the predicates in the law sentences. The further question why we say of laws that they are necessary is discussed in the next section.

In an axiomatic exposition of a theory we label 'fundamental' those laws that are the starting points from which we derive other laws. However, it is well known that we always have a choice as to what laws in a certain body of theory to take as starting points in derivations. In Newton's exposition of classical mechanics it is his three laws+ the gravitation law that are taken as fundamental, whereas Hamilton's equations are the fundamental laws in Hamilton's version of classical mechanics. (In addition, there are more alternatives.) So it clear that a law is in this sense fundamental only relative to particular *theory formulation*.

I call a law 'epistemically fundamental' when it further satisfies the condition that it belongs to the set of laws being most closely connected to empirical observations within a particular theory. In classical mechanics it is neither Newton's laws, nor Hamilton's equation that satisfy this requirement, but the law of momentum conservation, as described in Section 2. (The law of gravitation also satisfies this condition.) From momentum conservation applied to a collision of two bodies:

$$d/dt(m_1 v_1 + m_2 v_2) = 0 \tag{1}$$

we immediately get the equation

$$m_1 a_1 = -m_2 v_2 \tag{2}$$

where 'a' is short for acceleration. By introducing the quantity *force* ('f') as short for *mass · acceleration*, i.e., introducing Newton's second law, we get

$$f_1 = -f_2 \tag{3}$$

which is Newton's third law. Thus, Newton's third law is derived from momentum conservation and, obviously, Newton's second law is an *explicit* definition of force. So it is clear that momentum conservation is, from an epistemological perspective, a fundamental law of classical mechanics, whereas Newton's three laws are not. (Neither are Hamilton's equations; in order to apply these equations to real physical events one must equate momentum with mass times velocity, thus relying on mass, which is defined by the law of momentum conservation.) Hence there is reason to distinguish between the concepts *epistemologically fundamental* and *logically fundamental*. A law is fundamental in the logical sense only relative to a particular axiomatisation.

Inductive reasoning is intimately connected with theory development, but both inductivists and falsificationists have told a distorted story. The inductive process also involves concept development. Inductive reasoning is our way of finding out the structure of the world. The success of empirical science and in particular the usefulness of induction is explained fundamentally in the same way as other evolutionary processes; it is the result of adaptation and competition, in this case adaptation of concepts to the way the world is and competition among theories.

Summarising the argument, the answer to the question above is that the two predicates in a universally generalised true conditional are in fact conceptually dependent on each other, or can be so made, either by deriving the regularity from fundamental laws or else the criteria of application for the predicate in the consequent are a subset of those for predicate in the antecedent. This argument applies not to ordinary language, only to a well structured scientific theory with well defined predicates. So called 'laws' expressed in ordinary language are most often not strict regularities.

5. Laws and Accidental Generalisations

Suppose we have observed a regularity, 'All A:s are B' and have not hit upon any counterinstance. Is this a law or an accidental generalisation?

A well-rehearsed contrast is that between 'All spheres of gold have a diameter of less than 1 km' and 'All spheres of U-235 have a diameter of less than 1 km'. The first generality we label 'accidental generalisation' whereas the second is is believed to be a law. What is the reason for making this distinction between two true general statements with roughly equal amount of support from empirical evidence?

The reason is, I think, that we can infer the generality about U-235 from general principles (which also are called 'laws') of nuclear physics, while no such inference to the accidental generalisation is available, and we use the principle that if a true general sentence, not being logically true, can be inferred from a set of laws, it is itself a law. So accidental generalisations are true general sentences which cannot be integrated into a scientific theory built upon a set of well defined theoretical predicates.

Outside physics, chemistry and related sub-disciplines there may be many regularities called 'laws' without being derivable from fundamental laws. I my view we should be careful in calling these regularities 'laws', waiting until they can be integrated into a theory. The extension of the predicate 'natural law' in our vernacular is not very clear.

We saw above that Newton's second law in fact is an explicit definition of 'force'. It is not uncommon to label explicit definitions 'laws', Ohm's law is one further example. (For a long time it was the definition of resistance in terms of current and voltage, but nowadays it defines voltage in terms or resistance and current.)

From an epistemological point of view, implicit and explicit definitions differ. As already argued, those fundamental laws that are implicit definitions of theoretical predicates have empirical content, since such laws are inductive generalisations from limited sets of observations, and such a generalisation might prove wrong one day. An explicit definition, on the other hand, introduces a new general term as short for a longer expression, hence any such term may be replaced by its definiens without change of any testable consequences; thus it has no empirical content.

Why, then, attribute necessity to laws? For those laws that are derivable from fundamental ones, the necessity is 'inherited': if we say about P that it is necessarily true and can derive Q from P, (and perhaps using other sentences being necessarily true) we likewise say that Q is necessarily true. So the question comes down to the necessity of fundamental laws.

Epistemically fundamental laws are implicit definitions, which function as rules for introduction of new predicates into discourse. Hence, those laws are *necessary conditions* for the use of the defined predicates in an ensuing inquiry. This is, I think, the reason we say that fundamental laws are *necessarily true*. For example, the introduction of the predicate *mass* by means of accepting momentum conservation as true, is a necessary condition for the construction of the dynamical part of classical mechanics, and in fact for physics in its entirety. Thus, I interpret 'necessary' not as a modal operator, as is common, but as short for 'necessarily true', i.e., as a semantic predicate, just as 'true'. Thus I only need to enter into what Quine labelled 'the first grade of modal involvement' in his [15], when explaining the necessity of laws; no modal logic is needed.

An anonymous referee to an earlier version of this paper got the impression that my view on laws was close to Michael Friedman's account of fundamental laws as being *relativised a priori* conditions for empirical knowledge. This is not so. Friedman argued that some core principles, both mathematical and physical ones, are *preconditions* for empirical research. Thus he wrote:

> The idea is that advanced theories in mathematical physics, such as Newtonian mechanics and Einsteinian relativity theory, should be viewed as consisting of two asymmetrically functioning parts: a properly empirical part containing laws such as universal gravitation, Maxwell's equations of electromagnetism, or Einstein's equations for the gravitational field; and a constitutively a priori part containing both the relevant mathematical principles used in formulating the theory (Euclidean geometry, the geometry of Minkowski space-time, the Riemannian theory of manifolds) and certain particularly fundamental physical principles (the Newtonian laws of motion, the light principle, the equivalence principle). ([16], p. 71)

That mathematics is known a priori is uncontroversial. Furthermore, no one will oppose saying that *explicit* definitions of new predicates as shorthand for longer expressions are known a priori. However, Friedman's notion *relativised a priori* encompasses more things, viz., 'particularly fundamental principles' such as Newton's laws and the light principle. Now, Newton's second law is an explicit definition of force, thus it may be said to be known a priori[9], but the third law ('To every force there is an equal but oppositely directed force') is an immediate consequence of the law of momentum conservation and Newton's second law, as we saw above, and since momentum conservation surely is not known a priori, we may conclude that neither is the third law. In addition, the light principle, i.e., Einstein's postulate that the velocity of light is the same for all observers, is certainly not known a priori. It is in fact derivable from Maxwell's equations, which Friedman says belong to the 'properly empirical part' of physics; hence 'the light principle' belongs to the empirical part.

One might accept Friedman's general idea of dividing physical theories into two parts, an empirical part and a constitutive part, while holding that some laws are incorrectly classified. However, I do not really see the point with the notion of *relativised* a priori. Friedman holds, for example, that Newton's second law is a precondition for mechanics, and that we know that law a priori, so long as we accept classical mechanics. (In addition, there is a relativistic version of Newton's second law in relativity theory.) However, as already pointed out, there are empirically equivalent versions of classical mechanics (e.g., Hamilton's and Lagrange's) that do not need the predicate 'force'. So Newton's second law is not a necessary condition (nor a pre-condition) for doing classical mechanics, only for a particular formulation of this theory. In addition, since 'force = mass · acceleration' is a stipulative definition of 'force' one can systematically replace any occurrence of 'force' in the theory by its definiens; in fact, that is what we do when calculating observable consequences from initial conditions and theory. So it is not, in a logical sense, any precondition for doing mechanics, as Mach observed in [17].

From an empiricist point of view the trouble with Friedman's distinction between a proper empirical part of a theory and some relativised a priori principles is the same as the trouble with Kant's

9 The vernacular use of the term 'force' is quite another thing. Newton's second law may be said to introduce another sense of this common word.

distinction between an empirical level and a transcendental level of discourse. The transcendental analysis was by Kant conceived as a non-empirical inquiry into the functioning of our mind, which, Kant hoped, would explain how synthetic a priori knowledge were possible. However, we empiricists resolutely reject the idea that we can have a priori knowledge about nature, relativised or not.

6. Induction as a Heuristic Device

The picture emerging from all this is that induction should not be seen as a particular form of reasoning for which one needs independent and non-empirical justification, but as a heuristic device in theory construction. We observe in several cases a regularity using two more or less well-defined predicates. Sometimes we believe that the observed regularity reflects a structural feature in nature. This naturally induces the scientist to try to invent a theory which reflects this structural feature and the goal is reached when the theory entails the empirical regularity or some formulation reasonably close to it. When formulating this regularity we need new predicates, or refinements of old ones, and the sentences by which we express such regularities at the same time function as implicit, and sometimes partial, definitions of these predicates. Thus we arrive at epistemically fundamental laws.

What I have just said resembles to some extent what Aristotle claims in *Posterior Analytics*. According to Hankinson [18] (p. 168), Aristotle's word '$\epsilon\pi\alpha\gamma o\gamma\epsilon$' (epagoge) which usually is translated as 'induction', should not be interpreted as an inference principle, but rather as a causal term:

> The method in which we arrive at first principles is called by Aristotle 'epagoge'. Starting from individual perceptions of things the perceiver gradually, by way of memory, builds up an experience (empeiria), which is 'the universal in the soul, the one corresponding to the many' (Posterior Analytics 2.19.100a6-8); and it is this which provides the arche, or first principle:
>
> 'These dispositions are not determinate and innate, or do they arise from other more knowledgeable dispositions, but rather from perception, just as when a retreat take place in battle, if one person makes a stand, another will too, and so on until the arche has been attained.' (2.19.100a9-13)
>
> This process gives us universals (such as 'man') without which we cannot utter assertoric sentences, which in turn lead to higher-order universals, such as 'animal' from particular species. (2.19.100a15-b3). It is described in causal, not inferential terms (which is why 'induction' is misleading): the world simply impresses us in such a way that we come to internalize ever wider and more inclusive concepts. We are by nature equipped to take on form in this way; if we are diligent and unimpaired, our natural faculties will see to it that we do so. Thus in a relatively literal sense we just come to see that Callias is a man and, ultimately by the same process, what it is to be a man.

Hankinson here in fact says that Aristotle was a naturalist in the sense here given, and it seems to me that he has good evidence for this interpretation. Furthermore, Hankinson's remark that 'we just come to see that Callias is a man and, ultimately by the same process, what it is to be a man', is another way of saying that endorsing the truth of the sentence 'Callias is a man' is to hold that that sentence is a partial implicit definition of the predicate 'man'. It is thus clear that no justification for this sentence is needed, or indeed possible.[10]

Who is to say, in advance, that a particular inductive conclusion is justified or unjustified? In retrospect we can say of a particular inductive step and the resulting theory that it was successful or unsuccessful and hence in a sense justified or unjustified as the case may be. However, we cannot

10 Aristotle furthermore held that universals, such as 'man' exist as instantiated in individual objects. This does not follow from his account of induction, and I do not follow Aristotle on this point. Like other empiricists I see no need for assuming the existence of universals. Thus I reject the realist conception that laws somehow 'mirror' nature.

decide that in advance. In this perspective, to ask for a general rule for accepting/rejecting an inductive generalisation would amount to assume that we could know, a priori, the structure of reality and the future development of a scientific theory. A traditional metaphysician might think that that is possible, but a naturalist does not. In addition, it is the metaphysician who has the burden of proof.

A critic might say that all this presupposes what should be proved, viz. that nature is regular and not completely chaotic. The account makes only sense if there really are regularities to be found. I agree that a general faith in the regularities is presupposed, but that is also part of the naturalistic view-point. If nature were not sufficiently stable over longer periods of time, no biological evolution could have taken place and we would not be here to ask questions. The problem is not to justify the general assumption of regularity, since the demand for such a justification, again, is precisely what the naturalist rejects. Instead, the task is to discover which *particular* regularities there are in nature; that there are such regularities can be inferred from the fact that we human beings are here asking these very questions. Answering these questions is the task of natural science.

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The Digital and the Real Universe. Foundations of Natural Philosophy and Computational Physics

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Abstract: In the age of digitization, the world seems to be reducible to a digital computer. However, mathematically, modern quantum field theories do not only depend on discrete, but also continuous concepts. Ancient debates in natural philosophy on atomism versus the continuum are deeply involved in modern research on digital and computational physics. This example underlines that modern physics, in the tradition of Newton's *Principia Mathematica Philosophiae Naturalis*, is a further development of natural philosophy with the rigorous methods of mathematics, measuring, and computing. We consider fundamental concepts of natural philosophy with mathematical and computational methods and ask for their ontological and epistemic status. The following article refers to the author's book, "The Digital and the Real World. Computational Foundations of Mathematics, Science, Technology, and Philosophy."

Keywords: digitization; computability; complexity; reverse mathematics; quantum computing; real computing; theory of everything

1. Introduction

The conflict of a discrete and continuous model of the universe is deeply rooted in the beginning of natural philosophy. Ancient philosophers of atomism (Democritus et al.) believed in a world of interacting discrete particles as indivisible building blocks (atoms). These natural philosophers were criticized by Aristotle as an advocate of the continuum: In mathematics, a continuous line cannot be reduced to discrete points, like a chain of coupled pearls. Aristotle described change in nature by continuous dynamics. In the beginning of modern science, physicists assumed a mechanistic world of interacting atoms. However, mathematically, atoms were considered mass points with motions determined by continuous differential equations. Leibniz, as the inventor of differential calculus, tried to bridge the discrete and continuous world by his philosophical concept of monads, which were mathematically represented by infinitesimally small, but nevertheless non-zero quantities called differentials [1] (Chapter 4).

Later on, scientific computing in physics and chemistry was mainly based on continuous functions. In practical cases, the solutions of their (real or complex) equations could often only be approximated by algorithms of numerical analysis in finitely many discrete steps (e.g., Newton's method). Nevertheless, these procedures of numerical analysis depend on the continuous concept of real numbers. The discrete theory of computability is well-founded by the discrete concept of Turing machines (Church's thesis).

With respect to modern quantum physics, physical reality seems to be reducible to discrete entities, like elementary particles. Quantum processes are computed by quantum algorithms—the universe as a quantum computer. Nevertheless, quantum field theories also use continuous functionals and spaces, real and complex numbers, to compute and predict events with great precision. Are analog and continuous concepts only useful inventions of the human mind, to solve problems in a discrete world with approximations? Natural constants are defined by fundamental proportions of physical quantities, which are highly confirmed by experiments. The fine-structure constant is an example of a dimensionless real number in physics. In mathematics, the real number, π, is exactly defined by the relation of the circumference and diameter of a circle. However, as decimal expansion, there are only approximately finite values, which can be computed or measured by physical instruments in space and time.

If successful explanations and predictions of physical theories actually depend on real numbers as axiomatically defined infinite entities, then they could be interpreted as hints on a mathematical reality "behind" or "beyond" (better: Independent of) the observable and measurable finite world of physics. Is physical reality only a part in the universe of mathematical structures? It is the old Platonic belief in symmetries and structures as the mathematical ground of the world [2], (Chapter 4).

In a modern sense of natural science, Ockham's razor demands an economic use of theoretical assumptions for explanations of empirical events. Scientists should prefer explanations of empirical events that only need as few theoretical entities as possible. Ockham's razor concerns the assumption of theoretical entities, like the Platonic belief in the existence of ideal mathematical entities (e.g., infinite sets, cardinal numbers and spaces). For a constructivist of modern mathematics, these entities are only justified as far as they can be introduced by algorithms and constructive procedures. Historically, in the Middle Ages, nominalism also criticized Platonism in the sense of Ockham's razor. From Ockham's point of view, the Platonic assumption of abstract mathematical structures is a waste of ontological entities. However, the existence of abstract mathematical universes beyond empirical physics cannot be excluded in principle. Modern string theories and supersymmetries are possible candidates who, until now, have nearly no empirical justification. Nevertheless, they are used to explain the quantum universe.

The foundational debate on the digital and analog, discrete and continuous has deep consequences for physics. In classical physics, the real numbers are assumed to correspond to continuous states of physical reality. For example, electromagnetic or gravitational fields are mathematically modeled by continuous manifolds. Fluid dynamics illustrate this paradigm with continuous differential equations.

However, in modern quantum physics, a "coarse grained" reality seems to be more appropriate. Quantum systems are characterized by discrete quantum states, which can be defined as quantum bits. Instead of classical information systems, following the digital concept of a Turing machine, quantum information systems with quantum algorithms and quantum bits open new avenues to digital physics. Information and information systems are no longer only fundamental categories of information theory, computer science, and logic, but they are also grounded in physics [3] (Chapter 5).

The question arises whether it is possible to reduce the real world to a quantum computer as an extended concept of a universal quantum Turing machine. "It from bit" as proclaimed the physicist, John A. Wheeler [4]. On the other side, fundamental symmetries of physics (e.g., Lorentz symmetry and electroweak symmetry) are continuous [5] (Chapter 3). Einstein's space-time is also continuous. Are they only abstractions (in the sense of Ockham) and approximations to a discrete reality?

Some authors proclaim a discrete cosmic beginning with an initial quantum system (e.g., quantum vacuum). The quantum vacuum is not completely empty, like the classical vacuum in classical mechanics. Because of Heisenberg's uncertainty principle, there are virtual particles emerging and annihilating themselves. In this sense, it is discrete. In some models of the initial quantum universe with Planck length (quantum foam), even time is "granulated" (discrete). According to the standard theory of quantum cosmology, the initial quantum state has evolved in an expanding macroscopic universe with increasing complexity. In the macroscopic universe, the motions of celestical bodies can be approximately modeled by continuous curves in a Euclidean space of Newtonian physics. Actually, physical reality is discrete in the sense of elementary particle physics, and Newtonian physics with continuous mathematics only an (ingenious) human invention of approximation.

However, physical laws of quantum theory (e.g., Hilbert space) are also infused with real and complex numbers. Are these mathematical entities only convenient inventions of the human mind to manage our physical experience of observations and measurements? A mathematical constructivist and follower of Ockham's razor would agree to this epistemic position. However, from an extreme Platonic point of view, we could also assume a much deeper layer than the discrete quantum world—the universe of mathematical structures themselves as primary reality with infinity and continuity.

2. Complexity of Quantum and Real Computing

In digital physics, the universe itself is assumed to be a gigantic information system with quantum bits as elementary states. David Deutsch et al. [6] discussed quantum versions of Turing-computability and Church's thesis. They are interesting for quantum computers, but still reduced to the digital paradigm. Obviously, modeling the "real" universe also needs real computing. Are continuous models only useful approximations of an actually discrete reality? In classical physics, solutions of continuous differential equations are approximated by numerical (discrete) procedures (e.g., Newton's method). In quantum physics, a discrete structure of reality is assumed. Nevertheless, we use continuous mathematical tools (e.g., Schrödinger's equation, functional analysis, etc.) in quantum physics. Therefore, from an epistemic point of view, continuous mathematical methods are only tools (inventions of the human mind) to explain and predict events in an actually discrete reality.

What do we know about the physical origin of information systems? As far as we can measure, the universe came into being 13.81 ± 0.04 billion years ago as a tiny initial quantum system, which expanded into cosmic dimensions according to the laws of quantum physics and general relativity. In a hot mixture of matter and radiation, the generation of nuclear particles was finished after 10^{-5} s. After the separation of matter and radiation in nearly 300,000 years, the universe became transparent. Gravitation began to form material structures of galaxies, Black Holes, and the first generations of stars. Chemical elements and molecular compounds were generated. Under appropriate planetary conditions, the evolution of life had developed. The evolution of quantum, molecular, and DNA-systems is nowadays a model of quantum, molecular, and DNA-computing.

In quantum computing, we consider the smallest units of matter and the limits of natural constants (e.g., Planck's constant velocity of light) as technical constraints of a quantum computer. A technical computer is a physical machine with an efficiency that depends on the technology of circuits. Its increasing miniaturization has provided new generations of computers with an increasing capacity of storage and decreasing computational time. However, increasing diminution leads to the scaling of atoms, elementary particles, and smallest packages of energy (quantum), which obey physical laws different from classical physics.

Classical computing machines are replaced by quantum computers, which work according to the laws of quantum mechanics. Classical computing machines are, of course, technically realized by, e.g., transistors following quantum mechanics. However, from a logical point of view, classical computing machines are Turing machines (e.g., von Neumann machines) with classical states. Even a classical parallel computer (supercomputer) is only a Turing machine which connects Turing machines (e.g., von Neumann machines) in a parallel way. However, a quantum computer follows the laws of quantum mechanics with non-classical (quantum) states (superposition and entangled states). Therefore, R. Feynman demanded that the quantum world could only be simulated by quantum computers and not by classical computing machines.

Quantum computers would lead to remarkable breakthroughs of information and communication technology. Problems (e.g., the factorization problem), which classically are exponentially complex with practical unsolvability, would become polynomially solvable. In technology, quantum computers would obviously enable an immense increase of problem solving capacity. In complexity theory of computer science, high computational time of certain problems could perhaps be reduced from NP (nondeterministic polynomial time) to P (polynomial time). However, the question arises whether quantum computers can also realize non-algorithmic processes beyond Turing-computability.

A quantum computer works according to the laws of quantum physics. In quantum mechanics, the time-depending dynamics of quantum states are modeled by a deterministic Schrödinger equation.

Therefore, the output of quantum states in a quantum computer is uniquely computable for given inputs of quantum states as long as their coherence is not disturbed. In that sense, quantum computer can be considered as a quantum Turing machine with respect to quantum states [7] (Chapter 15).

However, are there logical-mathematical breakthroughs that undecidable and unsolvable problems become decidable and computable by quantum computers? The undecidability and unsolvability of problems depends on the logical-mathematical definition of a Turing machine. Therefore, even a quantum computer cannot solve more problems than a Turing machine according to algorithmic theory of computability. Problem solving with quantum computers will be accelerated with an immense computing velocity. However, algorithmically unsolvable and undecidable problems remain unsolvable even for quantum computers [6].

Even analog and real computing do not change the fundamental logical-mathematical results of undecidability and unsolvability [7] (Chapters 10–11), [8] (Chapter 1). Real computing transfers the digital concepts of computability and decidability to the continuous world of real numbers. Blum, Cucker, Shub, and Smale [9] introduced decision machines and search procedures over real and complex numbers. A universal machine (generalizing Turing's universal machine in the digital world) can be defined over a mathematical ring and with that over real and complex numbers. On this basis, decidability and undecidability of several theoretical and practical mathematical problems (e.g., Mandelbrot set, Newton's method) can rigorously be proved. Like in the digital world, we can introduce a complexity theory of real computing. Polynomial time reductions as well as the class of NP-problems are studied over a general mathematical ring and with that on real and complex numbers. Real computability can be extended in a polynomial hierarchy for unrestricted machines over a mathematical field.

Real and analog computing seem to be close to human mathematical thinking, with real numbers and continuous concepts. Human thinking uses the human brain, which has evolved during evolution with different degrees of complexity. In computational neuroscience, brains are modelled by neural networks. The biological hierarchy of more or less complex brains can be referred to a mathematical hierarchy of more or less complex neural networks. Mathematically, they are equivalent to computing machines with different degrees of complexity from finite automata to Turing machines [7] (Chapter 12). Otherwise, the simulation of neural networks on digital computers would not be possible.

Concerning the cognitive capacities of automata, machines, and neural networks, computing machines can understand formal languages according to their degrees of computability from simple regular languages (finite automata) to Chomsky grammars of natural languages (Turing machines). Neural networks with synaptic weights of integers or rational numbers correspond to finite automata resp. Turing machines. Analog neural networks with real synaptic weights are real Turing machines. They correspond to real computing. Siegelmann et al. [10] proved that they can operate on non-recursive languages beyond Chomsky grammars. However, they also have the logical-mathematical limitations of real and analog computing.

An example is the halting problem for a Turing machine, which is not decidable even for a quantum and analog computer. Another problem is the word problem of group theory, which demands a test of whether two arbitrary words of a symbolic group can be transformed into one another by given transformation rules. These and other problems are not only of academic interest. They are often basic for practical applications (e.g., whether expressions of different languages can be transformed into one another or not).

In the theory of computability, it is proved that there is no general algorithm that can decide everything. This is a simple consequence of Turing's undecidability of the halting problem. Quantum and real computing will not change anything of these basic results. Even in a civilization with quantum computers, there will be no machine that can solve all problems algorithmically. Gödel's and Turing's logical-mathematical limitations will remain, although there will be a giant increase of computational capacities.

3. Is the Universe Digital?

The universe is mathematically modeled by equations of quantum and relativistic physics. They are philosophically interpreted as “natural laws” [11]. The emergence of physical particles is mathematically considered as the solution of gauge equations describing the fundamental symmetries of the universe [12]. If we, for example, try to solve the Schrödinger equation for five or less quarks, there are only two stable possibilities of coordination. They consist of either two up-quarks and one down-quark or two down-quarks and one up-quark. The former cluster is called “proton”, the last one “neutron”. In a next step, we can apply the Schrödinger equation to protons and neutrons as “atomic nuclei”. In this case, we get 257 stable possibilities with hydrogen, helium, et al. We can continue the application of the Schrödinger equation to molecules, crystal grids, and more complex objects. The names of “protons”, “neurons”, “atomic nuclei”, “hydrogen”, “molecules”, et al. are, of course, human inventions. The whole information of these objects is involved in the solutions of mathematical equations.

Mathematical equations can be classified in physics (e.g., general/special relativity, electromagnetism, classical mechanics, statistical mechanics, solid state physics, hydrodynamics, thermodynamics quantum field theory, nuclear physics, elementary particle physics, atomic physics), chemistry, biology, neurobiology, psychology, and sociology with the objects of protons, atoms, cells, organisms, populations, et al. as solutions.

Mathematical structures are systems of objects with (axiomatic) relations and equations. Examples are spaces, manifolds, algebras, rings, groups, fields, et al. Isomorphisms are mappings between structures, which conserve their relations. They satisfy the conditions of equivalence relations with reflexivity, symmetry, and transitivity. Therefore, mathematical structures can be classified in equivalence classes. Modern mathematics studies categories of structures with increasing abstraction in the tradition of Dedekind, Hilbert, and Bourbaki. Categories correspond to set-theoretical universes and transfinite cardinal numbers with increasing size. In recent foundational programs, mathematical structures and categories are represented and classified by types of formal systems [7] (Chapter 9). Hilbert already tried to extend his axiomatization and classification of mathematical structures to physics (Corry 2004). Physical structures of space-time, fields, particles, crystals, grids, et al. are only special structures belonging to mathematical equivalence classes and categories.

The question arises whether the physical universe is finite with only finitely many mathematical structures or at least computable with computable functions and functionals. What about the natural constants, which determine fundamental forces of the universe? Mathematically, they are often real numbers with infinitely many decimal places, but practically, only finitely many decimal places are determined by our best measuring instruments and computers.

From a mathematical point of view, physical events are points of a four-dimensional structure of space-time. For example, in special relativity, the four-dimensional structure of space-time is definied by Minkowskian geometry, which is sometimes called block universe. The concept of a block universe can be generalized for the geometrical structure of general relativity. A block universe is a mathematical structure that never changes, which was never created, and which will be never destroyed. In a block universe, space-time is a four dimensional mathematical space with the three usual spatial dimension of length, width, and height, and the fourth dimension of time [13].

Human intuition of space is restricted to three dimensions. In the three-dimensional space of length, width, and height, the orbit of the moon round the Earth can be illustrated by an (approximated) circle. In this geometrical representation, time-dependence can only be considered by the motion of the moon round the Earth. In order to illustrate the dimension of time, the four-dimensional space-time is reduced to the vertical time axis and two spatial coordinates. In this case, the circle is replaced by a spiral along the time axis. Actually, there is no change and motion of the moon, but only the unchangeable spiral in the space-time of a block universe.

In a three-dimensional illustration, space-time is distinguished in parallel layers of two-dimensional planes each of which represents the three-dimensional space at this moment with all simultaneous events. If an observer belongs to one of these layers, then this layer represents his present time. The layers above his present layer are his future, and below the layer, there is his past. Anyway, the distinction of future, present, and past is relative to an observer or, in the words of Einstein, a "subjective illusion". From a physical point of view, there is no time-depending change, but only the mathematical structure of space-time with given unchangeable patterns (e.g., spiral of the moving moon).

The mathematical structure of four-dimensional space-time differs in special and general physics [14]. In special relativity, space-time is not Euclidean like in classical physics, but Minkowskian, with respect to relativistic simultaneity. In general relativity, we have to consider a four-dimensional pseudo-Riemannian manifold of curved space-time. A curved (non-Euclidean) Riemannian manifold (e.g., the curved surface of a sphere) consists of infinitesimally small Euclidean planes. In an analogy to Euclidean geometry, Minkowskian geometry of special relativity is embedded as local space-time into the global general relativity of curved space-time.

If Einstein's relativistic space-time is combined with quantum physics, the deterministic world is given up. In quantum field physics, we must consider possible worlds with different pasts, presents, and futures which are weighted by probabilities. The path of a quantum system (e.g., elementary particle) from one point to another cannot be determined by an orbit, like a ball in classical mechanics. We have to consider all possible paths with their weights, which are summed up in Feynman's path integral. Therefore, the initial tiny quantum system of the early universe in the size of Planck's constant could not develop in a classically well determined way. There are several possible paths of development according to the quantum laws. If we assume that all these possibilities are real in parallel, then we get the concept of a multiverse with quantum parallel universes [15]. We cannot get observational data from these parallel worlds, because they are separated from our world by different ways of inflation, which blow up the universes in different ways. Nevertheless, they can be mathematically modeled by the laws of quantum physics.

In all these cases, there are given mathematical structures [16]. The development of a quantum system is mathematically given by a pattern in quantum space-time (like the moving moon as a spiral in the Euclidean space-time). An organism, like our body, consists of a bundle of world lines representing the development of elementary particles, which are organized as atoms, molecules, cells, organs, et al. They converge during our growth as babies, develop during the period as adults in different ways (e.g., changing by diseases), but diverge again after our death [17] (p. 409). Thus, the human body is a complex pattern of converging and diverging word lines in space-time. From a mathematical point of view, the pattern of our body is part of a given and unchangeable mathematical structure of space-time. It is a solution of a mathematical equation characterizing this mathematical structure. Only as living bodies do we have the "illusion" of change and development with birth and death. Thus, in terms of ancient natural philosophy, the unchangeable mathematical structure of the universe brings Parmenides' world to the point.

Are these space-time structures continuous or discrete? In classical mechanics, fluids and materials are considered as dynamical systems, which are modeled by continuous differential equations. In electrodynamics, each point in magnetic and electric fields is characterized by real numbers of orientation, voltage, et al. Maxwell's equations describe their continuous time-depending development. In quantum physics, classical electrodynamics is replaced by quantum field theory as the foundation of modern particle physics. The quantum wave function provides the probability of a particle in a certain area of space-time. Mathematically, the wave function is an abstract point in the Hilbert space, which is an (infinite) mathematical structure. In analogy to fields of photons (light) in quantum electrodynamics, we can also consider quantum field theories of all the other known elementary particles. There are electronic fields, quark fields, et al.

However, we still miss a complete "Theory of everything" unifying all fundamental forces and their interacting particles in relativistic and quantum physics. The main obstacle stone is the continuous and deterministic structure of relativistic physics contrary to the discrete and probabilistic character of quantum physics. The physical structure of a complete "Theory of everything" would be isomorphic to some mathematical structure, which would contain all information of the universe. In that sense, the universe would be completely founded in that mathematical structure. The physical universe would even be equal to this particular mathematical structure up to equivalence and isomorphism.

However, does mathematical infinity have a physical reality? Is the infinitesimally small in the continuum physically real? Fundamental equations of quantum physics (e.g., Schrödinger equation) are continuous differential equations. A quantum system is defined by a Hilbert space, which is an infinite mathematical object. Dirac's delta function is a generalized function (distribution) on the real continuum that is zero everywhere except at zero, with an integral of one over the entire continuum. It is illustrated as a graph, which is an infinitely high, infinitely thin spike at the origin, with total area one under the spike. Physically, it is assumed to represent the density of an idealized point mass or point charge. There are natural constants, which are real numbers with infinitely many decimal places, but approximately measurable in finite steps. According to Emmy Noether, fundamental conservation laws of physics correspond to continuous symmetries of space-time. For example, the conservation of energy is equivalent to the translation symmetry of time, conservation of momentum to translation symmetry of space, conservation of angular momentum to rotational symmetry, et al. [2] (Chapter 3.3), [18] (Chapter 5).

Is the continuum with real numbers only a convenient approximation to compute the coarse molecular and atomic world of fluids, materials, and fields with elegant continuous procedures? Actually, the continuum is not only used in classical physics, but also in the quantum world. In quantum field theory, we use quantum fields with discrete computable solutions of crystal grids and emergent particles. Continuous space-time of the universe is assumed to become discrete in the Planck-scaling of elementary particles (quantum foam). Information flow in dynamical systems is measured by discretization in bit sequences (e.g., Poincaré cuts in [7] (p. 313, Figure 30)), the complexity of which can be measured by their shortest algorithmic description as computer program [7] (Chapter 13).

4. Is the Universe Computable?

Finite material structures in nature are isomorphic to equivalent finite mathematical structures (e.g., molecular crystals correspond to geometrical grids with group-theoretical symmetries), which can be uniquely encoded by natural numbers. Finite code numbers can be enumerated according to their size. Thus, in principle, all finite structures of the universe can be enumerated. Computable structures can be represented by Turing machines, which uniquely correspond to machine numbers as encoding numbers of a Turing program. Thus, all computable structures of the universe can also be enumerated.

In physics, infinite structures (e.g., space-time, fields, wave functions, Hilbert spaces) are practically handled by software programs (e.g., Wolfram's MATHEMATICA), which can compute arbitrarily large numbers [19]. Thus, infinite structures are approximated by finite structures, which can be processed by computers. However, do we actually need the continuum and infinity beyond Turing complexity in physics? Natural laws are mathematical equations. How far can they be represented in computers? The states in classical computers and quantum computers are discrete (bits resp. quantum bits). However, in order to model their dynamics, we need continuous mathematical concepts (e.g., Schrödinger equation as a continuous differential equation in quantum physics). Therefore, the epistemic question arises: Are these continuous concepts only convenient mathematical tools invented by the human mind to manage digital data or are they ontologically real.

In mathematical proof theory, we can determine degrees of constructivity and computation: How far can mathematical theorems be proved by constructive methods, like calculation in arithmetics? Since Euclid (Mid-4th century—Mid 3rd century BA), mathematicians have used axioms to deduce theorems. However, the "forward" procedure from axioms to theorems is not always obvious. How can we find appropriate axioms for a proof starting with a given theorem in a "backward" (reverse) procedure?

Pappos of Alexandria (290–350 AD) understood the "forward" procedure as "synthesis" (Greek for the Latin word "constructio" or English translation "construction"), because, in Euclid's geometry, logical deductions from axioms to theorems are connected with geometric constructions of corresponding figures [20]. The reverse search procedure of axioms for a given theorem was called "analysis", which decomposes a theorem in its sufficient conditions and the corresponding geometric figures in their elementary building blocks (e.g., circle and straight line) [21,22].

In modern proof theory, reverse mathematics is a research program to determine the minimal axiomatic system required to prove theorems [23]. In general, it is not possible to start from a theorem, τ, to prove a whole axiomatic subsystem, T_1. A weak base theory, T_2, is required to supplement τ:

> If $T_2 + \tau$ can prove T_1, this proof is called a reversal. If T_1 proves τ and $T_2 + \tau$ is a reversal, then T_1 and τ are said to be equivalent over T_2.

Reverse mathematics enable us to determine the proof-theoretic strength resp. complexity of theorems by classifying them with respect to equivalent theorems and proofs. Many theorems of classical mathematics can be classified by subsystems of second-order arithmetic, $\mathcal{Z}_2$, with variables of natural numbers and variables of sets of natural numbers [24,25]. In short: In reverse mathematics [26], we prove the equivalence of mathematical theorems (e.g., Bolzano-Weierstrass theorem in real analysis) with subclasses of arithmetic, $\mathcal{Z}_2$, of second order. Therefore, we could extend constructive reverse mathematics to physics and try to embed the equations of natural laws into subclasses of arithmetic $\mathcal{Z}_2$ of second order. Are there constructive principles of $\mathcal{Z}_2$, which are equivalent to the equations of natural laws (e.g., Newton's 2nd law of mechanics, Schrödinger's equation)?

Most natural laws, which are mathematically formulated in real (or complex) analysis, can be reduced to the axiom of arithmetical comprehension in constructive analysis [7] (Chapter 8). In general, no physical experiment is known that depends on the complete real continuum with non-computable real numbers. In this case, the universe would consist of constructive mathematical structures, which are classified in a hierarchy according to their degrees of constructivity. Only an extreme Platonism would believe that all mathematical structures are existent with the subclass of those structures that are isomorphic to physical structures of the universe. This ontological position cannot be excluded in principle. However, in the sense of Ockham's razor, it makes highly abstract assumptions, which are not necessary for solving physical problems and which can be avoided by constructive concepts. Modern physical research with its huge amount of data (e.g., high energy and particle physics of accelerators) strongly depends on algorithms and software, which must detect correlations and patterns of data.

If quantum physics is assumed as a general theoretical framework, then nature with Planck's length must be discrete. Nevertheless, quantum physicists use infinite and continuous concepts of real and complex numbers in their theories. The standard model of particle physics refers to 32 parameters with real constants. An example is the fine-structure constant, $1/\alpha = 137.0359\ldots$ Only finitely many decimal places are known with respect to contemporary capacities of measurement. From a strictly digital point of view, all infinitely many decimal places had to be input into a computer step by step for computing with real numbers, which is impossible. However, theoretical physicists compute with these parameters as "whole" quantities with algebraic representations, e.g., α^{-1} with $\alpha = \frac{e^2}{q_P^2}$, e elementary charge, and q_P Planck charge.

5. Computational Complexity of the Universe

In real computing (with real numbers), the physical question is still open whether real constants (e.g., the fine-structure constant, α^{-1}) or Dirac's function correspond to physically "real" entities. Otherwise, they are only approximate terms of a mathematical model. If there are non-computable real numbers (as natural constants of physical theories)), which:

- Definitely cannot be reduced to constructive procedures; and
- definitely influence physical experiments,

then, the unbelievable happens: Non-computable real numbers would not only be an invention of the human mind, but a physical reality. According to Hilbert's classical criterion, the existence of a mathematical object is guaranteed by its consistency in an axiomatic system. However, in constructive mathematics, we need an effective procedure to construct an object and to prove the existential statement. Further on, in physics, the object must be measurable in an experiment or observation (at least approximately exact).

The discovery of non-computable objects in physics would be as surprising as the discovery of incommensurable relations in Antiquity. The Pythagoreans were not only horrified by the discovery of incommensurable mathematical relations [27]. In Antiquity, Euclidean geometry was ontologically identified with really existing objects and relations. Therefore, incommensurability was historically understood as a loss of harmony and rational proportionality in the real world. However, incommensurable relations in Antiquity correspond to irrational numbers, which are computable like, e.g., $\sqrt{2}$. Non-computability in nature would be more dramatic. Turing introduced so-called "oracles" to denote concepts that are not known to be computable or not. They are the blind spots in the area of computability. In this case, there would be not only Black Holes in the universe (which are computable in quantum physics), but blind spots of computability or "computational oracles".

Obviously, there are practical limits of computation depending on the technical limitations of computers. There are also limitations depending on certain methods of problem solving: For example, Poincaré's many bodies problem is not solvable by standard solutions of integration. However, in principle, there is a mathematical solution with an infinite process of convergence. Further on, it is still an open question how far the highly nonlinear Navier-Stokes equations of turbulence are mathematically solvable. Until now, only special solutions under restricted constraints are provable [28]. In this context, we focus on the physical meaning of real numbers. Can we restrict their meaning to the constructive procedure of measuring in finite steps or do we need the whole information of an infinite object mathematically defined by the axiomatic system of real numbers?

Since the beginning of modern physics, physicists and philosophers were fascinated by the mathematical simplicity and elegance of natural laws [5] (Chapter 1). For example, the standard model is reduced to the symmetry group, SU(3) $\times$ SU(2) $\times$ U(1). Therefore, it is often argued that physics is finally founded in mathematical symmetries, which remind us of the old Platonic idea of regular bodies as building blocks of the universe [2,18,29]. Natural laws formalize regularities and correlations of physical quantities. In a huge amount of observational data, laws provide a shorter description of the world.

Algorithmic information of data is defined as the bit length of their shortest description [30]. In this sense, natural laws are a shorter description of data patterns. In order to illustrate the relation of simple laws and complex data, we consider a mathematical example in Figure 1 [17] (p. 491): The left pattern is very complex and represents the decimal places of $\sqrt{2}$ as binary numbers of 0 and 1, which are illustrated by white and black squares. It is assumed (but still not rigorously proved) that the decimal places of $\sqrt{2}$ behave like random numbers with all kind of patterns. Nevertheless, there is a finite computer program to compute $\sqrt{2}$, which only needs circa 100 bits. This computer program corresponds to a short (computable) law, which covers an unlimited huge amount of data. The description of the middle partial pattern in Figure 1 is even more complex than the whole left pattern, because it needs 14 additional bits to locate the beginning bits of the partial pattern in the whole pattern. The right pattern only needs nine bits. There would be no advantage to locate this pattern by additional bits in the whole distribution.

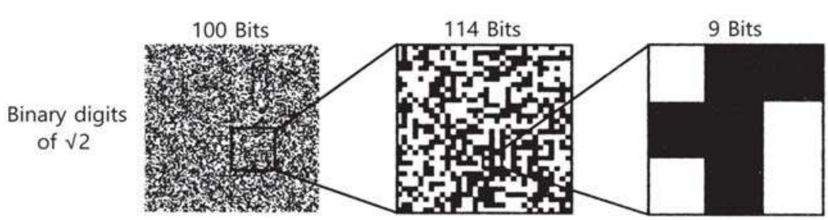

Figure 1. Complexity of patterns (e.g., binary numbers of $\sqrt{2}$) and their parts.

These examples illustrate that general laws may be short and simple to describe the whole universe. However, special conditions and individual situations may be more complex, because we need additional information to locate them in the distribution of the whole. In relativistic and quantum physics, individual entities from atoms and molecules up to organisms are represented by more or less complex patterns of world lines in space-time. Thus, in the whole distribution of patterns, individual parts must be located, which needs additional information: Therefore, the description of individual life and persons may be more complex than the general laws of life and even the whole universe!

In order to predict future events, we do not only need laws, but also initial conditions. Sometimes, initial conditions seem to be randomly contrary to regular laws. However, from a universal point of view, initial conditions are not random. They must be located in the whole data pattern of the universe and need more information (bits). In this case, the algorithmic information of initial conditions and individual events is larger than the algorithmic length of the applied laws.

6. Conclusions

In natural philosophy, the traditional dispute on the discrete or the continuum has a long tradition since Antiquity [31–33]. In modern quantum physics, the discrete structure of matter is explained by quantum systems with Planck length. In modern computer science, the discrete and the continuum are defined by digital and analog concepts. In digital physics, digital computing is related to discrete quantum systems. Thus, the question arises whether nature can be considered a huge quantum computer. Is nature computable? The article argues that we have to distinguish degrees of complexity and computability, which are well-defined in mathematics (e.g., reverse mathematics) and computer science (e.g., complexity theory).

Mathematical theories of nature are isomorphic to mathematical structures of different degrees and, by that, embedded in the categorical framework of mathematics. The ontological question is still open whether the categorical framework of mathematics is a creation of the human mind or has real existence independent of the human mind. In a naturalistic sense, one can argue that mathematical thinking is made possible by human brains, which have developed in the biological evolution on Earth. Following this line, mathematical concepts are only human inventions, like all human tools, which have been constructed to solve problems.

During history, humans invented different concepts to define and formulate the same mathematical structures: E.g., the Greeks used geometrical proportions to define "rational" and "irrational" numbers. In modern times, geometrical proportions were replaced by numeric representations as an expansion of decimal numbers and binary bits for computation by computers.

A well-known example is the definition of the number, π, which is independent of its representation as a geometrical proportion of the circumference and diameter of a circle or as an expansion of decimal or binary numbers. In any way, even intelligent aliens on exoplanets may have some concept of this crucial number of our universe, but perhaps in a completely different and still unknown representation. The development of their mathematical thinking will depend on the special evolution of their "brains" on their planets. However, in the end, the truth of proofs and theorems is invariant and independent of brains and psychology. Humans and these aliens may have the intellectual capacity to understand the structure of their universe. However, these structures and laws have governed the cosmic expansion and biological evolution long before our brains emerged. Thus, they are independent of our mind and brain and made them possible.

In some cases, invariant mathematical structures represent physical reality. However, in most cases, mathematical structures do not represent physical realities. Nevertheless, these topological and algebraic structures have a rigorously defined existence. The distinguished character of mathematics is its universality. Therefore, the ontological question is still open whether continuous concepts of mathematics are only convenient abstractions of the human mind or rooted in a deeper layer of mathematical existence "below" the discrete nature of the quantum world. From an epistemic point of view, constructive models of nature are preferred, because they avoid a waste of ontological assumptions in the sense of Ockham's razor. Anyway, the debate on the discrete and the continuum of nature illustrates that the ancient problems of natural philosophy are still alive and that modern physics continues natural philosophy with the new methods of mathematics, measuring, and computing.

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The Coming Emptiness: On the Meaning of the Emptiness of the Universe in Natural Philosophy

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Abstract: The cosmological relevance of emptiness—that is, space without bodies—is not yet sufficiently appreciated in natural philosophy. This paper addresses two aspects of cosmic emptiness from the perspective of natural philosophy: the distances to the stars in the closer cosmic environment and the expansion of space as a result of the accelerated expansion of the universe. Both aspects will be discussed from both a historical and a systematic perspective. Emptiness can be interpreted as "coming" in a two-fold sense: whereas in the past, knowledge of emptiness, as it were, came to human beings, in the future, it is coming, insofar as its relevance in the cosmos will increase. The longer and more closely emptiness was studied since the beginning of modernity, the larger became the spaces over which it was found to extend. From a systematic perspective, I will show with regard to the closer cosmic environment that the Earth may be separated from the perhaps habitable planets of other stars by an emptiness that is inimical to life and cannot be traversed by humans. This assumption is a result of the discussion of the constraints and possibilities of interstellar space travel as defined by the known natural laws and technical means. With the accelerated expansion of the universe, the distances to other galaxies (outside of the so-called Local Group) are increasing. According to the current standard model of cosmology and assuming that the acceleration will remain constant, in the distant future, this expansion will lead first to a substantial change in the epistemic conditions of cosmological knowledge and finally to the completion of the cosmic emptiness and of its relevance, respectively. Imagining the postulated completely empty last state leads human thought to the very limits of what is conceivable.

Keywords: natural philosophy; cosmology; emptiness; vacuum; void; dark energy; space flight; exoplanet; big freeze; big crunch; everyday lifeworld

1. Introduction

The cosmological relevance of the emptiness of the universe is not yet sufficiently appreciated in natural philosophy.[1] By the emptiness of the universe or cosmic emptiness—or, for short, emptiness—in what follows, it will be understood as the space in the universe that is free of bodies. Bodies occupy limited and isolated three-dimensional regions of space and consist of a quantity of matter in an aggregate state with values above a minimum density [2]. Typical examples of bodies are asteroids, moons, planets, and suns. The definition of a body excludes interplanetary, interstellar, and intergalactic media consisting of dust, gases, and low-density plasmas. On account of their low density, these media are almost like a vacuum, which as matter-free space, belongs to emptiness. The concept of a vacuum is ambiguous. Substances of low density are also referred to as vacuums [3] (p. 236). Thus, there is a shifting boundary between a vacuum and emptiness.

[1] The universe is observable space, and its rational description is called the cosmos. Because observation is rational description, I use the terms "universe" and "cosmos" synonymously. See also Kragh [1] (p. 1 ff.).

Emptiness can be interpreted in natural philosophy as "coming" in a two-fold sense: whereas in the past, knowledge of emptiness came to human beings, as it were, in the future, it is coming, insofar as its relevance in the cosmos is going to increase. In what follows, the space in the universe without bodies will be discussed from the perspective of natural philosophy, whose subject is nature, knowledge about nature, and human beings' relationship to it.[2]

Natural philosophy is, methodologically speaking, part of philosophy and has a systematic, historical, and practical character [5]. With regard to the cosmos, it inquires into its structures and the place of human beings in it, but also into the history of cosmological knowledge and its practical contexts. It has the same subject matter as the natural sciences, relies on their results, and shares with the philosophy of science an interest in the conceptual foundations and formal structures of scientific theories. However, its central point of reference remains the significance of nature for human beings. From a natural philosophical perspective, defining emptiness as body-free space recommends itself for two reasons. Firstly, natural philosophy, which concerns human beings' relationship to nature, should also be comprehensible for nonscientists. Bodies are tangible objects insofar as they are accessible to sensory perception, which is usually the case. Secondly, body-free space is characterized by a special, namely, a hostile relationship to human life.[3] I will defend the theses that in the past, the discovery of the cosmic emptiness occurred in a cumulative way and that the future living conditions of civilizations in the cosmos will be increasingly determined by their relationship to emptiness.

The theme of cosmic emptiness was and is closely linked to the concept of nothingness in natural philosophy, despite the controversial nature of this connection. In part, only space devoid of matter is called nothingness, and in part, the more inclusive concept of emptiness is used; sometimes, conversely, nothingness is contrasted with everything that exists, which also includes space devoid of matter.[4] In what follows, I will not examine the relationship between nothingness and cosmic emptiness more closely. However, I would like to preface my remarks by saying that they are essentially motivated by the conviction that today, the philosophical concept of nothingness cannot be understood without reference to the knowledge of cosmic emptiness.[5]

Today, cosmological knowledge is based on highly technical observational instruments and on exceedingly abstract mathematical theories and models. Its object domain extends from the tiniest spatial dimensions on Earth to the edge of the observable universe, which is about 45 billion light years away, and from the briefest times at the claimed beginning of the universe to the most distant future times of the claimed final state of the expanding universe. For natural philosophy, which inquiries into the relationship between human beings and the cosmos, and thus also into the significance of cosmological knowledge for the human understanding of the world, cosmological knowledge represents a challenge. How can nonscientists incorporate the results of this demanding and unintuitive knowledge into their conception of nature? That there are some starting points for this is shown by the widespread interest in popular accounts of cosmological knowledge. Insofar as the cosmological questions in natural philosophy refer to future possibilities for action and states of the universe, the natural philosophy of cosmology has a speculative character that also represents a challenge to its scientific character.

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2 Insofar as "nature" is understood as that which exists in itself without being produced by human beings, emptiness is a natural phenomenon. On the concept of nature, see Schiemann [4].

3 In highlighting its hostility to life, the natural philosophical thematization of cosmic emptiness differs from that of cosmology. From a cosmological perspective, emptiness can be regarded as a condition for the emergence of possibilities of life in the cosmos, insofar as a greater density of matter in the universe would have prevented this emergence.

4 The definition of nothingness as space devoid of matter (a vacuum) is widespread; see, for example, Genz [6], Close [7], and Krauss [8]. The epitome of cosmic emptiness is cosmic spaces of very low density (voids), which are also called nothingness; see, for example, Sheth and van de Weygaert [9] and Szapudi [10]. For the contradictory juxtaposition of nothingness and being, including space devoid of matter, see, for example, Albert [11].

5 The cosmic dimensions of emptiness are completely absent from definitions of nothingness in contemporary philosophy.

The assumption that modern cosmology can make predictions extending into the most distant future calls for an extended concept of natural philosophy, whose scope encompasses not only existing human beings. Cosmology deals with future times, concerning which we cannot know whether human beings or extraterrestrial civilizations will still exist, and with even more distant times, in which it is now assumed that life will no longer exist in the universe. Therefore, the concept of natural philosophy must also refer to the merely possible existence of humans and extraterrestrial civilizations as well as to a universe without thinking beings. Such a concept of natural philosophy is without historical precursors. Traditional natural philosophy denies the truth of statements that refer to states of distant past or future times in which subjects of cognition did not yet or no longer exist.[6]

I will concentrate on two aspects of cosmic emptiness that I regard as especially relevant: the distances to the stars in the closer cosmic vicinity of the Solar System and the accelerated expansion of the universe. Between the Sun and the stars, there lies an emptiness that is hostile to life and may not be traversable by humans, the accelerated expansion will probably empty the universe completely of bodies. I will leave other natural philosophical questions concerning cosmic emptiness aside, such as the problems of interplanetary space travel or the importance of the cosmic emptiness for the evolution of the cosmos and its habitable places, which would probably not exist without the cosmic emptiness. The two aspects selected are suitable for thematizing the cosmic emptiness from the closest cosmic environments to their most distant future states. These aspects are among the subjects that in recent times have experienced a stormy development in knowledge marked by paradigm shifts and are currently at the center of cosmological interest. This makes it all the stranger that to date, they have received scarcely any attention in natural philosophy.[7]

Part of the appeal of these two aspects is also their antithetical character with respect to the philosophy of nature. The distances between the stars in the closer cosmic vicinity of the Solar System can be discussed with direct reference to everyday knowledge. They are visible to the naked eye and their distance from the Earth can be translated into travel times measurable in human lifetimes. However, the accelerated expansion of the universe—assuming that it remains constant—leads into distant cosmic spaces and times that not only lie far beyond all everyday practical experience, but also extend to the limits of what is conceivable. At a time that is assumed to begin, at the earliest, about 10^{100} years from now (a period that can no longer be expressed in common words),[8] accelerated expansion will have led to the dissolution of all bodies. Thus, this aspect includes a period of time in which life will no longer exist. A consideration of the current epistemological conditions of cosmological knowledge will show that these distant scenarios can also be relevant for the human understanding of the world.

I will begin the first part with a brief outline of the history of the discovery of interstellar and intergalactic distances in order to show that the historical development of the knowledge of this aspect of cosmic emptiness was indeed cumulative and thus approached human beings, as it were. The closer cosmic environment will be localized within the observable universe as a vanishingly small section. Then, I will go on to discuss conditions of the future relevance of the cosmic emptiness of interstellar space for natural philosophy. Here, the focus will be on exoplanet research. In the second part, I will turn to the expansion of the universe. Again, I will begin its natural philosophical interpretation with a short summary of the cumulative character of the history of its discovery. In the third part, I will go on to discuss two future cosmic events resulting from the claimed accelerated expansion, namely, the substantial change in the cognitive conditions of cosmological knowledge that they will bring about in the distant future and the completion of emptiness that will be brought about in the final state

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6 In this, I am following Quentin Meillassoux's and Ray Brassier's criticism of natural philosophy in the tradition of Immanuel Kant. Brassier has applied Meillassoux's justification of the truth of prehistoric (ancestral) statements to post-historical (posterior) statements [12] (p. 229 f.).

7 Reflections on emptiness in natural philosophy are limited to the concept of the vacuum as space devoid of matter and can be found in popular accounts by physicists (e.g., [6–8]) and in discussions in the philosophy of science (e.g., [13,14]).

8 The character "^" is placed before power numbers instead of writing them as superscripts.

of the universe. In the concluding fourth part, I will discuss the objectivity and the current relevance of the cosmic emptiness.

2. Cosmic Distances and Interstellar Emptiness

2.1. The Emerging Knowledge

Until the beginning of modernity, cosmological conceptions of the relations of distance between the stars in the universe were shaped by the ancient notion of the closed celestial sphere. According to this notion, the stars were situated at the inner edge of a closed sphere encircling the Earth. The assumption that this sphere might not exist and that the stars might be arbitrarily far away from the Earth is characteristic of the modern revolution of cosmological ideas. The decisive impulse for this revolution was provided by the foundation of the heliocentric worldview by Nicholas Copernicus. Reflections in astronomy and the theory of gravitation subsequently supported the possibility of an infinite universe.[9] Blaise Pascal recognized that the presumed infinity of space is associated with a hostile emptiness when he wrote: "The eternal silence of these infinite spaces frightens me." [17] (p. 36).

It was not until the seventeenth century that improvements in measurement techniques made it possible to determine the distance to the Sun and thus to the planets. The values for the distance to the Sun exceeded the relevant assumptions of the medieval worldview by a factor of about 20 [1] (p. 26).[10] In the nineteenth century, it was also the advances in measurement techniques that enabled Friedrich Wilhelm Bessel to determine the distance to a nearby fixed star for the first time. The value of ten light years shocked the educated world. Edgar Allan Poe wrote with regard to Bessel's results of a "terrible gap" that separates the suns from each other and of an "immeasurable distance" that cannot be bridged by human beings [18] (p. 85 f.).

Since the technical possibilities of observation extended essentially only to the stars of the Milky Way and it was not possible to identify the neighboring galaxies as such without doubt, the vast majority of astronomers believed until the beginning of the last century that the stars of the universe were confined to the Milky Way. In 1925, Edwin Hubble, using the largest reflecting telescope at the time, succeeded in providing the groundbreaking first evidence of a galaxy (the Andromeda Nebula) outside the Milky Way, whose estimated distance of around one million light years was too small by about half, but nevertheless exceeded by far the previously assumed orders of magnitude for the Milky Way [19] (pp. 509 f.), [1] (p. 119).

Today, it is estimated that there are around two hundred billion galaxies in the observable universe, with the most distant galaxy being located at a distance of about 32 billion light years from the Earth [20,21]. The arrangement of galaxies probably exhibits a honeycomb-like structure, whose cavities have the lowest matter density in the universe and constitute its largest structures. At the provisional end of the discoveries of ever-greater distances between the cosmic bodies is the proof of the existence of these voids, whose diameters of up to one billion light years (of the Eridanus Supervoid) eclipse all previous notions about the size of body-free spaces [22].[11] In the regions of space close to the Sun, measurements of distances remain on the same scale as Bessel's discovery. The closest star is four light years away, and within a radius of 10 light years, there are just 15 more stars [23].

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9 If the sun and not the Earth is located at the center of the universe, it must be possible to measure the distances to not infinitely distant stars from the parallactic shift of their measurable positions. Since this shift could not be demonstrated (on account of deficiencies of measurement techniques), Giordano Bruno assumed that the stars were infinitely distant [15] (p. 11). According to Isaac Newton, gravitational attraction would inevitably lead to the collapse of the universe if it were not infinite [1] (p. 73).

10 On the amazement provoked in his contemporaries by Giovanni Cassini's first measurement of the distance between the Earth and the Sun in 1672, see Ferguson [16] (pp. 136 f.).

11 Measurements or estimates of cosmic distances can be regarded as certain for very large distances only since the end of the last century.

From the cumulative history of the discovery of cosmic distances, natural philosophy derives the insight that with every additional step in the disclosure of the scale of the cosmic emptiness, the space occupied by the Earth in relation to it diminishes. Spatially speaking, the Earth has, as a result, shrunk to almost nothing. The fact that all distances are measured in a single unit and that there is a gradual transition from the smallest distances to the largest means that the proportions of the cosmos can be illustrated by reducing the scale. If you reduce, for example, one million light years to one millimeter, you get a handy model of the universe of about 90 m diameter, in which, however, the Milky Way, with about 0.2 mm diameter, is already almost invisible. These analogies, with which the observer reduces him- or herself to nothing, form the basis for also rendering very large spatial magnitudes imaginable in terms intelligible from the lifeworld.

From the perspective of natural philosophy, however, there are also categorical differences between the spatial orders of magnitude. They can be explained in terms of the distance-dependent dominance of natural forces: within very small dimensions, different forces operate than in very large dimensions. In subatomic orders of magnitude, for example, the weak and strong nuclear forces are determinant, but not the gravitational forces that hold exclusive sway on the very large scale. In what follows, I will present a different, likewise natural philosophical explanation for the categorical differences between the spatial orders of magnitude, one based on the presumed limited possibilities for human action in cosmic space.

2.2. The Proximity of Emptiness

We can gain an initial impression of human beings' current scope for action in space by translating distances into the travel times of today's spacecraft. Based on the order of magnitude of the speeds for the Moon flights (10 km/s), all of the planets in the Solar System can be reached within travel times that still allow astronauts to return to Earth during their lifetimes. However, the outward journey to a star 12 light years away, that is, one in the immediate cosmic vicinity of the Solar System, would already take over 350,000 years.[12] This would justify a categorical difference, of course, only if it were not possible for human beings to travel at speeds sufficiently close to the speed of light to reduce travel times for stellar distances to a human scale. Traveling at approximately the speed of light would slow time down for the travelers so much that they could travel cosmically close distances without having to countenance substantial time differences from terrestrial time. Assuming that a spaceship were set in motion and slowed down at rates of acceleration and deceleration such that the passengers were exposed in each case to the same force as the gravitational force on Earth and that it reached a maximum of 99% of the speed of light, the astronauts would be back from a journey to a star 12 light years away (without a stay there) within 28 years, while for them, only 10 years would have passed.

In order to discuss the room for realizing such journeys allowed by natural laws, all technical difficulties will be set aside in what follows—for example, the problem of manufacturing and transporting suitable fuels or the problem of high-speed collisions with small particles located in interstellar space. A thought experiment for calculating an ideal rocket engine stems from the Nobel Prize winner Edward Mills Purcell [24] (pp. 6–9). In order to convert the fuel mass completely into energy, matter and antimatter would have to be brought together. Since in that case, the energy would be released in the form of light particles (photons), the speed of the emerging beam corresponds exactly to that of light. The relativistic rocket equation for this spaceship on a return flight to a destination 12 light years away with a maximum speed of 99% of the speed of light and a double constant acceleration and deceleration process still yields results involving a seemingly absurd ratio between the initial mass, when no fuel has yet been consumed, and the final mass. To transport a payload of ten tons, a spaceship with a total mass of at least 400,000 tons would have to be built [24]

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[12] It would take over 100,000 years to reach the closest star four light years away.

(p. 8). The power required to accelerate and decelerate such a spacecraft would be the equivalent of almost 60,000 times the current total annual primary energy consumption of the Earth.[13]

With this calculation, Purcell intended to show that plans for interstellar journeys with missiles are childish notions that should not be taken seriously. In the light of such criticism, physicists and technicians contemplating future space vehicles for interstellar journeys have been looking for forms of propulsion that make do without rocket technology.[14] Vehicles driven by external laser beams can be regarded as an example for a realistic option. The light source would be situated at a fixed location and would drive a spaceship even at great distances using the radiation pressure of light. With this technology, however, only speeds that remain significantly below the speed of light can be achieved. They require a power output that can only be generated for very low payloads on Earth, but otherwise would also correspond to many times the annual primary energy consumption of the Earth.[15]

There is no known physical theory according to which it would be impossible in principle to produce the physical power required to achieve speeds close to the speed of light. Given the current state of knowledge, however, there are valid reasons for doubting whether the necessary outputs of power can be generated in the future. Without relativistic velocities, the travel times of interstellar manned space travel must be assumed to be many times longer than the average current lifespan of a human being. In order for people to be able to live in complete isolation from the outside world over several generations, Earth-like conditions would have to prevail in the spaceships (intergenerational spaceships).

When it comes to human beings' scope for action, therefore, there are good reasons to assume a categorical difference between the interplanetary distances of the Solar System and the far greater interstellar distances. From a cosmic perspective, human beings' possibilities for action, taking into account their technical possibilities, are characterized by a connectedness to the Earth that essentially limits the spatial range of actions in the cosmos to the Solar System for the time being. However, this entails a further difference that is characteristic of the relationship between human beings and the cosmic emptiness: human beings' possibilities for acting on a cosmic scale are in clear contrast to their observational capabilities, which, as we have seen, extend to the limits of the observable universe.

I regard exoplanet research as a candidate for a paradigmatic case of this contrast. The successes of this research can be regarded as outstanding achievements of a technically perfected precision astronomy, whose beginnings can be traced back to the discovery of a planet in a different Solar System for the first time in 1995. Since then, over 3700 planets have been identified [30]. In the meantime, it is considered probable that suns normally have planets. Exoplanet research is a form of observation-based research that deduces its findings indirectly from the analysis of the radiation of the suns around which the exoplanets orbit. From changes in the stellar data, it infers not only to the existence of their planets, but also, where possible, to the extent of their mass, their volume, and their distance from the sun in question, as well as to the existence and the composition of the atmosphere. The precision of the measurements already allows researchers to study whether the planets in question are possibly habitable, where habitability refers to life as it is known from the Earth. Since very diverse forms of

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13 The power consumption of the spaceship was calculated following Purcell at 1.14×10^{18} watts [24] (p. 8); the annual primary energy consumption on Earth, at 1.73×10^{13} watts, was derived from the data for 2014 provided by the German Federal Agency for Civic Education [25].

14 Matloff [26] and Long [27] provide relevant introductions to alternative rocket propulsion systems.

15 The Breakthrough Starshot project plans to bring a very low payload of just a few grams to the closest star, Alpha Centauri, at about 4 light years away, with an Earth-based laser. Assuming a laser power of 10ˆ11 watts, with which it is planned to drive the spaceship from Earth, the hope is to reach 15–20% of the speed of light [28]. Ian A. Crawford calculates that in order to bring a spaceship with a total mass of 1920 t (with the payload accounting for 450 t) to Alpha Centauri in 36 years, a power expenditure of approx. 10^{14} watts would be required for an external laser drive in order to reach a cruising speed of 12% light speed after a period of acceleration of 0.35 m/s^2 lasting approx. three years [29] (pp. 388 f.). This represents over 10 times the annual primary energy consumption of the Earth (cf. [25]), and with current technology, could only be generated in space with sunlight.

life have developed under terrestrial conditions and in the case of many terrestrial organisms, it is uncertain whether they could develop under other conditions, establishing the criteria for habitability is an extremely complex problem—not least also because it has not been conclusively established even for the Earth which conditions must be fulfilled in order for simple and complex life to be formed.[16] The number of the exoplanets that have been discovered and are considered to be only possibly habitable currently ranges from 10 to 40. The closest of them is already located at our neighboring star 4 light years away, whereas the farthest is almost 3000 light years away [32]. Estimates of the number of possibly habitable planets in the Milky Way are currently of the order of one billion [33].

In future, further improvements in measurement methods and accuracies should make it possible to prove the existence of extraterrestrial (simple and complex) life forms and civilizations, assuming they exist. The existence of extraterrestrial life could become probable by proving that the only way either an observed change in the atmosphere of an exoplanet or a detected electromagnetic signal could conceivably be brought about is by an extraterrestrial civilization [34] (p. 161), [24] (pp. 9 ff.). The general prevalence of planets and the relative frequency of their presumed habitability mean that the probability that extraterrestrial life forms exist has increased significantly. Nevertheless, whatever the findings of further exoplanet research may be, it will be apt to underline the relevance of cosmic emptiness. Proof of the existence of extraterrestrial life forms could render the perhaps unbridgeable distance between the Earth and other stars palpable in a new way. The discovery of the first possible destinations of interstellar communication and travel would merely serve to render their inaccessibility apparent. Conversely, whereas the lack of proof might not yet be sufficient to demonstrate the nonexistence of other forms of life in the closer cosmic vicinity of the Solar System, it could reinforce the impression that an increasing number of exoplanets that are hostile to life merely increases the weight of the emptiness enclosing human beings.[17] Viewed from a natural philosophical perspective, human beings do not evade emptiness. As soon as they lift their (scientific) gaze from the Earth to the cosmos, they are struck by emptiness.

3. Distant Emptiness

The result of the discussion of cosmic distances and interstellar emptiness in natural philosophy will be made more evident by the phenomena of accelerated expansion. With the latter, the thematic focus shifts from spatial distances to future times. The knowledge of cosmic distances has rendered the contrast between cosmic and terrestrial dimensions and the difference between cosmic possibilities for action and observation apparent. The phenomena of the accelerated expansion of the universe are located in a future in which Earth's lifespan relative to the cosmic eons that will already have elapsed will be vanishingly small. With this, the predictions of cosmological theories extend into a time beyond all current scopes of action. One of the manifestations of cosmic emptiness discussed—the presumed enclosure of the Earth by a cosmic environment that is hostile to life—will be led to a new future level by the phenomena of the accelerated expansion of the universe, namely, to galaxies and their civilizations, assuming they still exist in the distant future, becoming isolated from the rest of the universe.

For a long time, the accelerated expansion of the universe will have no effect on the stars visible from Earth, even when viewed in cosmic terms. Assuming that it remains constant, the expansion consists of an inexorable enlargement of space that manifests itself in the increase in the distances between galaxies. It will give rise at a distant future time of around 100 billion years from now to a permanent substantial change in the cognitive conditions of cosmological knowledge and will finally lead to the dissolution of all bodies. Whether people originating from the Earth or other civilizations

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16 Cockell et al. [31] provide one of the many overviews of the criteria of habitability.

17 The term "emptiness" could be used in a metaphorical sense to refer to the life-threatening space as a whole and thus include both space devoid of bodies and bodies hostile to life.

will still exist in 100 billion years' time cannot be known today. Life will probably have ceased to exist in the universe long before the dissolution of bodies. In order even to thematize the accelerated expansion of the universe in natural philosophical terms, we need an expanded conception of natural philosophy that is not limited to the possible presence of human cognition.

3.1. The Discovery of Accelerated Expansion

Without disputing its cumulative character, the discovery of the accelerated expansion of the universe can be characterized as a breakthrough in cosmological knowledge in a number of respects.[18] It can be regarded as the final link in a chain of discoveries that refuted the assumption extending back to antiquity that the cosmos was unchangeable. This assumption was originally the temporal counterpart of the already mentioned idea of the closed celestial sphere, but it can be documented historically in related conceptions for a much longer time than the latter—namely, into the first three decades of the last century. It postulates that the size of the universe remains eternally constant [19] (pp. 517 f.). By contrast, the changeability demonstrated by the accelerated expansion of the universe involves an ubiquitous, constantly intensifying dynamic. The energy density attributed to accelerated expansion accounts for about 74% of the total value of the universe. Since this finding has not yet been explained, its discovery has revealed a profound gap in cosmological knowledge. The relative extent of cosmological knowledge was turned on its head, as it were, by this discovery. Whereas it used to be assumed that the essential elements of matter and force in the universe were understood, what was previously known about them now represents a small island in a largely puzzling landscape of cosmic phenomena.

The details of the history leading up to this breakthrough will not be discussed here. In order to demonstrate the cumulative nature of the phenomena associated with the discovery of the accelerated expansion of the universe, it is sufficient to cite some of the cognitive achievements through which ever more elements of changeability have been verified.[19] Evidence of the changeability of the cosmos in modern Europe goes back to the sixteenth century, when Tycho Brahe interpreted a supernova as a new star; in the nineteenth century, it was inferred from a law of thermodynamics that the universe may be developing toward a completely unstructured state—its so-called heat death; the expansion of the universe was demonstrated in the first two decades of the past century; and its accelerated character was discovered in 1998 through observations of the movement of exploding stars (Type Ia supernovae). Since then, this discovery has been confirmed by other phenomena.[20] Although the cause of the accelerated expansion is not known, that it is a fact is virtually beyond doubt. The data show that the rate of acceleration has been constant for billions of years. Assuming that the rate of acceleration also remains constant in future, then under certain theoretical presuppositions, other world models can be excluded, the most important being the gravitational collapse still regarded as probable in the last century, assuming a future decrease in the acceleration (the Big Crunch), and the future rupture of all bodies postulated just a few years ago on the assumption of an increase in acceleration (the Big Rip).

3.2. The Future of Accelerated Expansion

The accelerated expansion of the universe is essentially an expansion of cosmic emptiness, because it enlarges space itself. The change in the cognitive conditions of cosmological knowledge that it will

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[18] The significance of the discovery of accelerated expansion was acknowledged with the "Breakthrough of the Year" prize by the American Association for the Advancement of Science's journal *Science* in 1998 and with the Nobel Prize in 2011.

[19] The cumulative character would become clearer by combining the two stories of the discovery of emptiness, which are separated here for presentation purposes. The discovery of the accelerated expansion presupposes the discovery of distant galaxies and thus a large part of the history of astronomical measurements of distance. The connection is made evident by the relationship between Hubble's measurements of the distances between galaxies and his contribution to the discovery of expansion.

[20] The phenomena in question are the anisotropy of the cosmic background radiation and studies of the numerical density of galaxy clusters [35] (p. 455), [36].

bring about and the dissolution of all bodies to which it will ultimately lead presuppose that it will remain constant into the distant future. The unchangeability of expansion for distant future times has merely the status of a hypothetical assumption based on current measurements, since the latter can only draw on vanishingly small periods of time by comparison with the timescale of the predicted developments. A better assessment of the certainty of the predictions could probably be made if the cause of the accelerated expansion were known.

3.2.1. The Insurmountable and the False Emptiness

In roughly 20 billion (2×10^{10}) years, the galaxies of the so-called Local Group, to which the Milky Way and the Andromeda Galaxy belong, will coalesce into a single galaxy due to their gravitational attraction.[21] As Lawrence M. Krauss and Robert J. Scherrer have shown, this galaxy will be almost completely cut off from the rest of the universe in about 100 billion (10^{11}) years [38,39]. The separation will take place essentially through two mechanisms: On the one hand, in the course of the accelerated expansion, the distance from more and more galaxies outside the Local Group will increase at superluminal velocity, so that ultimately, there will be no causal interaction between other galaxies and the Local Group. On the other hand, the background radiation, which according to the current standard model of cosmology, testifies to the origin of the universe and its accelerated expansion, will probably exercise hardly any effects any longer. It will become more long-wave and will therefore be more likely to be absorbed by the interstellar gas and have only weak intensity [38] (p. 39).

Without sufficient interaction with the rest of the universe, its expansion would no longer be knowable. The relevance of this objective limitation of knowledge for natural philosophy is a function of the possible existence of life forms in the time following this limitation: it is predicted that the end of the stars, and thus the end of the possibility of life forms similar to organic life on Earth, will occur in 100 trillion (10^{14}) years. If civilizations existed in the Local Group from our era until the end of the stars, therefore, they would only have knowledge of the expansion of the universe based on their astronomical observations alone for about one-thousandth of that time.

It is conceivable that civilizations that were sufficiently isolated from the rest of the universe would mistakenly regard their own galaxy as an island enclosed by an infinite universe devoid of bodies. At the same time, they would probably overestimate the effect of gravity: without knowledge of the expansion of the universe, they might regard the gravity of the Local Group as sufficient to eventually bring about the end of the universe through a collapse [38] (pp. 40–41). From the perspective of present-day knowledge, this prediction is mistaken, because the accelerated expansion of the universe, assuming it remains constant, is incompatible with its gravitational collapse. Future civilizations would not be able to understand why their predictions did not come true.

It is not only possible future civilizations of the Local Group that would be affected by the prediction of the objective limitations and misdirection of the mind. Since the accelerated expansion affects space uniformly, the cosmic emptiness will create the same false impression throughout the universe of galaxies surrounded by an infinite expanse. This prediction of a universal impairment of cosmological knowledge is without precedent in the history of science and natural philosophy. It is tantamount to the prediction of the inaccessibility of truth. Not least, this prospect also relativizes the current basis of cosmological knowledge, since it could also be that present-day cosmology lacks access to observations that disprove existing theories.

3.2.2. The Completed Emptiness

The initial discussion of the prediction of accelerated expansion led us into future periods of time of between 20 billion and 100 trillion (10^{14}) years from now. The last period is around seven thousand times longer than the current age of the universe. Its end will be marked by the expected burning out

[21] For a relevant account, see Nagamine and Loeb [37].

of the last stars. The production of new stars is already now on the decline. In future, more and more stars will burn out as new stars are created [40] (p. 30). Without stars, all planetary life forms will come to an end. Provided that the expansion of the universe remains constant, the remaining bodies in the universe will then dissolve further into their constituents and in part be dispersed in space and in part collect in black holes.

This assumed development is an extremely intricate process, unfolding at an ever slower rate, of different forms of dissolution (of the various remainders of stars, types of galaxies, and clusters of galaxies) and of temporary formations of structures.[22] In its final and by far the longest phase (between 10^{40} and 10^{100} years from now or later), there will probably exist only black holes and elementary constituents of bodies dispersed throughout space [41] (pp. 107 ff.). The processes of disaggregation and solidification need not be described in detail here, because only the general tendency is of interest: finally, the black holes will have evaporated[23] and there will be only weakly interacting particles distributed in space at incredible distances corresponding to the diameter of the present universe, at the lowest temperatures or longest-wave electromagnetic radiation (the Big Freeze) [41] (pp. 153 ff.).[24]

When this final state of the accelerated expanding universe occurs depends on whether the protons, which together with the neutrons form the nuclei of atoms, decay or not. If the protons were to decay, which is currently thought to be unlikely, the destruction of physical structure in the universe would occur more quickly than with stable protons. Estimates of how long it will take until bodies dissolve in their entirety and emptiness is completely realized lie with proton decay, in the region of 10^{100} years (ibid.), and without proton decay, approximately between the already unimaginably large numbers of $10^{(10^{26})}$ and $10^{(10^{76})}$ years [42] (p. 653), [44] (p. 453).[25]

If someone were to enter this universe in its final state, they would find a vacuum in which it would be extremely difficult, if not impossible, to find any trace of the preceding development of the universe. Together with all material structure, the completed emptiness will presumably also erase all signs of the past. In this scenario, matter will be distributed more and more homogeneously in space, the temperature differences in space will undergo a progressive decrease, and events will occur increasingly rarely, so that the state of the universe will differ less and less from absolute stasis. [41] (pp. 161 ff.). If the burning out of the stars was still an event in the universe, events in the final state itself will come to an almost complete standstill. The probability that this final state will continue indefinitely is very high. It cannot be ruled out that it will exhibit instabilities that could lead to the creation of a new universe [41] (pp. 168 ff.). However, even this universe would have no knowledge of the evolution that preceded the emptiness. The coming emptiness will be completed in the presumed future of the accelerated expanding universe.

There is a similar relationship between the burning out of the last stars and the final state of the accelerated universe as between the two different forms of the end of the world discussed by Immanuel Kant in his essay "The End of All Things". What he calls the "natural end" consists in the perfectly imaginable complete destruction of physical orders before the last day. What he calls the "mystical end" is the humanly completely incomprehensible end of all change, and thus the end of time, which at some point follows that destruction: "But that at some point a time will arrive in which all alteration (and with it, time itself) ceases—this is a representation which outrages the imagination. For then the

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22 The authoritative account is still Adams and Laughlin [41].
23 Under the conditions of accelerated expansion, the complete evaporation of black holes is considered to be probable [41] (pp. 150 ff.), [42] (p. 650), [44] (p. 451).
24 This state is similar to the so-called heat death, cf. Section 3.1.
25 It is impossible to provide analogies to other time periods or spatial relationships of cosmological objects for the temporal relations in question. To provide at least an indirect illustration of the unimaginable objective reference of the number $10^{(10^{76})}$, one can try to illustrate its unrepresentability without exponential notation. It is a number with 10^{76} zeros. If humankind were to do nothing else from now on except write one zero per person per second, it would only be able to complete (assuming a constant human population) a vanishing fraction of these zeros within the time it will take for the stars to extinguish (approximately 10^{32} zeros). In order to write them all down, a further 10^{44} human populations doing nothing else would be required. This is 10^{22} times larger than the presumed number of stars in the universe (10^{22}).

whole of nature will be rigid and as it were petrified." [45] (pp. 227 f.).[26] What for Kant were still mere ideas that "lie wholly beyond our field of vision" [45] (p. 225)—that is, the natural and mystical end—become probable scenarios in modern cosmology: with the end of the stars, the physical orders will in all probability cease to exist; in the final state of the universe, the difference between change and stasis will become arbitrarily small. Nature will still exist, but it will be scattered in infinite spaces and will be "rigid and as it were petrified".

3.3. The Proximity of the Distant Emptiness

The periods during which the cosmic expansion exercises its effects on the conditions of knowledge and on the end of bodies are incommensurate with the horizon of everyday experience. They cannot be represented intuitively through analogies to spatial distances. It is all the more surprising that thematizations of the still-distant cosmic conditions in popular presentations have met with a broad interest.[27] They are objects of media attention that are not concerned with practical relevance, but with entertainment, education, and/or world orientation. Natural philosophy asks: How does everyday lifeworld experience, which nonspecialists can be assumed to possess, manage to share in cosmological knowledge? The thesis defended here is that the lifeworld imagination is able to bridge great temporal differences with relative ease. This assumption presupposes that the temporal horizon of the lifeworld and the cosmological temporal horizon have gradually drifted apart in modern times [15]. While the limits of what is cosmologically predictable lie further and further away from the present, the everyday practical stance has remained essentially concentrated on the present. The result is not only, as is generally assumed, a lifeworld-based weakness when it comes to perceiving the relevance of the future,[28] but also the opposite lifeworld deficiency in the ability to differentiate between orders of magnitude that are far removed from the present. Thus, what is temporally very distant can be shifted into the horizon of what is near in time.[29] Very distant events, such as the emptiness of the final state of an expanding universe, can therefore acquire increased significance despite their temporal distance.

But how should we conceive of the completion of emptiness? Does not thinking itself become empty when, paradoxically, it tries to imagine a condition of almost perfect changelessness and timelessness? How can it conceive of all products of life and thought being destroyed in the coming final state?

4. Coming Emptiness

I see the twofold sense in which the cosmic emptiness is coming as an expression of its objectivity.[30] I have described emptiness as coming, because knowledge of it has come to human beings, as it were (as discussed in Sections 2.1 and 3.1), and its relevance in the cosmos is likely destined to increase (as discussed in Sections 2.2 and 3.2). The longer and more closely emptiness has been studied since the beginning of modernity, the larger became the spaces over which it was found to extend and the

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[26] Sten Odenwald describes the difference between the burning out of the last stars and the final state of the accelerated universe as two different forms of death: "the death of the living biosphere, the death of the cosmos" [46] (p. 155). Paul C. Davies speaks more correctly of the eternally dying universe [47] (pp. 83–100).

[27] The topics of the expanding universe are very much present in the science pages of newspapers, on TV science programs, and in popular science magazines. See also the popular writings of physicists mentioned in Footnote 7 and [6,41–43,46,47].

[28] Thomä [48] and Großheim [49] are exemplary examples of this complaint, which does not criticize the lack of awareness of future cosmic events, but of events extending to the next generations at most.

[29] This assumption is based on the study of the temporal structures of the lifeworld in Schütz and Luckmann [50] (pp. 73 ff.); cf. Schiemann [4] (pp. 115 f.).

[30] "Objectivity {XE "Objectivity"}" does not only mean the independence of knowledge from individual factors such as attitudes, opinions, or convictions; it also denotes the property of facts that they are not susceptible to the effects of human action in an epoch- and cross-cultural sense, without thereby being historically unchangeable.

more reliable the knowledge of its nature became.[31] The impressive extent of the current emptiness of the universe is demonstrated by its average (baryonic) matter density of 10^{-30} g/cm^3, which is around 30 orders of magnitude lower than the average density of the bodies of stellar systems.[32] With the discovery of the accelerated expansion of the universe, emptiness acquires the status of an increasingly characteristic feature of the cosmos. If the value of the acceleration remains unchanged, the future of the cosmos is fixed: emptiness will continue to spread until it ultimately engulfs the entire universe. According to this, the universe is on a deterministic path to emptiness. For all the impressive range of this cosmological prediction, its hypothetical character must still be taken into account, which increases with the magnitude of the predicted time frames.

For the natural philosophical view concerned to establish the basic features of nature in its relationship to human beings, the fact that the determined future of emptiness contrasts with its indeterminate present is of interest. Compared to the previous cumulative increase in knowledge of the emptiness and its predicted distance dominance, the developmental trends in current research in the closer cosmic environment of emptiness are rather indeterminate. The results of exoplanet research on interstellar space, which has just begun, remain completely open. Is the Earth surrounded by habitable planets, some of which may even have life on them? Will we soon discover signs of extraterrestrial civilizations through observations of the atmospheres of habitable planets? Or will the observational search for extraterrestrial life remain unsuccessful for the time being? Will long and risky journeys by unmanned probes be necessary to gain reliable knowledge about planets in other solar systems?

The punchline of the natural philosophical reflections on the near future of the relevance of the cosmic emptiness for natural philosophy in the context of exoplanet research is that this relevance will probably increase, whatever the result of the research turns out to be. With the discovery of extraterrestrial life, interstellar destinations would adopt a concrete form that would first make the problems of reaching them painfully apparent. The permanent lack of proof of the existence of extraterrestrial life could be an indication of the rarity and loneliness of human life. The hostility to life of the cosmos would extend not only to the emptiness, but also to the other planets.

The problems of the reachability of planets of neighboring suns are primarily a function of the amounts of energy required for manned space flights or, alternatively, of the requisite travel times. If humans would not be in the position to provide a space flight with amounts of energy several times the current annual energy consumption of the Earth, they would have to countenance travel times many times longer than a human lifetime. Against the background of this dilemma, it seems plausible to assume that scope of human actions in the cosmos remains tied to the Earth for the time being. The limited scope of human action contrasts with the increasingly far-reaching and precise observational possibilities.

In addition to the findings mentioned in this section, the results of the natural philosophical study of emptiness include the justification of the expanded concept of natural philosophy obtained through the reflection of cosmological knowledge (see Section 1), of the categorical difference between interplanetary and interstellar distances (see Section 2.2), of the dependence of future cosmological conditions of knowledge on the accelerated expansion of the universe (see Section 3.2.1), and of the possibility that cosmological questions can be rendered intelligible in lifeworld terms, despite the fact that their spatial and temporal dimensions far exceed those of the lifeworld (see Section 3.3). On the one hand, the significance of the Earth-bound nature of human existence is being enhanced

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[31] The historical process could be formulated trenchantly as follows: "The closer a star was looked at, the greater the distance from which it looked back", echoing Karl Krauss's saying: "The closer you look at a word, the greater the distance from which it looks back at you" [51] (p. 362). Like words, the stars also lose their initially self-evident closeness and familiarity with increasing knowledge. On this general trend in the history of measurements of cosmic distances, see also Ferguson [16] (p. 180).

[32] The value for the mean density of the universe is generally accepted; see, for example [52] (p. 22). The values for the mean density of the stars and of rocky and gaseous planets are estimated to be between 0.5 and 5 g/cm^3.

(see Section 2.2). Presumably, in the long run, humans will not be able to reach Earth-like planets and return to Earth, if they so desire. The emptiness surrounding the Earth means that we must be very careful about how we deal with the conditions of existence of life on Earth. On the other hand, the future coming emptiness relativizes all meanings, not only cosmological ones, since in the final state of the universe devoid of bodies, these meanings will have crumbled to dust, as it were (see Section 3.2.2).

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Article

Temporality Naturalized

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Abstract: The Schrödinger equation for quantum mechanics, which is approachable in third-person description, takes for granted tenseless time that does not distinguish between different tenses such as past, present, and future. The time-reversal symmetry grounded upon tenseless time globally may, however, be broken once measurement in the form of exchanging indivisible quantum particles between the measured and the measuring intervenes. Measurement breaks tenseless time locally and distinguishes different tenses. Since measurement is about the material process of feeding and acting upon the quantum resources already available from any material bodies to be measured internally, the agency of measurement is sought within the environment in the broadest sense. Most indicative of internal measurement of the environmental origin are chemical reactions in the reaction environment. Temporality naturalized in chemical reactions proceeding as being subjected to frequent interventions of internal measurement is approachable in second-person description because of the participation of multiple agents of measurement there. The use of second-person description is found in the appraisal of the material capacity of generating, distinguishing, and integrating different tenses. An essence of the temporality to be naturalized is within the genesis of different tenses. A most conspicuous exemplar of naturalized temporality is sought in the origins of life conceivable exclusively on the material ground.

Keywords: causality; embodiment; measurement; regulation; retrocausality; second-person description; symmetry breaking; temporality

1. Introduction

One of the tenacious difficulties associated with addressing the issue of time resides within the scheme of addressing this issue itself. No discourse on time could be likely unless the temporality for making such an ongoing discourse possible on the linguistic ground is guaranteed in the first place. While any linguistic discourse of whatever kind may be sequential in time in its own making, the issue of time as a descriptive object would have to remain invariably concurrent with the sequential development of the discourse itself. Otherwise, the whole descriptive enterprise would have to collapse. The present collapse of the descriptive enterprise is about nothing other than a matter akin to an Aristotelian metaphysical aporia. It points to the difficulty in addressing something both sequential and concurrent, or equivalently, something both continuous and discontinuous, in a mutually congruent manner. There must be no likelihood of conceiving of a continuity in terms of the succession of discontinuities.

Of course, if one concentrates only on an epistemological aspect, as Kant took the lead in this endeavor, it could be likely to enshrine time as the transcendental condition saved for the sake of the invincible Ego overseeing the epistemological enterprise to be attempted there. Succession of time grasped in the form of causality connecting cause and effect in sequence can certainly uphold such epistemology. Nonetheless, the issue of time is more than simply being a matter of epistemology. Physics has been quite eloquent in addressing time as being a major physical issue. Put differently, physics might be open to such a possibility of conceiving of time in the mold other than that following the linear causality appreciating cause preceding its effect.

Physics has been unique in imparting the capacity of measuring or experiencing others to the measurement apparatuses at large without limiting such a capacity only to the transcendental subject. At this point, measurement is taken to be a scheme of directly and locally experiencing something concrete particular through a material means. In fact, physics has long set such a methodological stipulation that the act of experiencing others may be grasped by integrating both the law of motion and its supplementary boundary conditions. Then, the notion of time employed in the law of motion would come to assume a specific role. That is the time-reversal symmetry of the law of motion, whether in classical or in quantum mechanics. The time-reversal symmetry goes along with the block universe picture, admitting only tenseless time in which all of the future and the past are equally real as the present is.

In contrast, the act of experiencing in the mold of naturalized measurement that can survive in the empirical world is constantly breaking the time-reversal symmetry in that what has already been experienced cannot be undone in that world. We take this local act of breaking the time-reversal symmetry to simply be a brute empirical fact. Experiencing of a concrete particular nature is constantly about concrete particulars out there in the neighborhood. This is, of course, not intended to denounce the law of motion, which must remain legitimate under the adopted framework of an abstraction in one form or another. The law of motion in terms of a point-mass in classical mechanics or of the wave function in quantum mechanics would remain invincible insofar as the adopted abstraction is sanctioned. This observation would then come to invite an opportunity for a new alternative in place of the strict separation between the law of motion of an abstract nature and the boundary conditions of a concrete particular implication. That will be to critically examine the currently adopted stipulation of relegating the contribution of concrete nature exclusively to the boundary conditions while keeping the abstracted nature of the law of motion remaining intact.

Our objective of the present article will be to explicate the nature of temporality available to the empirical world under the much weaker condition. This exercise will be attempted under the condition such that the strict separation between the law of motion and its boundary conditions may be relaxed with respect to accommodating their implications of both abstraction and concreteness mutually in a more amenable manner. Our goal will be the appraisal of the material capacity of generating, distinguishing, and integrating different tenses that are pivotal to breaking the time-reversal symmetry latent in mechanics as summarized in Section 8: "Either Tenseless Time or Tenses." Facing the breaking of the time-reversal symmetry may eventually come to part with the block universe picture admitting only tenseless time, which has long been cherished in physics.

The emergence of past, present, and future does not require the tenseless time as a premise. It requires only the local perspective and the act of measurement. In contrast, an attempt for getting the past, present, and future out of the tenseless time unique to the global perspective does require an additional assumption that contradicts the presumed tenseless time.

2. Breaking Time-Reversal Symmetry

The Schrödinger equation of motion in quantum mechanics is taken to be a major law of motion for upholding the empirical world, and is parameterized in tenseless time, i.e., it is compatible with the one with time reversed. Although it can reveal a rich catalogue of empirical regularities when supplemented with the concrete boundary conditions, the Schrödinger equation will also have something to say even if it is not supplemented with its specific boundary conditions at all.

Just for the sake of an argument, let us imagine that a single quantum particle, such as an electron, is moving in a given potential field in a non-relativistic regime where it is not accompanied with preparing the actual experimental setup nor with detecting its whereabouts with use of an actual measurement apparatus. Furthermore, suppose the direction of the flow of time is suddenly reversed. The effect of this sudden time-reversal operation will then turn out to be equivalent to changing the positive mass of the quantum particle into the negative one of the equal magnitudes simply with respect to the phase factor of the concerned wave function only [1]. A similar change would also apply to the potential energy from the positive value to the negative one of the equal magnitudes, and nothing more.

The time-reversal symmetry of the Schrödinger equation could thus come to allow for both the quantum particle and its putative *counter particle* corresponding simply to the complex conjugate of the wave function of the original quantum particle. Of course, the counter-particle conceivable in this non-relativistic regime has no direct relevance to the antiparticle confirmed in the relativistic regime. The antiparticle has the same mass with the same sign the quantum particle has, but carries the equivalent physical charges, such as electric charge and magnetic moment, with the opposite signs.

The peculiarity of this temporal symmetry is seen in the potential likelihood for accommodating the linear complex of both the quantum particle and the counter particle at the same moment. Consequently, if both the quantum particle and its counter particle happen to meet at the same location, both can effectively disappear. For both the net mass and the net potential energy of the system vanish there due simply to the interference between the particle wave function and its complex conjugate [1].

The disappearance of the system of the quantum particle and its counter particle is thus ubiquitous in the quantum world unless measurement intervenes. If there is no chance of measurement in the empirical world, the likelihood of material embodiment of that world may be jeopardized in a non-relativistic regime because of the disappearance of any quantum particle meeting its counter particle with the use of the underlying time-reversal symmetry. Conversely, if the material embodiment of the empirical world happens to be the case as it should be, the breaking of the time-reversal symmetry imputed to the act of measurement would have to become inevitable insofar as the Schrödinger equation is referred to. Measurement distinguishes between measurements yet to come, in progress, and already done. That is about the distinction of the tense attribute specific to the quality of each measurement involved.

Since measurement is about the act of referring to a concrete particular aspect of an object to be measured, the agent of exercising such a specification could be sought nowhere other than the agent of measurement itself. The Schrödinger equation in itself is not agential. Although measurement is a quantum phenomenon, it is not subsumed under the scheme of what the Schrödinger equation would come to specify because the wave function adopted there has already been subjected to some sort of abstraction allowing for tenseless time.

Measurement in quantum mechanics is thus about a local activity for addressing the concrete particular nature of the object to be measured. On the other hand, the wave function in quantum mechanics, while legitimate in its own light, is about something global that has already been abstracted out from something else. This abstract nature, already being latent in the wave function, sets some limitation when it is used to decipher what measurement is all about in terms of the wave function. Even if the probabilistic interpretation of the wave function is taken to be factual, it would remain open at the least as to how it could be evaluated epistemologically or ontologically, or whatever else for that matter.

In any case, if both the global state description and the local act of measurement are accepted in the quantum realm, retrocausality in the form of retrodiction in addition to the standard causality upon prediction could also survive [1,2]. Retrocausality acting upon the quantum state is in fact a scheme of further modifying the state to meet the requirement for accommodating it to measurement [3]. It is meant to point to the implicit capacity already being latent in the state to further be qualified after the act of measurement.

One bottom line for addressing the act of measurement must be to refer to the common denominator available there, whichever sort of measurement may be attempted. That is to pay a legitimate attention to the concrete particular nature of the material body to be measured. One candidate for fulfilling such a stringent requirement must be sought in calling attention to the quantum particles to be transferred from what is to be measured on one hand to what is measuring on the other. Although an exhaustive specification of each quantum particle is beyond our reach at this moment as with the case of a Kantian thing-in-itself, one concrete aspect confirmed, at least empirically so far, is its indivisible character as a quantum. Transferring the quantum particles from where being measured to where measuring is concrete particular enough in preserving the indivisible nature of each quantum particle to be mediated in the exchange process.

Prerequisite to the process of measurement is the transference of quantum particles from the material bodies to be measured internally in the empirical world. Transference of quantum particles from one party to another one is in fact equivalent to updating and regulating the boundary conditions applied to each party. The agent of measurement in charge of regulating boundary conditions is thus by no means limited to our fellow physicists armored with the custom-made measurement apparatuses specially designed for specific purposes. Any material bodies that can feed upon the quantum resources of a concrete nature available from whatever sources may assume the agency of measuring those sources with the use of and in terms of the reference under the guise of the resources to be transferred.

3. Measurement of Internal Origin

Whatever kind it may be, any measurement makes the agent of measurement distinct from the object to be measured. The agent of measurement is unique in demonstrating the cohesive capacity of pulling in the mediating quantum particles—whether photons, electrons, or whatever else—that remain indivisible in the process. Put differently, measurement is distinctive in differentiating different tenses, say, between measurement already done and that currently in progress, whereas the unitary quantum mechanics applied to a closed system is faithful to observing tenseless time. Of course, quantum mechanics in tenseless time can survive in the limit that the distinction between different tenses may be marginalized.

In the standard scheme of doing physical experiments, the agent of measurement is assumed by the measurement apparatus as a surrogate for the physicists who are responsible for designing and preparing the apparatus. Of course, this does not imply that no measurement is likely in the absence of the physicists. Rather, the physical measurement regulated by the physicists can serve as no more than a prototypic example demonstrating the ubiquity of the phenomena of measurement available in the empirical world. In any case, measurement is about the activity of a concrete particular nature acting upon a concrete particular object whereas the law of motion is about the activity of an abstract nature acting upon concrete particulars. Measurement in the quantum regime is about a concrete particular acting upon something else, also a concrete particular, as exchanging the indivisible quantum particles between the two. Even if it can be referred to as being probabilistic, quantum measurement in and of itself is not specific enough to explicate what the underlying probability space may look like. Proposing the probability space in theory is one thing, but providing it with supportive evidence is quite another.

When we say that there is a molecule of carbon dioxide in a specially designed box tightly sealed so as to prevent even the quantum tunneling, it is taken for granted that the carbon dioxide molecule is constrained to the inside of the box. The sealed box does not allow the molecule to leave from the inside of the box towards its outside freely. The carbon dioxide molecule is then supposed to experience or to detect such a confinement internally in the long run. The internal identification or measurement of the confinement is certainly physical but is not the direct outcome from the law of motion. It is simply an internal attribute of material origin ascribed to the boundary conditions applied externally. Nonetheless, this internal measurement or experiencing of the confinement on the part of the molecule itself goes along with the external measurement attempted by the physicists installing such a sealed box to let the molecule not escape from the box freely. Internal measurement is about the regulative agency of a concrete particular nature as going beyond the scope regulated and covered by the abstract law of motion of a general universal nature.

One obvious lesson we learn from the present pedagogical example is that internal measurement of the environment by the participants from the inside would become inevitable. Such an inevitable intrusion of internal measurement must be the case even if the environment can be regulated to some extent by the externalists such as the physicists from the outside. Although it may be in accord with doing standard quantum physics to conceive of both an open quantum system and the residual environment cut out of a totally closed system in a top-down manner, internal measurement is about the agency of detecting and constructing the environment in a bottom-up manner.

In a similar vein, one can easily imagine the situation of a carbon dioxide molecule present in this earth-bound atmosphere. The relationship between the carbon dioxide molecule in focus and its entire environment is also of a measurement origin since the identification of the related partners is a prerequisite to establishing the relationship of whatever kind it may be. This does, however, by no means denigrate the role played by the law of motion. The only reservation with the standard law of motion is sought in its lack of the capacity of specifying the details of concrete particular nature of the material bodies in motion. Physics is already implicit in admitting its own capacity of being experiential or being susceptible to the influences coming from the outside by way of appreciating and accepting the notion called initial boundary conditions.

If it is intended to identify the specific nature of the relationship between a carbon dioxide molecule and the covering whole earth-bound environment, the process of measurement being competent in specifying the details of a concrete particular nature would have to be asked to take charge in place of the law of motion of an abstract nature. Prerequisite to installing the details of a concrete particular nature is the act of measurement by the agents of any sort, whether the physicists or whatever else for this matter. In this respect, the internal measurement by the participants is far more competent than the external measurement as a theoretical counterpart of the former.

The capacity of internal measurement on the part of the carbon dioxide molecule residing inside the environment can meet this challenge of internal identification. Internal measurement remains intact irrespective of whether external measurement intervenes. This is so even if the external measurement attempted by the physicist standing by on whereabouts that molecule is at all is made unfeasible because of the technical difficulties in one form or another. What is more, it may be simply inconceivable to put all the concrete specifications at the disposal of the physicist as the externalist. The bold enterprise of figuring out all the possible forms of regulation of a concrete particular nature is factually operative between the carbon dioxide molecule in focus and its naturalized environment. Internal measurement is thus bilateral in letting any participant be the agent of measuring its whole environment and likewise in letting the environment as an integrated body consisting of all the other participants be the agent of measuring each particular participant in focus [4]. Then, some inevitable convolution would come up to the surface.

Each participant can assume the two different roles. One is to measure its environment, and the other is to be measured by the environment. This may look like the contrast between action and reaction framed in the equation of motion available in classical or in quantum mechanics in a non-relativistic regime. However, what it eventually implies is quite different. The action and reaction conceivable in mechanics allowing for tenseless time only are totally synchronous because they are employing the abstraction of a methodological origin [5]. Once the equation of motion is taken to end up with a unique solution, there should be no room left for some indefinite arbitrariness to survive between any pair of action and reaction. Mechanics is thus quite peculiar in admitting both the time-reversal symmetry and the synchronous determination of both action and reaction in a totally coordinated manner.

Nonetheless, actual measurement breaks the time-reversal symmetry in the respect of observing that what has been measured cannot be undone any more. One cannot see its own eyes looking at something else at the same time. One loophole to escape from the present impasse arising from meeting both preserving and breaking the time-reversal symmetry in the same context would be to pay more serious attention to the act of measurement prior to framing the abstract law of motion.

This does by no means imply denunciation of the law of motion of an abstract nature. The issue will be to figure out the dynamics of the measurement origin that is principally concerned with the act of measurement of a concrete particular nature intrinsically from the local perspective as letting it be free from suffering those interventions of an abstract nature.

One of the intriguing aspects of the measurement dynamics is that the agency for measuring or identifying any participant should be sought in the whole environment housing that participant also. This is in conformity with the standard practice of doing physical experiments. The physicist takes it for granted that any individual material object placed under the fixed boundary conditions set by the physicist is assumed to abide by the conditions. The boundary conditions would come to have the measurement capacity of identifying that individual object abiding by the applied conditions themselves as such, otherwise the stipulation set by the boundary conditions would have to be jeopardized. Likewise, insofar as the dichotomy between any material participant and its environment is taken for granted, the environment comes to assume the measurement capacity of identifying that participant.

In short, the dichotomy between any material object and its environment is a prerequisite for asserting the presence of the object, even from the non-anthropocentric perspective. The environment is a necessary scaffolding for guaranteeing the occurrence of any individual. To put it simply, any individual is relative to its environment, even not to mention the relative state interpretation of quantum mechanics [6]. The act of measurement is already latent in making an individual participant relative to its environment that is supportive to any participant in focus. As much as the environment comes to measure each participant, the participant does the same to the environment because of the relative and bilateral nature of measurement involved there.

Once the measurement capacity of the environmental origin receives the due attention it deserves, the intriguing nature of temporality would manifest its distinctive character when the contrast between the environment and its participant is explicitly referred to. When one participant happens to be measured by its environment, the material basis of the measurement is in the transformation of the original participant into an alternative one. That is in parallel with the measurement in quantum mechanics proceeding as feeding upon the quantum resources and precipitating the accompanied transformation accordingly. At this point, it should be noted that the environment of the incumbent participant to be transformed into the alternative one differs from the emerging new environment to be applied to the emerging alternative participant. The transformation of the environment to be applied to the emerging participant is not simultaneous with the transformation of the incumbent participant but is sequential to the production of the emerging alternative one. For the measurement underlying each transformation takes time no matter how short it may be. In order to see what the eyes of one observer is seeing, it is required to have another observer nearby that can see the target observer and report the observed result accordingly.

The environment towards a product already made differs from the environment that was for its production. The active act on the part of the environment for measuring the incumbent participant resulting in the synthesis of an alternative one is sequentially, rather than simultaneously, following the passive consequence of the incumbent one synthesized by the environment. The consequence is to be registered in the production of the alternative transformed participant. Accordingly, the environment comes to constantly be re-organized to meet the newly emerged alternative one in sequence. Then, the reactively active act of measuring the alternative participant by the re-organized environment would follow suit, and ad infinitum.

The measurement dynamics is thus unique in revealing the lack of the concurrent determination of, or the simultaneous fixation of, both measuring and being measured. This exhibits a sharp contrast to mechanics observing the strict simultaneity of action and reaction. There is no danger of ostentatiously violating mechanics here, however. The measurement dynamics is principally about regulating something concrete particular due simply to establishing a correlation between being measured and measuring. In contrast, mechanics assumes a specific form of regulation in the mold of boundary conditions applied to something already abstracted in the form of a law of motion. Although it is of course conceivable in the classical scheme, regulation is ubiquitous under the much wider context in the quantum regime once the act of measurement is focused upon. The agent of regulation is not limited only to the physicist standing by. Measurement can be internalized there where regulation could be operative. The material agency of regulation is grounded upon the act of measurement of material origin. Both being measured and measuring that could not be frozen in fixed boundary conditions are the two faces of dynamic regulation met in the quantum regime.

The concrete particular nature of regulation in the quantum regime is certainly different from the abstract nature of regulation already latent in the classical counterpart. When the relationship between any material participant and its covering environment is approached with the use of measurement of an internal origin, the direct access to the material participant of a concrete particular nature is beyond the reach of any agent of measurement. This is due simply to the indefinite spillover of the act of measurement ad infinitum. Like the Kantian thing-in-itself, a concrete particular is inaccessible directly to the external observer with use of the measurement scheme that remains reaction-free.

Measurement constantly inducing further measurement to follow remains indefinite in its implication since measurement at any moment constantly remains indecisive about and open to what will be measured. In the dialogue practiced in second-person description, for instance, how the listener would respond to the incumbent speaker may constantly be open to any possibilities.

The indecisive nature of measurement is nested within the second-person status of the dichotomy of any material participant and its covering environment, rather than within the third-person status approachable in third-person description. Once the measurement result is accommodated in the third-person status, the external observer can refer to the result in third-person description in the present tense. This concurrent descriptive reference to the measurement result is, however, not available to the participants in the second-person status because no completion of measurement is in sight towards each participant residing in the whole environment. The act of measurement is constantly open and susceptible to the measurement to subsequently come on the scene. The descriptive reference available to the participant would have to be at most that of being likely in second-person description. The agents of measurement likely in the empirical world come to communicate with each other only through second-person description without being controlled by the single descriptive author assuming the third-person status.

4. Appraisal of Second-Person Description

Referring to second-person description is unique in its temporality compared to the standard one adopted in third-person description that is common in practicing empirical sciences, not to mention philosophical exercises. Any theory in physics has been austere in allowing no intervention of second-person description. In fact, third-person description long accepted in physics takes for granted the presence of the descriptive context that can remain invariable during the ongoing discourse. This is just another way of saying that any theoretical discourse likely to be plausible should observe an invariant object tightly guarded within a fixed context. There is nothing special and strange about this observation insofar as it is allowed for the externalist to take for granted an epistemological stance toward any descriptive object out there.

One of the outstanding advantages with the epistemological enterprise is the pre-guaranteed separation between the observing subject as the externalist and the descriptive object. Third-person description is already a guaranteed scheme of separating between the subject and the object. This epistemological split eventually enables us to accomplish an integration of both the invariable presence of the descriptive context to be paraphrased and its descriptive grasp as following the sequence of the discourse to be practiced by the externalist. In fact, computation is a prototypical example of demonstrating the ubiquity of third-person description.

Nonetheless, the conformity intended for a simultaneous coordination between the fixed context guaranteeing the presence of a descriptive object and the sequential development of the underlying discourse does not apply to second-person description. The dichotomy of any material participant and its covering environment is constantly open to the act of measurement to come internally. The material participant there remains indecisive in specifying how it will be transformed as being subjected to the measurement imputed to the environment, and the environment also remains indecisive as to what sort of material participant is going to be measured next. Despite that, the material participants are constantly decisive in revising the context for the act of measurement to be done on the spot [7]. In second-person description, there is no likelihood for the context, standing immutable, to be relied upon.

The uniqueness of second-person description is most visible in our long-held practice of valuing dialogues in the linguistic domain. However, the difficulty associated with the language of the dialogue is already latent in the endeavor of raising the question of what the dialogue is all about in terms of that language of a monologic nature. The trouble is that the language of the dialogue would come to constantly destroy the language of the monologue. This difficulty is already hidden in language itself, not in issues we are going to talk about in language [8]. In fact, second-person description or dialogue cannot be subsumed under the umbrella of third-person description or the monologue controlled by the single descriptive author while it can remain durable. At issue is the difference of temporality between second- and third-person descriptions.

Temporality latent in third-person description does coherently integrate both the invariable descriptive context and the linguistic exercise of following the sequential development of the discourse. This scheme certainly remains legitimate in the practice of doing empirical sciences. Insofar as the results of empirical observations by the empirical scientists are referred to and registered descriptively in the perfect tense, their reference in the present tense is unquestionably acceptable as a means for the evidence-based enterprise accessible in third-person description. The record registered in the perfect tense remains undoubtedly invariable even if it is referred to in the present tense by the external observer. In fact, the invincible advantage of doing empirical sciences upon evidence-based discourses compared to philosophical musing is in its capability of securing the invariable context of a descriptive object. The evidence-based context can remain immune to the sequential development of the consequential discourse. This immunity of the invariance to the sequential exercise of the discourse origin is not conceivable in second-person description.

In contrast, the advantage of practicing whatever discourse in second-person description is in its capacity of being able to refer directly to concrete particulars as practiced in the mold of measurement dynamics available to the empirical world. Insofar as the measured consequences to be registered in the perfect tense are concerned, they could certainly serve as the reliable references for practicing empirical sciences with use of the intervening third-person description. However, the capability of a second-person description latent in the measurement dynamics of a concrete particular nature is more than that of third-person description while it remains less definitive. It can tolerate some extent of incongruences or inconsistencies in the making that are constantly responsible for inducing the following measurements to come, while there remains no room for tolerating such inconveniences in third-person description [9]. The uniqueness of second-person description is found in the temporality of a generatively variable nature that is durable, as exhibiting a sharp contrast to third-person description observing the temporality of preserving an invariable context of a descriptive origin.

What is unique to second-person description is the participation of multiple agents imputed to the natural occurrence of the dichotomy of any material participant and its covering environment. Although it remains passive to its own environment, each participant can become active towards any other participant as functioning as the constituent member of the environment to the latter. Each participant is both passive and active depending upon the perspective to be taken. This co-occurrence of both passivity and activity cannot be tolerated in third-person description because the only active agent permissible there is the descriptive author involved in the monologic discourse. Furthermore, once the interplay among the multiple agents has been registered in the finished record, no agency is allowed within the record since it is addressable in third-person description. Nonetheless, it remains unavoidable to address what second-person description is all about in third-person description just as we are now committed ourselves to doing so in the present article.

One emergence measure for us to try to save second-person description in the face of third-person description being critical in observing the integrity of the finished record is to refer to the capacity already latent in the second-person description for leaving no inconveniences behind in the record. Nonetheless, second-person description has the capacity of tolerating inconsistencies internally at the present moment of Now, which is inconceivable in third-person description. The uniqueness of temporality associated with second-person description is found in transferring the incongruent mixture of both passivity and activity constantly forward. This constant forwarding of the internal inconsistencies is not addressable in third-person description, while it is indispensable for the wellbeing of the latter after the events.

One specific example demonstrating the uniqueness of second-person description compared to third-person description will be seen in a possible dialogic exchange between any pair of agents or discussants as figuratively embodied in the linguistic exchange of narratives. Exchanging my own stories between the participants of any kinds underlies second-person description. In the dialogical situation between any two parties, the rule applied there is that one party always monopolizes the chance of having a say on the scene while letting the other party listen to the one succeeding in grabbing that chance first. Taking turns at speaking is the rule adopted there. Even if the listening party is ready to start speaking, he would have to give up grabbing the chance for a moment once he finds the other party is faster in grasping the chance of starting speaking. That is retrocausal for the would-be late starter with respect to dismissing his prepared readiness of having a say for a while [10,11]. The listener going to take turns at speaking is to act for the present in the perspective viewed from the immediate future in the hopes of actually being able to take turns. That is to say, the listener is going to act in the immediate future for the sake of revising the present currently being shaped by the preceding speaker. Retrocausality is conceivable only when the present is open to its further revisions.

On the other hand, there is no such possibility as waiting for and seeking the chance of starting speaking once the discourse framed in third-person description happens to be adopted. The retrocausal action being exclusive to second-person description is unique in acting for the present in the perspective viewed from the immediate future, while the causal action addressable in third person description goes along with determining the tenseless future in the perspective from the present. Of course, the retrocausal action from the perspective in second-person description does not offend the third-person dictum as saying that the past cannot be changed at all in the perspective from the present since it has already been frozen in the record available to the present [12]. The past is an attribute of the verb whose subject has completed some action in an irrevocable manner. The past remains immune to any action from the present. Even errors made in the past remain as being an irrevocable fact in the perspective viewed from the present. In contrast, the present is susceptible to the action envisioned from the immediate future when the present is inclusive of those commitments towards the future that may allow for their further revisions. Thus, errors made in the past can be corrected by the concerned agents at the present in the perspective viewed from the immediate future under the provisional foresight such that their persistence without being attended may not be tolerated any further. Participation of anticipatory agents may make retrocausality irresistible.

The standard norm applied to the practice of doing empirical sciences allows for the contributions prepared by the descriptive authors having only one voice. No allowance is made for likelihood of the belated intervention from possible discussants carrying multiple voices into the finished text of any completed article. The prohibition of such belated interventions is customarily tolerated in the publication in the established discipline of empirical sciences or philosophy unless the article of concern is retracted for whatever reasons. This is so even if the contributions of the discussants are referable in the section of acknowledgments.

The bottom line is that the material basis of second-person description is sought in measurement dynamics. This is different from state dynamics that should be acceptable especially in physics under the condition that the effort of accommodating state dynamics to measurement dynamics may be suspended. There should be no argument against the proven competency of state dynamics in the physical world so long as the abstract notion called a state is taken for granted in whatever sense. In contrast, measurement dynamics anchored on second-person description would remain extremely clumsy. It cannot take advantage of the likelihood of the descriptive invariant of an abstract nature that state dynamics could enjoy. Put differently, an appraisal of second-person description in third-person description as being attempted right in the present article does require something equivalent to a descriptive invariant that may not necessarily be of an abstract nature.

5. Relating Second to Third-Person Description

One candidate for serving as the nexus concatenating second to third-person description may be to have recourse to referring to probabilities conditioned on the occurrence of the internal observers or agents accessible in second-person description. Introducing the notion called probabilities is equivalent to introducing some agents to whom probabilities may apply. The notion of probability has already been well established and worked out in mathematics framed in third-person description. In addition, conditional probabilities are also conceivable there. Once one pays due attention to them, it would become imperative to secure the participation of an observer that can set and identify the concrete nature of the conditions applied to probability. Of course, a mathematician can serve as a superb agent for setting such a condition to be applied to probability, but the agent setting various conditions is not limited to the mathematician.

What is required for the agents setting conditional probabilities is that the conditional probability of the occurrence of the internal observer itself must be unity. That is equivalent to saying that the internal observer can identify the conditions under which it may become durable. Consequently, if the internal observer happens to occur with probability unity within the framework of second-person description, it could also be referable as the durable agent as a type in third-person description by the external observer. The record available to the external observer could certainly confirm the invariability of the durable agent addressable in third-person description. The internal agent that may be durable could thus assume a dependable role of relating second- to third-person description. The durable agent, which may uphold its own first-person agency referable with use of an index in third-person description, can identify itself as going through second-person description.

In a similar context, a physician can identify the physiological conditions of a patient's wellbeing via an external inspection. The doctor's probabilistic diagnosis prescribed in third-person description certainly relates to the probabilistic physiological conditions maintained by the whole set of internal organs constituting the patient's body relative to the body staying alive and healthy. Since each organ is an agent, the interplay among the participating whole set of internal organs is directly approachable at most in second rather than in third-person description because of the multitudes of the participating internal agents. In contrast, no agents other than the descriptive authors are allowed in third-person description solely on the adopted methodological ground.

Although it may be possible to approach the population of agents in third-person description in terms of a probabilistic distribution, the notion of the population has already been subjected to an abstraction unique to the external observer standing by. The population of individuals may be conceivable only when each individual countable in the same unit remains indistinguishable among them on the methodological ground of an adopted abstraction.

On the other hand, if the notion of probabilities survives in second-person description, it would be imperative to see the participation of a durable agent relative to which the accompanied conditional probabilities may become conceivable. This is in parallel to the persistent presence of a mathematician who sets the conditions upon which conditional probabilities could be specified in third-person description. Thus, whether the durable agents addressable in second-person description could really be likely must totally be an empirical matter. Once the durable agents have turned out to be factual, they may certainly be addressed in third-person description. Nonetheless, this observation does not entail the occurrence of the durable agents guaranteed a priori theoretically in a manner of being accessible to third-person description. What third-person description can do in this regard is no more than referring to the consequence of the durable agents registered in the record. The registering agents are the durable agents themselves approachable in second-person description.

At issue must be how to figure out the occurrence of such durable agents strictly on the empirical ground. The role of the language here is simply in pointing to the durable agents already materially substantiated. One necessary condition for this task is that it is required to refer to some technical term of our linguistic origin that can have an indexical capacity pointing to something else. One typical example is something called temperature, which has been well established in the discipline called thermodynamics. What is specific to temperature is the indexical capacity of a material unit, sometimes called a thermometer, experiencing the environment it meets. While it may also be taken as a symbol representing the material context in thermal equilibrium, temperature can be more than simply being a symbol if the mixing up of both the usages, either as an index or a symbol, in an undisciplined manner happens to be avoided. In any case, both the merit and demerit of the technical terms adopted in empirical sciences may be found in the coexistence of both the symbolic and indexical implications in the same terms.

When we say that there is a dichotomy of a material participant and its covering environment in the quantum regime, it could also follow that the environment has the capacity of identifying the participant as its constituent member. The material means for such identification could be transference of the intervening quantum particles. Likewise, the participant experiencing its environment may come to interchangeably measure the temperature of the environment origin through its built-in indexical capacity. Each one of the dichotomies of any material participant and its covering environment thus comes to assume the agency of measuring the other. In order to proceed further, it would be required to figure out how the durability of the internal participant could be substantiated in the first place. After all, the covering environment comes to consist of such durable participants in the effect. What is required for the likelihood of those internal agents must be the material capacity of integrating both thermodynamics and quantum mechanics in a congruent manner [7].

At issue is the physical likelihood of second-person description required for addressing the interplay between thermodynamics and quantum mechanics. This inevitable recruiting of second-person description is due to the empirical fact such that both any material participant and its covering environment are the internal observers with use of measurement internal to each of them.

Internal measurement to be practiced by the participating agents thus comes to possess a unique temporality. When one agent measures any other one, the tense of the measuring agent differs from that of the agent to be measured. While the act of measuring is in the progressive tense, the tentative object to be measured must be registered in the perfect tense. What remains most primitive to internal measurement is its cohesive capacity of both generating and bridging the gap between the perfect and the progressive tenses [13]. Internal measurement is temporally cohesive in pulling the quantum particles from the body to have been measured into another body going to measure the counterpart. That generative and coordinative capacity extending over to different tenses, that is agential, is foreign to third-person description to be practiced strictly in the present tense.

The intrinsic affinity perceivable between internal measurement and second-person description is found in that both can exercise the capacity of concatenating the progressive to the perfect tense; that is, the temporality unique to second-person description, rather than to third-person description. Second-person description is in fact peculiar in distinguishing between the speaker and the listener. The speaker involved in the act of speaking is accessible in the progressive tense, while the listener who is attentive to what the speaker has spoken so far is alert to the speaking act registered already in the perfect tense. Moreover, the listener going to respond to the incumbent speaker would assume the role of the subsequent speaker if the chance happens to become available. There is an intrinsic affinity acting between the speaker and the listener while there is no such affinity available to third-person description. The alternation of the role of the discussant from the speaker to the listener and back is common in second-person description, while the speaker assumed by the single descriptive author having only one voice remains invincible in third-person description.

The descriptive author for any third-person description would have to be the durable dominant speaker abstracted from the underlying second-person description, as epitomized in the Kantian transcendental Ego. This abstraction of an invincible descriptive author does allow for no interruption from the possible listeners or critics during the act of developing the very discourse. Imperative to the present endeavor for grounding the durable descriptive author upon second-person description must thus be to point to the material capacity of harboring the internal agents with use of the indexical competence of our language. What is intended here should be to seek and then salvage the descriptive author from the durable internal observers that are at home with second-person description.

While practicing the indexical use of our language is first attempted in third-person description as we do in the present article, this attempt certainly differs from the symbolic use of our language [14]. Both the advantage and the disadvantage of symbols in language are found in that they can stand alone without recourse to any indexical means. The symbols can easily allow for their syntactic integration in a tenseless manner through their symbol manipulation as markedly demonstrated in the discipline called mathematics. Nonetheless, they remain indecisive and indefinite in relating themselves to the corresponding counterparts appearing in the empirical world.

In contrast, the indexical use of our language presumes participation of the authors who can relate themselves to something else out there, even with use of indexical reference alone while without recourse to symbolic reference. Furthermore, the relational capacity would not be limited to the language users like us. If the occurrence of the internal agents becomes likely with the indexical use of our language, the agents would also turn out to carry the indexical capacity of relating themselves to something else in the neighborhood. The indexical use of our language may be open to the potential for approaching the indexical activity of material origin as demonstrated in the operational procedure in the manner of faithfully following the written manual of an experimental protocol.

The outcome would simply be a self-consistency between the indexical capacity of our language user as a premise and that of the internal agents as a derivative. A common denominator is that both the language user like us and the internal agents to be derived are indexical in exercising their capacities. Then, the self-consistency would come to successfully be met and closed once we would admit that our language user could be a case of the derivable internal agents, though going through a long winding detour of a somewhat extraordinary nature. The detour is going to require first to start from second-person description as focusing upon the indexical capacity of material origin, then being followed by the indexical usage of third-person description, and finally to reach the first-person agency that can eventually be symbolized as a type. Of course, this observation has nothing to do with hailing the anthropocentrism. What may look like a metamorphosis of anthropocentrism is no more than an appreciation of the indexical activity of material origin.

An impending issue must be how to figure out the likelihood for the internal agents strictly on the material ground in which the role of our language is limited to its indexical use. A likely case in point may be chemical reactions available and ubiquitous in the empirical world since chemical affinity latent in reacting molecules is already indexical in finding and reaching the likely reaction partners.

6. Addressing Chemical Reactions in Second-Person Description

Chemical affinity is most evident in the contrast between any reactant molecule and its environment. When the parlance of quantum measurement is employed here, the detection of a reacting molecule by the environment is followed by the precipitation of the reaction product. That is in fact a consequence from setting up the quantum correlation as a prerequisite for upholding the measurement being realizable between the reactant and its environment. Setting up the quantum correlation is naturalized in chemical reactions.

Quantum measurement being ubiquitous in the material world of chemical origin is certainly a consequence from the intrinsic affinity acting between any reactant to be measured and the natural measuring apparatus of the environmental origin. Measurement of the environment origin is thus indexical in identifying the reacting molecule that can form a quantum correlation with the natural measurement apparatus available there in a bottom-up manner.

A typical example of such a formation of quantum correlation is the transformation of the initial reactant molecule with the help of the measurement capacity latent in the environment. The quantum measurement is the material activity of recruiting the quantum particles from the reactant molecule to be measured into the measurement apparatus of the environment origin. Accordingly, the synthesis of a transformed molecule thereupon is intrinsically an individual event. When there may be possibly more than one kind of transformation feeding upon the same set of the quantum particles, the most likely transformation to occur must be the one which is the fastest in the resource utilization. There must be no chance left for the latecomer since the quantum particles mediating the process of measurement remain indivisible. It is on a first-come-first-served basis. That is to actualize only the fastest out of the possible while necessarily trimming away the slower counterfactual conditionals without naming them as such explicitly. Of course, this exclusivity to the fastest alternative does by no means imply violation of the principle of linear superposition of the quantum wave functions that could be conceivable all on an equal footing strictly on the theoretical ground. For the likelihood for linear superposition of the wave functions must certainly be envisioned because of the adopted abstraction unless measurement necessarily of an empirical implication intervenes.

The reaction environment to any reactant assumes at least two different roles. One is indexical for identifying the reactant from which the quantum particles are transferred towards the environment as a regulative resource for making a new product accordingly. The other is for the actual material embodiment of the synthesis. What is unique to the interplay between regulation and embodiment is their sequential nature in processing. The material embodiment is to follow the regulation since identifying the material resource to be transferred sets the pre-condition for the embodiment. In this regard, classical mechanics is exceptional in setting both regulation and embodiment in a concurrent manner strictly on the adopted methodological ground.

When the law of motion in the form of an equation of motion is supplemented by its boundary conditions, the regulative means implicated by asking the boundary conditions at the same time is forcibly set to be concurrent with its application to the law of motion. This simultaneous assignment of both regulation and embodiment does not apply to the interplay between the actual reaction environment and any reactant inside there in the quantum realm.

Detection of any reactant by the environment is a material process that takes time. The instantaneous bird's eye view of everything included altogether may be conceivable only to the externalist such as the physicist exclusively on the theoretical ground. This observation limited to the externalist goes along with a reminder saying that third-person description as a dependable means for securing the externalist cannot get rid of the instantaneous bird's eye perspective towards everything. Exactly for this reason, second-person description appreciating a worm's eye perspective comes up to the surface. The internalist involved in second-person description is agential in locally implementing the actual deed for embodiment without presupposing such an instantaneous bird's eye view to the global extent. At issue would have to be how to secure the likelihood of the durable internalist to be precipitated from the environment.

Thus, it is rather ironical to address the agential role played by the environment in third-person description, which sets the descriptive author as the externalist to be acceptable as the sole agent. The obvious fact is that how the environment would come to detect a reactant could be revealed only after the event. The environment takes time for identifying what it is going to detect. The environment in and of itself is in fact agential on the spot because of its capacity of distinguishing between foresight and hindsight. This agential activity other than that due to the descriptive author is addressable in second-person description, while there is no doubt of descriptive accessibility to the completed consequence in third-person description.

To be sure, the material embodiment of the environment that has been completed remains fixed and global. Nonetheless, the on-going activity of regulation must be local in the sense that there is no regulation extending over to the global extent in an instantaneous manner. Quantum nonlocality may apply to the material embodiment whose regulation has already been completed and registered in the record, but not to the act of regulation right in the making. The act of regulation constantly poses the question of who or what in the world could be responsible for that action at all when, where, and how.

The response to those regulations coming from over the finite perceptual horizon to the internalist as the agent in the second-person status is in the activity of groping in the dark as constantly meeting unexpected surprises. A necessary condition for the likelihood of the agent in the second-person status is its durability even in the face of those inconveniences arising from groping in the dark. The durable agent must be the one that could identify the conditions making it durable as successfully discovering and implementing the scheme of necessary resource intake as outcompeting the counterfactual alternatives.

The dichotomy of any reactant molecule and its reaction environment does however raise a serious question regarding how to grasp the environment. One obvious stipulation is that the environment referred to in the present context is indexical as implying that the very environment as an object referable in second-person description must be durable and referable as a descriptive invariant even in third-person description. That is to say, if the environment is referable in both second- and third-person descriptions, it must be durable when approached in second-person description at the least. Such durable environment can also be referred to as a durable *type* in third-person description. The environment thus has the legitimate capacity of bridging the gap between second- and third-person descriptions. Such an environment carrying the agential capacity is, however, not conceivable in statistical physics addressable exclusively in third-person description. The statistical ensemble, whether it may be micro-canonical, canonical, grand-canonical, or whatever else for that matter, does not carry the agential capacity of changing the physical nature of the ensemble on its own.

The impending agenda is that when the dichotomy of any reactant molecule and its reaction environment is given, how one could come up with the environment that may be durable at least empirically. Crucial at this point is the material likelihood of an agential object referable as a descriptive invariant. This is by no means a theoretical issue addressable in third-person description. One plausible empirical example may be a material organization which can maintain its class identity while allowing for the constant exchange of the individual component elements of the same kinds.

When we use our language as a symbolic means, it would certainly be possible to symbolize the material organization supported by exchanging the component elements with use of a descriptive symbol called metabolism. At the same time, such material organization may look agential when we use the language as an indexical means. If each component element to be exchanged is referred to as an index, the agency of the indexical activity onto the individual component may be sought in nothing other than the material organization that constitutes the environment to that individual.

The distinction between the symbol manipulation and the indexical agency is subtle in the usage of our language, but its implication is decisive and far-reaching. In fact, the symbol manipulation allows for the descriptive author as the sole agent. Nonetheless, the indexical agency that is ubiquitous in the practice of second-person description has the potential capacity for constructing the material object to be symbolized in a bottom-up manner as processing each individual component.

The relationship between second- and third-person descriptions is neither dichotomous nor competitive. Second-person description is inclusive of third-person description in upholding the construction of symbols, which are badly needed for the descriptive enterprise for the latter, in a bottom-up manner. This observation is by no means a theoretical deduction upon an arbitrarily chosen premise, but is no more than an empirical likelihood. In a nutshell, precipitation of symbols and their syntactic integration conceivable on the verge of the origins of life in the material world, and since then, owes its likelihood to the indexical activities of material origin. We can also make access to such activities with the help of the indexical use of our language. Our effort for vindicating the first-person subjectivity as a symbol is originally sought within the indexical usage of our language in third-person description. In order to proceed further, more concrete explication by way of referring to examples should be in order.

In brief, let us imagine such a case that reactant A is going to be measured by its reaction environment E_A and is transformed into product B as also feeding upon the additional resources available from the outside if necessary. The measurement of A by the environment E_A proceeds through pulling the quantum particles constituting the individual A into E_A and is followed by the synthesis of product B thereof. In a similar vein, reactant B is successively going to be measured by its reaction environment E_B, which differs from E_A, and the synthesis of product C would follow if the synthesis of C is faster than the reversed reaction from B to A and any other competing reactions. As admitting the repetition of the similar sequence, further suppose that product Z is going to be measured by its reaction environment E_Z and the synthesis of A would be followed if it is the fastest compared to the other potential competitors. The net contribution would be completion of a reaction cycle as letting the synthesis of B in E_A cohesive directly to that of A in E_Z located at the remote-end point in the reaction sequence when it is followed along the forward direction, i.e., retrocausal cohesion. As a matter of fact, the retrocausal cohesion propagates backward as pulling in the products already made by the others in the immediate upstream.

The corresponding experimental observation has also been available. In the laboratory setting of the flow reactor simulating a hydrothermal circulation of seawater near hot vents on the ocean floor, it has been made possible to observe the operation of the citric acid cycle even in the absence of enzymes and co-enzymes of biological origin [4,15].

Crucial for the occurrence of the reaction cycle is that the reaction cycle referred to in third-person description at this point is simply an outcome of the construction referable in second-person description. The material embodiment of a reaction cycle could proceed without recourse to its linguistic representation available in third-person description [16]. Identification of the conditions for a likely reaction cycle to sustain its own indefinite duration owes the measurement capacity internal to the cyclic organization, which is itself accessible in second-person description. Furthermore, robustness of the organization may be thanks to each reaction step constituting the cycle that can steadily hold itself through the first-come-first-served basis for the necessary resources exploitations as trimming off the slower counterfactual conditionals.

There is no agent claiming for the bird's eye perspective of the whole reaction cycle in the operation accessible to second-person description. What is possible on the spot, on the other hand, is the indefinite spilling over of the dichotomous processing of any reactant and its reaction environment. The reaction environment may transform the previous reactant into a new one that can again serve as a new component for updating the reaction environment subsequently. The update may be repeatable ad infinitum unless disturbed otherwise. Emergence of a reaction cycle could be a natural consequence of updating the reaction environment from within. Second-person description is unique in implementing its temporality through the agential activity of updating. Repeated updates of the quantum correlation required for the quantum measurement underlies the durable reaction cycle in the temporality allowed for second-person description.

7. Naturalized Temporality

When one wants to figure out the nature of temporality addressable in third-person description in the present tense, it would turn out to be obvious that the temporality is already subjected to a specific stipulation. The notion of Now as the agency of coordinating and integrating different tenses within the descriptive object is forcibly marginalized in third-person description in the present tense. The now point, even though conceivable in third-person description like a mathematical point on a one-dimensional line, cannot be part of the temporal continuity, but rather serves at most as a boundary between successive parts of the continuum. Addressing the interplay between the different tenses conceivable within the descriptive object goes beyond the competence of the descriptive means limited to the present tense. Syntactic integration practiced in third-person description remains tenseless in the sense that once the integration has been completed, it remains non-temporal.

A typical example of such a tenseless integration is found in the standard practice of doing physics. Once one takes the global space-time coordinate system for granted, as is often the case with physics, the Now can find no room allocated for itself within the given coordinate system. As a matter of fact, the Now is punctual in distinguishing what has been completed. At the same time, it is also open and continuous to what is going to happen. The Now is specific in constantly updating its own agential capacity of making a distinction, as implying that the Now is the agency of filling the gap between discontinuity and continuity in the temporal domain. The Now is persistently durable in ceaselessly updating its concrete contents, while it is punctual in distinguishing the perfect tense from the progressive tense about its each content. Alternatively, each tense of the past, present, and future is no more than an abstraction from the Now. The eternal Now could thus survive unless the constituent concrete particulars are taken over by an abstraction.

Insofar as the space-time coordinate system is fixed, on the other hand, there must be only one clock to be read out as a reliable standard reference. The role of such a reliable clock is to let the time-coordinate to be assigned to whatever moving body be definitive all through the coordinate system. In fact, the time-coordinate is a remarkable artifact exercising the brutal force for letting us easily conceive of both the continuous flow of time and its discrete punctuation anywhere on it without giving any further physical justification. Once the time coordinate is introduced, the issue of letting an instant come to terms with duration or the Aristotelian aporia on how to obtain consistency between discontinuity and continuity could totally be dismissed simply by declaration. This has been a major issue of the Einstein–Bergson public debate in 1922 in Paris [17]. In fact, there is a significant difference between an actual temporal punctuation on the concrete level practiced by whatever agents accessible in second-person description and a meta-level punctuation anywhere on the time coordinate easily imaginable and acceptable to the physicists in third-person description [18].

A merit of the meta-level punctuation is found in that it presumes the flow of time beforehand as dismissing the Aristotelian aporia simply by decree. Instead, the agential punctuation comes to yield the flow of time only in the effect after the punctuational events as processing different tenses at the moment of Now. In fact, there is no likelihood for the Now as the agency for coordinating and integrating different tenses to emerge in the single coordinate system lacking tense attributes. There should be no need there for worrying about whether a given time point belongs to either the past, the present, or the future.

The absence of the Now also applies to two different coordinate systems in which one is moving relative to the other under the reliable empirical constraint such that the speed of light remains invariant whichever coordinate system may be focused. If one coordinate system is moving almost near at the speed of light relative to the other system at rest, the clock proper to the fast-moving system comes to proceed extremely slowly compared to another clock proper to the one at rest. There is no need of referring to the Now for the comparison. The issue of the Now remains irrelevant even in the present relativistic framework of the space-time coordinate systems when the allowable agent is limited exclusively to the single descriptive author who must be the physicist.

On the other hand, the issue of the Now would become most acute and relevant once more than one agent can intervene on the scene. It would become a serious matter to ask whether your Now and mine are the same when both of us are a bit separated in space. The difference between the Now of yours and mine reveals more than what the relativity of simultaneity would imply. At issue should be the concrete empirical contents of each Now.

To be sure, the relationship between the regulation initiated by one party and its perception by another party in the neighborhood is necessarily sequential rather than being simultaneous since nothing propagates faster than light. It is thus common to observe: "You do not yet receive my message that I have just sent out to you." If the message is a proposal of the delay of the appointment of a meeting, I would have to adjust and update my previous schedule already set accordingly. The second-person description addressing the adjustment of a meeting appointment thus accommodates itself to a peculiar temporality to which third-person description controlled by the single descriptive author remains incompetent in properly coping with. That is a revision of the previous commitment that has already been done.

The moment of the Now specific to the practice of second-person description is unique in maneuvering its capacity of letting different tenses be invited to meet there for their mutual adjustment. That is retrocausal in the respect of revising the present in the perspective envisioned from the immediate future. Of course, the present appraisal of the retrocausality unique to second-person description does not offend Kantian causality attempted in third-person description in any sense of words in the service of guarding the intended transcendental epistemology. Kantian causality set as a metaphysical pre-condition for making our experiences comprehensible for us may remain invincible insofar as the single descriptive author dubbed as the transcendental Ego can monopolize the practice of third-person description [19].

In a nutshell, retrocausality is to second-person description what causality is to third-person description. Retrocausality is dialogic while causality is monologic. Retrocausality is empirical while causality is metaphysical. Praising retrocausality in third-person description is an oxymoron, whereas retrocausality of itself is legitimate and ubiquitous in second-person description. It is thus the rule rather than the exception for one agent to nullify or disqualify the previous commitment as facing the updated commitments by the others in second-person description. Instead, there should be no such revision of the commitments allowed for once completed by the single author in third-person description [12].

The past cannot be changed nor acted upon in the present in third-person description since it has been registered in the record that is referable in the present tense as already being completed and frozen there. Nonetheless, the present can be acted upon in the perspective viewed from the immediate future in second-person description [18]. In the dialogic exchange, the utterance completed by one party at the present moment of Now turns out to be the reference that is going to be followed and addressed by the other party in the immediate future. The dialogic exchange is thus unique in integrating the utterer and the follower in a somewhat coordinated manner even though they live in different tenses at the present moment of Now. The follower is constantly following what the utterer has uttered. What is more, a pressing issue at this point will be a possibility of making our experiences more comprehensible as referring to the service of second-person description.

The relationship between second- and third-person descriptions is by no means antagonistic. If there were no use of referring to second-person description, the time-honored practice solely with use of third-person description in any theory would lose nothing by dismissing the potential role to be assumed in the body of second-person description. The obvious fact, however, witnesses just the contrary. If one can find a durable agent as practicing our language in the mold of second-person description, it may make access to a harbinger of the descriptive author acceptable to third-person description because of the invariable durability of its identity. Precisely for this reason, the issue of the origins of life would become decisively relevant here. The focus of attention would have to be on the likely emergence of durable agents through practicing our language in second-person description as having recourse to the indexical use of the language alone.

Although it may look plausible and also attractive to address naturalized temporality in third-person description in the present tense [20], this attempt would end up with a metaphysical exercise at best or self-defeating at worst. Metaphysics does not require factual evidence for its own sake even though the chance to be supplemented with supportive factual evidences, if any, must be most welcome.

When the descriptive object carries some implication referable in the tenses other than the present tense, referring to tenses other than the present tense in the present tense is inconsistent unless being supplemented with the additional present tense on the metaphysical level. Although one can admit the noun "yesterday" as the predicate referable in the present tense, the subject "yesterday" carries a multitude of the concrete contents unique to the past tense. Of course, we can say "Yesterday's tomorrow is today" in the present tense as a meta-level predication of the predicates of yesterday, today, and tomorrow. Despite that, no meta-level discourse can directly touch upon the empirical concreteness. One drawback with third-person description is to mix up both concrete-level and meta-level discourses quite easily in an undisciplined manner.

It then turns out to be obvious that the concrete content of each of yesterday, today, and tomorrow is about memory, experience, and anticipation, respectively. Admittedly, though, we cannot say "Memory of an anticipation is an experience" on the concrete or token-reflexive object-level [21,22]. There should be no likelihood of conceiving of the tense-sensitive temporality within the framework respecting the tense-insensitive temporality limited to third-person description exclusively in the present tense.

It is one thing to advocate naturalized temporality in third-person description on the metaphysical level, but is quite another to justify it on the physical or empirical level. Metaphysics would remain equivocal at best so long as its evidence to be sought on the empirical ground remains uncertain. Likewise, it would be of no use to charge tense-less nature of the physical world simply as being metaphysical on the ground of seemingly naturalized temporality addressable in third-person description. No conflicts between two competing metaphysics can be removed by introducing the third metaphysical alternative. Appraisal of naturalized temporality on the empirical level can be saved and found in the practice of second-person description that is tense-sensitive.

8. Either Tenseless Time or Tenses

An essence of the Einstein–Bergson debate in 1922 is on which is more appropriate to start with, either tenseless time or tenses, for addressing empirical issues. Einstein rejected the priority of tenses advocated by Bergson as saying that Bergson does not know physics, whereas Bergson charged that Einstein in favor of the priority of tenseless time must be a metaphysician [17]. The aftermath of the debate has still been reverberating even now under the rejuvenated guises. One might conceive of the likelihood of the internal observers to appear in the empirical world if it can be modeled as part of a huge block universe admitting only tenseless time. However, this effort is self-defeating. The initial premise of tenseless time is negated by the consequence of the emergence of the internal observers acting as agents which are competent in distinguishing between different tenses.

If the internal observer capable of gathering and utilizing information is likely in the totally closed block universe of quantum mechanics, some additional assumptions in favor of raising a quasi-classical domain amenable to the act of measurement would have to be called for [23]. One relevant issue requiring further scrutiny must be how both the unitary quantum dynamics and measurement of single outcomes could meet Born's probability rule. In particular, whether the initial premise of tenseless time conceived in quantum information could survive may still remain unsettled when the internal observers, such as the Wigner's friend or friends in the laboratory, are additionally allowed to intervene in the process [24].

A similar charge would also apply to the classical example of Maxwell's and Boltzmann's Stosszahlansatz or the hypothesis of molecular chaos in the gas as employed for precipitating statistical mechanics out of mechanics. The backbone of mechanics is sought within the block universe model admitting only tenseless time. The hypothesis of molecular chaos is about a negative expression of the agential capacity latent in each molecule in the gas, implying that each molecule loses the memory of all the past collisions with the others except for only the most recent ones. Again, the initial premise of the tenseless time supporting the block universe model is negated by referring to the memory being capable of addressing the distinction between different tenses.

If the theoretical hypothesis of agential material bodies additionally introduced into the original block universe model is more than just a theoretical artifact, it would be required to reflect upon the soundness of the initial premise of tenseless time once again. Nonetheless, we may meet an enormous difficulty if it is attempted to address this issue in third-person description being faithful to syntactic integration practiced in tenseless time. It would be of no use to examine the soundness of tenseless time in the discourse already accepting tenseless time. One alternative for circumventing this difficulty may have recourse to second-person description which can allow for the participation of a lot of possible agents distinguishing different tenses from the start. One practical appraisal of second-person description is found in figuring out a workable protocol of conducting de novo experimentation, say, for the sake of the study of the origins of life, instead of being involved exclusively in theory alone.

9. Concluding Remarks

The standard tradition of doing empirical sciences duly pays a legitimate attention to observing third-person description. However, this stipulation may sometimes stifle our sincere efforts towards addressing important empirical issues.

One such example is something called consciousness. At the heart of the issue of consciousness is the dichotomy of the conscious being and the descriptive author. The exchange between the two agents may be approached in the dialogic discourse between the two to be practiced in second-person description. If the monologic discourse controlled by the single author were to dominate on the scene, the conscious being that could potentially be conscious of the descriptive author as an invincible counterpart may methodologically and forcibly be dismissed. Third-person description is put under the queer condition of limiting the conscious being only to the descriptive authors themselves. The standard practice of doing empirical sciences in third-person description, whether in the classical or the quantum realm, necessarily dismisses the legitimate participation of the experiencing subject as a genuine subject matter. Asking what being conscious is all about exclusively in third-person description may end up in a pseudo-question.

One more example of this sort is something called qualia referring to individual conscious experiences. Again, there can be observed the dichotomy of the two agents, in which one is the conscious being out there and the other one is the descriptive author who is curious to know what consciousness is all about.

The common agenda must be how to vindicate the emergence of durable plural agents of whatever kind, in which one agent at the least is the descriptive author. The supporting descriptive vehicle could be second-person description that our language can afford in its latent potential. In other words, it may be conceivable to imagine some experimental procedure for raising a material organization which can identify the condition for making itself durable from within. If the protocol of such an experimental procedure is likely to be implemented linguistically, the outcome could be to accommodate the indexical usage of our language to a naturalized empirical outfit of material origin.

Our appreciation of second-person description on the empirical level may be approachable through the indexical usage of our language. Even physics could already be implicitly experiential enough in admitting the indexical activity arising from the material activity of specifying and identifying initial-boundary conditions from within. A decisive issue in this empirical endeavor is how to reach the threshold beyond which the indexical scaffolding of our linguistic origin could naturally be made conducive to emergence of the material organization durable on its own indexical activity. That is a naturalization of second-person description, which abides by the standard protocol of doing experiments. The origins of life approachable on the empirical basis must be the most significant instance among those alternatives indicating the competence of second-person description to be naturalized.

An advantage of second-person description in the practice of empirical sciences is to skillfully circumvent an Aristotelian difficulty of ameliorating the gap between instant and duration to which the standard third-person description is inescapably vulnerable.

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Article

Dimensions Missing from Ecology

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Abstract: Ecology, with its emphasis on coupled processes and massive heterogeneity, is not amenable to complete mechanical reduction, which is frustrated for reasons of history, dimensionality, logic, insufficiency, and contingency. Physical laws are not violated, but can only constrain, not predict. Outcomes are predicated instead by autocatalytic configurations, which emerge as stable temporal series of incorporated contingencies. Ecosystem organization arises out of agonism between autocatalytic selection and entropic dissolution. A degree of disorganization, inefficiency, and functional redundancy must be retained by all living systems to ensure flexibility in the face of novel disturbances. That physical and biological dynamics exhibit significant incongruencies argues for the formulation of alternative metaphysical assumptions, referred to here as "Process Ecology".

Keywords: agonism; apophasis; autocatalysis; centripetality; contingency; endogenous selection; heterogeneity; indeterminacy; process

1. A Clash of Scientific Cultures?

Ecology, although it deals directly with plants and animals, is more fundamentally the study of relationships within an ensemble or community. Now, the study of relationships among many disparate types is rarely a theme in physics, which concentrates primarily on collections of homogeneous objects acting according to universal laws [1]. While physics can certainly inform other disciplines, there is growing recognition that adequate treatment of heterogeneous interactions is missing from many fields of science and that ecology might provide a more comprehensive framework in which to study them. Witness the journals "Ecological Psychology" and "Ecological Economics" or books on "The Ecology of Mind" [2] and "The Ecology of Computation" [3]. Even evolutionary theory has been ordered in procrustean manner to follow the norms of physical theory. "Natural selection" is almost always considered to originate external to a population or a system and marginal attention is paid to the effects of interactions within the living community. Such insufficient emphasis upon collections of relationships has caused many to worry that the status quo in science could be leading society towards catastrophe [4].

In the late 1970s, Eugene Odum [5] presciently argued in a position paper for *Science* magazine entitled, "The Emergence of Ecology as a New Integrative Discipline", against obligate reductionism as an inadequate tool with which to address the natural living world. Ecology, which offers the possibility of top-down causality, provides the gateway to a fuller understanding of nature, he suggested. Years later, he personally related to this author that his intention in this essay was to propose that ecology replace physics as the central focus of ongoing science and even suggested that the metaphysical grounds of ecology probably differ from those of Enlightenment science.

Odum's posture contrasts markedly with the later assertion by Nobel Laureates Murray Gell-Mann, Stephen Weinberg, and David Gross that "all causality originates from below and that there is nothing 'down there' but the laws of physics" [6]. Today, if one surveys the literature, it would appear that Odum has lost out to those who believe that simply by compiling mechanism upon mechanism, one eventually will achieve a full understanding of ecological dynamics.

The argument here is that the dream of complete "mechanical reductionism" is a minimalist ideology. The contemporary focus in ecology on objects and mechanisms obscures perfectly natural dimensions that arise once one adopts a vision of ecosystems in terms of their constitutive processes [7].

2. Stumbling Blocks?

Space will permit only superficial mention of the problems associated with pure reductionism, and these include history, dimensionality, logic, insufficiency, and contingency. To begin with an historical aside, it is noted how Isaac Newton never presented his second law in its familiar form: force equals mass times acceleration (F = ma). That formulation belongs to Leonhard Euler, who saw the world as a continuum. Newton's statement, by comparison, was discrete and irreversible, and he argued strenuously against the continuum assumption, because it equates cause with effect [8]. The ensuing mathematics of Leibniz and Euler gave rise to a physics of "objects moving according to universal laws". Ecology, however, is intended to focus, not upon objects, but on relationships, most of which appear as irreversible **processes**. Processes explicitly involve time and thus cannot be fully characterized by the time-reversible force laws of physics.

In addition, there is the logic underlying the laws of physics, which Whitehead and Russell [9] demonstrated is irrevocably grounded in operations on homogeneous sets. Physics is all about homogeneous tokens. Biology, by contrast, involves **heterogeneity**—in fact massive heterogeneity [1,10]. The problem posed by heterogeneity is that the combinations and possibilities among differing types quickly become hyper-astronomical. Walter Elsasser, for example, showed how the number of combinations among 75 distinguishable types exceeds how many simple events could possibly have occurred anywhere over the whole duration of the known cosmos.

This enormity of possible combinations hampers efforts to represent heterogeneous systems in terms of homogeneous laws. One cannot simply write separate equations that govern each different type without running into major complications posed by combinatorics during the formulation of the boundary-value conditions. Stuart Kauffman [11] refers to such boundary-value complications as "unprestateable". His simplistic example of the problem is his challenge to enumerate all the possible uses of a screwdriver. Of more biological interest is the exaptation of an organism structure to some purpose other than the one under which that structure has developed (e.g., a lung transforming into a swim bladder).

But the inability to pose adequate boundary conditions is a matter of epistemology. It might still be possible that the laws of physics determine all outcomes, even if one remains incapable of formulating the problem. But the predictive ability of the laws is also challenged by heterogeneity. Massive heterogeneity usually results in a very dense array of combinations of very small differences arbitrarily near to any chosen starting condition. Whence, infinitesimal noise, at the level of the continuum assumption, can send the system onto a number of possible trajectories. All such pathways will continue to satisfy the law, but which one will manifest itself remains indeterminate. That is, the laws are not broken, they continue to constrain what can possibly occur, but beyond some degree of heterogeneity they lose their power to determine particular outcomes. They constrain but can no longer predict particular outcomes.

The mention of noise, however infinitesimal, introduces the role of **contingency** in influencing outcomes. Here it is useful to avoid the word "chance", because that term conventionally is applied to events that are simple, directionless, indistinguishable (homogeneous), and repeatable—assumptions that permit the application of standard statistical analysis. Such requirements, however, encompass only a small fraction of the much wider spectrum of contingencies. Elsasser [10], for example, argues that the number of compound events that can arise is so enormous that many will be *unique* over all space and time.

Obviously, such unique events are more radical than blind chance, whereas other forms of arbitrary phenomena can occur under increasing degrees of constraint. Conditional probabilities, for example, refer to events that exhibit some degree of bias in directions that are influenced by surrounding events. Such bias can grow quite dominant, resulting in almost law-like *propensities* that yield the same outcome in a large preponderance of instances [12]. Hence, we see that there exists an entire spectrum of contingencies, ranging from radical unique happenings through blind chance to conditioned outcomes to propensities that border on determinism.

3. Origins of Order?

It follows that the notion of complete mechanical reductionism *fails rational scrutiny*. But if physical laws can only constrain, what then does determine and maintain the obvious order we observe in living systems? Here it becomes tempting to identify the material genome as that which creates and sustains order. Material causality, however, is a poor basis for dynamical agency. The goal in ecology is to focus on processes, and especially upon configurations of processes. Descriptions of living systems are far better accommodated in terms of processes than as objects moving according to laws. [13]. Furthermore, processes, with their innate indeterminacy, interacting with the complexities of contingencies, become capable of providing the agency behind development and evolution. In particular, attention must be paid to chains of irreversible processes that fold back upon themselves—feedback loops that by their very nature defy the closure restriction of Aristotelian logic [14].

Among feedback configurations, one type deserves special attention—that of **autocatalysis**. An autocatalytic cycle is one wherein every constituent process (link) benefits its succeeding one. Such serial mutual beneficence grows whenever any component process becomes more beneficial to its successor and it declines whenever any benefit diminishes. The result is a ratcheting dynamic that will promote those changes that benefit the ensemble—a form of *endogenous* group **selection** [15,16]. Furthermore, because living entities always require energy and materials to survive, such selection will favor any change that augments the acquisition of resources. Such a contribution can be made by any member of the cycle, cumulatively resulting in ever greater flows of resources into the loop, or what might be called "**centripetality**". None other than Bertrand Russell [17] identified this dynamic as "the drive behind *all* evolution". Centripetality, after all is what induces competition. If two independent autocatalytic configurations exist within a field of resources, their respective centripetalities will grow eventually to intersect one another, the group that builds faster under prevailing contingencies will come to dominate or extirpate the other in a form of group selection. Competition is thereby seen as secondary. It cannot occur at any level unless active mutual beneficence is already transpiring at the next lower level [16].

To summarize thus far, physical laws and ubiquitous contingencies do not appear adequate to promote and sustain living systems. Ensembles having only those dynamics are more likely to fall apart and decay. Fortunately, combinatorics also make it highly likely that autocatalysis will arise among any sufficiently complicated collection of processes [18]. When autocatalytic selection and centripetality are combined with system memory, then growth and development become possible, such that the members of an autocatalytic system are constantly exposed to arbitrary contingencies. Most such disturbances do not affect the system in any significant way. Some are harmful enough to degrade system performance and survivors will adopt responses to redress such perturbations. A small minority of contingencies will enhance mutual beneficence, and memory can then incorporate such changes into a more developed system dynamic.

4. A Non-Random but Indeterminate World?

Two caveats are pertinent to this scenario. Firstly, it is not necessary that memory initially be vested in material objects (such as RNA/DNA). Ensembles of processes can take on very stable configurations that can serve as memory until such time as a material structure might appear to record memory. Terrance Deacon [19], for example, believes that the precursors of RNA originally performed some function like energy storage and/or transfer and only later were exapted to serve as a memory repository. Secondly, the scenario naturally develops a perceptible direction, although that course is always subject to change as a consequence of later contingencies.

One can characterize the developmental scenario as proceeding in a nonrandom, but indeterminate fashion. Now, "nonrandom and indeterminate" sounds at first like an impossible combination, but its palpability can be illustrated through a metaphor used by physicist John Wheeler [20] to describe the development of science:

Guests at a party decide to play a parlor game. One individual is sent out of the room, while the others choose a particular word to be guessed by that individual. Upon returning to the room, the subject questions members of the group in some loose rotation. Responses to the questions are limited to a simple binary "yes" or "no". As soon as the questioner leaves the room, one guest suggests that the group *not* choose a word. Instead, the first respondent can answer 'yes' or 'no' on unfettered whim. Similarly, the second person is at liberty to make either reply, the only constraint being that his/her answer may not contradict the first reply. Similarly, the succeeding answers may not contravene any of the previous answers. The game ends when the subject asks, 'Is the word XXXXX?' and the only possible response is 'yes'. At any time this game is nonrandom, being dependent upon the previous history of questions and answers. The end result, however, cannot be predicted at the outset.

5. A Fundamental Agonism

Serendipitously, the game metaphor also illustrates a second important feature of natural development. The exercise takes the form of a conversation, where the questioner seeks to narrow the realm of possibilities, while the respondents endeavor to broaden the field with each answer. Such **agonism** between ends is usually characterized as dialectic. The analogous natural agonism pits structure-building processes, such as autocatalysis, against entropic disorder and decay.

It has long been postulated in evolutionary circles that living systems progress towards ever more efficient configurations. Data on ecosystem trophic transfers, however, reveal that such progression is dramatically limited. It is possible, using information theory, to quantify both the efficient organization of a network of processes as well as its complementary (and mutually-exclusive) measure of its disorganization [21]. The data on values of organization/efficiency cluster around a level that is significantly below what is imaginable, and disorganization exceeds order by a reasonably constant ratio of 60:40 [22]. Exactly why this particular ratio is favored remains unknown, but the necessary persistence of disorganization, or *lack* of constraint, owes to the fact that the measure of disorganization also reveals trophic functional redundancy [23,24], which becomes necessary as "insurance" if a system is ever to recover from a novel perturbation.

6. The Missing Missing

Quantifying **apophasis**, or that which is missing, is virtually absent from physics, which is built almost entirely upon positivist objects [2]. Now, reckoning what is nonexistent is not as nonsensical as it may first seem [25] (Consider, for example, a glass that is half-full). Suffice it to point out that some degree of apophasis is necessary to enable the flexibility of every living system to persist. Biodiversity, for example, was first related to apophasis by Robert MacArthur [26], when he used the formula for *statistical* entropy to quantify it. That biodiversity is at its core an apophasis, clarifies why no positivist model has been able to justify its necessity for sustaining living ensembles. When one compares the biodiversity of an ecosystem with is trophic functional redundancy (a kindred apophasis), one discovers that the two are poorly correlated [27], underscoring the necessity for an alternative measure of system sustainability.

It should be noted that entropy, as it was originally defined by engineers, is pure apophasis, which is why so many have great difficulty apprehending the concept. It is also necessary to realize that the causal action of apophasis is very different from that of an active determining agency, such as the selection pressure exerted by autocatalysis. Entropy does not push or constrain, it withdraws or disappears. The result, more often than not, appears in a negative light as dissolution or decay, but alternatively can also manifest itself as opportunity. It is thus necessary to reflect upon the significance of the maximum entropy formulism when applied to ecosystem behavior [28]. In any event, attempting to understand ecosystem dynamics without any regard for apophasis is like observing nature with one eye shut.

7. An Alternative Metaphysics

It should be apparent that the dynamical narrative sketched here significantly challenges the Enlightenment metaphysics that has undergirded science for at least three centuries. Fully apprehending living nature requires an alternative and complementary **metaphysics**, which [7] has been called "Process Ecology".

Odum's proposal to pursue a single new dimension in ecology (top-down control) seems modest in comparison to the eight new directions that have been presented above. Unfortunately, experience has taught this author that some entrenched authorities, who cling irrationally to a mechanism-only ideology, will viciously attack and seek to censor all attempts to push the edge of the ecological envelope. This is not to say that new mechanisms won't continue to be discovered that will add pieces to the ecological puzzle. The prospect, however, is that their importance will pale in comparison to the incredible richness that ecology can uncover in developing directions that relate only remotely, if at all, to the realm of physics.

How then to proceed in the near future? Perhaps it might be helpful to take a page from the playbook of the engineers, who very often are contracted to work on problems for which no clue exists as to the underlying dynamics. The system is then regarded as a "black box" and the operative approach is one of phenomenology. That is, combinations of measurable parameters of the system (preferably chosen to have dimensionless units) are examined for either constancy or repeatable patterns of change across differing systems. A constant, such as the balance point between organization (40%) and disorder (60%) mentioned above, is indicative of an ordering principle that begs for further investigation. Similarly, a repeatable pattern of change exhibited by a parameter or group of parameters would hint at a law-like principle that likely would prove useful in ecosystem management. With eight new dimensions to explore, such a search is likely to yield significant new insights.

In any event, the time is ripe for ecology to advance to center-stage and become the "new integrative discipline" for the science of life.

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Essay

The Utterly Prosaic Connection between Physics and Mathematics

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Abstract: Eugene Wigner famously argued for the "unreasonable effectiveness of mathematics" as applied to describing physics and other natural sciences in his 1960 essay. That essay has now led to some 58 years of (sometimes anguished) philosophical soul searching—responses range from "So what? Why do you think we developed mathematics in the first place?", through to extremely speculative ruminations on the existence of the universe (multiverse) as a purely mathematical entity—the Mathematical Universe Hypothesis. In the current essay I will steer an utterly prosaic middle course: Much of the mathematics we develop is informed by physics questions we are trying to solve; and those physics questions for which the most utilitarian mathematics has successfully been developed are typically those where the best physics progress has been made.

Keywords: mathematics; physics; philosophical foundations

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1. Background

Mathematics is simply a way of codifying, in an abstract manner, various regularities we observe in the physical universe around us. Many trees have been sacrificed on the altar of obfuscation, in an attempt to make the situation appear more excessively mystical than it ultimately is. The problem is not with mysticism *per se*, but with excessive mysticism used as a tool to obfuscate—and to disguise limited competency and charlatanism or worse.

I shall argue that the apparent "unreasonable effectiveness" of mathematics in the natural sciences [1] is largely an illusion; there is a quite natural back-and-forth between mathematics and the natural sciences—a dialectic—whereby some branches of mathematics are preferentially worked on because they are so useful for the natural sciences, and some branches of the natural sciences make great leaps in understanding because the related mathematics is so well developed. This does not, however, mean that progress occurs in lock-step—sometimes mathematical formalism out-runs what the natural philosophers can measure/observe; sometimes the experimental/observational abilities of the natural philosophers out-run what the mathematicians can usefully analyze. Sometimes, (even in the modern world), progress can be out of phase by decades, (more rarely, even by centuries).

One of the great success stories in this back-and-forth has been the development and flowering, in the decades and centuries since 1666, of the differential and integral calculus; this was largely (and with due acknowledgement to the sometimes fractious and tendentious behaviour of some of the personalities involved) a collaborative effort between the natural sciences and the mathematical sciences. While it took decades to develop useful computational tools, it took almost a century and a half to make everything mathematically rigorous. One can still meaningfully argue over the precise experimental/observational relationship between infinitesimal calculus and empirical reality [2], but there is absolutely no doubt that infinitesimal calculus is pragmatically extremely useful over an extraordinarily wide range of situations. The *continuum* of differential calculus is currently, and for the foreseeable future is likely to continue to be, a key component in our understanding of physical aspects of empirical reality. [1]

In contrast the *discretium* of the discrete mathematicians has had lesser direct impact in physics itself, instead having more direct applications in computer science, (particularly, algorithm analysis), operations research, and to some extent in the social sciences. Again, in those fields, there is considerable back-and-forth between practitioners in those fields, and mathematicians either developing the relevant mathematics, or playing catch-up by codifying, making rigorous, and justifying empirically derived heuristics.

2. Quantum Conundrums

Quantum physics is another scientific enterprise where there has been much back-and-forth between the mathematics and physics communities. Some of the physicists founding the field of quantum physics had very pronounced mystical leanings [3,4], which in the hands of true experts is not necessarily a bad thing. In the hands of lesser mortals however, mysticism can often lead to unnecessary and excessive obfuscation [5].

2.1. Quantum Pedagogy

The notion of "quantum complementarity" is often phrased in terms of a quantum object being either a wave or a particle, but never both at the same time. This specific notion of quantum complementarity is seriously defective—and in my opinion close to vacuous—it is less than clear what is actually being asserted. A more nuanced version of quantum complementarity is the more precise and sensible physics statement that whenever two quantum observables (Hermitian operators) do not commute, then approximate knowledge of one observable constrains the extent to which one can determine the other—but I have no idea how to convert the phrases "this quantum object is a particle" and "this quantum object is a wave" into Hermitian operators acting on Hilbert space. This more nuanced version of quantum complementarity is effectively a variant of the Heisenberg uncertainty relation.

But the Heisenberg uncertainty relations (as commonly presented) suffer from their own level of excessive mysticism and obfuscation. A distressingly common (but utterly infantile) confusion is to treat the words "quantum" and "non-commutative" as though they are synonyms; they are not. There are many non-commutative objects in both mathematics and physics that simply have nothing to do with quantum effects; the two concepts overlap, but are by no means identical.

Perhaps worse, there is also a distressingly common misconception that "uncertainty relations" are intrinsically a quantum phenomenon—utterly ignoring the fact that engineers have by now some 60 years of experience with utterly classical time-frequency uncertainty relations in signal processing, and that mathematicians have by now over 80 years' experience with utterly classical time-frequency uncertainty relations in Fourier transform theory. The "central mystery" in quantum physics is not the Heisenberg uncertainty relations—the central mystery is instead de Broglie's momentum-wavenumber relation $p = \hbar k$, and Einstein's energy-frequency relation $E = \hbar\omega$. It is these relations, which

[1] An example where physics/engineering led mathematics (by about two decades) was Fourier's study of heat transfer, which led to the introduction of Fourier series in 1807, followed by rigourous mathematical work by Dirichlet in 1829 to confirm existence and convergence of these series under suitable conditions, followed by wholesale adoption of these techniques by the physics/engineering/applied mathematics communities. Similarly, a six-decade example was initiated in the late 1890's with the Heaviside calculus, which led to Dirac's delta functions, which were then not made fully rigorous until mathematicians developed Schwartz distribution theory in the 1950s. In counterpoint, an example where mathematics led physics was with the development of Riemann's differential geometry beginning in the 1850s, a mathematical structure that was then adapted by Einstein in 1915 to set up his general theory of relativity, again a six-decade timescale.

inter-twine the particle aspects of the quantum object with the wave aspects, and so lead to the concept "wavicle", that are utterly central to the quantum enterprise. [2]

Finally, let me mention "tunnelling"/"barrier penetration". Despite yet more common misconceptions, tunnelling is a simple wave phenomenon; it is not (intrinsically) a quantum physics phenomenon. Under the cognomen "frustrated total internal reflection", (see Appendix A.2 for details), the classical tunnelling phenomenon has been studied and investigated for well over 300 years, with the wave aspects (the "evanescent wave") coming to the foreground approximately 150 years ago, well before the formulation *circa* 1900 of even the most basic of quantum concepts (Planck's blackbody radiation spectrum).

Now the examples I have been discussing in this last subsection are, properly speaking, neither problems of physics nor problems of mathematics—they are problems of pedagogy and presentation. They should serve to remind us that some thought should be put into communicating clearly; not necessarily precisely. (Excessive precision is the hobgoblin of small minds; as anyone who has ever taught first-year calculus or first-year physics can attest—clarity is typically more important than hyper-technical precision.)

2.2. Quantum Foundations

So where are the "real" open problems in quantum physics? There are certainly many technical problems in (relativistic) quantum field theory (see below), but the truly foundational open issues have to do with the so-called "measurement problem" and the "collapse of the wavefunction"; issues that continue to plague quantum physics even after some 90 years. This is a physics problem, not a mathematics problem, and almost certainly will not need "new mathematics" for its resolution. Despite multiple and very loud claims to the contrary, quantum decoherence is simply not enough.

At best, quantum decoherence might reduce quantum amplitudes to classical probabilities—but this is still missing the last essential step—"reification" the "making real" of one specific outcome, one specific unit of history. Quantum physics in its current state simply cannot explain history—the observed fact that (as far as we can tell) the universe really does have a single unique history. If one takes the usual Feynman "sum over histories" seriously, then (without some realist solution to this problem) the notion of a single history simply does not exist. While I am sure that there are many political operators (from all over the political spectrum) who would like to use (abuse) quantum physics to undermine the notion of objective history, (and so undermine historical responsibility for past actions), at some stage one simply has to pay attention to observed reality and the historical record. Normally the "measurement problem" is phrased in terms of outcomes for future experiments; but philosophically, (and also in terms of the underlying physics), it is the past that is the crucial issue.

Without some real physical mechanism for the "collapse of the wavefunction", there simply is no physical basis for the notions of memory, or history, a circumstance which then utterly undermines (even as an approximation) any notion of classical physics and the very notion of causality. [3]

To have a notion of definite history one needs, at the very least, a dense network of classical collapse events, densely spaced in both space and time—at least in our past causal cone. Quantum physics would then live "in the gaps" between the collapse events, and the "collapse of the wavefunction" would have to be an objective feature of physical reality. (Probably the best-known models of this type are the Ghirardi-Rimini-Weber [GRW] model and the Penrose model; both

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[2] While Planck basically introduced the notion that electromagnetic radiation could interact with matter only in "little lumps", eventually called "quanta", it was Einstein and De Broglie who made much more quantitative and precise statements that the energy and momentum of the "little lumps" of electromagnetic radiation were proportional to the frequency and the reciprocal of the wavelength—this then immediately leads to the *quantitative* version of the Heisenberg uncertainty relation. For some technical notes addressing this point see Appendix A.1.

[3] Without some notion of collapse to define definite outcomes/events, there is simply no basis for any notion of memory or history. Without memory/history there is no notion of cause and effect. Without being able to separate cause and effect, I have no idea how to even begin to define causality.

of which suffer from quite serious physics limitations; but more importantly have suffered from malicious neglect by the physics community.) Despite the unquestioned success of the "shut up and calculate" non-interpretation of quantum physics, there are real physics issues still to be dealt with in the foundations of the subject. Consider for instance the fictional musings of the fictional physicist Shevek [6]:

> *"...the physicists of [Einstein's] own world had turned away from his effort and its failure, pursuing the magnificent incoherencies of quantum theory, with its high technological yields, ... to arrive at a dead end, a catastrophic failure of the imagination."*
>
> — Shevek *circa* 2500 CE

2.3. Quantum Field Theory

In contrast to the foundational physics problems considered above, the purely technical problems facing quantum field theory are more fundamentally mathematical in nature. While the mathematical aspects of quantum mechanics were placed on a firm foundation by von Neumann and others, the mathematical foundations of quantum field theory are much shakier. Consider for instance the well-known comments:

> *"In the thirties, under the demoralizing influence of quantum-theoretic perturbation theory, the mathematics required of a theoretical physicist was reduced to a rudimentary knowledge of the Latin and Greek alphabets."*
>
> — Res Jost *circa* 1964

> *"I am acutely aware of the fact that the marriage between mathematics and physics, which was so enormously fruitful in past centuries, has recently ended in divorce."*
>
> — Freeman Dyson 1972

What is going on here? While no one doubts that the quantum field theory representing the standard model of particle physics is a great success—as physics—the more mathematically inclined members of the physics community are less than happy with technical aspects of the situation. There are a number of issues:

- The fact that the Feynman expansion cannot possibly converge, (it is at best an asymptotic expansion even after you renormalize to effectively make each individual Feynman diagram finite), is probably just an annoyance...
- Haag's theorem is still an obstruction to constructing a fully relativistic interaction picture, rather completely undermining standard textbook presentations of how to derive the Feynman diagram expansion. This may have been fixed (or rather, side-stepped) as of 2017 [7].
- As of 2018, not one single non-trivial interacting relativistic quantum field theory has rigorously been established to exist in 3 + 1 dimensions; though rigorous constructions are available in 2 + 1 and 1 + 1 dimensions. (The technical difference seems to be that there are interesting super-renormalizable quantum field theories in (2 + 1) and (1 + 1) dimensions; but that the rigorous techniques used to establish these results to not quite extent to the physically interesting, but merely renormalizable, quantum field theories in 3 + 1 dimensions.)

Almost certainly these are merely nasty technical annoyances; places where the mathematics has not yet caught up with the physics. Remember that after Newton and Leibniz it took almost 150 years before calculus was put on a really firm mathematical foundation. This did not stop physicists and others from using calculus during that two-century interregnum, and using it to good purpose and effectiveness. Similarly, the standard model of particle physics clearly has very many features that are undoubtedly correct, very many features that are undoubtedly good representations of empirical reality, so physicists will continue to use it regardless of what the mathematicians feel about the technical details.

3. Usability Versus Precision

The key issue here is usability versus precision; while precision is sometimes important usability will always trump precision. This is a variant of the old debate between accuracy and precision; there are sometimes cases when precision (obtaining many decimal places) is important, but saner people will prefer accuracy (fewer decimal places; but ones that are actually correct).

This observation is important because, as long as there is plenty of reliable experimental/observational data coming in, then empirical reality has a way of trumping sloppy theory. Theorists can often afford to cut a few corners, (and be, from a mathematical perspective, more than a little bit sloppy), as long as there is steady stream of data to keep them on track. If the data-steam dries up, considerably more care is called for—the techniques that are effective in a data-rich environment, can quite easily and unfortunately lead to "forty years wandering in the wilderness" in a data-poor environment. This is partly the reason pure mathematicians make such a fetish of precision—since they are typically (not always) working at a greater remove from empirical data.

Interruptions in the data stream can come from at least two sources—possible technological limitations and/or sociological issues. Sometimes we just cannot collect the data because the equipment to do so simply does not exist; sometimes the equipment exists but collecting the data would be grossly unethical. Sometimes the barriers are subtler—even in Western societies over the last century and a half there have been occasions when experimentalists have looked down upon theorists and vice versa; sometimes tribalism within the theoretical physics community has hindered progress. (Remember the phrase "squalid state physics"? I have heard considerably worse.) Sometimes communication between mathematicians and physicists has essentially ground to a halt.

So the close connection between mathematics and physics is dynamic not static; the back-and-forth connections between the two will continually twist and strain in response to technological limitations and the personalities involved. After all, both mathematics and physics are in the end human endeavours; and human beings are a perhaps an excessively refractory material to deal with.

4. Instrumentalism Versus Realism

Philosophically there is also another relevant dialectic, that between instrumentalism (where theories are mere tools or instruments for prediction and calculation without pretension of description and/or explanation) and realism (where theories are intended for the description and explanation of empirical reality). I personally, and I think the majority of the physics community for that matter, ascribe to some version of realism. As long as I am working on problems of classical general relativity, I can even get way with naive realism—but once one focusses on the foundations of quantum physics the whole concept of realism becomes much subtler—and deeply inter-twined with the "collapse of the wave function". Insofar as one views the "collapse of the wave function" as an objectively real phenomenon, then one can continue to maintain a realist perspective on nature—the external universe hypothesis—external to our human perceptions and consciousness.

5. Mathematical Universe Hypothesis

> *"God created the integers; all else is the work of man."*
>
> —Leopold Kronecker

> *"Don't let me catch anyone talking about the universe in my department."*
>
> —Ernest Rutherford

At its most extreme the undoubtedly close connection between mathematics and physics is sometimes asserted to be an *identity*—this is the "mathematical universe hypothesis" [8,9].

I personally think this is excessive, unnecessary, and simply not useful. We do not need to imbue mathematics with more significance than it already undeniably has—the abstract codification of regularities in the empirical universe is quite enough. Ironically the "shut up and calculate" point of view advocated in [9] does not actually imply the mathematical universe hypothesis.

"Shut up and calculate" is a non-interpretation, a non-ontology which requires nothing specific in the way of a philosophical commitment; similarly the "shut up and calculate" non-interpretation of quantum physics requires nothing specific in the way of a philosophical commitment. Most physicists would agree with the "external universe hypothesis", but the gap between the "external universe hypothesis" and the "mathematical universe hypothesis" is a very large one, and the logic connecting the two is not at all convincing.

For instance, it is asserted [8] that "The [mathematical universe hypothesis] makes the testable prediction that further mathematical regularities remain to be uncovered in nature." This is not exactly a unique distinguishing characteristic of the mathematical universe hypothesis—just about any random philosophy of physics would predict that "further mathematical regularities remain to be uncovered in nature"; even in the "shut up and calculate" non-interpretation one would hardly be surprised if further mathematical regularities were to be found.

More alarmingly, the level I to level IV mathematical universes, (or rather, the level I to level IV mathematical multiverses), become increasingly disconnected from empirical reality. (The phrase "rampant speculation" comes to mind.) Now I have used the word multiverse myself [10], but in a very different context and with a very different and much more specific meaning—when speculating about wormhole physics the various universes in the multiverse are just reasonably large reasonably flat regions of spacetime that are connected to each other via Lorentzian wormholes; and the same (utterly standard) general relativity applies in each universe.

Experimentalists have an aphorism "never adjust more than one aspect of your experiment at a time"; theorists should pay heed—never heap multiple layers of speculation on top of one another. Speculation—controlled speculation—is fine; but try to extrapolate only one feature of well-known physics at a time. Uncontrolled speculation is a quagmire; a mare's nest; a necrophiliac deconstruction of the scientific enterprise.

6. Discussion

> *"And I cherish more than anything else the Analogies, my most trustworthy masters. They know all the secrets of Nature, and they ought to be least neglected in Geometry."*
>
> — Johannes Kepler

So what message should one take from all this discussion? Overall, I feel that Wigner's famous "unreasonable effectiveness of mathematics", the close relationship between mathematics and physics is not at all surprising—the reason for the close relationship is in fact utterly prosaic—ultimately there is a dynamic tension (a dialectic) between the experiments/observations of the natural philosopher and the mathematics then developed to encode the patterns and regularities in the data stream. The natural philosophers and the mathematicians can, and often do, get out of synchronization with each other—sometimes by centuries—but overall the most work will go into the mathematics that is the most pragmatically useful.

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Appendix A Technical End-Notes

Appendix A.1 Classical Uncertainty

Consider the purely classical commutators $[t, \partial_t] = -I$, (and similarly $[x, \partial_x] = -I$), with not an $\hbar$ in sight. Consider a purely classical signal $s(t)$ and take its Fourier transform

$$\hat{s}(\omega) = \frac{1}{\sqrt{2\pi}} \oint s(t)\, e^{-i\omega t}\, \mathrm{d}t.$$

Now define averages (assume all the relevant integrals converge)

$$\bar{t} = \frac{\oint |s(t)|^2 \; t \; \mathrm{d}t}{\oint |s(t)|^2 \; \mathrm{d}t}; \qquad \bar{\omega} = \frac{\oint |\hat{s}(\omega)|^2 \; \omega \; \mathrm{d}\omega}{\oint |\hat{s}(\omega)|^2 \; \mathrm{d}\omega};$$

and variances

$$\sigma_t^2 = \frac{\oint |s(t)|^2 \; (t-\bar{t})^2 \; \mathrm{d}t}{\oint |s(t)|^2 \; \mathrm{d}t}; \qquad \sigma_\omega^2 = \frac{\oint |\hat{s}(\omega)|^2 \; (\omega-\bar{\omega})^2 \; \mathrm{d}\omega}{\oint |\hat{s}(\omega)|^2 \; \mathrm{d}\omega}.$$

It is now a *theorem* of mathematics that

$$\sigma_t \times \sigma_\omega \geq \frac{1}{2}.$$

This is the classical time-frequency uncertainty relation. A common interpretation in classical signal processing theory is that the timescale for on-off switching is inversely proportional to the frequency spread in the Fourier transform. This is sometimes phrased as

$$\text{(bit rate)} \lesssim \text{(bandwidth)}.$$

A completely analogous result arises from the $[x, \partial_x] = I$ commutator where, now in terms of position and wave-number, one has

$$\sigma_x \times \sigma_k \geq \frac{1}{2}.$$

This is sometimes phrased as

$$\text{(bits per unit length)} \lesssim \text{(wave-number spread)}.$$

It only once imposes the Einstein relation $E = \hbar\omega$, and the de Broglie relation $p = \hbar k$, that quantum physics is introduced. Specifically, imposing these relations and using what we know about Fourier transforms, we see

$$E = i\hbar\partial_t; \qquad p = -i\hbar\partial_x;$$

and the usual Heisenberg uncertainty relations now follow

$$\sigma_t \times \sigma_E \geq \frac{\hbar}{2}; \qquad \sigma_x \times \sigma_p \geq \frac{\hbar}{2}.$$

Appendix A.2 Classical Barrier Penetration

Frustrated total internal reflection is a classical barrier penetration effect. It occurs when what would normally be total internal reflection is "frustrated" by having only a small gap of low refractive index material separating two regions of high refractive index. In this case the "evanescent wave" in the gap region (the barrier) allows some of the light to penetrate the second high refractive index region. Similar phenomena occur for sound propagation across fluid-fluid-fluid interfaces. The relevant mathematics is formally identical to that required to analyze quantum barrier penetration through a classically forbidden region. In short, barrier penetration is primarily a wave effect; it is not (intrinsically) a quantum effect.

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philosophies

Article

Natural Philosophy and Natural Logic

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Abstract: 1. Nature has its own logic, which does not follow the human will. Nature is itself; it exists, moves, changes, and evolves according to its own intrinsic ways. Human and human society, as a product of a specific stage of natural development, can only be a concrete manifestation of the logic of nature. 2. In the broad sense, nature refers to all, both phenomena and processes, in the universe. It includes human society spiritual phenomena. In a narrow sense, nature refers to the world outside the society and opposed to society as well, or refers to the research objects of natural sciences. 3. The narrow natural philosophy is in the intermediary position between the natural sciences and the overall philosophy (the supreme philosophy, an advocation of Kun Wu's philosophy of information. For further detail, please refer to the subscript in the following.). Furthermore, it is an independent sub-level philosophical discipline; the broad natural philosophy is a meta-philosophy or supreme philosophy, stipulating the entire world from the dimensions of nature itself. 4. Natural philosophy reveals the laws of nature's own existence, movement, change, and evolution. This determines that the way of expressing natural philosophy is necessarily natural ontology. The construction of the theoretical system of natural philosophy is inevitably a process of abandoning cognitive mediums of human beings through reflection. It is necessary for us to conclude that natural philosophy is the stipulation of nature itself, which comes out of the nature itself. So, we must explain the nature from the standpoint of the nature itself. 5. The true philosophy should move from the human world to the nature, finding back Husserl's suspended things, and establish a brand-new philosophy in which man and nature, substance, information, and spirit are united. This kind of philosophy is able to provide contemporary ecological civilization with a reasonable philosophical foundation, rebuilding natural philosophy in a new era, which is a very urgent task for contemporary philosophers. 6. The unity of philosophy and science cannot be seen merely as an external convergence, but also as an intrinsic fusion; a true philosophy should have a scientific character, and science itself must have a philosophical basis. The unity of such an intrinsic fusion of science and philosophy can be fully demonstrated by the practical relationship of development between human philosophy and science. 7. In addition to the narrow path along epistemology, linguistics, and phenomenology, the development of human philosophy has another path. This is the development of philosophy itself that has been nurtured and demonstrated during the development of general science: On the one hand, the construction of scientific rationality requires philosophical thinking and exploration; On the other hand, the progress of science opens the way for the development of philosophy. 8. In the real process of the development of human knowledge, science and philosophy are regulated, contained, and merged with each other in the process of interaction. The two are inlaid together internally to form an interactive dynamic feedback loop. The unified relationship of mutual influence, regulation, promotion and transformation presented in the intrinsic interplay of interaction between science and philosophy profoundly breeds and demonstrates the general way of human knowledge development: the philosophicalization (a term used in Kun Wu's philosophy of information. For more details please see in Kun Wu, 2016, *The Interaction and Convergence of the Philosophy and Science of Information*, https://doi.org/10.3390/philosophies1030228) of science and scientification (a term used in Kun

Wu's philosophy of information. For more detail, please see in Kun Wu, 2016, *The Interaction and Convergence of the Philosophy and Science of Information*, https://doi.org/10.3390/philosophies1030228) of philosophy. 9. We face two types of dogmatism: one is the dogmatism of naturalism, and the other is the dogmatism of the philosophy of consciousness. One of the best ways to overcome these tendencies of dogmatism is to unite natural ontology, and epistemic constructivism. The crisis of contemporary philosophy induced by the western consciousness philosophy seems like belonging to the field of epistemology, but the root of this crisis is deeply buried in the ontology. The key to solving the crisis of contemporary philosophy lies precisely in the reconstruction of the doctrine of natural philosophy centering to the nature itself and excluding God. The task to be accomplished by this new natural philosophy is how to regain the natural foundation of human consciousness after the God has left the field. 10. Since the 1980s, the philosophy of information established and developed in China has proposed a theory of objective information, as well as the dual existence and dual evolution of matter and information (a key advocation in the ontological theory of Kun Wu's philosophy of information). It is this theory that has made up for the vacancy existing between matter and mind, which apparently exists in Cartesian dualism, after the withdrawal of the God's from the field. Philosophy of information in China is first and foremost a natural philosophy that adheres to naturalistic attitudes. Second, this natural philosophy explains the human, human mind and human society in the interpretation of the process and mechanism of natural evolution. In this connection, philosophy of information (a key advocation of Kun Wu's philosophy of information) in China is a system of meta-philosophy or supreme philosophy. This system undoubtedly has the nature of a new natural philosophy. At the same time, this philosophy can better reflect the philosophical spirit of the information age.

Keywords: natural philosophy; the logic of nature; ontology; epistemology; in the name of nature; philosophy of information

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1. The Analysis of the Subject

The title of this article refers to "the logic of the nature". It is necessary to give a reasonable explanation to the word *logic* used here. The word *logic* derives from the Greek word *Logos*. The original meaning is thought, thinking, reason, and language. With the development of language, the word *Logic* has gradually become a more abundantly meaningful word. At present, for the meaning of the word *logic*, we can at least find the following four different stipulations: (1) the laws that represent the development of objective things, such as "the logic of the development of things" and the "logic of social development"; (2) the rules of thinking, such as "thinking must be logical" and "reasoning logically"; (3) representing science that studies the form of thinking and its laws, which is logic, such as "formal logic", "dialectical logic", "mathematical logic"; (4) Represents a particular position, point of view, and inference (argumentation) method, such as "absurd logic" and "jerk logic." [1].

The ambiguity of the word *logic* makes it necessary for us to explain the meaning of the word in terms of *the logic of the nature* involved in the title of this article. The word "logic" used in the title of this article does not mean that there is an "objective ideal", "absolute spirit", or supreme existence of the "God" behind the nature, nor is it to refer to the rules exiting in human mind and cognition. Here we follow the first provision of the word *logic* listed above, emphasizing an idea that nature has its own objective logic, which neither bases on nor changes with human will. Nature is itself, and it exists, moves, changes, and evolves through its own intrinsic ways. In this thinking, we also include such a view: human beings and human society as a product in a specific stage of natural development, it can only be a concrete manifestation of the logic of the nature [2].

The discussion about the logic of nature can be carried out on two different levels: one is the level of natural sciences and the other is the level of natural philosophy. The former usually refer to various natural sciences, while the latter is often carried out in a framework called "natural philosophy". The focus of this article is to explore the rationality of natural philosophy and its compatibility and unity with the natural sciences.

2. Modern Scientific System

To explore natural philosophy, we must first explain its nature and scope.

On the basis of the scientific paradigm provided by the theory of complex information systems, any research object can only be clearly defined in the relationship of the relevant overall system network. To determine the nature and scope of natural philosophy, it is first necessary to place it in the system of modern science to regulate and recognize it.

Science as a system for cognizing, reflecting, and constructing the object world always has an isomorphic relationship with the object world that it cognizes, reflects, and constructs. The object world is a world that has entered human cognition. Through the different stages of scientific history, the specific forms of the isomorphic relationship between scientific systems and the corresponding object worlds that are cognized, reflected, and constructed by the scientific systems have been changing. Consequently, the specific patterns of people's cognition to the object worlds have been changing accordingly. It indicates the clues and venations of incessant evolution of the ability of human beings' scientific understanding and the continuous development of science and technology.

The structural model of the modern scientific system embodies the general principles of the scientific paradigm provided by theory of complex information systems. This means that everything is a system, and all systems are integrated, hierarchical, and have the basic characteristics of universal interaction through internal and external networks of materials (including mass and energy) and information flow. As a whole network system, the modern science system must also exhibit the corresponding characteristics of the general system, namely integrality, hierarchy, constitutive property and the universality of interaction.

Figure 1 indicates the structure of modern science on the macro level.

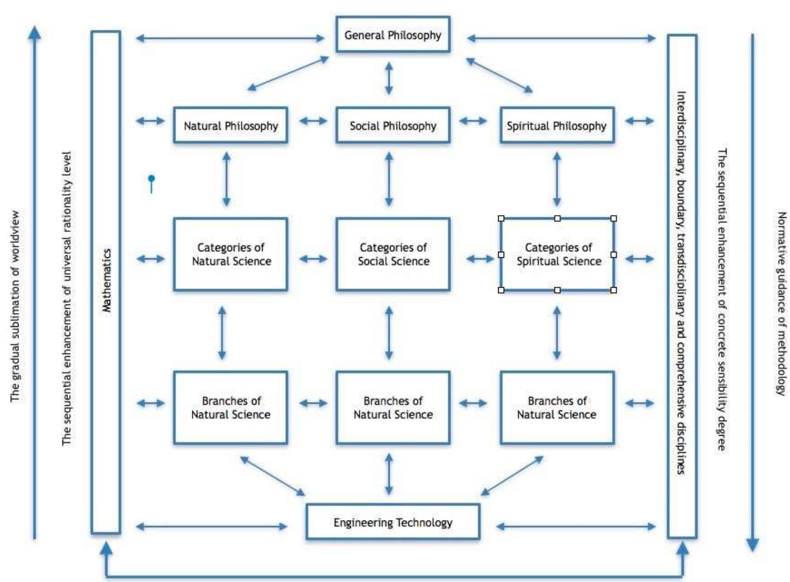

Figure 1. The Structure of Modern Science [3].

The following is an explanation for Figure 1.

2.1. The General Philosophy is the Science that Studies the General Nature of the Whole World and the General Laws of Movement, Change, and Development

The world, as a whole, is the largest and highest system. The disciplines that take this whole system as the object of study and reveal its overall nature and the general laws of movement, change, and development constitute the philosophy in an overall meaning and at the highest level. It can be called general philosophy, supreme philosophy or meta-philosophy. From the perspective of the history of philosophy and the situation of contemporary philosophy, general philosophy has always led to a large number of schools of thought.

2.2. The Philosophy of Nature, Social Philosophy, and Philosophy of Mind in a Narrow Meaning Are Sub-Disciplines under the General Philosophy

In general, the scientific community always distinguishes the existence world (in the philosophy of information advocated by Wu Kun, "the existence world" is a term referring to everything that exists, including the matter, mind and information. For more details, please see in Kun Wu and Joseph Brenner, 2017, Philosophy of Information: Revolution in Philosophy. Towards an Informational Metaphilosophy of Science, https://doi.org/10.3390/philosophies2040022; Kun Wu, 2015, The Development of Philosophy and Its Fundamental Informational Turn, https://doi.org/10.3390/info6040693; Kun Wu, 2012, The Essence, Classification and Quality of the Different Grades of Information, https://doi.org/10.3390/info303040) from the general sense, to the three basic fields: the nature, human society and mental worlds. Corresponding to these three fields, the natural philosophy, the social philosophy, and the philosophy of mind separately treats one field as its study object, revealing the overall nature of the field and the general laws of movement, change, and development within it. Because these three philosophical disciplines each use one of three basic fields as their research objects, they can only be sub-disciplinary philosophies under general philosophy, studying the whole existence world. Whether from the perspective of the history of philosophy or from the situation of contemporary philosophy, such sub-disciplinary philosophies also have many different schools of thought. It is necessary to emphasize that the differences among natural philosophy, social philosophy and philosophy of mind should not be viewed merely as differences in the fields of study, but rather, as differences in the directions of research. If we start from the general concept of nature, the social and realms of mind both are special natural fields developed from the evolutionary course of the nature. In this sense, the general concept of nature is higher than the concepts of society and mind, and holographically contains them. The aforementioned stipulation of natural philosophy as a sub-level philosophy juxtaposed with social philosophy and philosophy of mind bases on a narrow concept of nature. If we proceed from the general concept of nature, we can establish a general philosophy of nature. And the general natural philosophy can be a meta-philosophy or a supreme philosophy that stipulates the whole world from the dimension of the nature itself. We will discuss this point in the fourth section of this article.

2.3. Categories and Branches of Science

In the natural world, human society and the realm of mind, different object areas can be distinguished. The study of the characteristics and laws of these different target areas leads to more specific scientific disciplines. At this level, the more general discipline is the categories of science, and the discipline that is further differentiated under the categories of science is branches of science. In terms of the development of modern science, physics, chemistry, biology, geology, and astronomy . . . belong to the category of natural sciences; ethnology, economics, politics, law, ethics..., belongs to the category of social sciences; logic, psychology, intelligent science . . . belongs to the category of science of mind. The development of modern science presents a trend of being highly differentiated and highly integrated. In the highly differentiated direction, some sub-disciplines that have reclassified under the category of science have reached the fifth, sixth, and even seventh levels. In the highly integrated direction, on the one hand, it manifests itself in the emergence of new holistic disciplines in the synthesis of multiple disciplines. On the other hand, it produces various types of marginal interdisciplinary sciences in the process of scientific deep differentiation. This is the synthesis that emerged in the differentiation.

2.4. Engineering and Technology

Engineering is the discipline that applies the relevant scientific principles and methods to the direction, transformation, or control of the object world, and relates to the skills and methods of producing and using the corresponding tools. Obviously, engineering technology itself can also be divided into different areas or levels. In the horizontal direction, we can distinguish some major fields such as natural engineering technology, social engineering technology, and thinking engineering technology. In the vertical direction, we can at least distinguish two levels of basic engineering technology and applied engineering technology. The former is the discipline of skills and methods for the production and use of tools that act on general objects, while the latter is the discipline of skills and methods for the production and use of special tools that are applicable to certain specific sectors, industries, or objects. In the latest research trends, some scholars try to make a clearer distinction between technology and engineering: technology is the way and method of transforming the object world; engineering is the practical activity of creating and constructing new social beings.

2.5. The Mathmatics Is a Tool at a Special Status

People often see mathematics as a natural science, which is just as much of a misunderstanding as thinking of philosophy as a social science. Actually, mathematics reflects the abstract relationship of numbers and shapes existing universally in nature, society, and mental world. Therefore, it cannot be regarded as a natural science, nor can it be regarded as an integral part of social science and science of mind. Mathematics can be regarded as an omnidirectional discipline with relatively independent development characteristics. It can provide a powerful scientific tool of quantitative description for the study of natural sciences, social sciences, spiritual science, and philosophy.

2.6. Interdisciplinary, Borderline, and Transdisciplinary and Comprehensive Disciplines

The object world (a term used in Kun Wu's philosophy of information. For more detail, please see in the references mentioned in the previous subscript) people know is always in a complex and ever-changing relationship of mutual connection, mutual penetration, mutual regulation and mutual transformation. If the research on the object is only from large or small-scale perspective, it is still a simple mechanical research method with the characteristics of the reductive analysis method. This research method obviously lacks the needed comprehensiveness and scientificity for the study of things in the complex and integrative relationship. Since the middle of the 20th century, with the increase in the complicatedness of the problems faced by mankind and the accelerating development of modern science, a number of new disciplines has emerged, which have the complex and comprehensive relationships as their research objects. These emerging disciplines often cannot be simply subordinated to one the fields of natural science, social science or science of mind. They essentially exhibit the characteristics of domain intersection, marginal integration, transversal relationship, and complex omnidirectional features. For example, information science, systems science, self-organization science, chaos and complexity research, life science, ecological science, space science, ocean science, environmental science, cognitive science, and so on.

2.7. The Unity of Ontology and Methodology

The bottom-up arrow on the left in Figure 1 indicates discrepancy of disciplinary abstraction at different levels. It also indicates the ontological magnitude of different levels of disciplines. The top-down arrow on the right in Figure 1 indicates the methodological role of higher-level disciplines in paradigmatic guidance for lower-level disciplines. It also shows the differences in specific degree of sensibility of disciplines in different levels. These two reciprocal arrows clearly symbolize the concrete and realistic unity of ontology and methodology. The philosophy we usually refer to is both ontological and methodological, and it establishes on the two reciprocally reversed directions.

3. The Nature and Developmental Situation of Natural Philosophy

Judging from Figure 1, philosophy also has a systematic hierarchy. In Figure 1, according to the degree of general abstract understanding of the law of the development of things, two levels of philosophy are distinguished: the first level is general philosophy; the second level (sub-level) has three major paralleled philosophical disciplines—natural philosophy, social philosophy, and philosophy of mind. Of course, the systemic hierarchy of philosophy is not just these two levels. Under natural philosophy, social philosophy and philosophy of mind, some more specific lower-level philosophical disciplines can still be distinguished. We use Figure 2 to mark this kind of systematic hierarchy of philosophy.

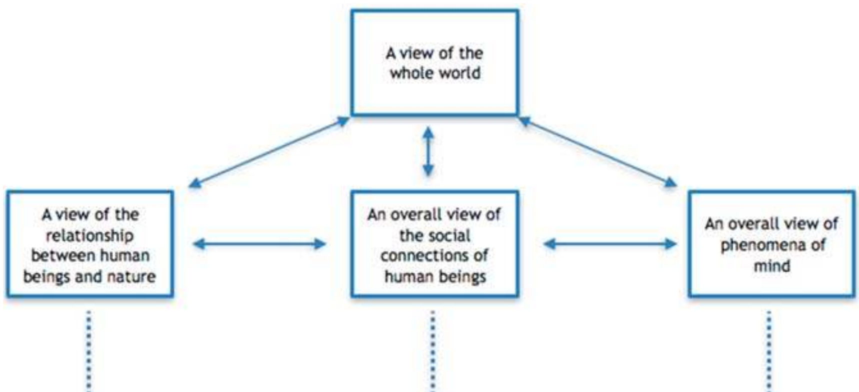

Figure 2. The Hierarchy of Philosophy [3].

From Figures 1 and 2, it is not difficult to see that natural philosophy is in the middle of the natural sciences and the general philosophy, and it is an independent sub-level philosophical discipline.

In the discussion of the previous section, we considered natural philosophy as a philosophical discipline that takes the whole nature as its object, revealing the essence of nature and the general laws of its movement, change, and development. In Figure 2, we also use the "overall view of the relationship between the man and the nature" to make provision for natural dialectics. However, the above two provisions are still relatively general and abstract, because people's understanding on the general quality and laws of nature and the general view on the relationship between man and nature are achieved through the intermediary of science, technology, and engineering. Science is the way and method of understanding the world. Technology is the way and method of transforming the world. Engineering is the concrete activity of transforming the world. This means that people reveal the overall quality and general laws of nature and deal with relationship between man and nature through knowing and transforming the nature. Thus, the levels and patterns that people realize the general laws of nature have to rely on the level and pattern of the development of science, technology, and engineering, and the relationship between human and nature naturally contains triple specific contents: First, people use the whole natural world as the research object, and specifically construct the relationship in the corresponding natural landscape; second, human beings get to know the natural world through concrete research behavior in natural science; human beings get to transform the natural world through technological methods and engineering activities.

It is based on the triple real relationship between man and nature as mentioned above that we have reason to identify the research object of natural philosophy as three specific aspects: the whole natural world, the whole natural sciences, and the overall technology and engineering activities. Or, we can also say that natural philosophy has the overall relationship between man and nature as its object, including the relationship of constructing natural model, the relationship of knowing the nature, and the relationship of transforming the nature.

In the same way, we also have reason for the following definition: natural philosophy is a philosophy about the nature and of knowing and transforming the nature. If this definition is more concretely developed, it is: philosophy of nature is a philosophical theory of the general quality, existential way, and development laws of the nature, natural science, and technology engineering activities.

From the above discussion, we have reason to determine the disciplinary content or disciplinary system of natural philosophy as four more specific aspects: philosophy of nature (natural landscape), philosophy of science, philosophy of technology, and philosophy of engineering.

Natural philosophy has a broad sense and a narrow sense. The natural philosophy listed in Figure 1 as sub-level philosophy, alongside social philosophy and philosophy of mind, is a natural philosophy in a broad sense. The broad sense philosophy of nature includes not only the philosophy of constructing and describing the natural landscape, but also the philosophy of science, philosophy of technology, and philosophy of engineering that know the intermediary approaches of reaching this construction and description. The narrow sense of natural philosophy refers only to the philosophy of constructing and describing the natural landscape, which has the whole model of the natural world as its specific object of study. It is a philosophical theory about the natural landscape, patterns, and the general laws of its development. Perhaps using the "view about the nature" and "natural landscape" to refer to the narrow natural philosophy is more apropos.

In the long course of development of science and philosophy, natural philosophy has also experienced different historical forms. The ancient natural philosophy is integrated with the ancient natural sciences, and its core mission is to explore the ontological queries of the natural world and the relevant description of the world landscape. Since natural philosophy at that time could not be based on empirical science, it was always intuitive and speculative. With the modern sciences gradually diverging from philosophy, some philosophers tried to establish a theoretical system about the natural world and beyond the natural sciences based on abstract speculation, according to certain materials provided by scientific development at that time. From the early 18th century to the early 19th century, natural philosophies in German classical philosophy, especially Hegelian natural philosophy, were outstanding representatives of this kind of natural philosophy. This kind of natural philosophy uses human ideological construction to surpass the history of human knowledge and to transcend the revealed quality of nature by empirical science. Therefore, it is clearly contrary to the development of science itself.

Since the 20th century, with the rapid rise and in-depth development of modern science represented by theories of relativity, quantum mechanics, modern cosmology, molecular biology, information science, systems science, complexity science, and intelligent science etc., a worldview of information system and complex integration based on relevant facts, theories and scientific paradigms provided by modern sciences has been gradually established and showed to us. It is such worldview of information system and complex integration that has become a new historical form of natural philosophy that matches our times.

4. About "Natural World"

The concept of "nature" can usually be interpreted in two ways. The broad sense naturally refers to all things, phenomena, and processes in the universe. It includes human society and mental phenomena. It is a concept having the same scale as the concepts of universe, world, and the existence in a broad sense. The narrow sense of nature refers to a world outside the society that is opposed to society. Or the general object world of natural science research.

It is a controversial issue that the category of "nature" should be interpreted broadly or narrowly in natural philosophy. More natural philosophers understand the nature from a narrow sense.

People who insist on such narrow understanding are likely to think that the entire field of existence can distinguish three parallel areas, which are nature, society, and thought. The nature is the part that exists outside the society (including thought) and opposes to, parallels to and distinguishes from the society (including thought)

Those who insist on broad understanding think that society (including thought) is a product of natural evolution and a special state of natural development. It should be included in nature and governed by the general laws of nature. Therefore, the law of nature must include the most fundamental aspects of the development laws of society (including thought). Therefore, the category of "nature" should be understood in a broad sense in natural philosophy.

We agree that in the philosophy of nature a broad understanding of the category of nature should be adopted. But this requires a few explanations:

4.1. Society (Including Thoughts) Is a Special Part of Natural History

In the direction of its evolution, the nature presents a series of evolutionary stages: primitive fireballs -> nebulae -> galaxies -> fixed stars -> planets . . . As far as the general evolutionary process of nature is concerned, the planet can be seen as its advanced development stage. Only on extremely few planets can it be possible to form conditions for the evolution to a higher stage of material development. Fortunately, the earth on which we live is just such an extremely lucky planet, and it is also the only basis for us to understand these higher levels of material development. According to the current situation of the Earth's evolution, this higher material development can be roughly divided into three stages: organic sphere -> biological sphere-> human society (including thought). These three stages of development can only belong to the evolutionary history of the planet Earth itself. The formation and development of human society is the highest product of the planet's evolution. Society is also part of the nature in broad sense. Of course, society (including thought) is also a special part of the nature. It has a series of new properties compared to all other parts of the nature.

4.2. Society (including Thoughts) Can Only Exist and Develop on the Condition of Obeying Natural Laws

Nature is an area that is more universal than society and thought. Society is a special item of nature. Thought is a special part of society. Although, as a special natural field, society has some specific operating rules that are different from all other natural fields. However, in any case, society cannot violate the laws of nature. The development of human society has so far not been able to change the mechanic movement rules of planets which the earth obeys. It is still unknown whether human society can have this capability in the future. There have been no results regarding the existence of aliens or even communication with them. As an evolutionary phenomenon of the Earth, human society has been playing a relatively important role in the Earth's biosphere. However, with such a small area of the Earth's biosphere, humans must also follow the basic operational laws of the biosphere. Any deviant behavior that ignores these laws will be relentlessly punished.

4.3. Natural Philosophy Examines Society and Thinking from the Perspective of Natural Qualities

The general view is that the differences among natural philosophy, social philosophy and philosophy of mind lie in the different fields of their research and generalizations. Natural philosophy studies the general problems and laws in the natural world (narrow sense). Social philosophy studies the general problems and laws in human society. Philosophy of mind studies the general problems and laws in thoughts. In fact, this view is extremely superficial. The differences among the disciplines of natural philosophy, social philosophy and philosophy of mind should not be viewed merely as a difference in field of study, but rather as a difference in the angle and direction of doing research. From the perspective and direction of nature, society and thought are by no means outside the realm of nature. The investigation on society and thoughts by natural philosophy takes place from the standpoint of inherent quality of nature, but neglecting the more individual or specific details in society and thought. The difference between generality and particularity constitutes the difference disciplinary differentiation among natural science, social science and science of mind. Although social philosophy studies the special laws of social operation, at the same time, it must inevitably examine the natural origins of society and the general aspects relates to nature. This is also true for the philosophy of the mind. When examining phenomena of thinking, it must also examine its natural and social origins, attributes, and so on. Reasonable conclusions can only be this: nature, society, and thought are by no means isolated from each other. All three are "holographic mapping" the other two fields or aspects from their own perspectives and directions.

Although we classify it according to the existing philosophical disciplines, we consider natural philosophy, social philosophy, and philosophy of mind as three parallel sub-level philosophical disciplines. However, if we look from the perspective of broad sense nature and "holographic mapping," natural philosophy must be higher than social philosophy and philosophy of mind, because society and mind are the areas derived from the development of nature, and nature is the mother and foundation of the existence and development of society and mind.

4.4. Society Is the Core Part of "Humanized Nature"

Obviously, as a special part of nature, the society is a natural field with new qualities and is a natural field that the human beings lives in and influences. In this sense, society is a natural part that has been humanized. The human factor is nothing more than knowing and transforming the nature. We have reason to regard humanized nature as the general name of the part of nature that has been known and transformed by human beings. Although not all natural areas that humans have come to know can be incorporated into the social sphere, society is, after all, a core part of this "humanized nature". Along with the increase of the ability of human beings to know and to transform the nature, the breadth and depth of humanized nature (including human society) will also grow. Human society has been treated here as a natural field with new qualities. At the same time, it has also been seen as a self-organizing system that develops itself.

4.5. In the Infinite Track of Natural Movement and Development, Human Society Is Merely a Trivial, Accidentally Generated, Transient Event

For nature, human beings can only be a small, insignificant and minor influential parameter, which is small enough to be completely negligible. In any case, society and thinking, as the highest form and an attribute of the development of nature, are an ability of natural seed hiding in the nature eternally, and this ability of nature will never disappear.

That is the case. No matter how advanced the society and thinking ability are, they still can only exist in the iron necessity of nature, rather than being beyond or on the top of it. If we say that from the perspectives of society and thoughts themselves, society and thoughts also have certain elements that are independent from nature, but from the perspective of the nature, this external independence is gone. What natural philosophy adopts is a method investigating from the perspective of the nature. This method requires us to grasp the trajectory of the overall operation of the nature in the unity of nature, society, and thought.

4.6. Natural Nature and Artifical Nature

Depending on the influence of human beings, the academic community divides nature into two categories: one is natural and the other is artificial. Natural nature is the entire world before human beings appear. Later, human beings had come to exist from the evolution of natural nature. At the same time, the society and artificial nature derived from the natural nature. Natural nature is nature that has not been transformed by manpower. It had been existing before mankind was born, and has been existing as the foundation of artificial nature after mankind was born; artificial nature is the nature that natural nature changes under the influence of mankind. Diachronically, natural nature is the first nature and artificial nature is the second nature.

5. The Exposition of the Method of Natural Philosophy

On the explanation of natural logic, we are obviously in a situation of dilemma: On the one hand, the logic of nature is purely free and objective; on the other hand, the expression of natural logic can only be mediated by human subjective understanding. Such an intermediary characteristic makes the level and pattern that the expression of natural logic can achieve has a certain dependence on it, so that it cannot be separated from the level and pattern of this medium's development. In this sense, the expressed natural logic must use the cognitive structure of the expresser as its own frame of reference, which inevitably brings some epistemological features to the expressed natural logic. Here, objective laws cannot be revealed at a purely objective level. From the perspective of the history of human understanding on the nature, the dependence of the expressed degree of natural logic on the level of human cognition is quite obvious. With the continuous development of human cognition, it also brings about the incessant change of the natural mode of human cognition.

Although the specific state of the natural model has a dependence on the level of human cognition, we can still distinguish the natural logic from the human cognition itself. Here, logic is about nature, but is not about human cognition itself (a certain unity of subjective logic and objective logic is another problem). For example, our description of the movement laws of celestial bodies is not about human cognition. Although this description passed through the medium of human cognition and some kind of transformation, distortion, selection, or reconstruction occurred while being mediated, this description was ultimately reflected in nature itself. Here, it is itself, rather than the knowing, that nature regulates through the medium of cognition. This gives us an insight: the expression of natural logic must adopt a method that is relatively external to human cognition.

From the perspective of philosophical methodology, ontology and epistemology are two of the most macroscopic methods of philosophy. They stipulate two different angles and directions in which we examine the problem. Ontological methods can be divided into human-based and nature-based. Although the study of natural philosophy has to base on human cognition, the expression of natural philosophy should not adopt epistemological methods, nor should it adopt human-based methods. Because natural philosophy reveals the objective laws of nature's own existence, movement, change, and evolution, this determines that the way of expressing natural philosophy has to be naturally ontological. Although the disclosure of objective logic must be based on human subjective understanding, and the construction of the theoretical system of natural philosophy must be mediated by the general achievements of science, technology, and engineering activities, as far as natural philosophy itself is concerned, it is neither equal to human existence theory and human epistemology, nor directly related to scientific epistemology, scientific methodology, technical epistemology, technical methodology, engineering activity theory, engineering methodology and so on. The construction of the theoretical system of natural philosophy is inevitably a process of abandoning human cognitive influence through reflection. On the basis of discarding the medium, it is necessary for us to conclude that natural philosophy is a kind of stipulation about itself from nature itself. In this sense, we must express nature in the name of the nature. Of course, "in the name of nature" must also be mediated through the medium of human cognition, and must also be subject to the constraints and regulations of this medium. The so-called ontological investigation of philosophy does not mean that it can naturally proceed without human cognition. It means that human beings, relying on their own understanding, explore the true essence of the existence, movement, change, and development of the nature itself, which is external to human cognition. In this search, human cognition has been recognized as the phenomena presented at a particular historical stage of natural evolution.

We have noticed that in modern times, especially since the development of the contemporary western consciousness, philosophies have embarked on a path of rejecting natural philosophy. In particular, the phenomenological trend of thought that has had the greatest influence in contemporary times is the rejection of natural philosophy as its highest program. The founder of phenomenology, the German philosopher Edmund Husserl (1859–1938), presupposed the "suspension" of nature and the "exclusion" of naturalism attitudes when constructing his philosophy of intentionality. And the content of its “suspension” and “exclusion” is so broad: everything outside the consciousness, including natural and social objects, cultural and social products, and the whole life, human, and community, and the objectivistic attitudes based on these things is included as well [4]. After that, the French philosopher Merleau Ponty (1908–1961), who used the phenomenological method to propose the philosophy of the body, regained the human body suspended by Husserl, trying to explain the phenomenon of human consciousness by combining body and mind. However, the field of his research is still limited to the world of human beings and the world of human mental activities. We maintain that true philosophy should move from the human world to the nature, find back everything that is suspended by Husserl, and establish a brand-new philosophy in which man, the nature, matter, information, and mind are united together. Such philosophy can provide contemporary information ecology civilization a reasonable philosophical foundation. In this way, in the development of philosophy in the future, based on the new achievements in the development of contemporary science, technology, and engineering, reinterpreting the essence of nature in the name of nature and rebuilding the natural philosophy of a new era, which must be an urgent task for contemporary philosophers.

6. Natural Philosophy and Natural Science

As we mentioned in the first section of this article, the discussion on natural logic can be conducted at two different levels, natural science and natural philosophy. This inevitably leads to a question: What is the relationship between these two levels? This problem is similar to the so-called “problem of the relationship between science and philosophy.”

In our time, philosophy and science are clearly separated from each other in their manifestations. There is now a discussion about the relationship between science and philosophy, more in the sense of being separated from each other, or simply in the sense of unity of external relations. The discussion in this section will explore another view that is contrary to or different from the views of separation and external unity of science and philosophy.

As early as 1991 and 2004, Kun Wu has published two articles devoted to the relationship between science and philosophy. The titles of the two articles are “The level and the transition of level—the internal unity of science and philosophy” [5] and “A discussion on the relationship between science and philosophy.” [6].

In these two papers, the author emphasizes the view that philosophy is the pursuit of universal rationality by human beings. However, universal rationality and specific sensibilities cannot be completely separated in human cognitive activities; science is constituted by universal rationality in nature. These principles are not equal to the direct presentation of some observations and experimental facts, and the rise from various factual statements to the principle of universal rationality depends on the ideas, rules and methods of a certain philosophical thinking. Any scientific universal reason is correspondingly infiltrated with a philosophical concept, and this scientific universal rationality has reason to be seen as a product of a combination of philosophical ideas and concrete statements. In the abstract of the article “A Discussion on the Relationship between Science and Philosophy”, Wu Kun wrote: “The unity of philosophy and science cannot be seen merely as an external connection, but also as an intrinsic fusion; the inseparability of universal rationality and specific sensibility in human cognition activities is the ultimate basis for the internal unity of philosophy and science; the inherent hierarchical differences in the universal rationality stipulate the level of science or philosophy, and the relative demarcation between philosophy and science. The transition from low-level general rationality to high-level general rationality and the elimination of limitation and the excavation of the universal characteristics of the high-level rationality exerting on the low-level rationality constitute a scientific transformation of philosophy and a philosophy-to-science criticism. Through critically accepting the low-level universal rationality, philosophy changes its old ideas, theories or systems, which constitutes a process of self-criticism in the development of philosophy.”

In fact, true philosophy should have a scientific character, and science itself will certainly have a philosophical charm. To say that philosophy should have a scientific character does not mean that philosophy is a vassal to science, nor does it mean that philosophy is equated or attributed to general science. Philosophy has a dual relationship to science. One is based on its rationale, and the other is beyond it. Based on rationale, philosophy cannot ignore the development of science, nor can it violate the general principles of science. What goes beyond this is that the general principles of philosophy for science should not simply remain at the level of specific sciences, because the relevant theories explained by specific sciences are often constrained by the fields, levels, perspectives, and purposes of which they are examined. These corresponding constraints bring about certain limitations to the related theories of specific sciences. To reveal the more general nature of things, it is necessary for philosophy to analyze, overcome and eliminate the narrow limits of specific science, which is philosophy's criticism on science. What is achieved on the basis of this criticism is philosophy's transcendence to science. In addition, the infinite nature of the universe and the limitation of the existence of human beings and the development of science stipulate our scientific understanding on the universe. It is always a limited understanding about the infinite: limited fields, limited levels, limited angles, limited vision, limited phases... In this way, human science always has an endless mission with respect to the infinite world. such a situation of science poses a contradiction to the general rationality that philosophy seeks. The way to resolve this contradiction is philosophy's criticism and transcendence to science. Through this criticism and transcendence, philosophy can liberate from the shackles of concrete sciences and obtain higher levels of freedom. Through free thinking, philosophy breaks through the boundaries of science, and wisdom is used to bridge the gap between the concrete sciences and general rationality. Therefore, compared to specific science, philosophy has a higher level of freedom.

The philosophical criticism on science and the scientific transformation on philosophy make philosophy and science no longer separate fields. The relationship between the two can only be mutual integration. In philosophical criticism on science, philosophy can establish a general way and mean of interpreting and developing science, thereby imparting a philosophical character to science; science can provide basic material support for the development of philosophy in the scientific transformation on philosophy, which gives philosophy a scientific charm.

If we say that philosophy is the knowledge that mankind pursues in search of universal rationality, then this is because the universal character of universal rationality clarified by philosophy determines that it must be a kind of universal light with the most universal explanatory power. In this regard, it can provide a certain degree of methodological norms for all levels and fields of human knowledge, through which all levels and fields of knowledge of humanity will be covered in varying degrees by the light of this general illumination. This is also consistent with the Platonic "participation" scenario. On the other hand, since science provides the basis for the transformation of philosophy, it will also allow the philosophy to manifest and "participate" the contents and spirit of science. In this sense, philosophy is not only on top of science but also in the science; science is not only under philosophy but also in the philosophy.

Here, we must also emphasize that the unity of such an inherent fusion of science and philosophy can also be fully demonstrated in the practical relationship between human philosophy and science development.

In fact, apart from the narrow path along epistemology, linguistics, and phenomenology, the development of human philosophy has another path. This is the development of philosophy itself that has been nurtured and demonstrated in the course of general scientific development. On the one hand, the construction of scientific rationality requires philosophical thinking and exploration. On the other hand, the progress of science opens the way for the development of philosophy.

One obvious fact is that, based on the development of experimental science since modern times, the development of Newtonian mechanics and the development of chemical atomism have deepened and developed the physical realism founded by ancient Greek philosophers, which is a philosophical ontology theory explaining the world is constituted by inseparable material particles; the energy field theories, like relativity theory, quantum mechanics, and modern cosmology, constitute the field energy realism, which is philosophical ontology theory explaining the world is constructed by the energy field without static mass; and the birth and development of contemporary information science provides a scientific basis for the ontological theory-dual existence and evolvement of matter and information. From this point of view, the study of philosophical ontology did not stop because of the rejection or suspension of those so-called specialized philosophers. On the contrary, with the development of human science itself, there is a certain mechanics existing within the process of scientific development itself. In the development of human science itself, metaphysics and physics has always been accompanying with each other.

Another equally obvious fact is that the development of human experimental science has also profoundly promoted the development of epistemology. The development of medicine, anatomy, physiology, neurophysiology, brain science, experimental psychology, and contemporary cognitive science has led to some philosophers in modern times using the relevant scientific research to study the processes and mechanics. For example, the British modern philosopher Francis Bacon (1561–1626) had also criticized the two extreme epistemologies of empiricism and rationalism, and he emphasized that the true philosophy should be a combination of scientific researches and human rationality. In order to criticize the extreme rationalist philosophy, he proposed that in the human mind structure, there are "four kinds of false impression"[7] theories that disrupt the mind and hinder scientific development; The French philosopher and scientist Rene Descartes (1596–1650), the father of "modern philosophy," once tried to find the basis of psychological activity from the physiological function, and proposed that the pineal gland is a combination of body and soul [8]; the French enlightening thinker Julien Offroy de La Mettrie (1709–1751) took advantage of the results of medical and anatomical physiology during his era to explain the content of human feeling and thinking ability from the perspective of human physiological characteristics, physical conditions, and the constructive nature of the human brain [9]. In the context of contemporary scientific development, many epistemological theories based on corresponding scientific development have been highlighted: e.g., embryological epistemology, experimental psychology, and behaviorist psychology, and the theories brain function and human cognition mechanism, cognitive sciences, and virtual epistemology, and information epistemology, and so on.

The above examples can fully demonstrate that at the different stages of the development of human science, there is also a corresponding natural philosophy. The corresponding natural philosophy not only makes an interpretation for the nature itself, but also carries out the nature-based scientific and philosophical exploration on human cognition.

In fact, if we take a closer look, the crisis of contemporary philosophy induced by the Western philosophy of consciousness looks like it stems from epistemology, but in fact, the roots of this crisis are buried in natural philosophy having nature as its basis.

We know that in the tradition of Western philosophy, the world is divided into three parts: God (including Plato's objective ideas), the material world, and the human mental world. In related doctrines, the material world and the mental world are separated from each other. The human spirit can only be derived from God and can only exist in form of "participating" the spirit of God. With the development of science, the God has been suspended by scientists, so that God has retreated gradually from science and philosophy. However, due to the inextricable separation of the opposition between the material and the mental in the Western philosophical tradition, the withdrawal of God makes the human spirit unable to find its external causes. Thus, the philosophers who hold extreme views can only seek to explain the causes of consciousness within the consciousness itself, and natural philosophy based on the nature itself can only be rejected consequently.

From this point of view, the key to solving the philosophical crisis is not to give up or reject the study of philosophical ontology or natural philosophy, but rather to reconstruct philosophical ontology having nature as its basis and reconstruct the doctrine of natural philosophy excluding the God as its foundation. The task to be accomplished by this new natural philosophy is how to regain the natural foundation of human consciousness after God has left the field. Here, one of the most tangible paths is how to describe the relationship between matter and consciousness as a process of interaction and mutual transformation. According to the evolutionary direction of the universe, and in accordance with the actual situation of cognition happening, a reasonable explanation on consciousness can be given. The existence of objective information, and the dual existence and evolution of matter and information proposed by contemporary philosophy of information just opened the way for such a natural philosophy.

7. Developing Science and Philosophy in the Feedback Loop of the Interaction between Science and Philosophy

A remarkable feature of the epistemology based on related theories of natural science is that they all combine science with philosophy, and combine the external factors of the subject with the internal structure and activities of the subject, rather than seeking explanation on the happening mechanism of cognition from some individual activity factors within the subject. Obviously, such kind of doctrines embodies the scientific approach of philosophy and the philosophical development of science. The methods they use are in accordance with the essence of the complexity methods provided by the theory of complex information systems. This is the method of the overall emergence of multiple synergies. This kind of method embodies the unity of nature and society, and the unity of nature, society, and human mental world. This is exactly the attitude and method of natural philosophy that reveals the logic of nature from the perspective of the nature itself.

The proponent of the complexity paradigm, the famous French scholar Edgar Morin (1921–) proposed a methodology of loop-back, contradiction (opposition and compatibility) and complementarity. He believes that two basic principles can be attributed to the complexity method: "The principle of dual-logics and the principle of the loop-back." He emphasized: "The principle and concept of opposition are complementarily connected in an inseparable manner", and the principle of the process of self-creation and self-generation of the universe and the principle that our understanding is a "loop of regression" [10]. Morin particularly emphasized that the interactions between opposing factors and among multi-factors create the complexity, and the method of describing such interactions process is a method of loop-back. He believes that the method of absolutely separating the opposition and diversity is an outdated principle of simplicity. He advocates to establish the general integration of loop-backs of the interactions within the steps of dual-elements opposition and multi-elements relationship in all fields and areas, including natural sciences, social sciences, arts, philosophy, the area of individual, society and race, the transdisciplinary field of physics, biology, anthropology and sociology, the relationship among order, disorder and organization, the relationship of science, politics and ideology, the interactions between the whole and its parts, the relationship of science, technology, society and the country, the relationships of subject and object, of mind and matter, of man and nature and of nature and society, etc. Moran believes that the corresponding comprehensive loop-back relationship reveals the intrinsic indivisibility and complexity existing between opposite-factors and multi-factors. It is the dynamic and cyclical universal interaction of this loop-back that embodies the general process and concrete mechanism of self-organization and development of things. In his view, complexity is constructed through the dynamic self-organizing activities of the loop-back between opposition and multiple factors. He wrote: "Descartes established a paradigm that has since been ruling the West all the time: the separation of subject and object, the separation of mind from matter, and the opposition between man and nature. If a new method can emerge from the principle of complexity, and grow and mature, then it may' give rise to revolution everywhere', even revolutionize the idea of revolution that is bland, aged and reactionary." [10]

From the point of view of complexity, science and philosophy are not necessarily separated. They regulate, contain, and integrate each other in the process of interaction. Philosophy is in science while science is also in philosophy. They are embedded together and form some dynamic feedback loops of interaction. Their development always influences each other, regulates each other, promotes each other, and transforms into each other.

The unity of mutual influence, regulation, promotion, and transformation presented by science and philosophy in the inter-integration of interaction profoundly breeds and demonstrates the general ways of human knowledge development: the philosophilization of science and scientization of philosophy.

8. Two Doctrines of Dogmatism

Husserl denounced the naturalist attitude in general scientific research as dogmatism, and considered that the material world identified by naturalist attitudes is a transcendental and nisi world, which is non-existence world. Corresponding to this, he put the so-called "phenomenological *epoché*" that "excludes the entire world including all things, creatures, people, and ourselves", which is also called "pure consciousness"—intentionality itself, in the position of absolute existence. At the same time, he also believes that this pure consciousness essentially is independent of all natural existence; and it also can exist without having any other existing worlds as the precondition for its existence (Existenz). The real existence of nature cannot be a precondition for the existence of consciousness world, because the nature itself eventually becomes a related thing of consciousness; the nature exists only as something that is formed in a regular consciousness connector. He also said:

> " ... ... what is given does not exist in spite of the continual consciousness of its own presence 'in person'." "Thus in every manner it is clear that whatever is there for me in the world of physical things is necessarily only a presumptive actuality and, on the other hand, that I myself, for whom it is there (when the 'part of me' belonging to the world of physical things is excluded) an absolute actuality or that the present phase of my mental processes is an absolute actuality, given by an unconditional, absolutely indefeasible positing." "Anything physical which is given 'in person' can be non-existent; no mental process which is given 'in person' can be no-existent." [4]

In this way, Husserl set an existence of transcendental ego having pure intentionality, which is independent and absolute existence, and starting from here he unfolded his entire phenomenological philosophy.

In fact, admitting the reality of self-consciousness and innate knowledge has always been a tradition of western philosophy. From the reminiscence of soul advocated by Plato (before 427–347), to Cartesian innate ideas, to Spinoza's "innate genuine concept" (1632–1677), to Leibniz's "innate ability" etc. When they talked about the origin of self-consciousness, it was always related to God. Although in Husserl's interpretation of "pure consciousness", "God" has retired (which is obviously the result of scientific development), but the priori self-consciousness has been reserved. Till phenomenology, the trend of philosophical understanding and scientific analysis on mind had been further strengthened.

However, in the experience of a person's specific cognition, the person's awareness, memory, thinking activity, and the person's actively subjective intentional activity are always carried on by the human body and the material brain of the person. Moreover, any significant change in the corresponding structure and activity of the physical body of human beings will bring about significant changes in the corresponding activities of human consciousness. In this sense, without talking about the origin of mind, the philosophical and scientific study on the content of mind is a kind of dogmatism. In this way, we are faced with two types of dogmatism: one is the dogmatism of naturalism and the other is the dogmatism of the philosophy of consciousness.

To overcome these two kinds of dogmatism tendencies, one of the best prospects is to unite natural ontology, epistemology, and cognitive constructivism, rather than building barriers among them or digging an insurmountable gap.

In fact, historically, ontology and epistemology are unified, but some philosophers are not willing to admit it; this has especially been the case since modern times, and some people have always rejected or suspended ontology. They have always been trying to limit their study within the scope of human cognition. It is believed that the analysis of purely conscious activities within human cognition can clarify the process and mechanism of human cognition, and on this basis, they are able to further clarify everything in the world and the universe. Husserl's phenomenology is as this. Then phenomenological theories about intentional activity and intentional construction appears. The linguistic turn of contemporary western philosophy also has a similar nature. They convert philosophical issues directly into linguistic analysis, simply attributing the clarification of human understanding and interpretation of the world itself to the analysis on a tool of human thinking-human language. Here, everything in the world, the complex physical and psychological activities of human beings, the diversity of people's understanding and practice, and the vivid processes and mechanism are all hidden away.

In detail, the method of seeking explanation of cognition from the consciousness activities within epistemology derives from the ontological separation of matter and consciousness. Since matter and consciousness are two poles of simple opposition, and since matter and consciousness are two different kinds of mutually opposing existences, then it is necessary to explain that the activity and nature of consciousness cannot be explained from the relevance of consciousness and matter. Since matter and mind are the two poles of separation, from the perspective of western philosophical tradition, the interpretation of the process and mechanism of consciousness cannot be clarified from its relevance to matter. This then leaves the only path of interpretation for the nature, process, and mechanism of consciousness that is sought within the isolated consciousness. This is the situation faced by philosophy of consciousness and mind in contemporary and modern western world. Kant's philosophy, illustrating an insurmountable gap between subject and object and a theory of a priori synthetic judgement, and Husserl's theory of intentional activity and intentional construction of pure consciousness, and the linguistic analysis of consciousness in philosophy of language and so on, are all inherit such a characteristic. Contemporary psychology, neuroscience, and brain science are trying to connect the consciousness or the mind to the body, which provides us an inspiration and strong empirical evidence to discuss the origin of consciousness. But there are mysterious psychological factors plaguing scientists and philosophers all the time. And those factors leave the ghost of dualism lingering.

The ontological doctrine that matter and mind are opposite and separated from each other directly leads to the epistemological theory that the object and the subject are opposite and separated. Western philosophy of consciousness claims that it can eliminate the dualistic opposition between subject and object through intentional activity and intentional construction. It is an attempt to replace the object of cognition with the subjective content of consciousness. Such an explanation cannot explain the relationship between the subjective content we know and some objects external to us, nor can we explain the reasons for the success or failure of our practical activities on the external things. Therefore, such a practice of setting up the relationship between the subject and the object only from the inside of the activity of consciousness does not really eliminate the dualistic opposition between the subject and the object, but merely evades the issue itself.

9. The Resolution of Conflict: Information, Intermediaries, and Processes

To break the opposite situation between nature and human, and between philosophy of nature and philosophy of mind, the key issue is to describe the relationship between matter and mind as a process of interaction and mutual transformation. This requires finding out an existing thing bridging matter and consciousness, because all interactions must have their intermediate links. Just imagine that, if an object is absolutely isolated from the outside and no intermediate is derived from it, then the object cannot interact in any way with the environment or other things. Modern science has also proved that the four basic interactions that sustain the order of the universe are achieved through the transmission of intermediary fields.

The intermediary of the interaction between objects derives from the interacting objects themselves, which is revealed by modern science. Any object can reflect or radiate energy field outwards through external or internal interactions. Because the corresponding energy field derives from the object itself, it can represent or show the property, characteristics and difference of the material thing that produce it through its nature and structure. And because of this, it can serve as a vehicle for the relevant information of the things that produce it. In addition, interactions at all levels can cause changes in the corresponding structures and states of the agents, and this change can be a coding of structure that generates or assimilate and dissimilate information in interactions. Because interaction is the way in which things exist, and the evolution of cosmic things does not have a starting point in time, in the existing nature, the structure of all objects is generated in the long evolutionary process, which also means that at the same time, all objects in the world are already informosomes whose related information is encoded by the structures generating them. In this way, all objects, and even the entire universe, are a dual-existence, which means that they are both material and informational. Based on the dual existence of matter (direct existence) and information (indirect existence) in the world, we can establish a new ontological theory. In order to distinguish it from the ontological doctrine in traditional philosophy, it is named information ontology. This ontological doctrine is the basic theoretical part of philosophy of information that has been established since 1980 by Wu Kun. According to the ontological theory of information, consciousness (or mind) is also information (indirect existence), but it is the subjective form of information, that is, the world of for-itself information and regenerated information. There is also an objective information world (a concept described in Kun Wu's philosophy of information) in the objective world. This is the in-itself information world. In this way, according to the information ontology, the world (existence) is composed of matter and information, and matter interacts with mind through the medium of in-itself information. In this way, the relationship between matter and mind is no longer simply pure opposite, but is linked through the intermediary of in-itself information. The relationship from matter to mind, and from mind to matter, can be described as a process of intermediary interaction and mutual transformation [11–13].

The philosophy of information advocated by Wu is very different from Floridi's philosophy of information. We believe that Floridi's philosophy of information is too narrow. First, the computational method is only a kind of measurement of information. So it cannot reveal the ontological features of information, and it is closely related to the intelligent agent. Second, we cannot deny the existence of environmental information that is independent from the intelligent agent. Floridi also mentioned the existence of such information. "We speak of *environmental information* when we wish to stress the possibility that data might be meaningful independently of an intelligent *producer/informer*." [14]. Dretske and Barwise and Seligman [15,16] also researched environmental information. At last, based on the fact that information is a study on relationships, structures, and forms, it is not appropriate to limit the understanding of information to a computationalist approach. From the origin of concept of information, Aristotle's interpretation of form in ancient Greek philosophy is the interpretation of the relationship in the early history of philosophy [17]. The understanding of information in statistical physics, thermodynamics, and bioinformatics cannot be equivalent to the computationalist understanding on information. Otherwise, the Floridi's philosophy of information hinders us from acquiring a unified information concept and a unified information science paradigm [18].

But staying at the level of objective relationship is not enough to reveal the essential characteristics of information. In my opinion, the essential characteristics of information should be represented by more specific reflective relationships. This kind of reflection can be reflected in classical philosophy by the famous "signet-ring-stamps-impressions-in-wax". That is to say, I learned from the pattern traces left by the ring on the wax plate that the ring exists in part of the ring. Thus, we obtained information about the ring. In addition, from the word "information", I can also see the relationship between *form* and *information*, which could be seen as that we can obtain the information of the idea from the participated forms on the basis of Plato's theory. And we suggest that the content of stamp impressions is the real information, since it indicates the existence of the ring.

In western world, Marcia Bates defined the objective information in a way similar to Kun Wu's definition. We can compare them in the following:

Bates [19]:

Information 1: Information is the pattern of organization of matter and energy.

Wu [20]:

Information is a philosophical category indicating indirect existence, and it is self-manifestation of existing ways and states of matter (direct existence).

Here, Bates advocates a matter-information doctrine like Aristotelian matter-form dualism, which is similar to Wu's matter-information ontological theory. Bates uses patterns to indicate various relationships, both subjective and objective. And an object usually has many kinds of pattern. For example, a tree can have a physical relationship, as well as a chemical relationship or biological relationship or environmental relationship, and so on. Those relationships are its different patterns, and it reflects the existence of its related things.

All in all, we advocate the existence of objective information, and also advocate that the objective information is more fundamental than subjective information and can work as an intermediary between matter and mind (the high-level activity of subjective information).

10. Multi-Dimensional and Multi-Polar Complexity Features of Human Cognition Activities

The establishment of information ontology provides a unified foundation for the transformation of all other domains of philosophy and also provides a unified basis for the transformation of epistemology. It is necessary to establish a new information epistemology theory accordingly.

Based on the investigation of information epistemology, human cognition activities are the emergence of multi-dimensional and multi-polar complexity with the most novel and innovative features. "As a multi-dimensional, multi-polar, complex and comprehensive construction emergence, the generation of consciousness is both internal and external to the consciousness, as well as a product of interaction between the internal and the external; it is both subjectively presented and potentially regulated, as well as a product of interaction, transition and transformation between presentation and regulation; it is both subjectively active and objectively passive, as well as a product of unification between activity and passivity; it is both natural and humane, as well as a product of interaction between nature and human; it is both individual and social, as well as a product of interaction between individual and society; it is both directly presented and indirectly intermediate, as well as a product of construction and virtualization in the interaction between the direct and the indirect; it is both present and historical; as well as a product of mutual transformation and generation in the interaction of the present and the past; it is physiological, psychological and behavioral, as well as a product of synergistic interaction of the three aspects; it is conscious, subconscious and unconscious, as well as a product of interaction and transformation of the three items." [21].

In his philosophy of information, Wu Kun proposed a "Epistemology of Information Intermediaries" (Wu Kun, 1984), which uses the construction of multi-level mediators and virtual activities to explain the general mechanism and processes of human cognitive activities. There are four corresponding mediums during the cognitive processes (Wu Kun, 1989): the objective information field, the neurophysiological structure of the subject itself, the cognitive structure that the subject has constructed first, and the materialized means of the subject's cognition (tools, instruments, facility). In addition, the complexity of human cognition not only lies in the current multi-dimensional intermediary construction and virtualization activity, but also lies in its natural evolution and socially-generated historical process. This includes both the natural history of the subject's physiological structure and the evolution and construction of the social history. It also includes the genetic ability of the subject's cognitive structure and the role of the natural, social, and cultural information environment. It also includes the history of the emergence and development of materialized tools which is consistent with the evolution of human social abilities [21].

From this point of view, the ontological and epistemological aspects of philosophy and other areas of philosophy cannot be separated, and all other fields of philosophy must be based on ontology.

The rejection or suspension attitude towards ontology of western contemporary philosophy looks like making epistemology independent of ontology. Actually, its essence is the contradiction and separation of matter and mind. Due to the lack of necessary links between matter and mind, Western contemporary philosophy has to retreat to the inner world, simply seeking to interpret consciousness itself within the conscious activities.

On the basis of information ontology and information epistemology, Kunian philosophy of information has also developed a series of theories, including information evolution theory, information production theory, information society theory, information value theory, and information thinking theory.

From this perspective, since the 1980s, the philosophy of information established and developed in China firstly is a natural philosophy that adheres to naturalistic attitudes. However, this natural philosophy in the process and mechanism of its natural evolution explains human beings, human mind and human society. Therefore, the philosophy of information in China is a kind of meta-philosophy or supreme philosophy. This system undoubtedly has a brand-new style of natural philosophy. At the same time, this philosophy can better reflect the philosophical spirit of the information age.

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Article

The Urgent Need of a Naturalized Logic

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Abstract: The naturalization of logic aims at a revision of mainstream logic. In this article, I contend it is an urgent task to be completed. This new project will permit a new collaboration between logic and cognitive science. This can be accomplished doing for logic what many decades ago Quine and other philosophers undertook in the case of epistemology. First of all, this article analyzes how the naturalization can be achieved thanks to some insights provided by the recent John Woods' book *Errors of Reasoning: Naturalizing the Logic of Inference*; important concepts that regard a naturalized logic are synthetically analyzed: errors (and the problem of fallacies), paradigm creep, third-way reasoning, consequence-having and consequence drawing, agent based reasoning. The article also takes advantage of my own studies, which are aimed both at exculpating the negative fallacious character of abduction (it is the fallacy of the affirming the consequent) and at illustrating the EC-model (Eco-Cognitive model) of it, I have recently proposed. Aiming at encouraging the project of naturalization of logic, the article specifically recommends the increase of logical research on abduction, and emphasizes how current philosophical and logical research on human inferences is indebted towards Charles Sanders Peirce, a philosopher whose importance and modernity are too often underestimated. The final part of the article will introduce an analysis of the importance of the so-called *optimization of situatedness*, a concept that is necessary to understand that maximization of "abducibility", which characterizes modern science.

Keywords: abduction; agent-based reasoning; creativity; eco-cognitive model; eco-cognitive openness; fallacies; errors of reasoning; third-way reasoning; naturalization of logic

1. Naturalization, Cognitive Errors, and Logic

Dealing with the importance of cognitive errors commonly committed by human beings immediately refers to the need of a new process of naturalization of logic.[1] If we aim at delineating this project of naturalization of logic first of all we have to state the extreme importance of cognitive science and of its commitment to empirical research: of course I am here referring to those empirical observations which regard how people reason in various contexts (also empirical studies of argumentation in context are of course important). Moreover, to the aim of clarifying the main aspects of this process the case of abductive reasoning is exemplar, as I will address in the second part of this article. A research agenda would have to be created for empirical-based research on the topic.

The idea of naturalization has been already important in philosophy: Dewey [2], Toulmin [3], Quine [4], and Finocchiaro [5] (pp. 6–7) already stressed its importance and capacity to innovate ways of thinking against the excess of speculations and idealizations. Just to refer to the two important authors of the modern times, the naturalization of logic is the grounding idea of Dewey's experimental logic: "Logic is a social discipline [...] [E]very inquiry grows out of background of culture and takes

[1] The book *Errors of Reasoning: Naturalizing the Logic of Inference*, by John Woods [1], depicts a well-defined program of naturalization of logic, also thanks to a strong attention to the importance of the role of cognitive science in this process.

effect in greater or less modification of the conditions out of which it arises. Merely physical contacts with physical surroundings occur. However, in every interaction that involves intelligent direction, the physical environment is part of a more inclusive social or cultural environment" [2] (vol. 12, p. 27). Toulmin too contends that logical has to become "more empirical": "A similar theme is present in the early writings of Toulmin: Logic [. . .] may have to become less an a priori subject than it has recently been [. . .]. Not only will logic have to become more empirical; it will inevitably tend to be more historical [3]" (p. 257).

Moreover, the idea of a naturalization of logic has been already promoted thanks to the fecund interplay between formal tools and the new twenty century studies in the area of artificial intelligence (AI) and cognitive science. For example, Kowalski's book *Computational Logic and Human Thinking* [6] lists and illustrates various types of reasoning (for example deduction, induction, abduction, nonmonotonicity, planning, decision making, temporal and meta-reasoning), and de facto realizes an extension of logic in action favored by research in computer science and AI. In addition, Stenning's book *Human Reasoning and Cognitive Science* [7] furnishes new ideas regarding the naturalization of logic which stresses the need for finding new logical systems able to account for how actual people reason.[2]

In the book *Errors of Reasoning*, Woods further emphasizes the importance of the so-called "empirical sensitivity": a naturalized logic has to take into account the results provided by cognitive science and at the same time it has to carefully check every difference that there is between the mainstream logical inferential standards and the findings of cognitive and other sciences. In summary, "It is not in the general case preferable—indeed it is not smart and not even possible—to upgrade our cognitive targets in ways that favor truth-preservation or experimental/statistical confirmation as general cognitive strategies" [1] (p. 198). In this perspective, naturalizing logic is the refusal of all kinds of normative "presumption", and it is indeed in this sense, as I have stressed above, that the naturalization of logic is in tune with the studies which characterize the AI tradition.

Abandoning the usual tendency to build formal systems, idealized, the novel naturalized logic favors the need of carefully considering the actual aspects of human reasoning, postponing the "obsession" regarding judgments of goodness or badness or at least submitting those judgments to the default rule called "Convergence of the Normative on the Normal" (*NN*-convergence principle): the rule states that, in the absence of special reasons to the contrary, humans reason well when they reason in the manners that humans standardly do reason in for the circumstances of actual life. The *NN*-convergence principle is not a safe default for all aspects of human reasoning; its use here is only referred to premiss-conclusion reasoning. It suggests to us that a human agent's premiss-conclusion inference is the correct manner to reason when his conclusion-generating cognitive instrumentation is in a good state and, and it happens in the right way thanks to an operation on good information and without the contrary effect of uncongenial adversities.

We perfectly know that the mainstream logical tradition is oriented by the so-called mathematical turn in logic that occurred in the last decades of the 19th century, with the birth of mathematical logic. The emphasis on the role of cognitive science offers a new perspective, which departs from the ideality furthered by classical logic to something open to the consideration of agents, goals, resources, actions and to the role of time. Of course, these new tasks will generate the need for an improvement of the already available formal technicalities, to build new ones more appropriate to the naturalization, thus possibly avoiding excess of complication. Updates will instead have to look for simplification, and we can also provocatively advance the following idea: the empirical turn in logic can also constitute

[2] In my article [8], I have also illustrated in detail other research that can be seen as connected to the naturalization of logic: it mainly consists of AI studies that take advantage of logical modeling—promoted by Luís Moniz Pereira—in counterfactual reasoning [9,10], moral reasoning [11–13], mutual debugging and argumenting [14,15]; objecting [16,17], preferring, forgetting, updating, intention recognition and decision making. Also the studies regarding evolutionary game theory in the case of emergent population norms and emergent cooperative moral behavior are related to the need of nuturalizing logic, considering agents belonging to populations and groups, and certainly point out fundamental issues which help to overcome the expressive inflexibility of the conventional logical systems [18–20].

a new effort to change some methodological habits, as Woods suggests, moderating the idea that it is a duty of the theorist to demonstrate theorems; after all, theorem-proving is not required for population biology; consequently, why, asks Woods, should it be requested in the case of a naturalized logic?

2. "Paradigm Creep"and "Third-Way" Reasoning

The new naturalistic approach is especially suitable to shed a new light on some central issues that refer to the current epistemologico/cognitive debate. Woods [1] (p. 481) contends that we are dealing with a kind "paradigm creep", related to the puzzling problem of the importation of mathematical instrumentation into scientific research about cognition. Woods' perspective could be summarized in the proposition "Do not for your present purpose employ successful methods", in other words: it is not said that methods that optimally work in a determinate field can automatically be good elsewhere. In this perspective, it is clear that, in human reasoning, particularly when consisting in a movement from premisses to conclusions, it is unlikely and uncommon that the usual criteria of deductive validity or statistico-experimental inductive power are ever at work. New criteria for what Woods calls "third-way" reasoning [1] (Chapter 7) have to be built taking advantage of the already available models regarding nonmonotonic, default, ceteris paribus, agenda-relevant, inconsistency-adaptive, abductive reasoning, for which neither common deductive validity nor inductive force are appropriate as good criteria of assessment. A great part of human "right" reasoning is third-way reasoning, and this rightness is reached thanks to the exploitation of requisites that are different from the standards of deductive validity (or inductive force).

I have just said in the previous paragraph that it is relatively unlikely that the standards of statistico-experimental inductive strength can be at work: Bayesianism is very well-known in current cognitive science: what is the consequence of the new perspectives on naturalizing logic with respect to Bayesian models of cognition? I agree with the skeptical attitude adopted by John Woods: Bayesianism, as an appropriate way of representing normatively assessable premiss-conclusion inferences as executed by human beings in the situations of everyday actual life, has to be rejected. A summary of various argumentations against Bayesianism—and in general against all normatively idealized models to human cognitive performances—is still illustrated in Woods' book [1] (Chapter 2 and pp. 75, 80, 142) and can be simplified as follows. As used to represent actual human reasoning performances—in the cognitive economies in which humans live out their lives—Bayesianism's abstract and ideal normative rules cannot be implemented mainly because their computational intractability for human beings. Norms, such as the closure of belief under consequence, are not only false of human actual praxis but transfinitely false of it. Humans, even when they are performing cognition in their own possible best way, cannot arrive close to this ideal norms in any finite degree. This huge gap is usually explained away by saying that we humans are very "bad" at reasoning.

Usually, Woods says, two argumentations are proposed to the aim of explaining the prescriptive authority of Bayesian rules, as described in [1] (Chapter 2). First, it is said that the potency of those rules derives from the truths (or analyticity) in–the model—second, that it derives from the "necessity" that is generated by their mathematical expression (given the fact that we in general accept the idea that mathematical truths are necessary). It is patent that they are very poor arguments. There is a third argument, more complex but certainly inadequate too. The argument resorts to, say, taking advantage of a kind of reflective equilibrium demonstration, that the prescriptive authority of the Bayesian norms are prescriptively binding on human individual behavior when they are clearly mirrored by the standard praxis of the communities in a broad way. The problem is: how can these communities be determined? Are they the everyday ones or do they coincide with the people who conduct studies on human reasoning, i.e., are they Bayesian themselves? In the case of this last argumentation, we still obtain a bad result because these expert people, from the point of view of their ways of reasoning, are not different from the rest of human beings and, moreover, in terms of what they consider good reasoning performances, a degree of conformity to their own prescriptive rules can emerge (but this is an obvious consequence!).

I have anticipated that abduction is a wonderful example of "third-way reasoning" and it is in need of a naturalization of logic: Bayesianism could be the solution because it is also at play when dealing with abductive cognition, and it is often preferred by some logicians and by some cognitive scientists who work on abduction. Still, the problem is that Bayesianism first of all does not present a proved (or even plausibly guessed) prescriptive legitimacy. Second, we have to recall that Peirce correctly maintained that a rationally optimal human abductive cognition is not related to the objective probability of the hypothesis at stake and, at the same time, should not raise its subjective probability. Consequently, enforcing Bayesian rules with the intention of saying the last word about abduction involves a betrayal of Peirce's ideas: of course, Bayesianism provides technical tools able to help us to perform abductions just offering an ideal method, among many others, that can occasionally be used (for example in AI). Indeed, the reader does not have to misunderstand me: it is certainly desirable that Bayesianism should be made more realistic by dropping the idealized condition of closure of belief under logical consequence, but this does not mean that having some standards of good inductions and abductions does not have to still be desirable too.

3. "Consequence-Having" and "Consequence-Drawing"

When dealing with a project of naturalization of logic, we have to distinguish between "consequence-having", which is related to the "logical space" concerning the usual concept of "logical consequence" of the mainstream logical tradition, and "consequence-drawing", which refers to the "the reasoner's mind" in a non-idealized space, pragmatically influenced. Consequently, consequence-drawing consists of a *pragmaticization* of consequence-having. Nonmonotonic and abductive logics already available have provided a naturalized account of various kinds of third-way reasoning: however, a stronger further naturalization will be intertwined with a reshaping of them to the aim of grasping more aspects of the conclusion-drawing structural relationships in various particular contexts. Indeed, Woods stresses that the conclusion-drawing is basically a special kind of inference that is referred to a cognitive agent X, the information I the agent reasons on, a background database Δ of information that is at disposal of the agent, a cognitive agenda A of duties for the agent, a conclusion α, derived after the application of the background Δ to I, and a disposition D to answer—if asked—justification requests for α's being drawn by citing $I(\Delta)$ [1] (pp. 285–286).

Naturalizing logic is certainly the improvement of the already available agent-based logics, probabilistic systems, belief-change and decision theories, epistemic and justification logics, and fallacy theory, but also the revision of some aspects of discourse analysis and argumentation and of normative psychology. However, a deep revision of the fallacy theory is still needed for the aim of exculpating "errors of reasoning" by showing their virtues and positive characters. To this aim, in the quoted book, Woods further promotes new perspectives on defeasible and default reasoning, nonmonotonic systems, autoepistemic and anti-closed world belief-formation, the role of presumption in the government of belief, etc. An interesting chapter also regards in a naturalized way the communication of knowledge when one individual tells something to another. In addition, abduction—see below in Section 6—a basic inference of human and animal life, is one of the main issues of the book.

In summary, as a new ambitious project, naturalizing logic aims at contrasting the priority of the prescriptive characters typical of the mainstream logic of premiss-conclusion reasoning, also taking advantage of the interplay between logic and the the new sciences of cognition. Here, the role of the relationship between cognitive science and empirical research has to be further emphasized, stressing that we are not referring here to empirical research merely interested in abstract models of the mainstream tradition, but to a much wider area of human cognitive behaviors. In this perspective, abductive reasoning is a good example, given the fact that this kind of reasoning cannot be satisfactorily studied in the framework of classical logic and, at the same time, refers to a broad area of human cognitive performances, which can only be ascertained empirically.

4. Agent-Based Pragmatically Oriented Logics

Peirce considered it unlikely to be able to build an agent-based "logic" and consequently—for example—a logic of human abductive cognition, pragmatically oriented. Indeed, Peirce thinks that logic (and scientific reasoning) and practical reasoning have to be clearly distinguished (it is impossible to imagine a practical logic in general and a fortiori a logic of abductive cognition): "In everyday business reasoning is tolerably successful but I am inclined to think that it is done as well without the aid of theory as with it" [21] (p. 109). "My proposition is that logic, in the strict sense of the term, has nothing to do with how you think [. . .]. Logic in the narrower sense is that science which concerns itself primarily with distinguishing reasonings into good and bad reasonings, and with distinguishing probable reasonings into strong and weak reasonings. Secondarily, logic concerns itself with all that it must study in order to draw those distinctions about reasoning, and with nothing else" (ibid., p. 143). It is curious that the founder of the first studies on abductive reasoning is not at the same time inclined to consider the possibility of what in this article I call "naturalization of logic".

Naturalizing logic overcomes Peirce's skepticim: a new naturalized logic is legitimate and certainly has to be *agent-based*. The particular example of a new naturalized logic of abduction is important because it also refers to the importance of showing the virtues of the well-known fallacy "affirming the consequent"—which indeed classically models abductive reasoning. Peirce's abduction is illustrated as both (a) a surrender to an idea, and (b) a way for examining/testing its consequences: these aspects certainly mirror in themselves some basic aspects of practical reasoning. Woods contends that already available logics of abduction [1] (Chapter 11) are still excessively idealized illustrations of the corresponding cognitive conduct of a human actor. To overcome this weakness, I myself have delineated the so-called eco-cognitive[3] model of abductive reasoning in [22]: the abductive human performer is naturalistically framed in the perspective of the distributed cognition tradition.

Given the fact, as Gabbay and Woods maintain, that a logic is a symbolized *idealization* of a kind of actor as a *logical agent*, which characters of a human agent will a logic of abduction take into account? Following these authors, it seems that an actual human agent is a kind of organic actualization of a nonmonotonic paraconsistent base logic: it is certain that the strategies furnished by classical logic and some closely related non-standard logics compose a tiny part of the cognitive capacities of a single person. The main reason is that real human agents usually are not committed to avoid errors like "classical" idealized logical agents. I repeat, Gabbay and Woods contend that a formal model is an idealized illustration of the performances of an actual agent and so it presents itself as very distant with respect to the empirical data that reflect a human reasoner: for these patent reasons, it is obvious to state that in the logic that represents a practical agent (for example abductive) problems of "contextual"—for example—*relevance* and *plausibility* are fundamental.

Moreover, we have to remember that a "real" human abductive agent runs at both conscious and unconscious levels, and at *both* levels he is committed to (or is oriented by) consider the truth conditions on propositional frameworks, to state conditions on belief structures and their stabilization, and also to groups of rules embedded in various argumentative frameworks, for example for assessing arguments. These three aspects cut through explicit and implicit cognition. I have to add that the majority of the central reasoning capabilities of a human actor are enriched by a "story", and are in turn related to the several propositional relations he detects in his cognitive environment and which he considers relevant, with several cognitive reasons to modify his mind or to reason in an alternative way, and with various motives to distribute different strategies of argumentation.

Naturalized logical systems have to be taken as *mimetic*: in this sense, they are "mimetic representations" (for example, nonmonotonic systems are certainly more able than classical logic to "mime"—an so they are more psychologically veridical—human beings' actual cognitive performances). Classical logical agents certainly embody ideals of "good reasoning"; unfortunately, in the perspective of

[3] I will illustrate the significance of this expression below, in Section 6.2.

a naturalized logical perspective, good reasoning is always good in relation to a target or an agenda which may also be tacit. In this sense, reasoning validly is never in *itself* something that leads to good reasoning; Gabbay and Woods say:

> It is that the reasoning actually performed by individual agents is sufficiently reliable not to kill them. It is reasoning that precludes neither security not prosperity. This is a fact of fundamental importance. It helps establish the fallibilist position that it is not unreasonable to pursue modes of reasoning that are known to be imperfect "Given the cognitive goals typically set by practical agents, validity and inductive strength are typically not appropriate (or possible) standards for their attainment" [23] (pp. 19–20, 25).

I have anticipated that abduction in the framework of classical logic is the fallacy of affirming the consequent, and so it is a kind of reasoning that can be affected by mistakes and failures, sometimes seen as an example of *imperfect reasoning*: at the same time, we all know that it is a kind of a very useful reasoning because we cannot imagine the prosperity of our civilizations without linking it to the extraordinary capacity of humans to guess good hypotheses of various kinds. Human agents are hasty inducers/generalizers, bad predictors, and hybrid abducers unlike ideal (logical and computational) agents: the naturalization of logic is devoted to illustrate and describe the force and the fruitful side of these inferential routines, otherwise considered "impaired".

5. "Redeeming" Fallacies

I contend that from Aristotle onwards logic has always treated fallacies in an excessive negative way. It would be better for logic to rethink fallacious reasoning in a novel perspective and the naturalization of logic is surely the correct method able to pursue this target. In this perspective, Woods's book *Errors of Reasoning* represents a kind of "manifesto" of the naturalization of logic: it exactly states the two main preconditions of the project, the need of both (1) redeeming fallacies and (2) criticizing the excess of prescriptive authority contended by formal models of ideal reasoners. In this framework, we can see fallacies not only as active, possibly in a negative way, both in everyday and scientific reasoning, but, also, the facto, as the occasional best tool for arriving to reliable cognitive results. These results are able to grant to human beings adequate fitness in everyday life but also consequent adaptive effects in more complicated inferential activities, such as in the case of scientific discovery and modeling.

The positive cognitive role of classical deductive and inductive fallacies such as ad baculum, ad hominem, ad populum, ad ignorantiam, ad verecundiam, affirming the consequent, denying the antecedent, hasty generalization, equivocation or quaternio terminorum, the gambler's fallacy and post hoc ergo propter hoc, has to be vindicated. Reasonings of this type have a pervasive presence in cognitive contexts and, as already said, often facilitate the reaching of crucial general rational cognitive ends. Similarly, Peirce said that humans' abductions are—and the reason is fundamentally evolutionary—"akin to the truth" [24] (7.220):[4] they work positively in various situations and actually consent good survival and successfulness. We have to abandon the old view that exclusively sees a fallacy as a mistake in reasoning, a mistake which is extremely frequent in human arguments and usually also effectively deceptive. Just to make an example, fallacies such as hasty generalization and *ad verecundiam* are classified as "inductively" weak inferences, and affirming the consequent is a deductively invalid inference. The problem is that, when they are exploited by real reasoners, that is in an eco-logical[5] and not only logical—that is "ideal" and abstract—way, they are *no longer* fallacies, but instead productive ways of inferencing important cognitive conclusions.[6]

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4 See also below, p. 9.
5 That is when fallacies are considered in an actual human and social flux of information and/or speech-acts.
6 Further illustration of the so-called "EAUI-conception" of fallacies (fallacies are Errors, Attractive, Universal, and Incorrigible) is provided in the already quoted Woods' book [1] (p. 136).

In [25], I have delineated a clear differentiation between strategic and cognitive rationality: in this perspective, various fallacies can be considered at the same time cognitive mistakes and strategic successes, that is, it happens that it is more appropriate (and sometimes rational) to go ahead strategically, even if we are committing a "logical" mistake (it is, for example, the case of hasty generalization, often useful in circumstances of real life):[7] in these cases, we can affirm we are dealing with the so-called *"casual" truth preserving* aspect of fallacies.[8]

It is important to note that, according to Woods (and I agree with him), it is not that it is often "strategically" excused to adopt fallacies, but rather that traditional fallacies simply *are not fallacies*. This consideration is insidious: we can clarify it by saying that the traditional conception of fallacies is embedded in a deep *aristocratic* idea of human thinking that neglects its deep eco-cognitive aspects. These cognitive acts that are based on fallacious inferences patently show that cognition can be good and fruitful even in front of limited information and knowledge and when sound inferences lack. In this light, a more profound and reliable knowledge and sound inferences are no more at the center of the attention, instead reserved to them by the philosophical, epistemological, and logical received views. After all, reliable belief is sufficient for human collectives to realize a good fitness, as they do, and, in this sense, belief seems more "economical" than completely attained knowledge.

6. Naturalizing the Fallacy of Affirming the Consequent: Abduction in an Eco-Cognitive Perspective (the EC-Model)

A lot of studies on abduction produced in several areas of research, such as logic, cognitive science, philosophy, and AI, have already vindicated the cognitive relevance of the the so-called fallacy "affirming the consequent" (I have already said that in the framework of the classical logic abductive reasoning is rendered by this fallacy), that is the error of possessing a conditional and its consequent, and from this consequent deriving the antecedent. In reality, this kind of reasoning is very useful, and, when reconsidered in the light of the naturalization of logic, the fallacy is shown to possess an extraordinary cognitive importance, in most of the every-day reasoning contexts, included diagnosis and creative processes, but also in sophisticated situations, for example regarding scientific reasoning. Abduction usually provides good hypotheses, so furnishing an example of what some logicians have called "material validity":[9] the invalid form (the fallacy) provides a cognitive good semantic result. In the last three subsections of this article, I plan to illustrate a naturalization of the fallacy of the affirming the consequent: it is in this way that we can detect and stress the cognitive very positive aspects of abduction, and, to this aim, I will adopt and further delineate the so-called Eco-Cognitive Model (EC-model) of abduction that I have recently proposed.

6.1. Ignorance-Preservation and Abduction

In my last book on abductive cognition [32] (Chapter 1), taking advantage of Gabbay and Woods' ideas, I have described that abduction is an inferential process in which something that lacks epistemic virtue is used and assumed because it has virtue of another kind. For example: "Let S be the standard that you are not able to meet (e.g., that of mathematical proof). It is possible that there is a lesser epistemic standard S' (e.g., having reason to believe) that you do meet" [1] (p. 370). Abduction, in the light of the naturalized logic delineated in the previous sections, and extracted from the fallacious destiny that the mainstream logic assigned to it, has to be fundamentally seen as a *scant-resource* strategy [23], which goes forward in absence of knowledge and exhibits an *ignorance-preserving*

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7 Various concrete examples are illustrated in [26].

8 Even if they are not committed to build naturalized logical models of reasoning Gigerenzer et al. [27–30] emphasized the "fast and frugal heuristics", and their strategic role in reasoning ("strategic rationality" they say) as tools that can solve various problems in settings characterized by limited knowledge and time. In these studies, strategic reasoning is seen, in a kind of evolutionary perspective, as an *adaptive toolbox*, related to an ecological and social view.

9 The concept of material validity is explained by Brandon [31], as a situation in which we face with a semantically valid inference, even if it instantiates an invalid syntactic scheme.

(or, better, an *ignorance mitigating*) character. Of course "[...], it is not at all necessary, or frequent, that the abducer be wholly in the dark, that his ignorance be total. It needs not be the case, and typically isn't, that the abducer's choice of a hypothesis is a blind guess, or that nothing positive can be said of it beyond the role it plays in the subjunctive attainment of the abducer's original target (although sometimes this is precisely so)" (p. 370). Abductive reasoning is the *answer* to an ignorance-problem: no knowledge is available to solve a problem, so we have three chances (1) looking for new knowledge, appropriate to solve the problem; (2) yielding our ignorance in a kind of provisional capitulation; (3) guessing a hypothesis able to solve the problem and to provide a new basis for action, that is we abduce (in a framework of constitutive ignorance).

In this perspective, Woods proposes a general scheme of an abductive inference that can be formally rendered as follows. Let α be a proposition that characterizes an ignorance problem. T will be the agent's epistemic target with respect to the proposition α at a given time, K his knowledge-base at that time, K^* an immediate accessible successor-base of K that regards the agent's means to produce in a timely way,[10] R the attainment relation for T, $\rightsquigarrow$ the *subjunctive* conditional relation, H as the agent's hypothesis, $K(H)$ the revision of K thanks to the addition of H, $C(H)$ refers to the conjecture of H and H^c its activation. The general schema of and abductive inference abduction can be illustrated as follows (GW-schema):[11]

1. $T!\alpha$	[establishment of T as an epistemic target with respect to a proposition α]
2. $\neg(R(K,T))$	[fact]
3. $\neg(R(K^*,T))$	[fact]
4. $H \notin K$	[fact]
5. $H \notin K^*$	[fact]
6. $\neg R(H,T)$	[fact]
7. $\neg R(K(H),T)$	[fact]
8. If $H \rightsquigarrow R(K(H),T)$	[fact]
9. H meets further conditions $S_1, ...S_n$	[fact]
10. Therefore, $C(H)$	[sub-conclusion, 1–9]
11. Therefore, H^c	[conclusion, 1–10].

> The schema seems very appropriate for abduction. It is a given that H neither in the agent's knowledge-set nor in its immediate successor. Given the fact that H is not in K, then the revision of K by H is not a knowledge-successor set to K. Even so, $H \rightsquigarrow R(K(H),T)$. Consequently, we have an ignorance-preservation, as required (cf. [1] (Chapter eleven)).

Note: Line 9 says that H does not have more plausible or relevant rival constituting a larger degree of subjunctive attainment. Of course, establishing the S_i is the most difficult problem for abductive inference: indeed, there are many potential candidate hypotheses. Woods says that this involves, for example, the *consistency* and *minimality* constraints. These constraints reproduce the lines 4 and 5 of the standard AKM schema of abduction,[12] which is illustrated as follows:

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10 K^* is an accessible successor of K to the degree that an agent has the know-how to construct it in a timely way; i.e., in ways that are of service in the attainment of targets linked to K. For example, if I want to know how to spell "accommodate", and have forgotten, then my target can't be hit on the basis of K, what I now know. However, I might go to my study and consult the dictionary. This is K^*. It solves a problem originally linked to K.

11 That is, Gabbay and Woods Schema.

12 This classical representation of abduction is rendered by what Gabbay and Woods [23] call AKM-schema, which is contrasted to their own (GW-schema), which I am just illustrating in this subsection. A refers to Aliseda [33,34], K to Kowalski [35], Kuipers [36], and Kakas et al. [37], and M to Magnani [38] and Meheus [39]. A full description of the AKM schema is contained in [22] (Chapter 2, Section 2.1.3).

1. E,
2. $K \not\rightsquigarrow E$,
3. $H \not\rightsquigarrow E$,
4. $K(H)$ is consistent,
5. $K(H)$ is minimal,
6. $K(H) \rightsquigarrow E$,
7. Therefore, H

[23] (pp. 48–49),

where obviously the conclusion operator $\rightsquigarrow$ cannot be classically interpreted. The target has to be an explanation and $K(H)$ bears R^{pres} (that is, the relation of presumptive attainment) to T only if there is a proposition V and a consequence relation $\rightsquigarrow$ such that $K(H) \rightsquigarrow V$, where V indicates a *payoff proposition* for T. In turn, in this schema, explanations are interpreted in consequentialist terms. If E is an explanans and E' an explanandum, the first explains the second only if (some authors further contend if and only if) the first implies the second. Of course, we can add that the AKM schema embeds a D-N (deductive-nomological) interpretation of explanation, as I have also detailed in [38] (p. 39).

Finally, in the GW-schema, $C(H)$ is read "It is justified (or reasonable) to conjecture that H" and H^c is its activation, as the basis for *planned* "actions".

In summary, the GW-schema stresses that H is *merely guessed, hypothesized*, so that the truth is not assured: $K(H)$ *presumptively* attains T, the agent just "presumes" that his target is now accomplished. Given the fact that presumptive knowledge accomplishment is not an actual knowledge accomplishment, the agent's abduction has to be thought as preserving the ignorance that already generated his (its, if we are dealing with a machine) original ignorance-problem. Consequently, abduction does not have to be considered the "solution" of an ignorance problem, but rather a simple response to it, in which the agent attains presumptive achievement of a cognitive task rather than actual accomplishment. $C(H)$ means the conclusion that it follows from the facts of the schema that H is a worthy object of conjecture. We have to add that, to the aim of solving a problem, it is not needed that an agent actually can guess a hypothesis, but it is only needed that he expresses that the hypothesis is *worthy of conjecture*. Moreover, conceiving H justified to conjecture is not equivalent to conceiving it justified to accept/activate it and finally to send H to experimental examination. In this perspective, H^c indicates the *decision* to submit H to further work in the field of enquiry in which the ignorance-problem originated, that is, the activation of H represents a good *cognitive* basis for acting. Of course, there are many cases in which abduction stops at line 10, that is, no activation is performed: "When this happens, the reasoning that generates the conjecture does not constitute a positive basis for new action, that is, for acting *on* that hypothesis" [1] (p. 371). When the hypothesis is instead evaluated, we have to note that this process of evaluation and so, of activation, does not have to be considered abductive, but inductive, as Peirce illustrated.[13] Hence, in the perspective of the GW-schema, testability is not constitutive of abduction.

A last note concerns an obvious characteristic of human abduction that has to be stressed. In the case of human abductive inner inferential processes, there are implicit routines, that is, unconscious cognitive performances that obviously cannot be contemplated by a formal model such as the GW-Schema. Peirce already indicated this aspect when illustrating the role of instinct [24] (8.223) and of what Galileo named the *lume naturale* [24] (6.477), a kind of an innate inclination for guessing right: we have to remember, following a Peircean basic insight concerning abduction, that this kind of reasoning is constitutively " akin to the truth": "It is a primary *hypothesis* underlying all abduction that the human mind is akin to the truth in the sense that in a finite number of guesses it will light upon the correct hypothesis" [24] (7.220). This and other cognitive and epistemological features can

13 Hintikka disapproves this Peircean employment of the word "induction": "I do not think that it is instructive to call such reasoning inductive, but this is a merely terminological matter" [40] (pp. 52 and 55).

be described in more detail thanks to the eco-cognitive model (EC-Model) of abduction that will be summarized in the following final two subsections.

6.2. The Eco-Cognitive Model of Abduction

Condition 9 of the GW-schema (cf. previous subsection) is really puzzling. Indeed, it is not said that consistency and minimality constraints have to possess a privileged status, even if they have been emphasized in the "standard view" (AKM model, see the previous subsection) of abduction proposed by various classical logical accounts, more inclined to deal with selective abduction [38]—for example, in diagnostic cognitions (in which abduction is mainly seen as an inferential process of "selecting" from a "repository" of pre-stored hypotheses) than with *creative* abduction (abduction that produces new hypotheses).[14]

For example, the consistency requirement is questioned by the banal fact that, as Paul Feyerabend observes in *Against Method* [41], contradiction plays a fundamental role in generating creative hypotheses, that is what I have called creative abductive cognition. In these cases, there is a kind of "counterrule" which works against consistency and "[. . .] advises us to introduce and elaborate hypotheses which are inconsistent with well-established theories and/or well-established facts" [41] (p. 20). This rule also implies that creating "alternatives" is a good policy because "proliferation of theories is beneficial for science".

Moreover, clause 9 in the GW-model is related to two problems: (1) determining criteria for hypothesis *selection* and (2) building appropriate conditions for *thinking up* potential candidate hypotheses for the selection itself. Woods labels the first the "cutdown" problem and the second the "fill-up problem". It is this twofold problem that indicates the main equivocalness of the ignorance-preserving character of abduction contended by Gabbay and Woods: indeed, we have to state that the inferential procedures of generation (fill-up) and of selection (cutdown) can both be enough—even when a standard inductive evaluation moment lacks—to *activate* and accept [clause (11) of the GW-schema] an abductive hypothesis, and so to reach important knowledge results. In this case, the results are the fruit of a knowledge enhancing activity, as I have extendedly illustrated in [32,42,43]: the instrumental components (which permit one's target to be reached) promote both abductive generation and abductive selection, and it is not needed that they should deal with classical plausibilistic worries, such as consistency and minimality.

In these knowledge enhancing cases, the best selection is accomplished in the absence of the experimental trial (which is instead basically characterized by the received view of abduction in terms of the well-known so-called "inference to the best explanation"). In a certain sense, the generation process alone can be sufficient: this is, for example, patent in the case of human *perception*, where the produced hypothesis is instantaneous and singular. We have to remember that perception was seen by Peirce as an "abductive" quick and ungoverned (and so automatic) process of production of knowledge. Perception, in the Peircean speculative light, is presented as a carrier for the immediate recovery of knowledge that was previously elaborated in our mind through more complicated inferential procedures. Peirce says: "Abductive inference shades into perceptual judgment without any sharp line of demarcation between them" [44] (p. 304).[15]

The idea of abductive cognition as perception immediately indicates central aspects of what I called its eco-cognitive character because, in this case, individual human agents, sensorial apparatuses, environment, and cognition are all regarded. To better grasp my eco-cognitive model of abduction, we must make a reference to the recent cognitive science studies on embodied and distributed cognitive systems: in my view of abductive cognition, the singular "practical agent" plays a dominant

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[14] I have suggested the distinction between selective and creative abduction in [38].

[15] In [8] and [32], I have further illustrated the Peircean philosophical idea of perception as a case of abduction by showing how it can be corroborated thanks to recent cognitive research, also related to AI.

role, an agent that is operating "on the ground", that is, in the situations of everyday actual life. The original work in distributed cognition was first of all related to the conviction that cognition is a socially distributed process, which is occurring in real practices. Cognitive processes are situated in and distributed across actual socio-artifactual contexts, against the standard view, inherited by the philosophical and psychological tradition, which privileged internalism and assigned to external representations, cognitive delegations, and collaborative processes a mere ancillary role. An ecological view helps seeing the central role in cognition of the agent-environment interplay: to make an example, in collective work environments, human beings and artifactual technologies are intertwined in manipulating representations, for example with the target of solving problems. It is exactly in this complex—socially, materially and temporally—distributed interplay that we can grasp the real structure of cognitive processes.

The theory of distributed cognition was proposed by Edwin Hutchins to analyze common problem-solving routines in actual human situations, but the theory soon acquired an important relevance for the entire research in cognitive science. In his well-known book *Cognition in the Wild* [45], Hutchins illustrates how agents exploit tools, props, and instruments (and, at the same time, external cognitive representations) to create, build, manipulate, and preserve representations. Hutchins thinks that the cognitive characters and properties of a distributed cognitive system is strictly connected with specific physical and "material" properties of the external representational mediators which are exploited.[16]

My eco-cognitive model of abduction (EC-model),[17] has to be seen in the cognitive perspective I have just described. In the various situations in which we see abduction at work, from the ideally logical and mathematical to the more or less empirical, I insistently stress the eco-cognitive character of abduction. Reasoning is something realized by cognitive systems and, as an approximation, a cognitive system is a triple (A, T, R), in which A is an *agent*, T is a *cognitive target* of the agent, and R refers to the *cognitive resources* which the agent can exploit during the process aimed at reaching a target, for example, information, time and computational capacity, to recall the most relevant. Hence, my practical agents are *embodied distributed cognitive systems*: cognition is embodied and the interplay between brains, bodies, and external environment constitutes its dominant aspects. Cognition happens thanks to a continuous flow of information in a complicated distributed system that is occurring in the intertwining of humans, artifacts, and the environment, in which instinctual and subliminal capacities also play a relevant role. I have to stress that this interplay is especially important and dominant in several forms of abductive cognition.

I have said above, just making an example among the many, that perception can be seen as an abduction in which a fast and uncontrolled knowledge production is at work. Consequently, this means that—at least in this wider perspective—GW-schema is not canonical for abduction. The schema refers to what I have called "sentential abduction" [22] (Chapter 1), that is, abduction performed by symbols conveying propositional content. In this schema, it is impossible to insert cases of abductive cognition such as, for example, perception or the production of models (cf. [42]) in scientific discovery.

This theoretical framework, I have to remember, is also coherent with Peirce's philosophical major tenets: he thought that the concept of "inference" has to be intended *semiotically*, in a wide sense, (and not merely "*logically*"): he clearly says that all inference is a form of sign activity, where the word sign includes "feeling, image, conception, and other representation" [24] (5.283). Indeed, I think that this Peircean semiotic framework can be fruitfully intertwined with my perspective on cognitive systems as embodied and distributed systems. On the contrary, the GW-Schema refers, even if in a very effective way, to that subset of cognitive systems abductive processes that are realized thanks to explicit propositional contents. I think Woods agrees with me: "[. . .] the GW-model helps get us

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[16] For a deeper illustration of this interaction and of the role played by external representations as "material anchors for conceptual blends" [46] is a mandatory reference. A summary of the so-called "cognitive ecology" is illustrated in [47].
[17] A first characterization of this model has been given in my book [22].

started in thinking about abduction, but it is nowhere close, at any level of abstraction, to running the whole show. It does a good job in modelling the ignorance-preserving character of abduction; however, since it leaves the S_i of the schema's clause (T) unspecified, it makes little contribution to the fill-up problem" [48] (p. 244).

Finally, it is important to stress that in my extended eco-cognitive framework the cutdown and fill-up problems in abductive cognition turn out to be stunningly related to the *contexts*. We can abduce a concept or a model when making science, where rationality is at play, but we can also abduce a hypothesis (a fictional character for example) in literature, or in moral cognition (the choice of a hypothetical judgment to motivate moral actions). We say that in these situations abductive hypotheses are basically evidentially inert and so admitted and actuated as a basis for further knowledge and/or action. In summary, the eco-cognitive research on abduction motivates a wide approach to "good reasoning", which certainly favors further studies on new "naturalized" logics of abductive cognition. In this way, we can overcome the average typical attitude of traditional logicians: it has been typical of them to manifest disinterest in abduction and other forms of third-type reasoning, as I have explained above, a skeptical attitude about unorthodox ways of good reasoning.

6.3. Abduction Naturalized: The Importance of Eco-Cognitive Situatedness

A good abductive logical system can be standardly illustrated by the following levels, which refer to the fill-up and the cutdown aspects:

- a *base logic* L_1 with demonstration procedures Π;
- an *abductive algorithm* which exhibits Π to look for missing premisses and other formulas to be abduced;
- a *logic* L_2 for deciding which abduced formulas can be chosen, the criteria and methods of selection, etc. This logic is associated to the indication of suitable constraints concerning consistency, plausibility, relevance (topical, full-use, irredundancy-oriented, probabilistic), etc., and economy, making the ideal agent able to discount and select information which does not resolve the task at stake [23] (we have also observed above that other more instrumental criteria—and not merely consistency, plausibility, and similar ones—can be at work in strong cases of creative abduction).

The EC-model of abduction immediately suggests that, if we aim at naturalizing the logic of the abductive inferences and of its particular *consequence relation*, which indeed must be powerfully "eco-cognitive-sensitive", the following requirements are mandatory:

1. *optimization of situatedness*: situatedness is related to eco-cognitive aspects. To promote the solution of an abductive problem starting data and cognitions involved in the production of new hypotheses have to be seen as *optimally positioned*;
2. this optimality is rendered possible by a *maximization of changeability* of the flux of information available to the abducer (initial data) but also of the generated hypotheses that have to be various but— fundamentally—optimally "excogitated";
3. therefore, abductive inferential procedures are extremely *information-sensitive*, that is, the flow of information which affects them is uninterrupted and human (or machine)-boosted and enriched when necessary. This is not the case of demonstrations in classical logic, in which the adjustments of the inputs are *minimized*, demonstrations are considered with "given" and relatively stable inputs, and the burden of demonstrations is dominant and assigned to the inference rules, and to the strategic selection of them together with the selection of their suitable sequentiality (see [32] (Chapter 7, Section 7.2));
4. indeed, in an eco-cognitive perspective, an abductive "inferential problem" can be enhanced by the emergence of new information in a temporal dimension that favors the restarting of the inferential process itself. In the case of this cycle of reasoning, we are dealing with the so-called

nonmonotonic character of abductive reasoning. Abductive consequence is characterized by new and newly appeared information, and so it is a defeasible kind of reasoning.

In summary, an appropriate naturalization of a logic of abduction has to consider the important role of the constant flux of information from the eco-cognitive surroundings in which the following two aspects count:

1. the *new information available*,
2. the *new information inferentially generated*.

Finally, let us stress again, as I have already indicated, the relevance of

- *multimodality*: the logical inferential procedure of adjustment of initial data must be clearly considered as *multimodal*, both from the perspective of *cognitive tools* "represented" (not only propositions, but also diagrams, or icons, for instance), and from the perspective of the *applied rules* that can be based on models (model-based). In addition, possible algorithmic computational components have to be considered pertinent.

In conclusion, optimization of situatedness is the major feature of logical abductive inference, which basically overcomes the other properties such as minimality, consistency, relevance, plausibility, etc. I have indicated above. These are special subsets of optimization processes, which refer to the particular type of situatedness required. I have often stressed in my studies the crucial case of abductions in science, in which the optimization of eco-cognitive situatedness has to deal with various constraints, which fundamentally regard the importance of the so-called epistemic virtues.[18] Some examples of epistemic virtues are: hearing various sides of the scientific "stories" during the interplay among various scientists, but also among scientists and artifacts, and scientists and results coming from the experiments; open-mindedness; tolerance; impartiality; carefulness and sensitiveness to details; "deference" to the evidence (avoiding to change at will the starting data and the involved rules); being willing to question assumptions; giving and asking for reasons (applying suitable rules and verifying their rightness); being curious; being intellectually brave—that is, not merely believing what it is convenient to believe; etc.

In the final chapter of my last book on abduction [32], I have also stressed that constraints, methods, cognitive virtues, etc., which are concerned in scientific reasoning, on one side depict "limitations" of the cognitive behaviors involved, limitations that otherwise are fruitful because on the other side they also incorporate a commitment to the preservation of that *optimization of eco-cognitive openness*, which uniquely can permit the prospering of "human" abductive creativity in science.

7. Conclusions

In this article, I have analyzed and criticized some basic tenets of the John Woods' book on "errors of reasoning", and my own perspectives concerning abduction, to promote the project of the so-called naturalization of logic. I have suggested a criticism of the tradition of mainstream logic able to favor a new collaboration between logic and cognitive science, doing for logic what, many decades ago, philosophers such as Quine have proposed for epistemology: a "naturalization" of the logic of human reasoning. I have also illustrated that naturalizing logic requires an agent-based approach, a reconsideration of the cognitive status of fallacies (and a vindication of their positive inferential role), and the acceptance of a new eco-cognitive framework, also intertwined with the recent studies in the area of distributed cognition. To assist the reader in appreciating the naturalization of logic, I have also afforded the problem of the exceptional positive cognitive importance of the famous fallacy of the affirming the consequent (that is abduction). I have contended that abduction is not

[18] I have described this problem of moral epistemology in [32] (Chapter 6, Section 6.1.2).

only an *ignorance-preserving* type of cognition, as Woods contends, but also a *knowledge enhancing* one. To corroborate this result, I have synthetically described my own *eco-cognitive model* (EC-model) of abduction, which also explains that, thanks to abduction, knowledge can be enhanced, even when abduction is not taken as an inference to the best explanation in the standard sense, that is, an inference that also involves an inductive (so-called by Peirce) empirical process of evaluation. Finally, the last part of the article provides an analysis of the importance of the *optimization of situatedness*, a concept which is necessary to understand that "maximization of abducibility", which is distinctive of modern science cognitive endowments.

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Article

Categories and Dispositions. A New Look at the Distinction between Primary and Secondary Properties

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Abstract: The distinction between primary and secondary properties establishes the absolute priority, both ontological and epistemological, of quantity (objective and measurable) over quality (subjective and ineffable). In between the two properties, primary and secondary, are the dispositional properties, for example fragility, malleability, rigidity, and so on. But, from an ontological point of view, what are dispositional properties? This contribution takes into consideration two possible answers to this question: the one according to which the dispositional properties are invariant in variation and another according to which they are powers. The second answer is in turn subject to two different interpretations. We can consider dispositions, or powers, as integrally reducible to behavioral events (solubility, for example, is reduced to the fact that a certain substance melts when immersed in a certain liquid), or physical (the fragility of glass, for example, is reduced to the physical structure underlying it). However, we can consider powers as ontologically autonomous and not-grounded. This contribution aims to investigate the latter solution, with particular reference to the apparently oxymoronic notion of physical intentionality. This notion will provide a new, dynamic, and evolutionary version of the concept of disposition and at the same time offer a new look at the distinction between primary and secondary properties.

Keywords: qualitative ontology; intentionality; dispositions; qualia

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1. Primary and Secondary Properties

The distinction between primary and secondary properties is one of the points in theory where, from the start of the modern era, the intertwining of science and philosophy is most openly visible. This distinction expresses a very simple idea, which is that measurable and mathematizable quantity has an absolute primacy, both ontological and epistemological, over quality. The qualitative, understood as that which concerns concrete lived experience (perceptual states such as colors, sounds, and smells; emotional states, such as desires and sentiments; evaluative states, such as the apprehension of aesthetic or moral values) is essentially dependent on subjectivity. This is not the case with the quantitative dimension, which can claim to be independent of the subject's experience.

The Galilean idea that the book of nature is written in mathematical terms[1] finds its full philosophical realization in the Cartesian perspective. For Descartes, the senses are untrustworthy because incomplete and partial (the perception of a coin will never be perfectly round, but only roundish, elliptical, flattened, depending on the angle from which we view it; the apparent form of a table will appear different according to its position, and so on); deceptive and illusory (the oar seems straight when out of the water, but broken when immersed in the water; asphalt in the heat seems

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[1] This is a fortiori true since Galileo refers to triangles, circles, etc., that is to geometry.

wet; if we look at snow and then at the sun, what at first was white appears yellow; sugar seems to taste bitter when we are ill, and so on); mutually conflicting (a surface can seem smooth to the eye but rough to the touch); erroneous (as in any type of hallucination in which we see things that do not really exist); ambiguous (as in famous Gestalt figures such as the duck-rabbit).

As is well known, Descartes signals an irreversible turn in relations between body and mind, and above all in the nature of the mental. The mind becomes something specifically immaterial, a substance separate from bodies (our own body included), totally extraneous to the material order of the world. Descartes' idea is this: the physical world is a great mechanism whose functioning is mathematically described by quantitative physics. The sole exception is thought, which does not allow itself to be reduced to such a mechanism and is substantially extraneous to the material and natural world. Quantitative-mathematical explanations can therefore be applied to everything, with the sole exception of the human mind. Thus, we come to create that explanatory void which is at the origin of the tension present in what Ryle calls the official theory of mind [1]: that is, mind–body dualism. In Descartes, this ontological antireductionism is the direct consequence of total adhesion to the scientific revolution initiated by Galileo. The presupposition is that if, in an illusion, even bodies are not as they actually appear, they will nevertheless be endowed with constituent properties necessary for being called things: extension, shape, quantity, size, number, place, time; in other words, the so-called primary properties independent of the subject's epistemic stance.

Descartes accepts without reservation the new science of material bodies: the primary qualities express the essence of material things, their objective nature. Mathematical and geometrical structure is not an object of experience but graspable only by the intellect.

At the same time, the famous example of wax expounded by Descartes in the second of his *Metaphysical Meditations*, constitutes a proof of the ontological priority of the primary qualities over the secondary, and of the epistemological priority of intellectual knowledge over the sensory, thereby setting a seal on the absolute priority of quantity over quantity on the one hand, and of cognition over sensory experience on the other: a priority with which we are ceaselessly presented even today, for example in the inexhaustible debate in philosophy of mind about the nature of the *qualia*.

But the example of the wax is also relevant, and perhaps for a different reason, which is the identification of a sort of intermediate level which dwells epistemologically in the imaginative faculty and ontologically in what we today would call dispositional properties; that is, those properties which express the disposition to behave in a certain way, such as fragility, malleability, rigidity, elasticity, ductility, etc. In this respect, the entire picture constructed by Descartes revolves around the concept of variation and the complementary one of invariance. The example of wax offers Descartes the opportunity to reaffirm the instability and unreliability of sensory experience. When brought close to fire, the sensory characteristics of wax are lost and yet, despite this, anyone who perceives the wax believes he has *the same* piece of wax before his eyes. Therefore, this identity seems to consist not in sensory characteristics, but in properties which indicate the potential for variation in the sensory properties themselves, as is clearly shown in the following passage.

> It could certainly be nothing of all that the senses brought to my notice, since all these things which fall under taste, smell, sight, touch, and hearing, are found to be changed, and yet the same wax remains. Perhaps it was what I now think, viz. that this wax was not that sweetness of honey, nor that agreeable scent of flowers, nor that particular whiteness, nor that figure, nor that sound, but simply a body which a little while before appeared to me as perceptible under these forms, and which is now perceptible under others. But what, precisely, is it that I imagine when I form such conceptions? Let us attentively consider this, and, abstracting from all that does not belong to the wax, let us see what remains. Certainly nothing remains excepting a certain extended thing which is flexible and movable. But what is the meaning of flexible and movable? [2] (p.11)

It is true that the sensory properties of wax change but, despite this, it remains the same since it is *flexible* and *movable*. In this way, Descartes makes the transition from sensory properties, essentially bound to the here and now, to dispositional properties based on the possibility of variation in the sensory properties themselves. We cannot, in the true sense of the word, *experience* the latter. We can perceive the breaking of the glass, but not its fragility; the melting of the wax, but not its ductility or malleability. In each case, the latter can only be imagined.

There remains one other step to take. For Descartes, any body can assume an indefinite variety of forms and yet remain the same piece of wax. Disposition, by its very nature, cannot exhaust this infinitude; nor can it be grasped by the imagination, which is still rooted in perception. This argument moves towards the priority of the primary properties on the one hand and of the intellective faculty on the other. The former guarantees identity when faced with the sensory properties' infinite possibility of variation, the latter the possibility of grasping that very possibility.

> No, certainly it is not that, since I imagine it admits of an infinitude of similar changes, and I nevertheless do not know how to compass the infinitude by my imagination, and consequently this conception which I have of the wax is not brought about by the faculty of imagination. What now is this extension? Is it not also unknown? For it becomes greater when the wax is melted, greater when it is boiled, and greater still when the heat increases; and I should not conceive [clearly] according to truth what wax is, if I did not think that even this piece that we are considering is capable of receiving more variations in extension than I have ever imagined. We must then grant that I could not even understand through the imagination what this piece of wax is, and that it is my mind alone which perceives it. I say this piece of wax in particular, for as to wax in general it is yet clearer. [2] (p.11)

Therefore, neither obscure and confused sensory knowledge nor incomplete and partial imaginative knowledge are adequate instruments for grasping the identity of an object in the given infinitude of its variations. Only intellective knowledge (which is clear and distinct) can guarantee such identification, and only the primary properties (which are quantifiable and measurable) can take account of the identity of the object in the infinite variety of its sensory characteristics.

The explicit signaling of infinitude is essential since it refers us back to the project of mathematizing nature, and more specifically the sensible material thing, which is a presupposition, not a consequence, of the Cartesian argument. The ontological priority of the primary properties over the secondary (or sensible) and dispositional properties, united to the epistemological priority of the intellective faculty over the sensory and imaginative, are branches of the same paradigm which conceives of the material thing as invariance in relation to infinite variations, and of the latter as accessory and residual in relation to the absolute priority of invariance. The autonomy of the primary properties from the subject, given the seal of approval by Galileo and reiterated by Descartes, has the precise aim of safeguarding a static conception of nature founded on fidelity to the postulate of invariance in variation.

2. The Mathematization of the Plena: The Phenomenological Paradigm

In *The Crisis of the European Sciences*, the Husserlian reconstruction of the Galilean approach to the science of nature is closely tied to the problem of the mathematization of the plena. It would be Husserl himself who proclaimed Galileo's limitations, but also his audacity, as "at once a discovering and a concealing genius [*entdeckender und verdeckender Genius*]" [3] (p. 51). What exactly has been concealed by Galileo? To answer this question, we need to recall what the nature of the sensible material object is, according to Husserl, and its relationship with the geometrical and mathematical thing. For Husserl, these are the characteristics of the things of experience: vagueness, inexactness, non-ideality, non-deducibility, singularity. In contrast, the mathematical or geometrical thing has these essential characteristics: univocality, ideality, exactness, deducibility, generality. The things of experience are morphological and do not tend towards any ideal limit: mathematical or geometrical things are exact, since they tend towards ideality: that is, they have an infinite possibility of variation with a *tendency* towards the ideal limit. While the imagination can only transform sensible forms into other sensible forms, idealization exploits the infinite possibility for improvement intrinsic in the oscillations of extension (the graduality of the more or less smooth, the more or less circular, etc.) in a process which tends towards an ideal limit. The fundamental forms (straight lines, triangles, circles) are founded on a characteristic of their form, and only on that: in other words, its possible variation towards an ideal limit or, if we wish, its graduality, which in turn makes its measurement possible.

This is where Galileo's first concealment resides. We have seen how the plena, though endowed with their own style, habit, and typicality, are essentially inexact, fluid, vague, morphological. They cannot be directly geometrized, since there is no approximation to ideality for the plenum and consequently no possibility of *direct* measurement. The operation performed by Galileo is to geometrize and arithmetize the sensible thing by reducing it to extension alone. Thus, the things of experience are transformed into numerical, algebraical forms, "sensory forms of something in general", "thinkable multiplicities in general". For Husserl, there would be nothing wrong in using this technique as long as it is employed *consciously*, avoiding that "concealment of meaning" which was later experienced in history and according to which "being clothed in the ideal makes us take as true being what is in fact only a method."

This is not Galileo's only artifice. There is another, yet more potent than the first, which consists in an *indirect* mathematization of the plena. We have seen how, for Galileo, the thing of experience composed of extension and plena is stripped of its plenitude. In a second step, every change to the plenum is considered as having its own "counter-figure in the realm of forms." Lastly, the order of the plena is considered as having a necessary causal nexus with the order of form. This move is what allows the emergence of physicalist reductionism for which "natures is given in formulae and can only be interpreted on the basis of the formulae." Galileo's ploy consists in disembodying and emptying one of the disembodied parts, and finally declaring its independence, creating that ideal clothing which the object will finally put on, in view of a physicalization of ontology, in which the colors, sounds, weight, and heat radiation of a body that warms nearby bodies are transformed into luminous, sonic, calorific vibrations: that is, into forms. The fundamental passages which define Galileo's inspired and concealing move are thus, extremely summarized, the following:

1. Acknowledgement of the ideality of geometry understood as the science of forms;
2. Stripping away extension from the plena and mathematization of geometry;
3. Acknowledgement of the impossibility of a direct mathematization of the plena, because of their essential and indispensable vagueness and inexactness;
4. Indirect mathematization of the plena, by means of a biunivocal association between plenum and the order of the forms;
5. Mathematization of nature, by means of the thesis that the entire book of nature is written in mathematical terms.

The argument in which Husserl reconstructs Galileo's scientific standpoint in phenomenological terms also includes the Cartesian idea of the material thing as invariant to the infinite varying of its determinations. The thing of experience has a vague and morphological character. The plenum which characterizes it, being rooted in sensible concreteness, cannot pass through infinite variations which tend towards an ideal limit. In fact, this tendency to ideality is proper only to form, not to the plenum. In this sense, *contra* Galileo and Descartes, one of phenomenology's principle aims is to requalify the secondary properties by considering them irreducible to primary qualities. Experience has its own autonomy, and the vagueness which marks it is not only not a defect to be overcome, but is the original dimension from which every abstraction and idealization takes its origin.[2] In this sense, it is possible

[2] See also [4,5].

to speak of a reversed methexis (in the Platonic sense of the term), in which the thing of physics is secondary to and derived from the thing of experience, and not vice versa.[3]

However, there is an aspect on which it is worth dwelling for a moment and which refers to an enduring conception of the qualitative as residual. Indeed, for Husserl the thing of experience is a “synolon” of extension and sensible plenum configured in various ways.

Concretely, however, the actual and possible empirical shapes are given, at first in empirical sense-intuition, merely as “forms” of a “matter” of a sensible plenum; thus, they are given together with what shows itself, with its own gradations, in the so-called “specific” sense qualities: color, sound, smell, and the like [3] (pp. 29–30).

In other words, the plenum can be conceived of as the “residue” of a formal structure idealizable and mathematizable in itself, which makes it phenomenologically possible to speak of a “pure something” totally emptied of content, an empty dimension which stands above every material or containing region. Insofar as they are safeguarded by their specificity, the secondary qualities or plena remain substantially “secondary” by virtue of their need to spread themselves over an extension, which constitutes the idealizable and primary invariant that alone permits the subsistence of the plena (colors, sounds, tactile properties, etc.).

For its own part, the plenum has neither ontological nor epistemological autonomy. From the ontological point of view, the plenum is to all intents and purposes dependent on extension. It is extension that guarantees the structuring of experience into independent parts, a fact which is fundamental for Husserl. Furthermore, if it is true that the relationship between extension and plenum is mutually foundational, it is equally true that extension enjoys an autonomy of its own, not in concrete experience but in the realm of geometrical idealization, which is not the case for the plenum. From the epistemological point of view, it is impossible to experience plena that are not diffused in an extension. This impossibility also holds for extension, but only in concrete experience since it is possible to have an intellectual intuition of geometrical figures, whereas it is not possible (*contra* Plato) to have an intellectual intuition of the plena because of their non-ideality.

For Husserl, however, non-ideality does not coincide with non-essentiality. The sensory qualities produced by eidetic reduction are authentic essences understood as invariants in variation (for example, in different kinds of illumination). A particular shade of red is a phenomenological essence, albeit vague and morphological. Eidetic reduction has the precise aim of identifying the boundaries of determined and identifiable sensory attributes, even though they are inexact. These attributes nevertheless need an extension in order to be manifest; an extension which enjoys the requisites of ideality, measurability, and fragmentability.

The morphological and inexact character that is typical of experience is, once again, a property of the sensible (qualitative) dimension and not the extensive (quantitative) dimension. Determination, invariant in variation, in fact implies the ontological primacy (although not the exhaustiveness) of extension. Thus, in the phenomenological paradigm, the distinction between primary and secondary properties is weakened but not eliminated.

3. The Hard Problem: The Problem of the Qualia in Philosophy of Mind

Let us begin with an example that is very well known in philosophy. Does a tree falling in a forest make a noise when there is nobody nearby to hear it? The immediate answer is taken for granted: naturally the tree produces a sound, even when there is nobody listening to it. But we all know that this naïve response can be replaced by a less naïve, but equally plausible one: the fall of the tree emits sound waves which radiate outwards from a center like concentric circles in water and exist irrespective of whether or not a subject receives them. If the waves are intercepted by a human ear, they are heard as the noise of a fall. If, however, the sound waves are not intercepted the sound is

[3] Even if measurement, by senses or by constructed instruments, is the only form of access we have to the physical world.

not perceived. The fact that a tree falling unobserved may emit a sound depends, therefore, on what we mean by sound. If by "sound" we mean a heard noise, then the tree falls silently. If, instead, by "sound" we mean "a distinctive spherical pattern of impact waves in the air open to public inspection and measurement given the right instruments" [6] (p.1), the falling tree does indeed make a noise.

When we speak of sound in this second sense, we are referring to physical sound; when we speak of sound in the first sense, we are referring to sound as it is experienced. The latter has two essential characteristics: it depends to an essential degree on the observer and reaches her by private access [7,8], and has an essentially, not occasionally, qualitive or phenomenological character [9,10]. The example of listening to the sound can naturally be extended to embrace all other types of experience: colors, odors, tactile qualities, and so on.

Many problems in philosophy of mind start from this observation and from what is called "the hard problem of the philosophy of mind": that is, the problem of the qualia. In other words, the problem of how subjective, qualitative states essentially linked to the first person and to the effect of experiencing them (because of which they are distinct from the quanta, which are measurable, quantifiable, and expressible in the third person) can emerge from something that is no longer qualitative in nature but quantitative: that is, material. The origin of the term qualia can be traced back to Charles Sanders Peirce, who in 1866 proposed that "there is a distinctive quale to every combination of sensation [. . .] a peculiar quale to every day and every week—a peculiar quale to my whole personal consciousness" [11]. After Peirce, Lewis in *Mind and the World Order* [12] was perhaps the first to whom the technical use of the term qualia can be attributed. For Lewis, conscious experiences present something specific, and this something is the quale. But Dennett was the first to focus on the precise nature of the qualia:

"Qualia" is an unfamiliar term for something that could not be more familiar to each of us: the ways things seem to us. As is so often the case with philosophical jargon, it is easier to give examples than to give a definition of the term. Look at a glass of milk at sunset; the way it looks to you—the particular, personal, subjective visual quality of the glass of milk is the quale of your visual experience at the moment. The way the milk tastes to you then is another, gustatory quale, and how it sounds to you as you swallow is an auditory quale; These various "properties of conscious experience" are prime examples of qualia. Nothing, it seems, could you know more intimately than your own qualia [13] (p. 381).

From the viewpoint of their ontological status, the qualia are either phenomenal and qualitative properties related to the content of subjective experience (Nagel's 'what it is like to be'), or phenomenal and qualitative properties related to the objects experienced. These are two sensibly different definitions, but the boundaries between them are rarely well addressed in philosophy of mind even though they underlie a central concept in phenomenology, one much discussed in philosophy of mind: intentionality. Among intentional states we can include convictions, desires, beliefs, and feelings: that is, all states directed towards something (perception, judgment, devotion, determination, hatred, disdain, scorn, guilt, surprise, stupor, shame); whereas among phenomenal states we can contemplate sensations (auditory, visual, gustatory, tactile, olfactory); somato-sensory experiences such as proprioceptive perceptions (pain, hunger, etc.); emotions, moods, or affective sensations (depression, anxiety, affliction, discouragement, despair, joy, cheerfulness, ill humor, fright).

The hard problem of the qualia is founded on the irreconcilability, or incommensurability, between description in the first person and description in the third person, and on the difficulty of narrowing that methodological bifurcation between manifest image and scientific image paradigmatically proposed by Sellars [14,15]. On the one hand we have the "external" or "real" world (sound waves, light radiation, etc.) and its properties (mass, form, size, surface, motion), and on the other the "internal" or "phenomenal" world and its properties (felt objects, aromas tasted, sounds heard, colors seen, and so on).

The problem of the qualia, if posed in this way, would reiterate the traditional distinction between primary and secondary properties, between the way objects actually are and the way in which they are experienced. Except that, in the particular case of the relationship between mind and brain, this distinction causes a sort of short circuit that is hard to overcome.

Let's try to apply the distinction between primary and secondary properties to this case. The brain undoubtedly has primary properties: form, size, mass, position. The point is that the brain is associated with a mind that has qualitative experiences. The brain is not an object endowed with primary and secondary properties, but an object endowed with primary properties and capable of *producing* those experiences which will then create the opportunity for the secondary properties. But where are those experiences located? In the case of the mind–brain relationship, the distinction between primary and secondary properties does not seem so easy and natural. Hence the problem of the qualia and the proliferation of perspectives dragooned into irremediably contradictory solutions: on the one hand, reductionism of an eliminativist stamp [16,17], according to which the qualia are epiphenomena lacking any causal efficacy, or even fictitious entities, as phlogiston and the philosopher's stone were in their own time [13], and on the other hand dualism of properties which considers the qualia irreducible to any third-person scientific account. Indeed, according to the anti-reductionists [7,10,18], analogies with the identity between heat and median kinetic energy or between the lightning bolt and its electric charge often used by theorists of the identity between mental and cerebral states, are in reality misleading since mental states have a subjective dimension which is absent in the image of the world offered by science. The gigantic debate which philosophy of mind has developed around the conflict between reductionists and antireductionists constitutes the umpteenth reproposition of the irreducibility between primary and secondary properties and, in a more general sense, between scientific and manifest image.

4. Dispositions and Powers

The Cartesian and Husserlian phenomenological models share two fundamental theses. The first is the thesis of the priority of the so-called primary properties (first of all, extension) over the sensory and qualitative dimension. This thesis has a strong version (Galileo, Descartes, Churchland) which consists in the eliminability of the secondary properties in favor of the primary properties, and a weak version (Husserl) which confines itself to maintaining the ontological autonomy of the primary properties and the non-autonomy of the secondary properties. The second is a categorical conception of the qualitative: i.e., in the last analysis, the idea that the qualitative is expressed by means of attributes, which are in turn conceived of as categorical invariants. The same eidetic reduction in phenomenology is founded on the notion of invariance, which has the scope of determining and bounding the dimension of the qualitative in qualitative determinations. A categorical conception of the qualitative and the priority of extension are theses which seem to go hand in hand. We have seen how this model, attributable to a conception of the qualitative as residual, leads to the hard problem of the qualia.

However, there is an alternative path along which the two theses I enunciated earlier are replaced by the following: the priority (and not secondarity) of the sensible and qualitative dimension over extension and an agentive (not categorical) conception of the qualitative founded on the idea that qualities cannot be derived from attributes but from dispositions understood not so much in the functional sense as invariance in variation, but as powers or forces. The relationship between disposition and power can have two interpretations. The first, a deflationist type derived from so-called conditional analysis (Hume, Carnap, Lewis, Ryle), holds that the dispositions are integrally reducible to events and have no autonomy. Solubility, for example, is reduced to the fact that if a certain substance (salt, for example) is immersed in a liquid, it dissolves; fragility is reduced to the fact that if a certain substance (glass, for example) is struck, it breaks. In other words, ascribing a dispositional property amounts to no more than asserting the truth of a conditional. Apart from conditional analysis, the other theory which denies the existence of powers is reductionism of a physicalist stamp. According to Armstrong [19] (p.193), to every disposition there corresponds a categorical property to which the disposition is entirely attributable. Microphysical reductionism belongs in this line of thinking:

the fragility of glass, for example, is entirely reducible to its underlying physical, or more precisely microphysical, structure. However, it is possible to maintain a realist thesis independent of (i.e., not grounded in) power. According to this [20–24], power enjoys an ontological independence from both its manifestation and its microphysical structure. It is precisely this hypothesis that we wish to investigate.

According to Molnar [25], there are five characteristics of power. Of these five, it is the first on which we wish to dwell in particular, because it too is attributable to one of the most important notions in the phenomenological tradition, that of intentionality. The fundamental characteristic of power—that which, in other words, distinguishes it *prima facie* from non-power—is directness. Its other characteristics are the following: independence (powers are ontologically independent of their manifestations), actuality (powers are "fully actual properties of their bearers"), intrinsicality (powers are intrinsic properties of their bearers and not attributable to a relationship with something external), and objectivity (powers are endowed with an objective existence and are not mere projections of something else: for example, microphysical structure). Lastly, for Molnar all powers have a causal basis. All the characteristics listed here aim to emphasize the autonomous, independent—i.e., not derived—character of power.

Ontological priority, according to this theory, belongs not to determination but to power, not to invariance, but to force [26–28]. Among the five points, the first is the most significant, since it aims at highlighting what power might actually be, while all the others aim at consolidating the meta-ontological characteristics of power.

Power is essentially connoted by directionality: that is, by being directed towards something. The allusion to the traditional (in particular, Brentanian) notion is explicit. Intentionality in the phenomenological tradition is characterized by three fundamental theses. According to the first, intentionality is directed towards something beyond itself, the so-called intended object. We have seen how examples of intentional phenomena are representing, judging, hoping, desiring, etc., and each of these acts tends to, or is directed towards, something in a specifically relevant sense: in representation something is represented, in judging something is judged, in hoping something is hoped for, in desiring something is desired, and so on. The second thesis is the independence of intentionality from the existence of the intended object. While a non-intentional relationship (like riding a horse, being shorter than Pietro, dropping a book) subsists between two entities only if both of them exist, the intentional relationship holds independently of the existence of the intended object. I may be afraid of encountering the abominable snowman, see an oasis in the desert, hope for the discovery of the fountain of youth, independently of these entities' existence. The third thesis concerns the partiality and perspectivability of the intentional relationship. Being intentionally addressed towards an object means not only determining the intended object, but also the way in which it is intended. If this way is different, the same object may turn out to be different: I may be afraid of the man who keeps telephoning me and not be afraid of my next-door neighbor; Oedipus may despise the man he killed on the road to Delphi without despising his father Laius, or hate Laius's murderer without hating himself, or desire Queen Jocasta without desiring his own mother. Intentionality, to use Nagel's words, is not a "view from nowhere", a "naked" perception of the object, but a perspectival slant on things. It is not in principle possible to perceive, imagine, judge, feel something without incorporating a point of view. Furthermore, intended objects can be fuzzy—that is, indeterminate—objects. For example, I may perceive something in a vague way, as when I hear an indistinct noise or see a figure without identifying its outlines. The classical theory of intentionality maintains two further theses, which frame the three theses listed here. According to the first, intentionality constitutes either a criterion for demarcation between psychic and physical phenomena [29] or else the essential characteristic of consciousness [30]. The second interprets intentionality as closely connected to representational activity. The principle according to which "Every act is representation or founded on a representation" is considered by Husserl, and before him by Brentano, as a founding thesis of phenomenological investigation.

It is precisely these last two theses which are diminished in the proposition of physical intentionality. Indeed, this is not essentially bound to consciousness and has no representational structure. The general frame in which to locate intentionality turns out to be profoundly modified and yet—and indeed in this resides the theoretical relevance of the theory of physical intentionality—the three theses which define the concept of intentionality are maintained. Physical intentionality is also in fact directed towards something. The intentional object of a physical power (such as solubility or electromagnetic charge) is its manifestation.[4] The nexus between power and its manifestation, like the nexus between perception and perceived, is not contingent. The second characteristic of psychic intentionality is also traceable back to physical intentionality. The latter holds irrespective of its existence or non-existence. Something may be soluble without ever being dissolved, or fragile without ever breaking. The manifestation of physical power may exist or not without detriment to the existence of the physical power itself. The third characteristic, the vagueness and indeterminacy of intentionality, also holds in the case of physical intentionality [31]. Just as men have heights although one can think of them not in terms of their heights, so bearers of powers have their locations, although their having the power is not dependent on their having the specific locations they have. Physical powers can also have fuzzy objects. For example, the propensity of unstable elements to decay is indeterminate as to timing.

The identification between property and power and between psychic intentionality and physical intentionality profoundly transforms the distinction between primary and secondary properties. Dispositional properties or powers are not identified with their primary properties, nor derive necessarily from them. As we have seen, we may adopt a reductionist perspective and identify the dispositions with underlying physical structures. But we may also quite plausibly adopt an antireductionist perspective and consider the powers as totally *groundless*: that is, ontologically independent of non-powers. This position renders the powers autonomous and primary with respect to what is traditionally held to be primary: that is, extension, figure, motion—in a word what is measurable. This position has many consequences, first of which is the priority of time (understood not as succession—spatialized time—but as duration, or as history) over extension. From this perspective, time is not a lack compared to stability and fixity (invariance in variation), but is efficacious or creative (stability or continuity in variation); it has, in fact, power.

Dispositional properties or powers are not identifiable with secondary or qualitative properties, nor reducible to them, even partially. In this case, too, there are two strategies we could adopt. According to the first, powers and the qualitative/categorical dimension are two sides of the same coin [22]: that is, "a power is only a face/facet/side of a property that also has a qualitative face/facet/side" [25] (p. 159). According to this theory, all properties have something about them that is irreducibly and ineliminably dispositional, and something else about them that is irreducibly and ineliminably non-dispositional or qualitative in the categorical sense. In this case there is a temptation to think of the qualitative/categorical and the dispositional as 'parts' or 'aspects' of the single underlying property. But we can also argue that when we think of a property as a qualitative/categorical concept[5] we are not thinking of a part or an aspect of the property, but are thinking of the whole property *in a certain way*. Equally, to think of the property as a dispositional concept is not to think only of an aspect of the property but again to consider the whole property in a certain different way [33,34].[6]

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4 "Of the many ways of characterizing a power, the only one that reveals the nature (identity) of the power is the characterization in terms of its manifestation" [25] (p.63).

5 Borrowing a useful idea from Lowe [32], we can say that qualitative/categorical properties are *occurrent*.

6 A good example of this idea is the case of the Gestalt shift, as in the example of the famous ambiguous figure which can be seen as a duck or a rabbit. When we consider the figure as a rabbit or as a duck we are not considering only a part or an aspect of the figure. Rather, we are considering the whole figure in a certain way. Similarly, referring to the famous example of Frege, Hesperus and Phosphorus are identical with Venus. The concept 'Hesperus' and the concept 'Phosphorus' are genuine entities which are identical with each other and also with Venus, just as both dispositional properties and qualitative/categorical properties are genuine entities that are identical with each other [35,36].

However, there is a further possibility: that powers are considered as neither different aspects nor different modes of the same thing. From this perspective, which we can call neutral and monistic, disposition or power is the only reality and the qualitative/categorical dimension is not an aspect or a certain mode of an underlying, whole property, but the only true, vital dimension [37,38].

5. Conclusions

Conceiving of disposition not as invariance in variation but as power means placing the emphasis not on the concept of determination or of data (the qualitative/categorical dimension) but on the concept of force (forceful qualities) and giving priority not to space (extension, figures, size) but to time understood as duration, or as history [39–42]. The concept of physical intentionality is the theoretical instrument which permits this shift and, with it, a profound revision of the distinction—one of enormous relevance and wide range in science as well as in philosophy—between primary (objective, independent, essential) properties and secondary properties (which are subjective, dependent of the subject, inessential). Physical intentionality maintains the essential characteristics of mental or psychic intentionality: directionality, perspectivity, background, and vagueness. But it profoundly transforms the meaning of these notions, since it does not tie them more closely to the concept of representation nor to the more general one of psychic state. In this reversed sense, as it were, of the concept of intentionality, the notion of background assumes special significance, together with those of vagueness and indeterminacy. The concept of background presupposes a spatial declination (the vague horizon against which an object stands out) but also a temporal declination (the background, memory, understood not in a subjective sense but in the objective sense of what is withheld in our life, by our past and also by the past of the species, by the animal—even vegetable—past). In the second volume of the *Ideas*, Husserl refers to a "dark background"[7] far distant from the attentional present, which nevertheless constitutes the foundation of experience, especially the bodily kind. In this sense, his traditional objectifying attitude, which indicates an undiscussed priority of the theoretical attitude, is moderated by the acknowledgement of the fact, fundamental for introducing a possible phenomenology of the unconscious, that the objectifying attitude is founded on a terrain of passivity, precategoriality, pregivenness, a terrain which Husserl does not hesitate to call 'confused'.

Now it is precisely such a background, understood as a subcategorical dimension, which assumes a central importance in the concept of physical intentionality and, more generally, of disposition, with the static interpretation of this concept, as invariance in variation, replaced by its genetic and evolutionary interpretation as temporal duration.

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7 "This realm includes 'sensibility, what imposes itself, the pre-given, the driven in the sphere of passivity. What is specific therein is motivated in the obscure background" [43] (p. 234).

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Discursive Space and Its Consequences for Understanding Knowledge and Information

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Abstract: The paper develops the idea of discursive space by describing the manner of existence of this space and the world of facts. The ontology of discursive space is based on the idea of discourse by Foucault. Discourse, being a language phenomenon, is a form of existence of knowledge. The discursive space is a representation of knowledge and can be interpreted as the system of acquiring this knowledge. This space is connected with the world of facts by a relationship of supervenience, which can be interpreted as a flow of knowledge. At the same time, the existence of the world of facts (world of affairs) assumes that it covers all phenomena and processes, and therefore, necessarily, also the discursive space. Hence, this space is not a separate system but a system that emerges from the world in order to allow the gathering of specific knowledge about it. Treating the discursive space as one of the possible cognitive systems, one can imagine other systems of knowledge that emerge from the world (the whole), as parts subordinated to particular goals (the use of knowledge), which can have a multilevel character. The flow of knowledge on the border of such a system and the whole of it can be interpreted as information. This paper tries to justify this possibility, which could lead to a general model of the flow of the knowledge.

Keywords: discourse; discursive space; information; knowledge; humanistic management; language

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1. Introduction

This paper is a continuation and development of the theses presented in a text published in January 2018 [1]. The concept of discursive space as a complex space of knowledge has been presented and justified there as dynamic space, the concept of which has been borrowed from physics [2,3]. Discourses (discourses), being a common knowledge representation, traverse the trajectories in that space, the dimensions of which are qualitative and arbitrary. The concept of discourse and justification for its complex character was based on the theory of Michel Foucault [4–6]. The support for using the dynamic space model for the description of quality phenomena was provided by Byrne and Callaghan [7].

In this text, I try to develop the presented idea. This intention has two phases; firstly, it consists of supplementing the idea of a discursive space with a description of the necessary and assumed world, called the world of facts. Secondly, the idea of a mutual relationship between the world of facts and the space of discourses can lead to further conclusions that concern an important and interesting descriptive construction of knowledge and, perforce, information. The second phase is necessarily just the opening of a certain reasoning and is limited to the formulation of initial statements. Of course, according to Popper's classic approach, such statements must then be subjected to a critical check. Popper describes this process as follows: "From a new idea, put up tentatively, and not yet justified in any way—an anticipation, a hypothesis, a theoretical system, or what you will—conclusions are drawn by means of logical deduction. These conclusions are then compared with one another and with other relevant statements, so as to find what logical relations (such as equivalence, derivability, compatibility, or incompatibility) exist between them" [8] (p. 9). In the next paragraph, he points out four ways how practically the testing of the theory could be carried out. This paper executes this part of the scientific process that Popper called "the new idea" and its first steps, which stops shortly before the formal formulation of the hypothesis, preparing some of its premises. An analysis of the empirical phenomenon (e.g., the Internet) is taken as a starting point for the generalization that appears as possible to perform. This generalization is not an end in itself, but a necessary consequence of earlier reasoning. It cannot be omitted in this situation, especially since the area it deals with, i.e., the theory of knowledge and information, is extremely important. This type of research proceeds from detail to general. The generalization is not a theory in itself at all, and the presented reasoning is not intended to present a finite or internally justified theory, but it can be a contribution to the reconstruction of thinking about the mentioned area. In this way, it is also subject to the necessary verification.

Taking these assumptions into consideration, a slightly different than usual structure of the paper has been introduced. The biggest part of it is the chapter that entitled Results of the Theorizing. The conclusions regarding the ontological foundations of the discursive space are in the first part of this chapter. The adoption of these conclusions, however, does not end our reasoning but, on the contrary, it starts a new stage. A model of knowledge circulation in the world becomes possible to propose by expanding and generalizing our understanding of the ontology of the discursive space. The second part of the chapter contains a description of this idea. The third and fourth part are devoted to the consequences of adopting this model for the interpretation of the existence of information.

The Initial Theoretical Context

The world of facts appears as a reference to the concept of Ludwig Wittgenstein presented in his Tractatus logico-philosophicus [9], continued by D.M. Armstrong [10]. Armstrong also provides the concept of supervenience as a specific relationship between two entities, which has been chosen to describe the type of dependence that connects the world of facts and the discursive space. This kind of assumption paves the way for further conclusions that concern a key area in which language, understood as a tool for acquiring knowledge, comes into contact with the world.

Wittgenstein, in Tractatus logico-philosophicus, determined the relation of language and the world in a very decisive way, which can be explained by quoting Wittgenstein's two basic pairs of statements. The first pair of statements is as follows:

"3 A logical picture of facts is a thought"

and

"3.01 The totality of true thoughts is a picture of the world" [9] (p. 12).

The second one is:

"4 A thought is a proposition with a sense."

and

"4.001 The totality of propositions is language" [9] (p. 22).

The logical construction of Wittgenstein's idea is therefore simplified in the following: world, facts, thoughts, propositions, and language create the tight construction of ontological relations of the mutual identifications. This issue is extensively analyzed by McGinn [11] (p. 134) *passim*. These relations are not easy to explain, and all that McGinn can say in general is that "the essence of language is held to be a reflection of the essence that reality has prior to, and independently of, the construction of a language that describes it" and that "Wittgenstein's attitude towards this conception of the relation between our language and the reality it represents is problematic" [11] (p. 135). However, from the point of view of this text, it is essential to formulate the dependence of language and the world as a possibility, which makes it justified to omit the rich description of logical dependencies connecting sentences and the world presented by Wittgenstein. In Philosophical Investigations, he proposed a modified nature of language and the relations between language and the world that was even more complicated [12].

The world which is the subject of description by Wittgenstein is also vague and complex. Wittgenstein states:

> "1.1 The world is the totality of facts, not of things." [9] (p. 5)

and

> "2 What is the case—a fact—is the existence of states of affairs.
> 2.01 A state of affairs (a state of things) is a combination of objects (things)." [9] (p. 5)

This kind of statement is also essential for this paper. According to this view, the world is a combination of objects (things) that are the facts. The word "combination" introduces the necessity of mutual relationships between objects. Understanding these relationships as complex seems obvious. Armstrong clarifies this view: "The general structure of states of affairs will be argued to be this. A state of affairs exists if and only if a particular (at a later point to be dubbed a thin particular) has a property or, instead, a relationship holds between two or more particulars. Each state of affairs, and each constituent of each state of affairs, meaning by their constituents the particulars, properties, relations and, in the case of higher-order states of affairs, lower-order states of affairs, is a contingent existent. The properties and the relations are universals, not particulars. The relations are all external relations." [10] (p. 1). In this way, a specific world is a moving and variable convolution of certain elements (Armstrong's particulars), which, however, appear as significant only as an internally connected whole. This connection, of course, can be seen as a certain structure, as a certain order. The temptation to define this order is obvious, and it is hardly surprising that Wittgenstein tried to do it.

In this paper, there is no need to penetrate deeply enough to propose a fundamental description of the existence of the world. The starting point here is a much weaker assumption that language as a discourse reflects the world, but that does not necessarily lead to the use of such categories as truth or falsehood. This means that the possibility of resolving the problem of the existence of the world and its phenomena is also ultimately removed. It is only known that this world exists in some way and its elements, whatever they are, are observable and definable; here, it was assumed that this possibility is realized as a set of the constructions of knowledge built by means of language (discourse). In this way, the necessity of an arbitrary order managing the relation of discourse and the world (in particular, the logical order), which was the subject of Wittgenstein's extensive effort in Tractatus, is also removed. The relationship between language (discourse) and the world can be defined as supervenience in the meaning given by Armstrong: "We shall say that entity Q supervenes upon entity P if and only if it is impossible that P should exist and Q not exist, where P is possible. [. . .] For our purposes here, it is convenient not to restrict the scope of our definition in any way. Hence the use of the term 'entity'" [10] (p. 11). This definition is very general and does not limit the objects to which it can be used but only indicates their relationship.

Relationality is also the most important premise of the reasoning presented here. Armstrong also sees relativity as a fundamental feature of the world, and what is more, believes that relativity on this level is ordered. The world is also subject to some kind of order, because the relations that create it are external, universal, or contingent. This reference to the Luhmann nomenclature [13] will be developed further. In the proposed concept of discursive space [1,14], relations combine discourse with the world of facts, but at the same time both the world of facts and the discursive space have a complex character, i.e., they are connected internally, which results in the necessity of a suitably advanced model, which is provided by the dynamic space mentioned above.

The discursive space has been described in the following way: "[it] is the epistemological construction i.e. the discursive space (DS) which is the method of the description of the massive and ubiquitous phenomena like the internet chosen as an example. This method could be also treated as the model of knowledge about the chosen phenomenon. This knowledge is understood from the point of view brought by sociology and philosophy which present the so-called constructivist attitude which means that the knowledge is treated by them as a social, temporary and spatially local creation. [. . .] Two essential ingredients appear as the base of DS: complexity as a generic model and discourse as its direct substance." [1]. The discursive space should be treated as a convolution of partial discourses concerning a selected part of the world of facts. Because it relies on the idea of complexity, it is possible to visualize it by the parallel coordinates as a dynamical space with the arbitrarily chosen dimensions, which are built through the qualitative analysis of the discourse. This is also the place for further development of the idea of the discursive space and a cause of controversy, which has been partially resolved by the example of the existing application of the formal idea of the dynamical space in the sociology [7].

Thanks to the analysis performed by Foucault and others, discourse as a knowledge phenomenon is widely justified. Foucault also performed an extensive analysis of the relations between language (discourse) and the world [6] as the fundamental description of the history and the essence of the human knowledge and science. The reasoning presented here is not intended to raise ontological disputes but to pragmatically describe the dynamic of the knowledge. The starting point of this effort was the intention to describe such phenomena like Internet, digital transformation, and so on, which seemed to be important, pervasive, and ubiquitous, and which are under the careful consideration of such pragmatic approaches like management. However, issues of a similar scale, complexity and level of abstraction required improvement of the idea of management, which led to the construction of the theory of advanced humanistic management [15]. Thanks to epistemological self-reflection, it can serve as a universal research platform.

The discourse defined by Foucault, however, appears much later than the concept of discourse invented by Augustus de Morgan and developed and described by George Boole. In particular, Boole proposed the idea of the universe of discourse, which, according to current definitions, is complete from the point of view of the process of solving a problem belonging to this universe. To confirm this belief, the following words of Boole are usually quoted: "The office of any name or descriptive term employed under the limitations supposed is not to raise in the mind the conception of all the beings or objects to which that name or description is applicable, but only of those which exist within the supposed universe of discourse." [16] (p. 42). On the one hand, this construction is an analogue of the isolated system, and on the other it draws inspiration from the idea of mathematizing the language process, whose most-known creators are Leibniz and Descartes. The idea of mathematization, which was an important context of thinking about knowledge, and created the circumstances in which digital technology was born, was described by Maciąg [17]. Boole's structure does not ultimately include the social or subjective foundations of creating knowledge by man, or resulting phenomena such as the discourse defined by Foucault. However, it is subject to the processes of formalization, which is a very serious advantage in the context of a quantitative approach upon which the idea of the discursive space is also based.

The quantitative approach in language research is otherwise very extensive. It differs fundamentally from the approach used in the case of discursive space, being in a sense complementary to it. A good example of this is intensively developing text mining, which can be considered part of the more comprehensive field of data mining. This is confirmed in much literature devoted to this technology. Although the idea of text mining is not new, it has been favored by the technical progress in the field of hardware and software, which allowed one access to various types of data, for example, provided by various web platforms, including social networking sites [18] (p. 1). The origins of text mining can be found in the 1950s and 1960s in the field of information retrieval, because document indexing is similar to the document classification used in text mining. By the 1980s, AI technology was already being used for this purpose [19] (p. 13). Aggarwal & Zhai write that "research in information retrieval has traditionally focused more on facilitating information access [. . .] rather than analyzing information to discover patterns, which is the primary goal of text mining" [18] (p. 2).

Text mining, for the most part, is based on a linguistic approach that can be described as bottom-up, i.e., it specializes in the study of basic linguistic structures. Wiedeman [20] is an example of an approach that also uses sociological inspirations, but he remains at the level of basic text structures, though understood more broadly than linguistically. He also reminds us that Michel Pêcheux created automatic discourse analysis in the 1960s [20] (p. 45), [21]. This concept of discourse actualizes the social context and enables a qualitative approach; however, Wiedemann sees the discourse primarily from the perspective of a sociological method named Qualitative Data Analysis (QDA): "QDA methods provide systematization for the process of structuring information by identifying and collecting relevant textual fragments and assigning them to newly created or predefined semantic concepts in a specific field of knowledge" [20] (p. 2). His approach also refers primarily to the level of direct text and not abstract higher structures. The definition of QDA he delivered corresponds well with the definition of text mining by Heyer: "computer based methods for a semantic analysis of text that help to automatically, or semi-automatically, structure text, particularly very large amounts of text" [20] (p. 2).

2. Results of the Theorizing

This section is not based on empirical research but on speculation. The ideas presented here are not in the nature of findings in a sense of discoveries but, rather, are the result of reasoning and, in accordance with Popper's presented guidelines, try to present a new idea. For this reason, following free thought, this reasoning does not feel limited. It is neither exhaustive nor finite. In light of this, the following part discusses conclusions that are a generalization and development of initial assumptions regarding the ontological status of discursive space based on the idea of supervenience. These conclusions concern the model of knowledge circulation in the world and the way the phenomenon of information exists.

2.1. Initial Remarks: Supervenience

The first step in this reasoning consists of drawing conclusions from the construct's proposal, which is the discursive space. As it was assumed, it exists in the relationship of supervenience with the world of facts, which means that the shape of this relationship does not in any way preexist but is born as a result of the properties of the interacting parties (Figure 1). The only thing we know about the relationship of supervenience in the case of discursive space is that every element of the world of facts must have a reflection in the discursive space. Of course, the dynamics of achieving such a state is in no way determined. Adding the time factor to the definition of Armstrong, which he allows, emphasizing the lack of restrictions on the scope of its definition, removes the objection concerning the incompleteness of the discursive space. In fact, the discursive space tends to be a state that implements the principle of supervenience, or knowledge tends to embrace the whole world of facts. This assumption is non-controversial.

The next conclusion concerns the nature of the discursive space. The world of facts is complex—this assumption is also uncontroversial—so the complex nature of discursive space is necessarily complex too, which results from the relation of supervenience. The complexity of discursive space subsequently allows for emergent phenomena. Such phenomena are, e.g., the internet or digital transformations that exist as linguistic entities. However, they are also expressions of knowledge, which result from the idea of discourse. They can therefore also be called epistemological constructions, if we assume that knowledge is the result of the cognitive process. This last observation seems to transfer the problem to a level strongly associated with the subject in the meaning of man. However, such a relationship is not necessary; Burgin wrote: "cognitive systems, e.g., intelligent agents or cognitive actors, store and employ a variety of epistemic structures in different forms and shapes" [22] (p. 177). A similar possibility in the process of dealing with knowledge I assumed independently in [23] as an element of the so-called pragmatic management concept.

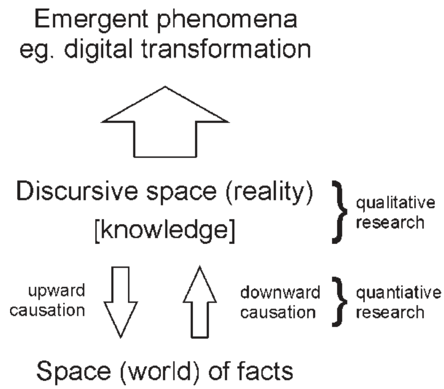

Figure 1. Ontological relations between discursive space, space of facts, and digital transformation.

Discourse (discourses) may be presented as a trajectory (trajectories) in discursive space, the dimensions of which define the existing knowledge associated with them. This is described in more detail in [1]. In the space described there, 20 dimensions create a discursive space for a discursive entity like the Internet, which represents knowledge about it. The position of the Internet in these dimensions changes over time.

Such reasoning leads to a serious problem concerning the best way to realize the relationship of supervenience, which is known to have certain dynamics and to develop over time. The presented concept assumes that it has a reciprocal character, which results from the specifics of discourse, which on the one hand is shaped by the world of facts but on the other affects this world. Foucault draws attention to the various effects of the discourse in the social world [4,5], which can be summarized as power relations, but this possibility also opens other modes of the influence of the discourse on the world of facts, but these are not necessarily clear. This situation appears as a separate case requiring exploration and study. The mentioned problem is in the nature of these relations. In other words, how practical is the mutual influence realized in a situation in which the ontological status of the world of facts and language (discourse) is different? This question is not usually asked, since we assume silently that this is the nature of the language used to describe the world.

2.2. Further Findings: Towards the Unification of the World

This section describes the wider context of the functioning of the idea of discursive space and the further consequences of such an approach. The presented reasoning is an extrapolation of assumptions and conclusions regarding the discursive space.

We are dealing with the situation presented in Figure 2 according to the presented idea of discursive space. The combination of a qualitative and quantitative approach in the case of the construction of the idea of the discursive space as a dynamical space makes it possible to present the space using the parallel coordinate system that was described above. However, there is no reason to treat the discursive space as unique or the only system devoted to acquiring knowledge. Let us treat the discursive space as any similar system aimed at this goal.

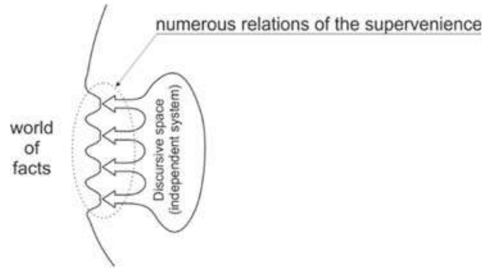

Figure 2. The world of facts and the discursive space.

The situation presented in Figure 2 could be treated as the well-known schema of interaction between the separated system and its environment, which is the canonical situation in the system theory. The main conceptual achievement of the General System Theory (GST) by Bertalanffy and others is the representation of the world as separated but interconnected entities. Skyttner, who collects the efforts of many researchers, presents a list of hallmarks of the theory of systems. Among them, on one hand, there is holism, on the other differentiation and even the hierarchy of related and interdependent objects and their attributes [24] (p. 53). Other attributes mentioned by him are goal seeking, the transformation process, inputs and outputs presence, entropy, regulation, equifinality, and multifinality.

The situation becomes more complicated, however, as the scope of the system approach increases. In the area of cybernetics, for example, this is about moving to a level of the second order of the cybernetics; the so-called cybernetics of cybernetics. [25,26]. Umpleby called this move "a fundamental revolution in science" [27] and perceives it as a contribution and an introduction to the wider project entitled second-order science [28]. Skyttner sees a breakthrough in the rejection of the deterministic approach, which takes place at the beginning of the twentieth century with the appearance and development of quantum theory, which forces science to fundamentally reorient the relationship of the observer to the world [24] (p. 23) *passim*. Examples of the most recent and very advanced analysis of this problem appear as issues of the presence and status of an observer in the context of the artificial intelligence [29,30]. It is worth noting that the issue of the scale of the complex systems is also a problem in itself (e.g., [31]).

An important contribution to understanding this situation is made by Mark Burgin. He introduces the *observer-oriented approach* to knowledge, which means "that an observer (user or knower) characterizes and utilizes some epistemic structures as knowledge" [22] (p. 80). Introducing the idea of an observer can solve the problem of the truthfulness of knowledge, which becomes irrelevant. Criteria of knowledge ("the *existential characteristics* of knowledge") could have the temporal and subjective character. The striving to acquire "objective" knowledge, Burgin reminds us, results from the condition formulated by Plato in his dialogue entitled Theaetetus as a part of the definition of knowledge: *Dóksa alethés metá logú* in English translation by Waterfield: "true belief accompanied by a rational account" [32] (p. 115), usually shortened to *justified true belief* [33]. However, various objections, among them the famous Gettier problem [34], undermine the possibility of such knowledge.

As one can see, we deal with the two directions of the problematization of the second-order approach and they are not identical: in the first case, we deal with the cognitive process of extension of the system under investigation by introducing the higher level of its self-referentiality. In the second, this self-referentiality concretizes itself to the existence of an observer who is the subject (agent) of this self-referentiality. Both these directions, however, mark a truly fundamental movement against the isolation of the system, and thus towards all the possible relations that it creates. Such a transition to the second-order analysis level in this paper leads to the conclusion that the situation presented in Figure 2 is simplified, because without a doubt the discursive space, which has been presented as an independent system, is actually the part of the world of facts (world of affairs), since the nature of facts (affairs) is unspecified. Wittgenstein uses the notion of object or thing; more general is the notion used by Armstrong, who speaks about the "particular" and underlines its relational character. The discursive space fulfills these demands, since it contains interconnected discourses, and each of them is a complex system of notions, cognitive constructions, and so. The definition delivered by Armstrong is intended to be as general as possible in order to gather as wide a spectrum of entities as possible. If so, we deal with the situation that the system that is established to acquire knowledge (i.e., the discursive space but any other such a system, too) is the part of the world of facts or, in other words, the whole. This situation is presented in Figure 3.

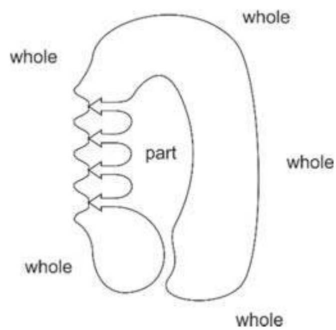

Figure 3. The real situation of the existence of the discursive space.

The next step of our reasoning can be justified by the definition of the observer presented by Burgin: "Usually, an observer is treated as a physical system that in the same way, i.e., physically, interacts with the observed object. Very often, an observer is interpreted as a human being. However, here we use a broader perspective, allowing an abstract system also to be an observer because in our case the observed object is knowledge, i.e., it is an abstract system itself. In addition, it is necessary to understand that interaction between abstract systems involves representations of these systems and the performing system, which perform interaction and is usually physical" [22] (p. 83). From this definition, knowledge systems are numerous, can be interrelated, and can exist for very different observers.

In our case, the system of knowledge is the discursive space that is the convolution of discourses. An observer is a human being as a social being, in accordance with the idea of discourse immersed in a certain spatial and temporal reality. This reality affects the formation of discourses and the knowledge they articulate in a variety of ways. Because discourse is a linguistic creation, it is undoubtedly at the disposal of man, but, on the other hand, both language and discourse implement the idea of abstract systems in the meaning of Burgin: *abstract observer* [22] (p. 83). According to Burgin, on the one hand, the discourse has an internal character. It is knowledge, and thus fulfills the assumptions of the abstract internal observer; on the other hand, it has an external character, because it exists in opposition to the world of facts. Burgin devotes very little space to the description of differences between the internal and external observers. In the case of the situation described in this paper, the game between what is internal and external has a key importance.

Combining the idea of the abstract observer by Burgin with the Armstrong construction of the existence of the world (state of affairs as the continuation of the world of facts by Wittgenstein), we can assume that the part (the system, e.g., the discursive space) realizes the self-observation of the (certain) whole in order to achieve the knowledge about it in a particular goal. The scope of the whole could be various and primarily means everything (the world) but could also mean the specific part of the world that is functioning as a whole for its parts. The combination of numerous and related knowledge systems within the chosen whole is possible thanks to the ontological assumption that enables the extension and unification of the world of facts. A similar holistic approach appears in the cited definition of Burgin, although it is implemented as a list of possible and different ontologically variants:

real external observer, abstract external observer, and internal observer. Ontological unification also opens up the possibility of the existence of an unlimited number of knowledge systems. They can acquire knowledge from various areas of the world of facts, including other knowledge systems, since every knowledge system must be part of the world of facts. Such a situation allows for the existence of a mutual knowledge structure of potentially infinite complexity. A simplified scheme of such a structure could look like the image presented in Figure 4.

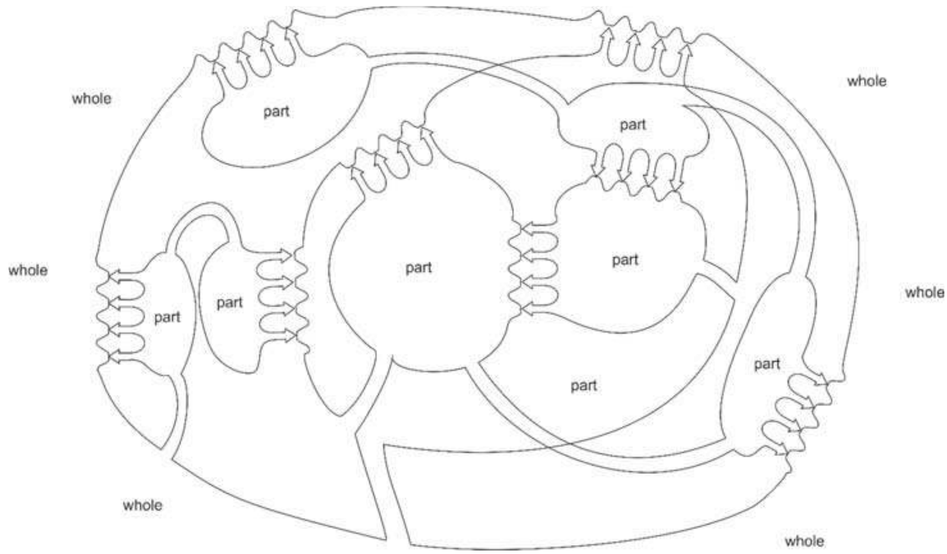

Figure 4. Simplified example of the structure of knowledge acquisition.

The suggestion of a similarly unlimited approach in the perception of systems is presented by Luhmann. Although the subject of his analysis is social systems, he treats them as representative variants of the systems as such: "general systems theory does not fix the essential features to be found in all systems. Instead, it is formulated in the language of problems and their solutions and at the same time makes clear that there can be different, functionally equivalent solutions for specific problems" [13] (p. 15). This statement also means that there is a level of abstraction in which one descriptive system structure is allowed; however, it cannot be unified, because it needs local and different descriptions of problems articulated in a specific way. That means that this level of abstraction cannot be gathered by the unified and coherent knowledge if this knowledge is articulated in language—such a knowledge is considered here as a consistent and homogenous system. From our point of view, this is obvious, because knowledge, as a rule, is not consistent but broken into an undetermined but potentially large number of knowledge systems.

The mechanism that replaces, e.g., knowledge understood as onefold system as a unifying platform for system analysis is, according to Luhmann, a mechanism of double contingency: "Something is contingent insofar as it is neither necessary nor impossible; it is just what it is (or was or will be), though it could also be otherwise. This concept thus describes something given (something experienced, expected, remembered, fantasized) in the light of its possibly being otherwise; it describes objects within the horizon of possible variations. It presupposes the world as it is given, yet it does not describe the possible in general, but what is otherwise possible from the viewpoint of reality" [13] (p. 106). The construction connecting the fact of the real existence of something and the possibility of "being otherwise" in the same moment is the key to this reasoning. In other words, something must happen even if something else is possible. This means selection. In our case everything is ontologically identical, and we deal with facts or states of affairs, so the mutual influence takes the form of the change that occurs in the two sides that meet (shown as the deformation on Figures 2–4). The change introduces differentiation to the previous, known state. In the case of social systems according to Luhmann, "[the double contingency] enables the differentiation of a particular world dimension for socially distinct meaning perspectives (the social dimension) and it enables the differentiation of particular action systems, namely, social systems" [13] (p. 106). Differentiation takes place at the same time on both sides, comprising a certain given social system and its surroundings that are important for this system. Differentiation has been also used for the explanation of the most difficult part of the information: the reference and significance. The idea proposed by Deacon tries to cross the border between the separated worlds and offers a way of the formalizing the "aboutness" [35].

2.3. Possible Proposals: Information

This part has the most uncertain nature, partially because of its speculative character and partially because of its preliminary state. Because of the extraordinary scope of existing reflection, it seems irresponsible to take such a topic as information. I must underline again that the purpose of this paper is not general information theory. Such bold and labor-intensive attempts have already been made, e.g., in references [36–38]. However, as it has been written, it is necessary to draw conclusions from reasoning about the dynamics and role of discursive space.

According to the presented analysis, the discursive space can initially be understood as a separate being, which is the realization of certain knowledge. However, developing this theory based on the concepts of Wittgenstein and Armstrong leads to the simple conclusion that, in fact, we are dealing with one world. If so, the discursive space is simply a creation within this world that aims to gather knowledge about it. Using the assumption presented directly by Burgin, knowledge is gathered in many places and for many reasons. Of course, this assumption is present in the literature devoted to information, e.g., in references [36,39,40]. Because of the existence of a single world of facts, the place of gathering knowledge must always carry out the model shown in the case of discursive space. Instead of the concept of "place", according to the prevailing principle of description in the area of the theory of knowledge and information, the term "system" is used here. So, knowledge systems are parts of the world of facts. If so, we will have to deal with two further consequences: first, these systems create a structure within the world of facts and, secondly, differentiation can be the answer to the question of how they exist.

The introduction of the differentiation notion in the context of knowledge requires the presence of the reflection in the information phenomenon. As a starting point, take the remaining most famous and the most frequently cited definition of the information by Bateson, here quoted in a shortened form that nevertheless introduces the most general and basic interpretation (a comprehensive review of such definitions is provided by Burgin [37]). The whole passage is as follows: "Information, in the technical sense, is that which excludes certain alternatives. The machine with a governor does not elect the steady state; it prevents itself from staying in any alternative state; and in all such cybernetic systems, corrective action is brought about by difference. In the jargon of the engineers, the system is "error activated." The difference between some present state and some "preferred" state activates the corrective response. The technical term "information" may be succinctly de-fined as *any difference which makes a difference in some later event*. This definition is fundamental for all analysis of cybernetic systems and organization" [41] (p. 386).

As one can see, the "de-finition" by Bateson refers to the technical cybernetic systems and introduces three important elements: one deals with one system, which remains in a certain state, which in turn changes over the time. There is the past state, which is in some way different than expected, and the future state, which is the consequence of the past state. The future state is difference in the system caused by past difference and must happen after. One can say that we deal with the reconciliation between the past and future, which has the technical term the feed-forward and is not very original. The originality comes with the idea of difference, whose ontological status is not obvious. The papers of Derrida [42] present the most comprehensive analysis of difference; Derrida coined the complex term *la différance*, which was the combination of difference and deferring. Both the inclusion of a time variable into the process of revealing difference and the field of problem analysis, which is the reality of meanings and text, mean the reference to Derrida may be justified and fruitful in our context; however, the present concern is the level of abstraction used by Bateson. This level has a paradoxical character: in the context of the reflection it is physical, but with the introduction of the term of difference it becomes also ontological, i.e., metaphysical (what could be understand as speculative). It is worth adding that the definition of information appears as a digression in the context of the main problem of Bateson, which is the development of bilateral symmetry of animals and plants. This context is, on one hand, clear in its reality and, on the other, it shows the generality of the notion of the information, the generality that could be understood as a high level of abstraction.

A similar approach appears in Luhmann theory about the double contingency, which is not a surprise, since Luhmann makes the communication the basis of the social processes: the communication that he understands as transmitting the information [13] (p. 139) *passim*. At the same time, Luhmann criticizes the metaphor of transmission as a suggestion of the transfer of something identical for both sides, and even as something substantial, and points out that information is only a selection: "communication constitutes what it chooses, by virtue of that choice, as a selection, namely, as information" [13] (p. 140). Different contexts (horizons) of this selection cause it to be perceived differently. The concept of selection by Luhmann is based on the theory of Shannon and Weaver.

Differentiation and selection are terms that are complementary in the temporal sense; selection takes place thanks to the existence of differentiation. There is no selection without diversity. Information in this light is at the same time a diversification and selection, because one does not exist without the other (and this conclusion belongs to an uncomplicated ontological reflection). Moreover, both terms refer to a certain pre-existing reality; something is subject to differentiation as something is the subject of selection. The former means another, although this otherness may result from both the time shift (Bateson) and the existence of a specific social world, which is the context of the social system (Luhmann). Such an alternative is a signal that the question of diversity should not be understood too simply, and, in particular, it should not be simplified ontologically.

Trying to explain the mutual location of these closely-situated concepts (difference and selection), it is worth noting a proposal of a completely different understanding of information by Burgin. In the Theory of Information, he presents a complete ontological description of information, which consists of seven principles. The Ontological Principle O2 (the General Transformation Principle) is of particular importance: "In a broad sense, information for a system R is a capacity to cause changes in the system R" [37] (p. 99). In the next five principles, Burgin deals mainly with the presence and functions of the factor that he calls "the carrier", fulfilling the function of the information vehicle. In the first principle (OP1), Burgin distinguishes the information "in general" from information "for a system R" [37] (p. 92); this distinction can be considered void in the light of his subsequent book *The Theory of Knowledge* [22]. The fundamental difference that separates Burgin from Bateson and Luhmann in the approach to information is the omission of the presence of the precendent area, which so significantly appears in Bateson and Luhmann, and the "shortening" of the existential process in which information becomes.

For Hofkirchner, the basis for the existence of information as a system is self-organization, and what is more, it emphasizes the network nature of this phenomenon, placing it in the general context of the physical world: "We can conclude: information is involved in self-organisation. Every system acts and reacts in a network of systems, elements and networks, and is exposed to influences mediated by matter and/or energy relations" [36] (p. 170). It also treats information as a result of a special type of differentiation: information "is generated if self-organising systems relate to some external perturbation by the spontaneous build-up of order they execute when exposed to this perturbation." [36] (p. 172). The term "perturbation" comes from Maturana and Varela and means "the influence from outside self-organisation" [36] *ibidem*. This reasoning assumes that the world is a structure of identifiable systems. Information that is the result of an unexpected cause-and-effect process within the system enables their formation and development in a self-organizing way. Precise analysis of the processes that accomplish this leads to the idea of universe of information, which is possible to describe on one side using the typology of the information, i.e., the specific abilities of the information and on the other by the different kinds of its functionality giving a clear array of possibilities of the combinations [36] (p. 197). It is only in the light of this type of conclusion that such phenomena as knowledge and wisdom are interpreted.

Hofkirchner considers knowledge as a variety of the capability of the reflexivity, "which is a feature of human thinking only" [36] (p. 205). In this paper, knowledge is regarded as "a feature" of any cognitive system. This assumption makes knowledge the general notion for the analysis. This completely reverses the point of view compared to the fundamental and definitely broader and more detailed reasoning by Hofkirchner and could be regarded as potentially fruitful. The intention of this change, which inevitable in the light of the analysis of the discursive space, is to create the more general base for the reasoning, while knowledge becomes a phenomenon offering such a possibility. Information in this situation becomes a derivative of knowledge processes and only has a supportive character that realizes different features such as those described by Hofkirchner. Relations between knowledge and information should then be reworked substantially, which is the task for future work. In the light of such approach, one can speak about the universe of knowledge that is not understood through a typological and functional description but through the ontological wholiness it possibly creates.

2.4. Conclusions of the Possible Proposals

From the above-presented reasoning, the approach presented by Bateson and Luhmann and partly by Burgin is fundamental. It involves perceiving information as a manifestation of a larger whole, not an individual, which is accompanied by the exclusion of substantiality of the information. This manifestation occurs as disorders (differences). Foucault similarly describes the trait of the existence of discourse, which is for him the way knowledge exists. He calls this feature "exteriority" [4], which "calls for the abandonment of the immanence of discourse, which reveals itself as the action, but not as the substance" [1]. Such a point of view is also imprinted in the schema presented in Figure 4. Knowledge systems emerge as the sovereign elements of larger entities, maintaining the principle of double contingency. Formation of these knowledge systems runs in time. Thanks to this, the needs of the system as a whole regarding knowledge are realized. In this context, the concept of knowledge must trigger the existing concept of information.

The only places in the diagram in which we can deal with the flow of knowledge are the points indicated in Figure 5 that must also indicate the flow of the information. The information described in this way may have a slightly different character than previously thought, although it has precedents in science. Its nature is revealed only in a larger whole, for which a maximum increase in the perspective of the research look is needed, which can be described as an upper level or second-order approach. This view is represented by Bateson and Luhmann. In the case of Burgin, the horizon of the ontological definition of information reaches only the limits of the factor called "carrier" (the idea of the existential triad of the world demands separate analysis in this context). Hofkirchner assumes information as the main phenomenon and treats knowledge as a secondary phenomenon necessarily connected with human capabilities only. Such an approach is completely different than the one chosen here.

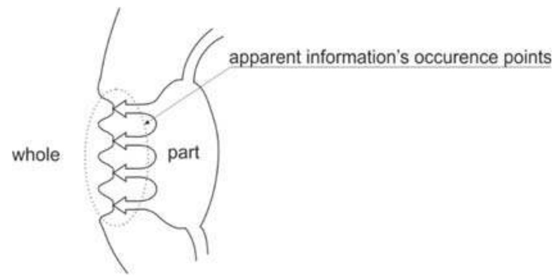

Figure 5. Apparent information localization in the knowledge circulating process.

Information perceived from the perspective of the whole world according to the scheme shown in Figure 5 appears to be an interface, a gate, a synapse that is created to allow the flow of knowledge. From the point of view of the whole, the information enables synchronization of all processes of flowing knowledge that are constantly developing and complicating, thus maintaining the circulation of it in the world. In this sense, information can be seen in each of the places in which it reveals itself as a kind of interaction, and from the perspective of the world as a certain interacting whole. This is basically the Hofkirchner stance, which analyzes the ways the information occurs in detail [36] with the proviso that the information is only the tool for realizing the knowledge system, which should be considered as a whole. Because information reveals itself indirectly and as an impact, the subject of impact determines its phenomenal shape. If such a way of the existence of information is assumed, it would be a functional whole that is structured internally, develops in time, and is the source of numerous interactions.

3. Discussion on the Discourse Notion

The concept of discourse, which is of key importance, needs to be discussed in more detail. The most important problem of discourse from the point of view of the presented reasoning is its ontological status, which is out of focus. The two main interpretive traditions of discourse (the idea of Boole and the idea of Foucault) followed different paths, although they had a common starting point. In the first case, the abstract approach prevails, in the second, the real social context. Discourse as a cognitive construction (and at the same time a descriptive category) reflects the fundamental problem of describing the world by trying to reconcile two realities: the description and the world, which are combined in a relationship that is extremely difficult to grasp. In literature devoted to discourse, one can find evidence for the realization of this relationship as a fundamental feature of discourse: firstly, defining discourse as articulation/retention of knowledge; secondly, because this knowledge has a specific, local (temporal and spatial) character. These two factors are understood in a qualitative way, but it does not exclude their more formal interpretation.

Van Dijk, who is one of the most important researchers in this phenomenon in the 20th century, emphasizes the immersion of discourse in a social context: "We need to account for the fact that discourse as social action is being engaged in within a framework of understanding, communication and interaction which is, in turn, part of broader sociocultural structures and processes" [43] (p. 21). Fairclough, however, emphasizes the existence of a specific order of discourse, which social practice enriches for a certain existence which is spontaneous: "I see discourse analysis as 'oscillating' between a focus on specific texts and a focus on what I call the 'order of discourse', the relatively durable social structuring of language which is itself one element of the relatively durable structuring and networking of social practices" [44] (p. 3).

Fixing the discourse in the reality of social practice, i.e., the perception of discourse as a real social being is justified by its direct participation in the circulation of knowledge. This is strictly admitted by Hyland & Paltridge: "discourse is socially constitutive as well as socially shaped: it constitutes situations, objects of knowledge and the social identities of and relationships between people and groups of people" [45] (p. 39), and Jørgensen & Phillips: "the struggle between different knowledge claims could be understood and empirically explored as a struggle between different discourses which represent different ways of understanding aspects of the world and construct different identities for speakers" [46] (p. 2). The relationship between discourse and knowledge can also be understood as an indirect dependence that is still very important: "discourse theory often revolves around the nexus of power, knowledge and subjectivity" [47] (p. 6), "the role of context in the production and understanding of discourse is fundamental. Since knowledge is part of the context, each level of discourse structure depends on the knowledge of the participants" [48] (p. 592).

The concept of discourse as a social phenomenon has been introduced in 1952 by Zelig Harris and since then has developed into many different approaches. Two basic directions are indicated by Paltridge: "range from textually-oriented views of discourse analysis which concentrate mostly on language features of texts, to more socially-oriented views of discourse analysis which consider what text is doing in the social and cultural setting in which it occurs" [49] (p. 1). This division also appears in the reflection of knowledge in the context of discourse. On the one hand, it concerns, for example, a particular problem (organizational knowledge); on the other, it allows a philosophical approach of great generality [5,6,50]. Michel Foucault is still the author, whose thought is still the most important inspiration for most contemporary discourse researchers [44] (p. 2), [46] (p. 13), while presenting such a far-reaching description of his ontological status [4].

The concept of discourse, however, appears much earlier and in another research tradition as a component of the phrase "the universe of discourse". The Cambridge Dictionary of Philosophy states "the concept of universe of discourse is due to De Morgan in 1846, but the expression was coined by Boole eight years later". This expression describes the rather formal and strict entity: "universe of discourse, the usually limited class of individuals under discussion, whose existence is presupposed by the discussants, and which in some sense constitutes the ultimate subject matter of the discussion. Once the universe of a discourse has been established, expressions such as 'every object' and 'some object' refer respectively to every object or to some object in the universe of discourse" [51] (p. 941). A Companion to Philosophical Logic underlines the arbitrary and restricted character of the concept of the "universe of discourse" in an even more limited way, which is "still generally used, as a way of targeting statements to a class of objects under discussion, rather than the entire universe" [52] (p. 42). Similarly, The Computer Science and Communications Dictionary states: "in a particular context, all of the entities or elements that (a) are of interest and (b) may include (i) many entity worlds and (ii) entities that are not yet perceived or considered" [53].

These explanations gravitate towards a strict, formal, and theoretical kind of the description, whereas the intention of the Bool was different: "In every discourse, whether of the mind conversing with its own thoughts, or of the individual in his intercourse with others, there is an assumed or expressed limit within which the subjects of its operation are confined. The most unfettered discourse is that in which the words we use are understood in the widest possible application, and, for them, the limits of discourse are co-extensive with those of the universe itself. But more usually we confine ourselves to a less spacious field. Sometimes, in discoursing of men, we imply (without expressing the limitation) that it is of men only under certain circumstances and conditions that we speak, as of civilized men, or of men in the vigour of life, or of men under some other condition or relation. Now, whatever may be the extent of the field within which all the objects of our discourse are found, that field may properly be termed the universe of discourse. Furthermore, this universe of discourse is in the strictest sense the ultimate subject of the discourse" [16] (p. 42). The intention of embedding this concept in reality is very clear. This is partly explained by the relatively early time of its creation. This is the period just before the crucial breakthrough in the understanding of the character of the relation of the mathematics and, above all, of geometry to the real world, and in particular before the emergence of issues raised by Hilbert regarding the existence of mathematical structures (e.g., the famous Hilbert letter to Frege from 1899 [54] (p. 40)).

4. Conclusions

The reasoning presented here has two structurally significant phases: in the first one, the construction of discursive space has been clarified as a construction of knowledge, the concept of which was presented in [1]; in the second, using the gathered premises, the conclusions were generalized by presenting ontological analysis of the possibility of knowledge and information existence in the light of the concept of the discursive space. The second part is an extrapolation of the particular example of the discursive space.

Summarizing the reasoning presented here, we must, therefore, return to the original descriptive structure, which is the discursive space. The way of understanding it has been greatly expanded here. The initial space that has been assumed as the environment of discursive space is language that is functioning not as a certain independent system but as the implementation of this system in the world; discourse is language realized in reality, which has the ability to gather and organize knowledge, in accordance with the theory of discourse stated by Foucault. It is this ability, it seems, which distinguishes the idea of Foucault's discourse from the idea of Boole's discourse, because the latter is only an undetermined environment of opportunities, whereas Foucault's discourse is determined in the sense that it is historical, local, and significant, i.e., it is knowledge. The sources of this intuition undoubtedly came with Wittgenstein. The way in which this kind of discourse exists describes Foucault with the help of the following four rules: reversal, discontinuity, specificity, and exteriority, and this is the existence that I tried to interpret as complex. Foucault, from the moment of his doctoral presentation in 1961 based on thesis entitled Folie et déraison. Histoire de la folie à l'âge classique [55], devotes a lot of space and time to providing evidence for the existence of discourse that he described by analyzing the specific impact of discourse on the world, which is, both social and cultural.

The key step here is to assume that discourse is also part of the world (world of facts, state of affairs), which has become possible thanks to the premises provided by Wittgenstein and Armstrong. In particular, it is about the withdrawal from thinking about discourse as a certain entity possessing a substantial character and replacing it with a relational character, which makes the discourse visible only through its influence. This property has been predicted and described by Foucault, who called it exteriority. In a similar way, Armstrong describes the world as such, drawing inspiration from Wittgenstein; the existence of the world, which he calls the state of affairs, he builds from the properties and relationships of certain indeterminate (arbitrary) particulars. Characteristic features of particulars are properties and relationships that are universal; relations are also external relations. Because language undoubtedly belongs to the world, its realizations such as discourse also belong to the world. The complex nature of discourse means that its existence must be based on relationships.

Thanks to this reasoning, we can try to construct a model of the world in which, by analogy with the idea of discourse, every flow of knowledge has dynamics similar to those that occur in the case of discourse. This is the result of the ontological unification of the world (discourse is also part of the world), which strictly means that it is a set of relations (and properties, which here are less important) of certain particulars. On the other hand, by reversing the approach, discourse can also be considered as not only specific or accidental but as one of many realizations of the set of relationships.

The ontological unification of the world and basing it on relations can lead to interesting conclusions about the circulation of knowledge. This circulation has been described using a slightly modified concept of information. The final conclusion presents a model of interrelated, equivalent knowledge systems, for which information enables mutual relations of parts within the whole world. In this model, something that Burgin calls the carrier changes its role and becomes even irrelevant, and the existence of relationships that are evident as changes on both sides becomes important. This change must take place in the entity that Armstrong called a particular, in its properties and relationships, but what is considered a particular at the moment is irrelevant to the world of affairs.

From the analysis of the mutual position of the world of facts and discursive space, which by assumption are connected by a supervenience relationship, the necessity of introducing the variable of time emerges, which results from the historical and local character of discourse. Actually, an infinite process to realize supervenience proceeds, which, due to the complexity of the world of facts, is impossible to achieve in the foreseeable future, and which agrees with the ordinary experience of knowledge development. On the other hand, the relational configuration does not determine such values as truthfulness or falsehood. These categories are not applicable here; relationships are not judgments about the world. Putting aside the classical knowledge requirement of truth (knowledge as justified true belief) is also the result of a long process of understanding knowledge, including scientific knowledge, and appears in papers by Foucault, among others. This process, however, is based on the observation of internal procedures for collecting knowledge by a human being as a subject and as a social being. This type of approach appears in the developing trend of the so-called constructivist. Support for such an approach also appears unexpectedly on the part of advanced digital technologies. It seems, however, that a large part of the discussion devoted to knowledge, in particular, scientific knowledge, especially in the 20th century, resulted from the need to solve the problem of its truthfulness, which from the point of view presented here is a kind of misunderstanding. This aspect certainly requires further work.

On the other hand, if discourse is a nonspecific case of the universal process of knowledge transfer, which takes place as a network of relations that leads to changes that are later sources of further functioning of the world of facts (world of affairs), it can be assumed that some features of this process are also universal. From this, it would appear that the discursive space model can be used to describe other flows of knowledge. Such an approach would present the possibility of applying the idea of dynamical space to all situations in which we deal with knowledge that can be described as trajectories of its partial components (discourses or concepts). Of course, this would mean abandoning the idea of stable and objective knowledge in favor of ad hoc processes of flow, which would result in a completely different model.

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Article

Exceptional Experiences of Stable and Unstable Mental States, Understood from a Dual-Aspect Point of View

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Abstract: Within a state-space approach endowed with a generalized potential function, mental states can be systematically characterized by their stability against perturbations. This approach yields three major classes of states: (1) asymptotically stable categorial states, (2) marginally stable non-categorial states and (3) unstable acategorial states. The particularly interesting case of states giving rise to exceptional experiences will be elucidated in detail. Their proper classification will be related to Metzinger's account of self-model and world-model, and empirical support for this classification will be surveyed. Eventually, it will be outlined how Metzinger's discussion of intentionality achieves pronounced significance within a dual-aspect framework of thinking.

Keywords: acategoriality; state-space approach; mental representation; dual-aspect monism; exceptional experiences; intentionality; mind-matter relations

1. Introduction

In this article, we address a few points of Thomas Metzinger's seminal account of self and world as representations [1] and propose some connections to areas of research that he himself did not consider much (so far). One of these areas is a dynamical-systems point of view toward his representational approach. The second is an application of this view to recent research on the phenomenology of so-called exceptional experiences. Our third focus in this essay is to link key features of his representational account with the metaphysical position of dual-aspect monism.

In the following Section 2, we give a terse introduction into one property of dynamical systems that is of fundamental significance for their understanding in general: *stability*. The study of stability in dynamical systems dates back to the work of Lyapunov, Poincaré and others at the turn of the 20th century. It is the conceptual core of recent work that gained publicity in cognitive neuroscience as a "free-energy principle" [2]. States of a dynamical system (such as the brain, or the mental system) can be stable and they can be unstable, depending on the potential landscape that constrains and governs their evolution.

Section 3 employs the different kinds of stability or instability to characterize mental states and representations. An important point here is the systematic distinction of different kinds of dynamics: states typically evolve on timescales that are short as compared to those of representation changes. As a consequence, one can discuss the time evolution of states "adiabatically", i.e., for a quasi-fixed collection of representations modeled by a potential landscape. This leads to a threefold classification of states (first proposed in [3]): categorial states (actualizing mental representations), non-categorial states (in the absence of representations), and acategorial states (between non-actualized representations).

Section 4 utilizes these concepts of states to address different classes of exceptional experiences (EEs), i.e., experiences that deviate from a subject's ordinary phenomenal model of reality (Metzinger's

PRM). Within a dual-aspect framework of thinking, where the two aspects resemble Metzinger's distinction of self-model and world-model, we outline four basic classes of phenomena constituting EEs and describe the rich empirical evidence that has been established in support of this classification. Moreover, we indicate how the phenomenal experience of EEs relates to categorial, non-categorial and acategorial mental states.

In Section 5, we address a few conspicuous links between Metzinger's representational account and a particular variant of dual-aspect monism: the Pauli–Jung conjecture [4]. The notion of intentionality, central in Metzinger's work as a technical term to address meaning as a reference relation between elements of the self-model and of the world-model, is used to characterize EEs that relate the mental with the physical. The phenomenal model of the intentionality relation (Metzinger's PMIR) is transparent if the relation is not explicitly experienced as meaningful, and its opacity increases with an increasing intensity of experienced meaning.

Finally, we outline how Metzinger's framework of thinking can be elegantly embedded in a dual-aspect framework with a self-model (roughly) corresponding to the mental aspect and a world-model (roughly) corresponding to the physical aspect. While the former is key to Metzinger's position, the latter is less well articulated in his work and might profit from some clarification.

2. Stability Properties of Dynamical Systems

The state ϕ of a dynamical system, evolving continuously as a function of time t, is characterized by a number n of properties (technically speaking, observables) that are represented as the coordinates of an n-dimensional state space. The trajectory of the state $\phi(t)$ in its state space represents the evolution of the system. The stability of dynamical systems under small perturbations or fluctuations can be evaluated by a stability analysis.[1] Such a stability analysis yields so-called Ljapunov exponents λ_i $(i = 1, ..., n)$, quantifying how and to which extent fluctuations vary as time proceeds.

Positive Ljapunov exponents indicate an exponential growth of fluctuations, whereas negative ones indicate that fluctuations are damped exponentially. The sum of all Ljapunov exponents is smaller than zero for dissipative systems and vanishes for conservative systems. In the dissipative case, there exists a subspace of the state space, onto which the trajectory of the system is restricted (after an initial "transient" phase). This subspace is called the *attractor* of the system. Another (larger) subspace, which covers all those (initial) states asymptotically evolving into the attractor, is called the *basin of attraction*. For a given attractor, the Ljapunov exponents are invariant with respect to continuous transformations of the coordinates of the state space.

The simplest case of an attractor is a "fixed point" in state space, where all λ_i are negative. If there is no other attractor in the state space, the entire (admissible) state space is the corresponding basin of attraction. More interesting (and more complicated) are situations in which the sum of all λ_i is negative, yet individual λ_i are positive. In this case, one speaks of "strange attractors" or "chaotic attractors". Even though the behavior of such systems is governed by strictly deterministic equations, it appears "chaotic"—which is the origin of the notion of *deterministic chaos*.

The stability of attractors can be studied *qualitatively* using a method also introduced by Ljapunov (see [8], chapter 7.6). In order to do so, a function $V(x) \geq 0$ is considered in a neighborhood G of a reference point $x = x_r$.[2] The significance of $V(x)$ is that of a potential, which does *not* need to be a (physical) energy, whose extremal properties in G determine the stability of a state ϕ at x_r. The first derivative $\nabla V(x) = \frac{dV(x)}{dx}$ of $V(x)$ with respect to x describes the change of $V(x)$ in G, and the second derivative $\nabla^2 V(x) = \frac{dV^2(x)}{dx^2}$ indicates a local maximum ($\nabla^2 V(x) < 0$) or minimum ($\nabla^2 V(x) > 0$). Using V, the following definitions of stable and unstable states can be formulated.

1 See, e.g., [5,6] or other relevant literature for details of this procedure; see also [7].

2 For the sake of simplicity, we consider V as a function of only one variable x. Of course, this can be generalized to any number n of variables.

1. A state ϕ at x_r is *stable* if $\nabla^2 V(x) \geq 0$ in G. In this case, $V(x)$ is a Ljapunov function:
   (a) A state ϕ at x_r is *marginally stable* if $\nabla^2 V(x) = 0$ in G.
   (b) A state ϕ at x_r is *asymptotically stable* if $\nabla^2 V(x) > 0$ in G.
2. A state ϕ at x_r is *unstable* if $\nabla^2 V(x) < 0$ in G.

For the simple example of a fixed point attractor in one dimension, Figure 1b illustrates case 1b for a quadratic potential $V(x) = \alpha x^2$, $\alpha > 0$, which is concave in the neighborhood of the minimum of $V(x)$ ($\nabla^2 V > 0$). This minimum represents a fixed point with one negative Ljapunov exponent, and a state at this fixed point is asymptotically stable. In case 1a, the gradient of the potential vanishes, $\nabla V = 0$, and the second derivative too, $\nabla^2 V = 0$, so that each point for this potential is marginally stable (Figure 1a), corresponding to a vanishing Ljapunov exponent.

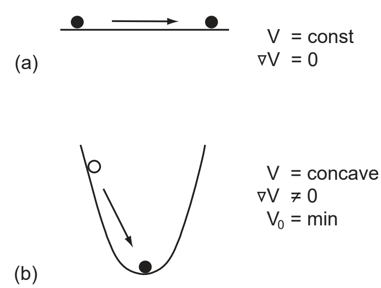

Figure 1. Kinds of stability of a state: (**a**) marginal stability for a constant potential V with $\nabla V = 0$ and $\nabla^2 V = 0$; (**b**) asymptotic stability at a critical point V_o of a concave potential with $\nabla^2 V > 0$.

A combination of case (2) with case (1b) is illustrated in Figure 2. In the neighborhood of x_r, at the local maximum, V is convex ($\nabla^2 V < 0$), whereas V is concave ($\nabla^2 V > 0$) around the potential minima. A state at or around the local maximum is therefore unstable. If the system is in such a state, it will spontaneously relax into one of the two asymptotically stable minima. During this relaxation, the potential difference ΔV will be converted into the motion of the state. The regions left and right of the local maximum are basins of attraction for two coexisting attractors. (For potentials with more than one independent variable, V_1 is often a saddle point rather than a local maximum.)

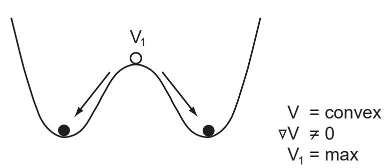

Figure 2. States in the neighborhood of a critical point V_1 of a locally convex potential are unstable and relax into adjacent potential minima.

Note that in equilibrium thermodynamics the potential V has the concrete meaning of free energy, its derivative with respect to temperature is entropy, and the second derivative is specific heat. However, under conditions far from thermal equilibrium, which are compulsory for pattern formation in general and the behavior of living systems in particular, the observables of equilibrium thermodynamics are typically not well-defined.

For this reason, Haken ([9], Chapter 6.7,) suggested a generalized terminology using potentials rather than free energy, control parameters rather than temperature, action (output) rather than entropy, and efficiency (change of output) rather than specific heat.[3] The state distribution for a given potential is related to the potential by a maximum information principle. The state dynamics simply follows the gradient of the potential—or of the set of potentials, if there are multiple coexisting attractors.

Note also that the distribution of an ensemble of states at some given time equals the distribution of one state over time if and only if the considered system is ergodic. Living systems typically violate ergodicity [10], so that ensemble average and time average (taken over infinitely long time, i.e., asymptotically) differ. Additional problems arise since the time evolution of most systems in nature is only piecewise stationary or not stationary at all (see [11]).

3. Stability Properties of Mental States

Recent decades saw a steady trend to describe the behavior of neural and mental systems as nonlinear dynamical systems. Freeman [12] was the first to introduce corresponding approaches, for other accounts see [7,13–16].

The central idea (cf. [17]) is that internal mental representations, the basic elements of a mental system, play the role of attractors (in the sense of Section 2) for external (sensory) or internal stimuli. The relation between the description of mental systems and the formal theory of dynamical systems can be characterized by three points:

1. The mental system, which may be materially realized by a neural network, is treated as a dynamical system S.
2. Mental representations within the mental system are treated as co-existing attractors of S with particular stability properties.
3. Internal or external stimuli within the mental system are treated as initial conditions of S, whose temporal evolution leads to an attractor.

In this scenario, mental processes, which map a stimulus onto a mental representation, are illustrated by the motion of a state in a potential (or a potential landscape). The form of the potential reflects the stability properties governing this motion. The states themselves and their associated observables can be conceived in two basically different ways. One can consider either mental states or states of the material/neural system correlated with them—notwithstanding the fact that these correlations are often poorly understood.

Our subsequent discussion focuses on the former option, so that the notion of "state" refers to a mental state ϕ of a mental system (which can be conscious or unconscious). The state space mostly remains unspecified insofar as there is, to the best of our knowledge, no (canonical) formalization of mental observables. Furthermore, there is no analytic form of the dynamics of states $\phi(t)$ because no corresponding equations of motion are known. The significance of the potential V, including its operationalization, remains undefined as well. In particular, we resist the temptation to interpret V as "mental energy" or "psychic energy" as long as such terms are not developed beyond the status of metaphors.

3.1. Mental Representations and Stable Categorial States

For conceptual clarity, it is not only helpful but compulsory to distinguish mental representations from mental states. While mental representations are modeled by potentials V constructed over a state space, mental states ϕ moving across a set of representations (a potential hypersurface) can aquire different kinds and degrees of stability. The dynamics of states and of representations typically operate at different time scales: state changes (e.g., thinking) are expected to be fast as compared to changes of representations (e.g., learning).

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[3] Although Friston's "free energy principle" [2] does not follow this terminological move, it should be charitably understood in this generalized way.

A state ϕ can be located anywhere on a potential hypersurface, which defines whether ϕ is stable or unstable at its location. This means that mental representations (potentials, attractors) provide constraints for the motion of a mental state $\phi(t)$ as a function of time. If a mental state is located in the minimum of a potential (i.e., on an attractor), the corresponding mental representation is "activated" or "actualized". This means that both its intentional and phenomenal content are subject to experience.

If a mental state is located in a particular mental representation, it is (asymptotically) stable with respect to perturbations (compare Figure 1b). The degree of stability can be quantified by Ljapunov exponents. Representations with shallow potential minima stabilize mental states less than those with deep potential minima. Accordingly, less or more "effort" is necessary for a mental state to "leave" a particular representation. If this happens, the corresponding mental representation may be considered as "deactivated", but as such it stays intact for future "reactivation".

Effectively deactivating a mental representation means that the state $\phi(t)$ has to be changed to such an extent that it leaves not only the attractor but also its basin of attraction. In a landscape of multiple coexisting attractors, $\phi(t)$ will then move towards another attractor to eventually arrive there. A corresponding dynamics of $\phi(t)$ obviously exceeds the conceptual repertoire of a situation with a stable state in the presence of one single representation (as depicted in Figure 1b).

However, not only states can change over time, $\phi = \phi(t)$, but also potential surfaces $V = V(t)$ can evolve. Not only can the dynamics of a state activate or deactivate an already existing mental representation, but new representations can be generated or existing ones can be altered. New representations are created when the mental system generates new potentials; old representations are changed when the corresponding potentials are deformed.

It should be pointed out again that the illustration in Figure 1b refers to an especially simple special case, a cartoon picture as it were. Mental representations are not limited to fixed point attractors or limit cycles (periodic processes), but in general correspond to chaotic attractors [18]. Any such asymptotically stable state that activates a mental representation with intentional and phenomenal content, is called a categorial state after Gebser ([19], p. 285; see also [3]):

> Every categorial system is an idealized ordering schema by which actual phenomena are fixed and absolutized; as such it is a three-dimensional framework with a static and spatial character. Such categorial systems are able to deal with the world only within a three-dimensional and conceptual world-view.

In the representational account of mental systems due to Metzinger [1], stable categorial states and mental representations (potentials, attractors) that they may activate are the key players. The model of reality that a subject develops consists of two major components: a *self-model* and a *world-model*. These models become successively differentiated during an individual's development so that they can map all internal and external experiences that this individual learns to model in order to successfully cope with her or his environment.

By being "fixed and absolutized" à la Gebser, the established repertoire of stable categories that a mental system has at its disposal executes a "censor-like" or "filtering" function [20].[4] This function enables clear-cut yes/no attributions of experiences to representations, but it fails to explain how representations are formed and changed, and how states move across representations. If a mental system would be comprised of nothing else than categorial states, this would exclude a manifold of experiences that we will address in the next sections.

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[4] Note that this kind of filtering is at variance with the notion of the "filter" metaphor often ascribed to the 19th century psychologist Myers. In her knowledgable study of Myers' work on the mind–body problem, Kelly [21] finds that, rather than being due to Myers himself, the metaphor was launched and popularized by Bergson, Broad, Huxley, and others to address the interface between the ordinary conscious experience of an individual and what Myers called the "subliminal self", the *tertium quid* beyond mind and body.

3.2. Marginal Stability of Pre- or Non-Categorial States

Marginal stability of a state ϕ as illustrated in Figure 1a characterizes the limiting case in which V is constant anywhere in the neighborhood of ϕ. This case can be interpreted as an "unbounded" state which cannot activate any representation, simply because there is none. Consequently, no intentional content will be experienced. Nevertheless, such states can be experienced phenomenally, and it feels somehow if they are. In this respect, one can speak of a non-categorial or pre-categorial state in the absence of representations. Smallest perturbations, which are neither damped nor amplified ($\lambda = 0$), will cause ϕ to change.

Metzinger ([1], Chaps. 4 and 7) discusses such states in considerable detail, mostly in relation to his main target: the representation of the self, the phenomenal self-model. It is Metzinger's thesis that the self-model can be modified or lost in altered or pathological states of consciousness. As an example, he refers to the phenomenon of "oceanic" self-dissolution, which he relates to "mystical" states. The associated loss of the phenomenal self does not only presume a change of perspective but rather abolishes experiences of intentional content as they occur under ordinary circumstances.

However, phenomenal experience does not (necessarily) get lost together with a lost self-model. Here, a "window of presence" is activated as a limiting case of state consciousness, a minimal or basic kind of phenomenal content capable of becoming conscious. Because no representations are involved in this limiting case, the experience is unstructured, a uniform atemporal nowness without the perspective of a first person.[5] Since this scenario abstains from any categories, it refers to a non-categorial state.

Non-categorial states in the absence of particular representations are examples for a subclass of experiences with *non-conceptual content*, a topic that has gained momentum since it was introduced into the philosophy of mind by Evans [22]. A comprehensive review of this development is due to Bérmúdez and Cahen [23]. For a discussion of non-conceptual content in connection with non-categorial states see [24]. Non-categorial states without conceptual content may be an interesting theme in relation to the spectrum of mental autonomies [25], but this would go beyond the scope of this article.

3.3. Mental Instabilities and Acategorial States

Insofar as mental states are asymptotically stable, a transition from one to another is possible only via an unstable intermediate state. Figure 2 illustrates this situation. To effect the transition, $\phi(t)$ has to overcome the potential barrier ΔV. The higher the barrier and the steeper the gradient of the potential, the smaller is the probability of a spontaneous transition and the longer the dwell time of $\phi(t)$ in the potential.

William James ([26], p. 243) gave a succinct description of this interplay of stable and unstable states across a potential landscape:

> When the rate [of change of a subjective state] is slow, we are aware of the object of our thought in a comparatively restful and stable way. When rapid, we are aware of a passage, a relation, a transition *from* it, or *between* it and something else.... *Let us call the resting-places the "substantive parts", and the places of flight the "transitive parts", of the stream of thought.* It then appears that the main end of our thinking is at all times the attainment of some other subjective part than the one from which we have just been dislodged. And we may say that the main use of the transitive parts is to lead from one substantive conclusion to another.

A particularly illustrative and frequently studied class of such transitions is the perception of bi- or multistable stimuli (see, e.g., [27] for an overview). In James's terminology, the process leading

[5] The experience is subjective only in the weak sense that it is based on an internal model of reality ([1], p. 559). There is just a *ground* of reality—the unstructured *fundament* of the manifold of structured aspects of reality.

from one to another "substantive" state corresponds to a temporal sequence of "transitive" states. The unstable point at V_1 in the bistable example in Figure 2 is a "transitive" state distinguished by a local maximum of V. James ([26], p. 243) continued:

> Now it is very difficult, introspectively, to see the transitive parts as what they really are. If they are but flights to a conclusion, stopping them to look at them before the conclusion is reached is really annihilating them. Whilst if we wait till the conclusion *be* reached, it so exceeds them in vigor and stability that it quite eclipses and swallows them up in its glare. Let anyone try to cut a thought across in the middle and get a look at its section, and he will see how difficult the introspective observation of the transitive acts is.... The results of this introspective difficulty are baleful. If to hold fast and observe the transitive parts of thought's stream be so hard, then the great blunder to which all schools are liable must be the failure to register them, and the undue emphasizing of the more substantive parts of the stream.

This is a clear appeal to the effect that the study of unstable, transitive states deserves more attention, but it is also clear why this is hard to do. It is a matter of time scales. While stable states are (usually) adopted long enough to become a subject of conscious experience, this is (usually) not the case for unstable states. Gebser ([19], p. 308) addressed transitive states at a local maximum of V with his concept of *acategoriality* and emphasized their temporal, dynamical aspect:

> Something with a temporal character cannot be spatially fixed. It cannot be fixed or prescribed in any form, and if we attempt to do so we change it by measurement into a spatial quantity and rob it of its true character. This is a clear indication that the qualities of time which are today pressing toward awareness cannot be expressed in mere categorial systems.

Gebser's "unfixable temporal qualities" can—in a more prosaic way—be related to the evasive, transient behavior of complex systems around instabilities. Even if there were known equations of motion to govern the system's behavior on its attractor, its trajectory in the vicinity of instabilities could not be predicted by them.

Acategorial states offer a second option to look at so-called "mystical" experiences, in addition to what Metzinger focuses on. The ground of consciousness cannot only be experienced in the non-categorial minimal kind of representing activity, but also in an acategorial mode. This is possible if some representational ground is present simultaneously with the presence of representations—however, not as an unstructured background as in non-categorial states. Representations remain intact as such and coexist with an awareness of the representational ground. In this case, the self would not be experienced as dissolved but as a sustained yet non-activated representation.

Acategorial states enable an experience of both representational ground and particular representations simultaneously. This is possible if a mental state is not located within a representation (category) but betweem them. In such "in-between states" different representations can be experienced as possibilities without being individually actualized. Dynamically speaking, the continuous representational ground of a mental system can flash up between individual actualized representations and become consciously and phenomenally accessible.

4. Exceptional Experiences

If a mental representation is activated by a categorial mental state, this amounts to an experience of both its intentional and phenomenal content. Such experiences are called ordinary if they are consistent with typical *models of reality* that individuals develop to cope with their socio-cultural and physical environment. In modern societies, basic elements of such models are established epistemological concepts (such as cause-and-effect relations) and scientific principles and laws (such as gravitation). Experiences inconsistent with those basic elements or deviating from them are considered exceptional (see [28] for more details).

A suitable and viable classification of exceptional experiences (EEs) has been proposed by Fach [29] on the basis of a few key postulates of Metzinger's theory of mental representations. According to

Metzinger, human mental systems produce a phenomenal *reality-model* (PRM) that comprises all mental states consciously experienced at a given time. Two fundamental components or base representations within this global model of reality are the *self-model* and the *world-model*.[6] The distinction between the two may seem to resemble the Cartesian distinction of *res cogitans* and *res extensa*, but there is a decisive difference: While Descartes' dualism is ontologically conceived, Metzinger's distinction is explicitly epistemic.

The PRM is the overall representation without which no representation in conscious experience can manifest itself—it is the carrier of the experiencing subject and the world that it experiences. Subject-centered experiences condense into cognitive models of reality that subjects create, develop, modify during their lifetime. Since the formation of these models is always embedded in the fundamental structure of the PRM, experiences and the resulting reality concepts are determined by the duality of self-model and world-model.

The world-model contains representations of states of the material world, including an individual's own bodily features. The referents of these representations are observationally accessible and provide intersubjective knowledge, sometimes called "objective" or "third-person" knowledge. The self-model contains representations of internal mental states, such as sensations, cognitions, volitions, affects, motivations, inner images. As a rule, experiences of these states are possible only by an individual itself—they are "subjective" and based on "first-person" accounts.

World-model and self-model are often experienced as strongly correlated. For instance, the bodily organs or limbs, representations in an individual's world-model, and bodily sensations, representations in an individual's self-model, are usually experienced in strong mutual relationship. Nevertheless, we can distinguish self and world. Mental states induced by external sensory stimuli differ from states generated by internal processing. Individuals are usually capable of distinguishing their inner images, affects and fantasies from their perception of physical events in their world-model.

EEs typically appear as deviations[7] in an individual's reality model. This entails a classification of EEs based on two pairs of phenomena [29]. One pair refers to deviating experiences within the subject's self model and world model, while the other refers to the way in which elements of those models are merged or separated above or below ordinary ("baseline") correlations. The resulting four classes of EE will be characterized in the following.

4.1. EEs as Deviations from Ordinary Reality-Models

Whether or not mental representations in the PRM are perceived as exceptional in the sense of a deviation from the ordinary depends on individual and collective knowledge and assumptions about self, world and their interrelation. Even if people are able to integrate EEs in their reality model (their worldview), an EE will continue to deviate from ordinary experiences. The deviation can be attributed either directly from the subject's first-person perspective or through the social environment's third-person perspective on the experience. Deviations from ordinary reality models can occur in both the self-model and the world-model. We refer to deviations in the world-model as external phenomena and to deviations in the self-model as internal phenomena.

1. *External phenomena* are experienced in the world-model. They include visual, auditory, tactile, olfactory, and kinetic phenomena, the impression of invisible but present agents, inexplicable

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[6] This definition is based on a footnote in Metzinger ([30], p. 62): "Repräsentationale Gesamtzustände werden durch die Gesamtheit aller zu einem gegebenen Zeitpunkt bewusst erlebten mentalen Modelle gebildet. Sie bestehen aus dem aktuellen Weltmodell und dem aktuellen Selbstmodell und bilden das gegenwärtige *Realitätsmodell* des Systems."

[7] Such deviations are often referred to as "anomalies", or else "psychic" or "psi" experiences. We prefer the notion of a deviation because the theoretical approach taken here entails particular basic classes of such deviations that can be systematically distinguished. This renders the term "anomalies" (in the sense of singular unsystematic occurrences) to be at least arguable—if not inappropriate.

bodily changes, phenomena concerning audio or visual recordings or the location or structure of physical objects.

2. *Internal phenomena* are experienced in the self-model. They include somatic sensations, unusual moods and feelings, thought insertion, inner voices, and intriguing inner images. As in class (1), the affected individual is convinced that familiar explanations are suspended, and the experiences appear egodystonic.

In addition to classes (1) and (2), which are constructed as opposites, i.e., independent, there are also deviations in the correlations between self-model and world-model. Strictly speaking, they are experienced as *relational* between internal (self-model) and external (world-model), so their characterization is based on internal and external phenomena though not contained in (1) or (2). Key to their proper understanding is the relation between (1) and (2), and how it is constituted.

3. *Coincidence phenomena* refer to experiences of relations between self-model and world-model that are not founded on regular senses or bodily functions, but instead exhibit connections between ordinarily disconnected elements of self-model and world-model. Typically, these *excess correlations* are assumed to be non-causal, often experienced as a salient meaningful link between mental and physical events.[8]
4. *Dissociation phenomena* are manifested by disconnections of ordinarily connected elements of self-model and world-model. For instance, individuals are not in full control of their bodies, or experience autonomous behavior not deliberately set into action. Sleep paralysis, out-of-body experiences[9] and various forms of automatized behavior are among the most frequent phenomena in this class, which is characterized by *deficit correlations*.

Atmanspacher and Fach [33] showed how this classification can be drawn from a specific kind of dual-aspect framework of thinking originally proposed by Pauli and Jung: the *Pauli–Jung conjecture*, some details of which we will address in Section 5. Moreover, they indicated how the idea of correlations beyond (excess) and below (deficit) a baseline can be sensibly incorporated into the picture. This baseline is neither universally prescribed, nor is it rigid—it is likely to depend on cultural contexts as well as on previous experiences of the concerned individual. This should be testable for intersubject distributions over individuals and intrasubject distributions over time, respectively. In addition, the intensity of an experience can be regarded as a measure of its distance from the baseline, i.e., of its degree of exceptionality or the extent to which it deviates. See Sections 5.2 and 5.3 for more detailed discussion.

4.2. Empirical Material

4.2.1. Documentation of Counseling Cases

In order to check how relevant the classification outlined in the preceding section is, it must ideally be compared with empirical data. Since the experiences are denoted as exceptional, one might assume that their frequency of occurrence is low in an interindividual sense and that, as a result, not much empirical material be available. However, this is in fact not the case. Several studies have estimated frequencies of about 50% for populations in Western countries, and higher than that within other cultural contexts (see, e.g., [34] and further references therein). The reason why EEs are denoted exceptional is that their intraindividual frequency is small as compared to ordinary, non-deviant mental experiences.

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[8] Meaningful coincidences such as "synchronicities" à la Jung [31] are examples, including extrasensory perception and related phenomena.

[9] A challenging discussion of out-of-body experiences based on the concept of phenomenal models of intentionality relations is due to Metzinger [32]. We will come back to this concept in Section 5.2.

First tests of the classification proposed above were peformed at the Institute for Frontier Areas of Psychology and Mental Health (IGPP) at Freiburg,[10] where a comprehensive corpus of reports of EEs has been collected since 1996 with a documentation system especially developed to capture EEs in great detail. Principal component analyses and variable-oriented cluster analyses yielded a distribution of reported phenomena as shown in Figure 3 (for more details, see [28,29]). A recent study with a second sample of IGPP clients from 2007 to 2014 as well as the evaluation of the total sample of 2381 reports of counseling cases from 1996 to 2014 confirmed these results [35].

These studies allow us to conclude that the classification of EE patterns into four basic classes of phenomena is on solid empirical ground. Figure 3 shows that classes (1) and (2) are uniquely mapped by the empirical material, whereas classes (3) and (4) split into two subclasses each. Those subclasses can be delineated by a slight dominance of external or internal features in the overly disconnected or overly connected psychophysical relationships that define them.

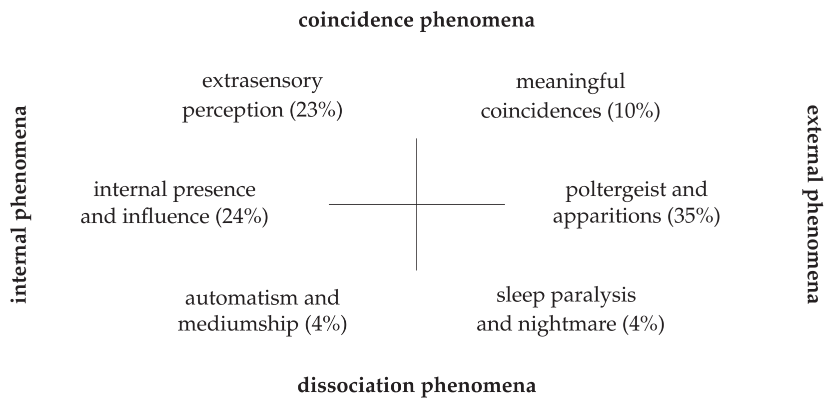

Figure 3. Empirically assessed experience patterns (based on a total of 2356 reports of counseling cases at IGPP that could be assigned to the six EE-patterns) support the classification derived from the conceptual scheme in Sections 4.1 and 4.2. Internal and external phenomena are deviations in the self model and world model, respectively. Coincidence phenomena show connections (excess correlations) of ordinarily disconnected elements of self and world model. Dissociation phenomena show disconections (deficit correlations) of ordinarily connected elements of self and world model.

More than 95% of all EE reports discussed so far invoke categorial states, i.e., are about experiences that are made when a categorial state is located in a mental representation. Classes (1) and (2) are clearly categorial since they concern elements of *either* self- *or* world-model. In contrast, EE reports in classes (3) and (4) refer to elements of *both* self- *and* world-model, but their experiential substance is *relational* rather than *reified*. In this sense, classes (3) and (4) are conceptually different from (1) and (2): the particular correlation they express, be it excess or deficit, is typically experienced as meaningful (or salient). Ultimately, it is the relation that constitutes the EEs, not the related categories. This is a key point for an interesting link to Metzinger's discussion of intentionality that we will pick up in Sections 5.2 and 5.3.

Note that all EE reports were assessed with respect to their phenomenology only, not concerning their veridicality or even psychopathology.[11] A premature and unjustified identification of EEs with

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[10] The acronym IGPP derives from the German "Institut für Grenzgebiete der Psychologie und Psychohygiene".
[11] The issue of how to assess the veridicality (or "truthfulness") of EEs is delicate, since it bears critically on assumptions about ontology. From a physicalist perspective, the veridicality of an EE requires that it must not contradict the laws of physics. If it

mental disorders is avoided by the phenomenological approach. In line with previously published results [36,37], health assessments indicate that the majority of clients is mentally healthy. An estimated 1/3 to 1/2 of EE clients seeking advice were either previously or at the time of counseling in psychotherapeutic or psychiatric treatment [35]. Even if 46% of the clients show signs of mental disorders, the symptoms are often subclinical or not directly associated with EEs.

4.2.2. Comparative Questionnaire Studies

In addition to the analysis of case reports from 1996 until 2014 at IGPP, a number of studies with different data pools, diverse target variables, and varied analysis techniques have been conducted with the revised "Questionnaire for Assessing the Phenomenology of Exceptional Experiences" (PAGE-R) [38].[12] The PAGE-R was created to collect data systematically by self-assessments of subjects reporting EEs. While the documentation by IGPP counseling staff (Section 4.2.1) records EEs relevant during the ongoing counseling process, the PAGE-R registers EEs over the entire lifetime of subjects. In four sections of eight items each for the basic phenomena classes and a five-level Likert scale, the frequencies of particular phenomena are assessed. Time frames, states of consciousness, external circumstances, subjective evaluation, and personal importance of EEs are also retrieved. The PAGE-R items are formulated to record localizations of and relations between mental representations in the subjects' PRM.

As part of a research project with the Psychiatric University Clinic Zurich, an online survey of Swiss general population ($n = 1352$) with the PAGE-R was carried out in 2011. A comparison with IGPP clients ($n = 176$), questioned in a follow-up survey in 2012, resulted in different frequencies and intensities [28]: IGPP clients rated their EEs significantly higher (about 50%) than subjects from the general population.[13]

Meanwhile, data from six PAGE-R samples in total, collected between 2011 and 2017, are available:[14]

1. an online survey sample of Swiss general population ($n = 1352$) collected in 2011 as part of a research project of the Psychiatric University Clinic Zurich with Collegium Helveticum Zurich [28].
2. a sample ($n = 334$) of students attending lectures by Ott (IGPP) at the University of Giessen from 2011 to 2014, as well as students from Freiburg [40];
3. an online survey sample ($n = 148$) collected by Simmonds-Moore (University of West Georgia) in 2014 on the geographic spread of EE in the United States (the first use of the PAGE-R in English translation);
4. a sample ($n = 272$) with subjects seeking advice at the counseling service of IGPP between 2007 and 2015 completed the PAGE-R in follow-up surveys from 2012 to 2015;
5. an online survey sample ($n = 176$) with subjects with (at least subjective) near-death experiences was analyzed by Nahm and Weibel with scientific support by IGPP in 2015 to examine EE as aftereffects of near-death experiences;
6. a sample with meditators ($n = 59$) of between 3 and 46 years practice to study effects of meditation [41].

does, the EE will likely be ditched as a psychopathological impairment, a hallucination that, however, will still be regarded veridical from a phenomenological perspective. From a dual-aspect perspective, there may be EEs that are subject to neither physics nor psychology, e.g., relational experiences connecting the physical with the mental. To dismiss the veridicality of such EEs as hallucinations because they do not follow the laws of physics would be an obvious category mistake.

12 The acronym derives from the German "Phänomenologie Ausser-Gewöhnlicher Erfahrungen—Revidiert". It is a proprietary product of IGPP and can be made available for scientific purposes upon requested permission.

13 In this context, let us point out that Wyss [39] showed for the first time how subjects tending to coincidence experiences can be delineated from subjects tending toward other phenomena classes based on psychophysical laboratory experiments.

14 In-depth descriptions of these samples, their analyses, and results can be found in [35]. Publications by the indicated investigators who collected the data for samples 3, 4 and 5 are in progress.

Factor analyses, cluster analyses, item analyses and scale analyses were used to examine the reliability and validity of PAGE-R in the German-language samples 1, 2, 4, and 5 [35]. The theory-compliant extraction of four factors turned out to be the most robust and best-generalizable model in all these samples not only from an ensemble point of view. Rather, they support a universal latent order in the manifestation of EEs for each individual, in agreement with the theoretical dual-aspect framework indicated in Section 4.1. We may assume that the four-factor model is appropriate for populations of individuals with a PRM exhibiting an intact dichotomy of self-model and world-model.

Figure 4 shows the frequencies of phenomena of the four basic classes of Figure 3 for the six samples mentioned above. The relative distribution of frequencies over the basic classes constituting EEs is comparable for all samples. The US sample 3 indicates that this distribution even holds for non-European populations. As one might expect, frequencies are lowest for samples from general population (samples 1 and 2) and highest for meditators (sample 6) and subjects reporting near-death experiences (sample 5). For the latter, it is unclear whether increased EE frequency favors near-death experiences or is rather a consequence of them.

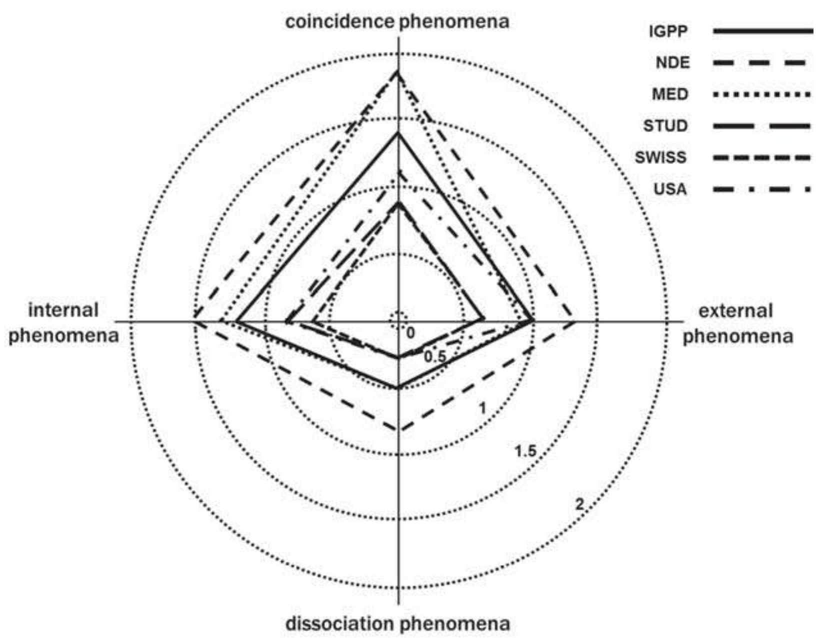

Figure 4. Frequencies of the four basic classes of phenomena from the six samples mentioned in the text. Dotted circles represent frequency levels as assessed individually on a scale from 0 (never) to 4 (very often). IGPP—sample 4, NDE—sample 5, MED—sample 6, STUD–sample 2, SWISS—-sample 1, USA—sample 3.

The fact that all EE patterns occur not only in clients seeking help, but also, although less often, in the general population shows that EEs are widespread and continuously distributed in their intensity and frequency. In all samples, EEs occur predominantly in the waking state and mostly spontaneously. Mental techniques, drugs, contact with occultism and healers do not play major roles.

A final note of caution: based on a sample with $n = 206$ of Swiss general population, Unterrassner et al. [42,43] found a factor-analytic solution with three factors and use these factors as scales for measuring "psychotic-like experiences" by "odd beliefs", "dissociative anomalous perceptions" and "hallucinatory anomalous perceptions". As shown in [35], this analysis suffers from two technical shortcomings: (1) a sample size of only 200 persons is too small for reliable conclusions if the general population with its low EE-scores is to be examined and (2) an interpretation of factors as scales is not straightforward and, in this case, does not satisfy the criteria of test theoretical standards.

More serious at the conceptual level is that Unterrassner et al. [42,43] confused the phenomenological paradigm underlying the PAGE-R with their psychiatrically motivated approach. Mistaking experiences for "odd beliefs" or other psychiatric symptoms means to seriously misunderstand the psychopathologically neutral intention that is an essential ingredient of the PAGE-R. From a more general point of view, it is illegitimate to identify EEs with beliefs anyway: believing in EEs does not require having ever experienced one, and experiencing an EE does not presuppose believing in them.

4.3. Categorial EEs versus Non-Categorial or Acategorial EEs

Categorial EEs as deviations in the PRM are to be distinguished from experiences of an altered PRM. This can occur in basically two ways: either the differentiation of self-model and world-model regressively fades away in a non-categorical EE or it is progressively transcended in an acategorial EE [7,29]. Only categorial mental states (with their intentional content) have the stability properties necessary to be subject to ordinary experience. Non-categorial and acategorial states are either marginally stable or outright unstable and (usually) do not permit the experience of a stable state with intentional content in the usual sense.

EEs based on non-categorial or acategorial states are likely to be more radical than those based on categorial states. Non-categorial states are states in which categorial distinctions are dissolved or not yet established; they form a representational ground as discussed in Section 3.2. Acategorial states are unstable and usually evasive states between existing representations. It remains to be studied whether, and how, they may be stabilized, i.e., prevented from relaxing into neighboring representations, with particular techniques or under particular conditions (see [44] for examples). Other than non-categorial states, typically reported as descending into dark, diffuse and unconscious depths, acategorial states are experienced as light, lucid, and sublime—*immanent experiences*, as some have called them.

Such experiences sometimes even transcend the distinction between self and world, inside and outside, subject and object. Marshall [45] has an impressive example of a light experience that starts relational, i.e., between inside and outside, and becomes immanent, i.e., transcends that distinction:

> I suddenly found myself surrounded, embraced, by a white light, which seemed both to come from within and from without, a very bright light but quite unlike any ordinary physical light...I had the feeling of being "one" with everything and "knowing" all things...I had the sense of this being utter Reality, the real Real, far more real and vivid than the ordinary everyday "reality" of the physical world.

More examples concerning the rich phenomenology of EEs in acategorial states have been described in [7]. Their relevance for the topic of mental states with non-conceptual content [23] has been addressed in [24].

5. Self-Model and World-Model as Dual Aspects?

5.1. Models as Aspects

Emphasizing that the notions of self and world ought to be understood as models, namely self-model and world-model, entails that they must be models of something. This something could be an ontic reality as such, if reality were not already understood as a model, namely the reality-model, in the representational account that Metzinger advances. This leaves us with the question of how his metaphysical position actually looks. Neither in *Being No One* [1] nor in the precis of it [46] does he spend much time or space to concisely unveil this position to his readers. Given the very detailed and comprehensive, clarifying and insightful definitions, explanations, and consequences that Metzinger formulates in his texts, this appears to be a noteworthy point.

Often Metzinger talks about brains or organisms as if they were physical entities, and this may have led some commentators (such as [47], pp. 80–100) to assume that he defends a physicalist stance. However, brains and organisms are part of the world, so if the world is actually to be conceived as a model, then this includes brains and organisms. Thus, alluding to brains or organisms as "real" physical carriers of models means to treat them both as physical entities and as their models at the same time. This injects a poignant ambiguity into an assumed physicalist ontology for Metzinger's framework.

Of course, there is nothing wrong in principle if one talks about both an object domain of reality and models of this domain. However, it is well known that an assumed ontic reality is everything else than in one-to-one correspondence with models that physicists, biologists, or brain scientists have developed and utilize. This is obvious from the fact that different viable models of the same object domain can be incompatible or even logically exclusive, for instance deterministic and stochastic approaches, or computational and phenomenological approaches to "the brain". In view of these complications, it is quite difficult to delineate an object domain and its model(s) in a way that is clear-cut enough to avoid confusion between the two.

We think that this confusion can be most elegantly avoided by turning to a powerful alternative to physicalism that receives increasing attention in recent years: dual-aspect thinking. Now it has to be understood right away that dual-aspect thinking is not a monolithic building of thought, but comes in a number of variants to be sketched below. A basic feature of dual-aspect accounts is that the mental and the physical (self and world, roughly) are not conceived as ontic entities but rather as aspects, or perspectives. The question then is, very similar to models in Metzinger's parlance, aspects or perspectives of what are they?

With respect to this question, dual-aspect thinkers bite the bullet and admit that present-day science has almost nothing to say about the base reality, except that it should be psychophysically neutral, i.e., neither mental nor physical. (It is certainly not the reality of fundamental physical particles or fields.) Nevertheless, there are several speculative ideas of how to characterize this psychophysically neutral in more detail. We will return to this below in Section 5.5. For the discussion right now, let us just assume the psychophysically neutral as a *tertium quid* from which its mental and physical aspects (self and world, roughly) arise or emerge.

There are basically two conceptions in which this emergence can be addressed.[15] In one of them, psychophysically neutral elementary entities are composed of sets of such entities and, depending on the composition, these sets acquire mental or physical properties. Major historic proponents of this *compositional* scheme are Mach, James, Avenarius, and Russell. In the literature, this is often referred to as "neutral monism" [49,50] A neo-Russellian version of neutral monism proposed by Chalmers [51] has been quite influential, both in the philosophy of mind and in cognitive neuroscience (cf. the work of Tononi and his group [52]).

The other base conception is close to Spinoza's way of thinking, where the psychophysically neutral does not consist of elementary entities waiting to be composed, but is conceived as one overarching whole that is to be decomposed. In contrast to the atomistic picture of compositional dual-aspect monism, the holistic picture of the *decompositional* variant is strongly reminiscent of the fundamental insight of holism and nonlocality in quantum physics. Quantum systems are wholes that can be decomposed in infinitely many complementary ways, very much like how Spinoza's idea of the divine has been interpreted.

Inspired by quantum holism, modern decompositional dual-aspect thinking has been mainly proposed by philosophically inclined physicists in the 20th century, starting with Bohm and Pauli (together with the psychologist C.G. Jung). Subsequent work along the same lines has been due to

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[15] A compact account of 20th century examples of dual-aspect thinking can be found in [48], including commentaries by Horst, Seager, and Silberstein.

d'Espagnat, Primas, and our own proposals refining the Pauli–Jung conjecture [4].[16] A key difference between compositional and decompositional accounts is that the mental and the physical are reducible to neutral elements if these are the basis for composition, but they are irreducible (in the standard understanding of reduction) to a neutral whole if this is the basis for decomposition.

Another important point is that decomposing a whole necessarily implies correlations between the emerging parts, while composition does not necessarily give rise to correlations between different sets of composed elements. In this way, decompositional dual-aspect monism has been highlighted as the one philosophical framework that explains mental-physical correlations most elegantly and parsimoniously. The price to be paid is that the metaphysics of a psychophysically neutral whole is largely undeveloped and leaves much work to be done.

5.2. Intentionality

At a panel discussion some time ago, one of us (HA) had an exchange with Godehard Brüntrup (GB), a Munich based philosopher, that was directed at the nature and our understanding of psychophysical correlations. Quoted from memory, it went like this:

> GB: You know, we have sensory capacities for vision, the eyes, for hearing, the ears, and so on. However unfortunately, we don't have a sense for psychophysical correlations!
> HA: Wait a minute! I'm not sure about this—though the latter may differ fundamentally from the former. How about the sense of meaning?
> GB: What do you mean, meaning? Intentionality?
> HA: Yes—if you want to use this phil-of-mind term. Anyway, it's about the experience of something that, roughly speaking, connects a mental representation with what it represents. Meaning in this sense is a relational experience, and this is what makes it fundamentally different from the ordinary senses.
> GB: I can see where you're going ... I have to think about it.

Intentionality is the technical term for the reference relation that may be colloquially called a relation of meaning. The notion of the intentional content of a mental representation, in addition to its phenomenal content, addresses what the representation refers to. Metzinger ([46], Figures 1 and 2) illustrates the way in which the traditional way to conceive intentionality ("good old-fashioned intentionality") according to Brentano deviates from his conception. While intentionality is traditionally conceived as a relation between a mental representation and what it represents *in the world out there*, he conceives intentionality as a relation between a mental representation and *the representation of the world out there*.

In other words, Metzinger does precisely what we were asking for in Section 5.1: he talks about models of the world rather than the world itself. The brain, or the organism, or the universe as a whole, all need to be addressed in terms of models. This does not exclude that there may be some reality out there, but it would be illegitimate to identify it with the various ways in which it can be modeled. Thus, Metzinger's focus in [46] is clearly on intentionality as a relation between self-model and world-model, not between self-model and world itself.

Insofar as the phenomenal experience of intentionality is relational, it cannot be the phenomenal content of one of the related representations. Now, in order to account for the actual experience of intentionality (as meaning!) in a representational way, Metzinger postulates a phenomenal model of the intentionality relation (PMIR) as a meta-representation transcending the level of those first-order representations that are related by intentionality. The PMIR allows him to address the experience of meaning in terms of the phenomenal content of a meta-representation.

From the dual-aspect perspective on exceptional experiences outlined in Section 4.1 (see also Figure 3), the classes of coincidence and dissociation phenomena in EEs can be straightforwardly linked

[16] In recent years, an increasing number of affective and cognitive neuroscientists have emphasized the potential of dual-aspect approaches, such as Damasio, Friston, Hobson, Panksepp, Solms, Velmans, and others.

to PMIRs. EEs are experiences of relations between elements of the self-model and the world-model of an experiencing subject. The phenomenal expression of those experiences is encoded in the meta-representation of the PMIR as its phenomenal content. The degree of exceptionality of an EE depends on its deviation from the baseline of a default intentionality that subjects employ under ordinary, everyday circumstances.

5.3. Transparency and Opacity

In addition to relational EEs as PMIRs, Metzinger's approach even gives us a clue to characterize the deviation of relational EEs from the baseline by a special property of representations in general and PMIRs in particular. Representations can be *transparent* or *opaque* ([53], p. 7):[17]

> Transparency is a property of conscious representations, namely that they are *not experienced* as representations. Therefore, the subject of experience has the feeling of being in direct and immediate contact with their content. Transparent conscious representations create the phenomenology of naive realism. An opaque phenomenal representation is one that is experienced as a representation, for example in pseudo-hallucinations or lucid dreams. Importantly, a transparent self-model creates the phenomenology of identification ([1], Section 3). There exists a graded spectrum between transparency and opacity, determining the variable phenomenology of "mind-independence" or "realness".

What we denote as a baseline of relational experiences, a default intentionality that subjects employ under ordinary circumstances, is hardly ever explicitly experienced, and even less so as meaningful. For instance, no one attributes meaningful experiences to the correlation between their mental states and their neural states. The corresponding baseline, thus, perfectly illustrates a relational experience whose PMIR is characterized by complete transparency. Note that this example differs from a transparent first-order representation of, say, an apple, which appears to us as an object of reality out there, in the sense of naive realism. However, even if we realize that the apple actually is an element of our world-model, a transparent PMIR of this situation would mean that we do not attribute any explicit meaning to seeing the apple.

There is one key feature in mind–body relations whose PMIR is typically transparent in many instances: the experience of mineness, or ownership. This is the impression that a particular mental representation of a bodily state (or action) of a subject is related to the bodily state (or action) of that same subject—"my" bodily state (or action). In dissociation phenomena, mineness and ownership can be severely impaired, i.e., ordinarily connected elements of the self-model and the world-model of the subject become disconnected. In this situation, we speak of deficit correlations, below the baseline. Out-of-body-experiences are an illustrative case in point: The mental state of the subject represents its body, as an element of the world-model, in a way that appears disconnected from the representing self-model.

In such a case, the subject realizes that the connection of its body-model to its self-model deviates from the ordinary, so the PMIR of this connection is not transparent but achieves (gradual) opacity. And insofar as such a case is experienced as highly meaningful (especially if it is the first time it happens), it deviates considerably from the baseline. This leads us to the hypothesis that the extent to which an EE deviates from the baseline of relational experiences be a measure of the opacity of its corresponding PMIR. Furthermore, this hypothesis is equally sensible if coincidence phenomena are at stake, where excess rather than deficit correlations are responsible for the deviation from the baseline.

We should add that the concept of a baseline sounds more rigid than we think it should be thought of. Although our empirical material provides evidence that we have a pretty stable baseline on an average over thousands of subjects (in Western cultural contexts), individual variation has to be

[17] This important distinction goes back to Moore [54] and, later, Harman [55], who used the term "transparent" roughly in Metzinger's sense, while van Gulick [56] applies it differently. An informative discussion of a number of readings of transparency is due to Stoljar [57].

expected. For instance, it will be likely that subjects who learn how to induce EEs of a certain kind will shift their baseline toward the corresponding class of phenomena. As a result, an EE that was outstanding when it was experienced first will lose intensity if it is volitionally reproduced. More work on EEs and their link to opaque and transparent PMIRs is in progress.

5.4. Self and World Again

Metzinger's main thesis in *Being No One* "is that no such things as selves exist in the world: Nobody ever was or had a self. All that ever existed were conscious self-models that could not be recognized as models" ([1], p. 1)—because of their transparency. While Rudder Baker's move [47] is to reinstantiate experiencing selves as ontologically existing subjects, we think with Metzinger that the notion of the self in the sense of a "mediator" of first-person experience should not be given ontological significance. However, as pointed out above, we would insist that this equally applies to the physical world insofar as it is a world of modeled and observed, hence *epistemic*, physical objects. While Baker wants to pull the self into ontology, we would argue that even the physical world is basically epistemic—namely, conceived as a world-model à la Metzinger —and should be pushed out of ontology.

It is central to most dual-aspect approaches that the mental and the physical are considered as epistemic insofar as their experiencable and observable structures and dynamics are by definition subject to knowledge. However, over and above this dual-aspect thinking posits a knowledge-independent ontic reality without the mind-matter or subject-object split. As mentioned In Section 5.1, decompositional dual-aspect monism is inspired by the wholeness or nonlocality of quantum theory, which illustrates why observed objects need to be regarded as epistemic. Physical nonlocality is empirically demonstrated by measuring correlations between subsystems that are generated by measurement itself, so that the original wholeness of the not-yet-measured (ontic, as it were) system is destroyed.

On the psychological side, Jung ([58], supplement) has argued that this view on quantum measurement has an analogy in the transition from unconscious to conscious states: the wholeness of mental states at the archetypal level of the unconscious is destroyed when they are transformed into selected conscious contents. Ultimately, the idea is that the most comprehensive level of mental unconsciousness and the most comprehensive level of physical wholeness converge—a limit in which there are no distinctions left at all.

The notion of the self, as Metzinger and most other philosophers of mind use the term, is essentially bound to the so-called first-person perspective of "what it is like" to be in a given mental state. An individual which mistakes its self-model as an individual self is bound to a number of interpretive flaws that Metzinger's account discloses. It may be interesting to see that the role of Metzinger's self-model resembles the Jungian notion of an ego that fails to realize its status as being purely epistemic. However, Jung also has the notion of an impersonal, non-individual "self" characterizing an overarching archetypal structure within the psychophysically neutral reality, whose fragmented projection in an individual's conscious psyche functions as an ego, i.e., Metzinger's self-model.[18]

5.5. From One to Many, and Back

In the decompositional variety of dual-aspect monism, the ultimate psychophysically neutral reality is one whole, a whole with no internal structure, no distinctions, no parts, no time, no space. In the Pauli–Jung conjecture, this is called the *unus mundus*, the one world, from which all diversity arises. It's a modern creation myth, if you wish. In addition, since there are no distinctions, there is no

[18] For commonalities (and differences) of this conception with Eastern philosophies such as versions of Buddhism and Hinduism see the readable collection of essays by Siderits et al. [59]. Notably, some of the authors discuss concrete relations to Metzinger's work.

discursive epistemic access to this reality. It is "unspeakable", or "ineffable". Alter and Nagasawa [50] discuss a number of options to conceive this unspeakable—which they refer to as "inscrutable".

A formal way to approach the undividedness of this reality is in terms of symmetry principles. A symmetry in the technical sense is an invariance under transformations. When we say that a circle is invariant under the transformation of a rotation, we mean that it does not change its appearance, no matter which angle it is rotated about. In this sense, the circle is symmetric with respect to rotation. Casually speaking, symmetry is about "change without change".

Quantum field theory is a success story of the power of symmetries in physics: The way we understand the fundamental physical forces today is a series of symmetry breakdowns, leading to more and more refined concepts of matter and energy. Now, the *unus mundus* is not physical of course, it is psychophysically neutral, and its mental and physical aspects are undefined because of their lacking distinction. However the mathematical principle of a symmetry transcends its applications in physics, so symmetry offers itself as an interesting candidate to address other domains of reality as well.[19]

Increasing refinements of an *unus mundus* due to successive distinctions are expressible as symmetry breakings, such as the mental versus the physical, subject versus object, inside versus outside, self versus world. In the Pauli–Jung conjecture, there is a primordial split-up of the *unus mundus* into a collective mental unconscious (transcending individual subjects) and a holistic physical world (transcending observable objects), raw forms of the mental and the physical that are yet to be differentiated. More refinements lead to the full-blown mental domain with its multiplicity of consciously experienced states (a self-model) and a full-blown physical domain with its multiplicity of observable and manipulable phenomena (a world-model). Other variants of dual-aspect thinking propose different accounts [48].

The unspeakability and inscrutability of an *unus mundus* block cognitive discursive access, and relational experiences are impossible if there are no distinct mental and physical states to be related. However, the *unus mundus* need not exclude experience altogether. As indicated in Section 4.3, there are conceivable modes of experience that do not require well-defined distinct states and relations between them. Rather, they may be targeted directly at the undifferentiated ground from which distinct states emerge. Such *immanent* experiences may be understood as non-categorial (or even acategorial) states without conceptual, or categorial, content [24].

Immanent experiences are experiences reversing the direction "from one to many" back to one, from the refined concepts of our familiar consciousness back toward the limit of total undividedness. The literature on mystical experiences contains numerous examples of this move, as for instance displayed and discussed in [45]. Mystical experiences are hard to communicate in conventional language and logic, and corresponding attempts often result in paradoxical formulations such as Plotinus' *identity in difference* or Nicolas of Cusa's *coincidentia oppositorum* (see also [60]). They express experiences of the one undifferentiated ground that itself does not enter into the contents of representations arising from it.

Are immanent experiences meaningful? If meaning is a relation explicated through an epistemic split, as in intentionality, then they are not. However, insofar as immanence points to the source of those representations that are related by intentionality, experiences of immanence may refer directly to this source and unveil the implicit origin of a meaning that is yet to be explicated. However careful: without the epistemic split of subject and object, such experiences cannot be subjective in the usual sense any more! William James [61] speculated about them with his notion of "pure experience", others have called them experiences of "pure presence" or "non-dual awareness".

[19] Symmetry principles do not exhaust the range of possibilities to address the psychophysically neutral formally. Other options that one might think of are non-commutative structures, non-Boolean logic, or even mathematical fields as general as category theory.

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philosophies

Article

Hylomorphism Extended: Dynamical Forms and Minds

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Abstract: Physical objects are compounds of matter and form, as stated by Aristotle in his hylomorphism theory. The concept of "form" in this theory refers to physical structures or organizational structures. However, mental processes are not of this kind, they do not change physical arrangement of neurons, but change their states. To cover all natural processes hylomorphism should acknowledge differences between three kinds of forms: Form as physical structure, form as function resulting from organization and interactions between constituent parts, and dynamical form as state transitions that change functions of structures without changing their physical organization. Dynamical forms, patterns of energy activation that change the flow of information without changing the structure of matter, are the key to understand minds of rational animals.

Keywords: hylomorphism; mind; form; matter; neurodynamics

1. Introduction

Identity of physical objects has been conceptualized in history of philosophy in various ways. The most obvious distinction that has been made is between matter and form. Abhidharma Buddhist tradition acknowledges the material form or body (rūpa) as the basic type of aggregate, and adds four types of aggregates to characterize mental level: sensations, apperception, volitions or dispositional formations, and consciousness [1,2]. In ancient Western philosophy Aristotle in *Physics* has introduced distinction between form and matter that considered together characterize physical and mental objects. This idea, called hylomorphism, became the foundation of Thomist philosophy in the 13th century [3]. Hylomorphism has been quite influential philosophical theory since antiquity, and is still frequently discussed in contemporary analytical philosophy and theology [4,5], including mechanistic philosophy of biology and neuroscience [6,7]. In preface to the book "Neo-Aristotelian Perspectives on Contemporary Science" John Haldane writes about "shared sense that Aristotelian ideas have much to offer", and the introduction, written by the editors of this book, starts with a claim "A recent revival in (neo-)Aristotelian philosophy is beginning to transform the landscape of contemporary analytic philosophy" [8].

Form and matter establish properties of physical objects. Frequently form has simple interpretation as structure, arrangement of constituting elements, such as bricks in the building or atoms in molecules. It unifies matter into objects that have specific properties, determining interactions with other objects. Form may also refer to the organizational structure based on interactions between elements that define the identity of the whole. Aristotle has extended hylomorphic concept into the animal and human realm in his *Metaphysics* and other works. In *De Anima* he describes body and soul as a special case of matter and form. Living organism is not identified on the basis of anatomy, but also all functions that characterize it. The form of a dead body is different than living body although the arrangement of atoms may be quite similar. In *Metaphysics* "form" is presented as an essence of things composed of "substance", making the concept of hylomorphism more abstract. Form is not restricted to physical structure, functional organization, nor dynamical states of matter, it is the stable essence that endows substances with particular properties, making different types of things. This idea has been linked to the *phenotypic plasticity* by Austin and Marmodoro [8] (Chapter 7 and 8), continuous dynamically connected landscape that unfolds in morphological space, maintaining the identity of evolving organisms.

Ancient philosophers have been struggling to adapt the concept of form to describe living beings and in particular humans. The substantial form of a material body, called in Thomist philosophy "soul", was understood as the animating essence of plants, animals and rational humans. De Haan [7] calls this approach "hylomorphic animalism" (HMA): Animals are complex unified psychosomatic substances endowed with integrated biological and psychological attributes. Explanation how this animated principle relates to sensory and intellectual powers was of course well beyond the capability of ancient and medieval philosophers. Full description of mechanisms responsible for the structure and behavior of animals requires development of phenomics at many levels: genetic, molecular, cellular, network and tissues, organs and organisms, interactions with other organisms and ecosystems at different spatial and temporal scales. The Research Domain Criteria of the National Institute of Mental Health, developed to understand mental disorders, are the first step in this direction [9], but achieving this goal will take many decades. Mechanisms explain how component elements forming structures at some level are organized, how they interact, creating various phenomena such as gene expression, binding of neurotransmitters to receptors, or activating brain structures that lead to phobias. These mechanisms may be stochastic, distributed, and may refer to irreducible multi-level organization.

This paper has been written in an attempt to understand better the concept of form and to distinguish between different kinds of forms. Form may be understood as physical structure or as functional organization that involves interacting physical entities. The third kind of form, called here "a dynamical form", has not been clearly distinguished from other two types, but seems to be vital for understanding brain-mind connections. Characterization of different kinds of forms should help to develop hylomorphic ideas further.

2. Different Kinds of Forms

Hylomorphism is based on the conviction that substance and form are basic ontological and explanatory principles. Modern science is concerned with matter, energy and information. Matter and energy may be connected to substance and form, but information has no counterpart. Physical entities are composed of elements: atoms, molecules, or more complex structures arranged in some ways. Matter is a form of energy, interactions between elements lead to formation of physical structures, some transient and some stable. The most common sense of "form" is relatively stable physical structure.

Physical form of objects may not be sufficient to determine specific ontological category. A unique chair may have many attributes defining its shape and materials that it is made from. However, general ontological concept of a "chair" cannot be defined listing various shapes and material compositions. It cannot also be understood by its function, as one may sit on the bench, stool, tabouret and many other types of pieces of furniture. Moreover, natural concepts are understood in a different way by people, depending on their age and culture [10]. Still, we can say about each particular chair that it has specific shape and it is built from some kind of matter. Form may substantially change, but the category of the object may still be preserved. Here we are touching on the problem of categorization in cognitive psychology and the definition of ontological concepts (cf. Handbook of Categorization in Cognitive Science [11]). The exemplar theory of categorization defines "a chair" as an object that may be used to sit on, and is similar to some examples of objects known as chairs. Hylomorphism simply says that real objects are irreducible unified form-matter wholes, with specific organization of material components, but it does not help to define ontological categories.

Some objects do not have permanent or definite form. Clouds behave in chaotic way. Kinetic sculptures moved by the wind may demonstrate various structures that change in unpredictable way. Molecules oscillate between various conformations, have vibrating and rotating fragments, taking several shapes that have different properties. **Flexible forms** may have finite number of spatial arrangements if local structures are preserved (chemical bonds, snowflakes), or an infinite number of possible shapes (clouds).

How stable are forms? Larger objects change much slower, enabling reification, naming of objects that preserve their forms for a longer time. At the microscopic level everything is moving incredibly fast, atoms vibrate and interact changing their arrangements at the timescale of picoseconds. Complex molecules, such as amino acids, are formed even in deep space. The $C_{25}H_{52}$ molecule has 25 carbons and 52 hydrogens, but these atoms may be arranged in about 36 million of different spatial forms, or isomers. Each spatial structure may be in many different dynamical states (electronic, vibrational and rotational excited states), most of which are stable only for a very short time. Each dynamical state has different properties, such as probability of interactions with other molecules or interactions with light, responsible for the absorption and emission spectra. Small molecules at quantum level may assume many discrete dynamical forms, influencing structural form to various degrees. For larger molecules or for highly excited states there are so many similar transient forms that in practice there is a continuum of possible structures.

Form may also be understood **as a process** that changes physical structure in a way that is typical for some objects. Transitions between specific forms may be slow, preserving the identity of objects for some time, or may have character of rapid phase transitions, like changing water into ice or vapor. Form can also change in a stochastic way. Each snowflake has unique form coming from the crystallization of water. The theory of dynamical systems describes different kinds of system behavior using the concept of attractors: point attractors leading to stable structures, limit cycles, strange attractors that characterize chaotic movements. Objects may change form, or have multiple forms, but preserve their identity and be categorized in the same way.

The concept of form as structure applied to biological processes results from reification based on perception in short time scales of common characteristics that are roughly preserved. Organisms have specific, relatively stable organization at macroscopic level, that relies on dynamic processes supporting life at the microscopic (cellular and genetic) levels. Structure of adult organisms at macroscopic level may change slowly and there are many developmental pathways that lead to the relatively stable structures. Conrad Waddington wrote 20 books illustrating how gene regulation modulates development, using the metaphor of "epigenetic landscape". The idea that organisms are processes, has been recently emphasized in the philosophy of biology [12]. Evolutionary biology has Metamorphosis is quite common in animal kingdom, leading to a fast complete change into another structural form. Caterpillars change into butterflies, various insects change from larvae to very different forms, tadpoles change into frogs and tunicates start as swimming animals and end up as filter feeders. Fish can change their sex and even size in relatively short time. In the lifetime of animals structural stability is observed only in some time windows, where form as a structure can be applied. Quick growth from a single cell, metamorphosis and decay are better characterized by understanding form as a process. Even in the period of relative stability at the macroscopic level, structure at the cellular level may change quickly: New cells replace old ones within days, outer layer of skin is replaced every two weeks, and the whole human skeleton is renewed in a decade. Identity of structural form depends on the time window and the tolerance for small differences that are always present. Changes at the atomic level are always taking place, so one may claim that there are no static structural forms. As all natural concepts "structural form" is only an approximation that has limited applicability.

Form as a process represents regularities of transitions between structural forms, developmental path, but it is still based on rearrangement of physical elements. However, there are processes that do not require such rearrangements even at atomic level. In electronic circuits structure of connections does not change at all, atoms are not moved, but patterns of electrical activations bind different elements without changing physical structures. Information in computers flows through different pathways, engaging multiple threads in complex processors, or recruiting a number of processors in parallel. Internet networks send information through different routes. **Dynamical forms** emerge at the macroscopic level and are qualitatively different from other types of forms [13]. Although spatial arrangement of atoms is not changed electric potentials create various patterns that can be measured. Information stored in computer memory does not occupy space. Magnetic moments of atoms are used to store information, gates in semiconductors direct currents without moving any physical structures, light intensities in optoelectronic devices decide on the light patterns. Such changes are based on internal states of atoms, but do not require their physical movements.

One can imagine intermediate cases where distinction between dynamical forms, and forms as processes based on physical rearrangement is blurred. Time scale for changes of brain structure (learning, aging) and changes of mental processes (perceptions, thoughts) allow for clear distinction of forms that are almost static physical structures, and rapidly changing dynamical forms. Connectomes, specific sets of connections between different brain areas, offer unique individual fingerprints explaining intellectual and sensory power of animals, including humans [14]. The structure of these connections is changed due to neuroplasticity at different time scales, so the brain anatomical form and functions are constantly changing. Mental phenomena are a result of dynamical processes taking place on networks defined by connectomes, creating patterns of quasi-stable bioelectrical activations.

The functional connectome has been intensively studied in the last decade [15]. Functional connections are formed on a network of structural connections, but do not change in a significant way their physical form in the short time scale. Percepts, thoughts and feelings result from activations that change states of groups of neurons, exciting or inhibiting them, but there is no new arrangement of matter involved. Dynamical forms in the brain are observed at the macroscopic level using electrophysiological and neuroimaging methods. Minute changes at the atomic level are not relevant to understand emerging global activation patterns.

The concept of **form** may be applied to population of entities **at different level of abstraction**. Biological taxonomy is based on a selection of distinctive properties in a hierarchical way, from species to domains, with more general taxa having fewer properties. This is not the same as the form understood as the essence of organism capturing its whole organization. Characterization of species is not based on accidents, all properties at this level belong to the essence of biological organisms. At the rank of domains very few properties are left. The essence of the abstract concept of eukaryotes is based on cells that have a nucleus enclosed within membranes.

Amorphic hylomorphism [16] searches for the essence of objects not in their physical form, but in "how they come to exist and what their functions are (the coincidence of formal, final, and efficient causes)". Intention of agents creating artefacts from their initial matter to perform specific function gives them identity. Evolution may act in similar way as agents that creates organisms.

Various approaches to hylomorphism are based on different concept of "form": Physical static or flexible structures, processes that have distinct stages, dynamical forms based on activation patterns, highly abstract categories, or intentions of agents behind creation of artefacts or organisms. "Form" is thus a very general concept that refers to quite different phenomena. The should be clearly recognized in discussions on hylomorphism.

3. Mental States as Dynamical Forms

Since hylomorphism assumes complete integration of form and matter there is no place for the mind-body separation, and thus there is no mind-body problem. It is the organizational structure of the animal that animates it. Mental properties are simply attributes of the whole organization of form-matter complex. They are implemented by lower level mechanisms, but it is the whole animal that has sensory powers, perception, memory, emotions and volition, grounded in its ecosystem [7]. Physical, chemical, molecular properties evolved to maintain "efficient animation", leading to organization of the organism that helped it to survive.

Environment may have critical influence on the form of brain activity, leading to the ideas of extended mind [17,18], embodiment and enactivity [19]. In case of strong coupling between organism and environment form should encompass whole organism and the part of the world that has influence on this organism. On some accounts it should even be extended to encompass the whole evolutionary history [16]. Since everything in the Universe is interdependent boundaries between different forms of objects are always approximate. At the microscopic level this becomes a serious problem because in quantum mechanics there is no way to describe separate objects that have interacted in the past [20].

Relation of the hylomorphic view to strong emergence have recently been discussed by de Haan [7]. He has used distinction between mechanistic organization and psychological organization. Mechanistic organization "explains the way psychosomatic powers, their operations, and diverse forms of psychological organization among these powers and operations are constituted from and enabled by the organized sub-psychological level interactions among neural and other biological components". "Psychological organization explains the psychological level interactions between the animal's psychosomatic powers and objects in the animal's environment". From the point of view of phenomics [9,21] this corresponds to mechanisms at the level of genes, molecules, cells, circuits, and physiology responsible for "mechanistic organization", identifying behavioral level with "psychological organization". Constructs used in neuropsychology include also self-reports, subjective aspects of phenomenal experience, that only partially are manifested in behavior.

The physical brain structures are a substrate in which dynamical forms arise. Structural connectivity is also called anatomical, because it is based on direct structural connections between neurons, axons interconnecting brain regions. Such connections may be traced using magnetic resonance imaging fiber tractography methods and observed using various forms of microscopy. However, neurons that are anatomically connected are not always functionally connected. On anatomical networks sparse, rapidly changing patterns of activation arise, creating virtual subnetworks that are needed to accomplish various functions. Each neuron may be a member of one subnetwork and a moment later of another subnetwork. These patterns are correlated with subjective experiences. **Mental states supervene on dynamical forms**.

Aristotle described perception as the reception of form without matter. Perception of sensory or mental events needs a substrate of brain matter, but (at least in the short time scale) does not require structural changes in the brain. Most of the things that appear briefly in our short-term memory do not leave permanent traces in brain structures. The same physical structure of computer circuits may carry an infinite number of dynamical patterns, some of them appearing as different images on the screen. The meaning of these patterns is analyzed internally in the computer system or by biological brains. Results are expressed through activation of effectors: images on the screen, sounds from speakers, transmission of internet signals, robot movements, gestures and speech. Animals express their mental states on the "canvas of the body", as Damasio [22] has put it.

Dynamical forms are based on energy flow in complex networks, rather than rearrangement of material elements. Neuroimaging and EEG/MEG studies allow for decomposition of brain states into basic patterns that correspond to affective and cognitive psychological factors [23]. Objects that people see or imagine can be reconstructed from brain activity using functional magnetic resonance [24]. Detailed images of faces seen by a monkey have been reconstructed from just 205 electrodes measuring spiking activity of neurons in visual cortex [25]. Our ability to reconstruct mental states, such as intentions, decisions, memory, emotions or imagery, from analysis of brain activity has been greatly improved in recent years and is used now in brain-computer interfaces.

At molecular level every neuron and other cells change constantly, but at the macroscopic level these changes are not visible. This fact may be called "**stochastic stability**" of structural forms. Form of the brain includes organization of matter that has different temporal dynamics: connectivity, neuronal structures, biochemistry, signaling pathways, genetics. The concept of form refers to structural phenotypes that involve multiple levels of description. **Dynamical form** that rapidly changes in time and is the basis of mental states and behavioral functions may be defined at different structural levels, from the activity of single neurons to the activity of large brain regions. Anatomical form is observed using structural imaging techniques (such as MRI), while dynamical form is observed using functional neuroimaging techniques (such as fMRI). On a longer time scale changes of the structural connectome must precede new dynamical forms that can be observed in functional connectomics [26].

Computers may run infinite number of different programs that support quite different functionality. Their dynamics may be emulated on other computers, all processes may be repeated in the exactly the same way. Although a computer chip may contain billions of elements and perform many complex functions its whole organization does not support spatiotemporal states that are similar to those created by biological neural networks [27]. In case of brains only neurodynamical states that can be distinguished from noise (in agreement with the signal detection theory [28]) may become percepts. These continuous dynamical processes differ in a fundamental way from those of a Turing machine. They include seeds of many new accessible brain states that may follow. History, context and stochastic processes determine next brain state, dynamical pattern that contributes to a new interpretation of meaning of mental state.

Brains that have the same physical form, structure of connections and properties of neurons, may support huge number of functional, neurodynamical states. A large number of processes go on in parallel in computers and brains, but only a few are change behavior in a noticeable way, either by activating effectors (motor actions) or by facilitating internal recognition, interpretation and memory processes. Psychological organization is based on dynamical forms that arise in the space of possible activations of the brain or sufficiently complex brain-like artificial networks. Mental states arising in this space are constraint by knowledge embedded in the structure of neural networks, following certain associative logic between accessible brain patterns. Each mental event—a thought, feeling or intention—changes this dynamical structure without changing the form of physical brain structures in a perceivable way. Brain dynamics cannot be replicated in exactly the same way by other brains, but also cannot repeat itself exactly in identical way in the same brain. The basic structure of the brain is genetically encoded and develops later through neuroplasticity as a result of learning, repeated interactions with the environment and one's own body. Describing all these phenomena requires detailed analysis of different types of structures, processes, and dynamical forms.

Because the brain neurodynamics contains much more than conscious mental processes (unconscious regulations of huge number of bodily processes, precise muscle coordination etc.) one can justify the metaphor "**mind is a shadow of neurodynamics**" [29]. Words and gestures point at some brain activations and processes at the mental level facilitating transmission of meaningful information, creating a kind of resonance of mental forms. Only recently it has been shown using information theory that macroscale description (symbolic) can be more informative than detailed microscale description (neural activity). This phenomenon has been called the "**causal emergence**" [30]. Knowledge contained in the whole structure cannot be derived from knowledge contained in separate parts that constitute some structures. The mathematical apparatus of quantum theory has been applied to various aspects of psychology (see [31]). There is no assumption that real quantum effects are needed to understand cognition. Holistic approach offered by quantum mechanics is used to describe some counter-intuitive results in the psychology of decision-making without involving internal mechanisms.

Conscious processes engage a large groups of neurons leading to activations of specific subnetworks that are sufficiently strong to be identified and distinguished from noise, in agreement with the signal detection theory, one of the most influential of all psychological theories [28]. Conscious processes may be viewed as perceptions of dynamical forms, synchronous activations, that arise in the brain. Scientists search for neural correlates of conscious processes [32,33], trying to characterize which patterns are perceived as conscious and which will decay unnoticed. Learning processes change physical connections in the brain and thus change patterns activated by neurodynamics. Studying such processes tells us which mental states (dynamical forms) are potentially accessible for brains that have specific structure, depending on the individual connectome and other factors (neural properties, ion channel types and their distribution, neurotransmitter release etc.).

Mental processes are supported by the brain that provides a substrate in which what is potentially possible may be actualized, influence behavior and become conscious experience. Dynamical form is an information process that changes the state of matter, but not the matter itself. Mind is thus truly non-materialistic, based on dynamical forms that are actualized by neurodynamics in a way that depends on many circumstances, including personal history.

4. Conclusions

Psychological and philosophical constructs are high-level abstractions that may help to understand phenomena only if they reflect the relevant scientific knowledge [11]. Otherwise we shall abide in the sea of abstract concepts that are disconnected from reality, but allow to produce wise statements that have little meaning. In case of hylomorphism the concept of "form" has been used to describe quite different phenomena that should be clearly distinguished: static structures of physical objects, evolving structures that rearrange physical elements, amorphic forms based on intentions, dynamical forms that change states of matter without changes of physical structures.

Recognizing many ways in which the concept of form is used should help to clarify and develop further hylomorphic ideas. In particular dynamical forms have not been distinguished clearly from other types of forms. They arise in the networks that send streams of information to the distributed devices, computational systems that relay on patterns of coordinated activity between their processors, and the brain neural networks that show complex patterns of activations. In all these cases patterns of active elements change rapidly without physical changes of network structures. The anatomical connections in the brain create a substrate in which huge number of dynamical forms may arise. The functional connectome shows these dynamical patterns that arise in the brain resting state and task-dependent patterns arising in different experimental conditions. There is a lot of evidence that all mental states supervene on these dynamical forms [14,15]. They seem to provide a natural bridge between mental and physical states. Therefore dynamical forms are an important concept that should be included in discussions of the hylomorphic theory and the mind-body problem in general.

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The Natural Philosophy of Experiencing

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Abstract: A new philosophy of nature is urgently needed. The received ontological view, physicalism, is unable to account for experiential phenomena and in particular for consciousness in all its varieties. We shall outline the concept of experiencing which should figure as a new conceptual primitive in natural philosophy. Experiencing refers to a process which comprises the interaction of an agent with its world through action based on phenomenal experience. This process can be viewed under two different aspects. One regards the subjective aspect of experiencing, the other one regards it in terms of physical objects. The first case illustrates the "what-it-is-likeness" of experiencing, the second illustrates how experiencing gets "objectified" in nature. We furthermore wish to delineate our concept of experiencing from the concept of (meta-cognitive) awareness. Scientific theories that explain how awareness comes about in sufficiently organized brains should respect the distinction between experiencing and awareness. We also sketch how experiencing could be related to theoretical biology in terms of information processing by organisms. Experiencing is non-exclusive; it refers to a primitive and a-personal natural process and not to a property possessed only by humans or other persons.

Keywords: natural philosophy; subjective experience; process; dual aspects; consciousness; information-theory; theoretical biology; 1st-person and 3rd-person perspectives

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1. Introduction

Natural philosophy (*philosophia naturalis*) fell into oblivion in the course of the 20th century, because it appeared that the natural sciences—an outgrowth of natural philosophy which originated in the 17th and 18th century—could in principle account for any natural phenomenon. In academic philosophy, the scientific success story led to the broad endorsement of a position known as "physicalism", which could roughly be stated as the ontological claim that all being is or "supervenes on" the physical [1]. To put this definition into the perspective of natural philosophy, we hasten to add that physicalism, as we understand it in this article, implies the thesis that being is describable comprehensively[1] in terms of our best physical theories, and only in their terms.

Physicalism is still the dominating metaphysical view in contemporary analytic philosophy (a little less so on the continent). Yet, a big shortcoming of physicalism is its seeming inability to account for subjective experience as part of the natural world, most notably for consciousness in all its forms. Even though the cognitive and neural sciences made substantial progress in understanding the relation of brain and world, it is still unclear (to some it is even "inconceivable" [3]) how a science of the brain could ever explain the inherently subjective and qualitative nature of consciousness. This is

[1] Up to some phenomena which seem not relevant for subjective experience: This is expressed most clearly in Sean Carroll's idea of a "core theory" [2] that accounts for the vast majority of natural phenomena, including meaning and consciousness, but not quantum gravity or grand unification.

clearly an area where a rejuvenated philosophy of nature that provides conceptual space for subjective experience is urgently needed. One possibility is to embrace "emergentism", understood roughly as the idea that complex arrangements of matter give rise to novel properties in nature [4]. But emergentism, while *prima facie* plausible and conceptually close to physicalism in its "non-reductive" variety [5], has its inherent problems: So far, no universal theory of emergence has been accepted within the scientific or philosophical community. Even less intelligible are accounts of emergence in the field of consciousness studies: Suppose that "emergence" in fact turns out to be a useful concept for science, it will probably not be useful enough to account for a supposed emergence of thought [6,7].

An alternative view regards subjective experience as fundamental, which would mark—in contrast to emergentism—a true rival to physicalism in its conception of nature. But how best to conceive of such a new philosophical world view? In contrast to mainstream physicalists, we propose that nature is only intelligible in terms of processes which comprise subjective experience (qualia) but also decisions and actions. We refer to such processes as *experiencing*, objectified by *any* natural phenomenon. Our concept of experiencing is based on the interaction of an agent with its world. A comprehensive understanding of experiencing necessitates a description of it in terms of dual aspects [8]: one in terms of phenomenality, another one in terms of object-structures. Importantly, we do not equate "agents" and "persons". The notion of "person" is taken to refer to an evolved biological structure. Agents are primitives; persons are historical and biological entities.

To start the analysis, we shall first look at the most difficult problem for physicalists: explaining consciousness. One could make the case that there is *not even conceptual space* to allow for consciousness within physicalism. In Section 2 "Working definitions of consciousness", we briefly outline and discuss two often-heard proposals which try to give a (short but concise) "working definition" of consciousness. Closer inspection reveals that both definitions are each limited to a particular perspective. On the one hand, it is the perspective of a naturalist who looks at biological systems "from the outside"; on the other hand, it is the perspective of an introspectionist who only looks at the system "from the inside". Both are faced with difficulties when urged to account for consciousness as natural property. Any notion of consciousness which is (i) adequate to its phenomenology and (ii) conceives of it as referring to a natural phenomenon should be able to consistently relate a subjective 1st-person and an objective 3rd-person perspective without reducing one to the other. We call this the "consistency requirement" for studying consciousness, and we propose that the resolution of the distinction "subjective-objective" shall be found on a higher, ontological level.

In Section 3 "Experiencing", we thus introduce a conceptual stance which regards the process of experiencing as primitive[2]. It derives from the simple idea that an agent (a primitive, a-personal entity) perceives its environment, autonomously makes decisions and acts. An agent's environment could be regarded as entity that carries the disposition to cause (qualitative) experiences in the agent, whereas the agent could be regarded as entity that is responding appropriately. The subjective perspective of the agent is assumed to be the dual of a theorist's description of the whole process. "Awareness", referring to a (meta-cognitive) biological phenomenon, could then be understood as complexification of the process of experiencing. A description of this complexification should explain the transition from a-personal embodied agents to evolved persons, and it should satisfy the consistency requirement. Once we have accepted the conceptual innovations proposed in this section, there exists a chance to make substantial progress on the problem of consciousness. If we stick with physicalism, this will likely not be the case.

As a concrete example, we introduce and discuss the prospects of the notion "meaningful information" (in the *phenomenal* sense of meaning) in biological systems and its relation to experience and awareness in Section 4 "The biology of meaning". We shall first review some empirical work

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[2] We are not the first to propose this. Similar ideas could be found, for example, in the works of Charles S. Peirce [9], William James [10] or Alfred North Whitehead [11].

that might justify the belief in the ubiquity of experiencing in biology, which is closely related to an understanding of "information", not as purely syntactic but as inherently meaningful (semantic) concept. This will eventually lead to a tentative discussion of awareness, understood as biological phenomenon based on experiencing. Our model bears some formal similarities to established approaches in theoretical biology; however, the concepts that underlie it are quite different.

2. Working Definitions of Consciousness

2.1. Consciousness = Whatever-Is-Lost in Dreamless Sleep

"Everybody knows what consciousness is: it is what vanishes every night when we fall into a dreamless sleep and reappears when we wake up or when we dream" [12] (p. 216). Does this mean that consciousness is an object that could be lost just as one could lose his car keys? Could we perhaps locate it somewhere in the brain? Does it "consist of [other things, such as] inner, qualitative, subjective states and processes of sentience or awareness" as John Searle [13] (p. 559; our italics) believes? Is it of a certain size or at least a concrete "going-on" that is located in space and time [14] (p. 3)?

These and similar descriptions ground most research that is done in consciousness studies today. Phenomenologically, this seems to miss an important point. This can be illustrated using a metaphor that likens consciousness to the process of waking up in the morning. After a deep and peaceful slumber, our metaphor's protagonist awakes in the morning when the first rays of sunlight are tickling his eyes. While he senses the smell of coffee from the kitchen, the thought of his overdue tax filing is forming in his mind and enters his consciousness together with a stream of perceptual experiences: the visual scenery of his bedroom, the sounds that are coming from the streets through the window, and a strong itching in his left foot. Is it reasonable to assume that something emerged here? Clearly, the answer is "yes": Certain objects formed in the protagonist's conscious mind when he woke up, but it is not consciousness that (re-)emerges, nor is it "phenomenal experience" or its "what-it-is-likeness".

This could further be illustrated by taking a phenomenologist's perspective: We never experience a world without being consciousness, all there is for us is the world as it is "given to consciousness". It would be even more adequate to say that as soon as we fall asleep the (experienced) world is what "vanishes overnight and reappears when we wake up or when we dream"—not consciousness. The guiding intuition behind this is that we should not think of consciousness as a property of some (natural) object, but (perceived or intentional) objects as emerging within consciousness. Phenomenologists have argued for this on philosophical grounds at least since Edmund Husserl has criticized the "natural attitude" [15]. (Cf. [16,17] for a similar point in a contemporary setting). We need to let go of the intuition that consciousness corresponds to a property of physical objects: Being conscious is unlike having mass and position. Consciousness is what lets us see objects in space and what lets us feel their masses.

But why is it so natural to suppose that consciousness is just like any other (physical or biological) property of an organism, something which might be lost or regained? "Consciousness = whatever-is-lost in dreamless asleep" is a useful circumscription, when we read it the following way: Given an outside perspective on a particular organism, part of its (overt and neuronal) behavior is such that it vanishes when the organism falls into a dreamless sleep and reappears again when it wakes up or when it dreams. But this does not directly inform us about phenomenality—how it feels like for the organism to have an experience. It is a description of how the organism would appear to an external observer. However, we must not confuse this external perspective with the subjective experience of the organism itself.

2.2. Consciousness = Having Qualia

Another competitor for a working definition of consciousness stems from the fact that being conscious implies that "it-is-something-like" [18] to have a particular experience. It is sometimes heard that consciousness is tantamount to having certain things, namely qualia[3], where, more precisely, qualia are understood as intrinsic, non-representational and unstructured properties of experience; or for short: "consciousness = having qualia".

It therefore comes as no surprise that with respect to a 1st-person perspective this definition is more adequate. Yet, it seems that this definition does not help much when trying to relate consciousness to the (neuronal or manifest) behavior of an organism just because the definition is only about the intrinsic perspective of a subject. Whereas the first definition, "consciousness = whatever-is-lost in dreamless sleep", misrepresents the subjective perspective of an organism, the definition "consciousness = having qualia" seems to imply that consciousness is an inaccessible, ineffable and purely internal thing. It precludes any chance of relating it consistently with a scientific account of the world (even if consciousness figures as primitive concept in our account of it).

This finds expression in the skeptical claim that, as involved as it might get, no explanation could ever make it plausible why physical dynamics should be accompanied by phenomenology at all, instead of "going-on in the dark". It seems to imply a form of dualism, which is mirrored in conceiving of a purely internal 1st-person perspective and a purely external 3rd-person perspective. Some thinkers have hoped this would give rise to two corresponding sets of "data" [22]. Accordingly, one would be able to arrive at a science of consciousness by demanding consistency between these two kinds of data and derive "bridge laws" between them. So far, this dualist proposal has not been fruitful, though, and it is doubtful whether the notion of "1st-person data" is at all coherent. Data, by definition, belong to the domain of recordings. They result from reports or measurements, they are inherently "post-subjective", or, as one might wish to say: "they only exist in the world of objects". 1st-person data are thus more like the chimera than like pointer readings of measuring devices for subjectivity.

2.3. Consistency between Perspectives

Neither "consciousness = whatever-is-lost in dreamless sleep" nor "consciousness = having qualia" is able to express an adequate concept for the phenomenon of consciousness as natural property. The former because it misses a crucial property of experience: To any conscious being, consciousness means its world; to any outside observer, consciousness is invisible and all she could see are correlated brain states or the conscious being's behavior; the latter if it is taken to imply an ineffable, purely internal notion of experience.

This indicates a fundamental conceptual asymmetry. Given one perspective, consciousness is all there is, and the experienced world with all its objects emerges within consciousness. Given the other perspective, all there is are atoms in the void; no consciousness to be seen anywhere, neither in our heads nor behind curtains, but only neurons firing and ions moving. An important constraint for a theory of consciousness then is that the first story—call it "the phenomenal story"—is consistent with the second—"the physical story". We call this the consistency requirement which states that two descriptions of the very same process need to be consistent with each other.

To respect the consistency requirement, it is logically not necessary that consciousness is identical to a certain physical structure (e.g., the brain) or is caused by it. In other words, it is not the case that only forms of physicalism could guarantee such a consistency. The challenge for many contemporary approaches in consciousness studies is therefore not (only) to overcome skepticist arguments regarding

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[3] For example, Hameroff & Penrose [19] (p. 40) in a review of their Orch-OR theory of consciousness state that "phenomenal conscious awareness, experience, or subjective feelings [are] composed of what philosophers call 'qualia'". To be fair, the authors arguably do not explicitly state that consciousness is a thing-like substance, composed of elementary qualia. However, they could easily be seen to imply exactly this. In another example, Leopold Stubenberg wrote a book centering around the notion of "consciousness as the having of qualia". [20] Importantly, he notes that both the notions "having" and "qualia" need to be qualified due the problematic relation between qualia and their bearers. Stubenberg finally arrives at a "bundle theory" of experience that is very dissimilar from the (ordinary-language) concept of "thing-ness". Similarly, Galen Strawson argues for "selves", the subjects of experiences, to be "things" but later qualifies this to be understood in a "thin" way [21], actually more in line with Buddhist teachings of the no-self and primarily referring to an a-personal phenomenon.

the bridging of an "explanatory gap" [23] but also to state the mind-matter relation in a way which satisfies the consistency requirement. But there are possibilities other than stating subject-object identity to ensure consistency. Recall, for example, the assumption of "functional coherence" proposed by David Chalmers [3]. This assumption restricts the possible structure of theories of consciousness to those theories where "awareness" (taken as an access-related psychological property, cf. [24] is systemically linked to phenomenology without being identical to it. In contrast to the notion of functional coherence, however, we propose that consistency should be understood as perspectival and dynamical. If our concepts only referred exclusively to the "intrinsic" or "extrinsic" properties that things have, then it would be hard to see how statements about experiences could be related to statements about physical structures without making a Cartesianist assumption (that is, without assuming that consciousness resembles a "thing-like" substance that "is contained" in a body). A different strategy would think of consciousness as pertaining to the interaction between an organism and its environment (hence consistency is dynamical), and that a comprehensive description would correlate different aspects of these interaction (hence consistency is perspectival), without reducing one to the other. In many cases it is futile to approach a resolution of a conceptual distinction (such as "subject-object" or "mind-body") at the same descriptive level. Rather, one could only resolve it on a more fundamental descriptive level. Such is what we wish to propose in Section 3 "Experiencing", where we introduce the concept of experiencing, which eventually plays the role of establishing consistency on a fundamental level.

3. Experiencing

3.1. Experiencing as Fundamental and A-Personal Process

It is sometimes heard (e.g., by Eric Kandel [25]) that the mind will be to the sciences of the 21st century what the gene was to the sciences of the 20th. We believe this to be an accurate prediction, however, one that will only turn out to be true, once the philosophical image of nature is revised such that it includes the concept of *experiencing as primitive*.

We would also like to distinguish two senses in which the notion of "consciousness" is used in the literature: On the one hand it refers to the notion of "subjective experience", which we take to be an irreducible part of experiencing; on the other hand, it refers to a particular biological phenomenon which we henceforth denote as "awareness" to distinguish it from pure experiencing (we simply use the term "awareness", which is sometimes also referred to as meta-cognitive form of consciousness). In addition, we postulate that *experiencing is a-personal*, whereas awareness is intimately related to the concept of a "person". Awareness should be explained on the basis of the more fundamental notion of experiencing.

Experiencing has a subjective aspect and is assumed to manifest itself in any natural phenomenon, which we could study in the physical, chemical and biological sciences. Experiencing gets "objectified in nature", in the terminology of Arthur Schopenhauer [26], or it is "embodied" in a slightly more contemporary façon de parler. While awareness denotes a species-specific (and hence evolutionary constrained), 1st-personal phenomenon, experiencing denotes a fundamental process in nature and thus a primitive concept for a renewed philosophy of nature, similar as "mass" or "extension" were primitive concepts in the mechanistic philosophy of René Descartes [27]. We could circumscribe the concept of experiencing as follows:

> *Experiencing refers to a* structured process of interaction *of an agent with its world. Experiencing can be studied under different* aspects. *One of these pertains to the* subjective *perspective of the agent, which is irreducibly* phenomenal *for that (and only for that) particular agent; the phenomenality of experiencing couldn't thus be accessed by an external observer. However,* experiencing is also structured. *This makes it possible to precisely describe this structure and trace experiencing empirically. This leads to a second perspective which corresponds to the* physical aspect *of experiencing.*

The onto-epistemic thesis says that experiencing manifests itself in any natural phenomenon. Given this, experiencing could be scientifically studied. The thesis does not say that subjectivity or consciousness reside "within" matter or that physical objects "ground", "produce" or "give rise" to experience. For the onto-epistemic thesis to be substantial, though, it should be the case that whenever we look closely enough at nature, we find bits and pieces that hint at experiencing.

3.2. A Post-Kantian Model

It seems helpful to illustrate the concept of experiencing using a model inspired by Immanuel Kant's transcendental philosophy put forward in his *Critique of Pure Reason* [28]. (But we shall also point out some necessary adjustments that need to be made to this framework in our opinion). There, mind is "affected" by a "thing-in-itself", and the raw sensory material is structured according to space-time and categories such as causation[4]. Using a schematic representation this could be depicted as:

$$W \overset{p}{\to} X, \tag{1}$$

where a "world" W stands for Kant's (hypothetical) thing-in-itself that affects a receptive mind in the act of "perception" p which, in turn, sculpts experience X. It is crucial to note that the only things one could attend to are the contents of X. Neither the "world" as such nor the mind's conceptual faculty that "sees through" the sensory apparatus is consciously given to it. That is why the world must first and foremost be regarded as a hypothetical entity that triggers perception. This should not be confused with the "world" in a physicalist's sense, i.e., with the totality of material systems, but could simply be taken as everything that has the disposition to cause changes in X.

While the Kantian analogy serves an illustrative purpose, there are many differences between Kant's transcendental philosophy and our proposed natural philosophy. First, we explicitly reject any notion of a world-mind dualism on our account. Our model comprises a "world" of dispositions to cause (changes in) the experiential content of a receptive "mind". "World" and "mind" do not, however, refer to two distinct entities of our ontology but merely to different conceptual abstractions (cf. the notion of a "conceivable world" by Ivan Havel [30]). Second, there are cognitive connotations when discussing "conceptual schemes" or "categories", eventually turning into a kind of neuro-Kantianism, which we reject. Experiencing is taken to refer to any natural process, rather than to processes ascribable to only humans or other persons. Third and perhaps most importantly, the mind-world relationship is sometimes conceived of as merely passive "stimulus-matching" relationship. We approach it instead in terms of active participation or interaction. In other words, instead of a (passive) mind-world model, we need to consider the *agent-environment interaction*,

$$W \underset{p}{\overset{a}{\leftarrow\atop\to}} X, \tag{2}$$

which is reminiscent of the sensory-motor (perception-action) cycle known to biologists [31,32] and philosophers (e.g., John Dewey [33]). In particular, from an empirical point of view, the feedback component of such a model is crucial because it permits us to experimentally engage with the agent: Without having the possibility of getting responses from the agent there would in principle be no way to test any claims pertaining to the structure of experiencing, and researchers would need to exclusively rely on philosophically motivated *a priori* arguments. Even though the phenomenality of an agent's

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[4] To be a little more precise, Kant explicitly distinguishes between "forms of intuition" (=space and time) and genuine "mental" categories such as causation, substance or unity. For the sake of this article, however, we shall not ponder deeply on this distinction. In the course of 19th and 20th century philosophy, the Kantian a-priori has been subject to various interpretations and modifications, see for example the symbolic constructivism of Ernst Cassirer [29]. We do not wish to engage in the debate how to best conceive of the a-priori in this article.

perceptions is in principle inaccessible from an external perspective, a stimulus-response architecture of the kind expressed in Equation (2) in principle allows us to derive and test predictions relative to the dynamics of the agent-environment system, unlike a "negative theology of experience". This also marks a methodological advance compared to physicalist approaches toward the mind, where the mental is often defined solely in terms of the "negative" (the so-called "*via negativa*" approach to physicalism; cf. [34,35]). While our model seems primarily related to perceptual processes, any general account also needs to say something about "internal" mental phenomena, such as abstract thoughts, emotions or moods. The following is preliminary (self-consistency and empirical adequacy need still to be worked out further), but it shows how the model seems in principle able to accommodate such phenomena as well. In general, there exist two possible approaches toward internal mental phenomena. The first reduces them to (implicit or explicit) representations of the workings of the physical body. Such a strategy is the default approach in physicalism, and largely faces the same problems as physicalist accounts of perception. Another strategy would acknowledge the possibility of endogenous "self-interactions" of agents. A description of this process is projected onto an "external world" relative to the agent. (Recall that "world" should not be understood in terms of a *physical* environment, but rather in the sense of a totality of dispositions to cause experience.) The consistency requirement furthermore demands this projection to be consistent with a description in terms of the agent's subjective experience.

To make the model more powerful, we consider in addition some "internal processing" or "decision-mechanism" that connects the agent's experiences to the agent's actions. This can be motivated on empirical grounds too. Decision mechanisms are now found to be ubiquitous in biological systems (see also Section 4 "The biology of meaning"). Such a model has been proposed recently in terms of a very general mathematical structure by [36],

$$W \;\begin{array}{c} \overset{a}{\leftarrow} \\ \underset{p}{\rightarrow} \end{array} \left(\begin{array}{c} G \\ \uparrow \; d \\ X \end{array} \right), \qquad (3)$$

which consists of perception-, decision-, and action-Kernels p, d and a that loop through the world W, the experiential content of an agent X, and the group of possible actions G available to that agent[5]. Such an account aims at understanding what experiencing *does*, not what it is; it is a model of experiencing and not a theory about its essence.

In the next section we discuss how the new philosophy of nature could be related to recent empirical studies. We argue that (i) the biological dynamics should be re-conceived in terms of *information* theory. This is largely an epistemic point, based on well-established scientific work[6]. It could be interpreted along the lines that it merely "appears as if" a system were processing information meaningfully, but one might alternatively conclude that (ii) it refers to an embodied process of experiencing. One could justify this second interpretation by appealing to the necessity to account for jointly irreducible perspectives in order to exhaustively describe biological phenomena. In other words, the physical dynamics of biological systems could be thought to *objectify* experiencing in the physical world. One could relate this (iii) to the study of *awareness* as biological phenomenon which arises from a complexification of experiencing. While this would explain, why it is "something-like"

5 Expressed mathematically, $\boldsymbol{W}, \boldsymbol{X}$, and $\boldsymbol{G}$ each represent measurable spaces, i.e., a set $\boldsymbol{Y}$ equipped with a sigma algebra $\boldsymbol{Y}$; and the "pda-loop" represents the succession of Markovian Kernels $\boldsymbol{p}$, $\boldsymbol{d}$, and $\boldsymbol{a}$ which mediate between these spaces such that $\boldsymbol{z}$: $\boldsymbol{Y_j} \times \boldsymbol{Y_k} \rightarrow [\boldsymbol{0}, \boldsymbol{1}]$. Intuitively, this means that the Markovian Kernel $\boldsymbol{z}$ assigns to any combination of an "element" $\boldsymbol{j} \in \boldsymbol{Y_j}$ and an "event" $\boldsymbol{k} \in \boldsymbol{Y_k}$ some probability between 0 and 1. Finally, there exists an integer n that counts the number of pda-loops executed by the agent.

6 There is a well-known difficulty in exhaustively defining the concept of "information" when used other than in the syntactical (Shannon) sense. Any appeal to "information" is therefore provisional. However, we note that "information" does not refer to an ontological primitive in our philosophy. It thus resembles notions such as "cause", "probability" or "purpose" which all need further conceptual clarification in a renewed philosophy of nature (cf. also the discussion in Section 4.2).

to be conscious (because experiencing has an irreducibly phenomenal aspect), two important and non-trivial constraints are that any description of this complexification should make it intelligible why it results in a 1st-person perspective and that it satisfies the *consistency requirement* for the study of consciousness introduced in Section 2.3. In contrast to the "hard problem", this line of inquiry seems promising and is rooted in a philosophy of nature that takes experiencing as primitive.

4. The Biology of Meaning

4.1. "Meaning" and Information

The principles governing biological systems are increasingly studied from the angle of information theory [37–39], and it is often claimed that the study of energy transfer through these systems should be re-conceived in the language of information theory in order to arrive at a more comprehensive understanding of biological processes. Consistent with this, one could regard biological systems as units that process information acquired via sensory organs to adjust their behavior.

We also know from genetic, cellular and systems-level analyses that the behavior of biological systems is not only dependent on the incoming (sensory) information but, as least as much, on the organization and the internal processing (sometimes also referred to as "internal decision mechanisms") embodied in the organism, for example, in gene regulatory networks or predictive neuronal mechanisms [40–43].

This is not premised on any ontological account of "information," but it only requires acceptance of the claim that certain systems are best described in terms of information-processing units and could be regarded as quasi-intentional or quasi-perceptual. In biology, this has been recently argued for a large class of systems (e.g., [44,45]); in philosophy, similar claims were put forward as "mind-life continuity thesis" based on sensory-motor coupling (for example [46]). This perspective necessitates understanding of how biological systems manage information flows and integrate exteroceptive signals with bodily sensations (interoception), anticipations about the future (predictions) and past experiences (memories). The information processed by a biological system could then be regarded as "meaningful" in the sense that it underlies behavior which limits entropic tendencies or leads to various adaptive changes. Accordingly, organisms embedded in an environment could be conceived of in terms of systems that use information that "stands for" and thus "refers to" external entities or internal processes in order to guide adaptive behavior.

One particular approach that has been postulated to analyze information processing in (neuro-) biological systems is "integrated information theory" (IIT: [12,47]), originally conceived as "measure of consciousness" but recently applied to information processing in biological systems more generally [48]. The main idea behind using IIT to analyze information flows in biological systems is to quantify how much an element or a set of elements within the system constrain the system's past and future states. The exact mathematical form of how this should best be measured has changed over the course of publications, but it crucially involves calculating differences between state repertoires, e.g., KL-divergences or the "earth mover's distance" (for details we refer the reader to [47]). This distance measure is evaluated for the total system and a "minimum information partition", and thus quantifies the amount of information in the system "as whole" as compared to the sum of its parts. Importantly, while one might be skeptical regarding the claim that IIT resembles a modern-day version of panpsychism [49,50] or whether its "central identity" claim does not in fact propose a reductionist account of consciousness "through the backdoor", its concepts might still be useful to study the properties of information-processing networks, in particular, how "meaningfulness" could be encoded by the way how an organism's current state constrains its (past and future) evolution, mirroring Bateson's dictum that "information is a difference that makes a difference" (cf. [51]). In other words, IIT could be thought of as pertaining to the physical aspect of a meaningful process objectified in biological networks.

4.2. Meaning and Perspective

The previous subsection argued that sufficiently complex biological systems could be understood in terms of entities that process information "meaningfully". But are we justified to conclude that such processing really is meaningful (from the system's perspective), rather than merely "appearing as if" it were meaningful (from a theorist's perspective)? "Meaning", as it was used in the last paragraph, refers primarily to our 3rd-person perspective as theorists or observers, and it is unclear how this is related to any notion of subjectivity at all.

Let us repeat the discussion so far. By interacting appropriately with the world, we recorded some physical dynamics which looks as if they were meaningful. We could interpret this along the lines that we have interacted with a complex mechanism that "causes our perceptions" and "informed our minds" accordingly. Another, perhaps more natural, interpretation would be that we have interacted with something that in fact is (phenomenally) meaningful and the physical dynamics we have recorded reflected this. The benefit of this position—in addition to being metaphysically more parsimonious, that is, without postulating a "jump" from the physical to the subjective at some place—is that it explains why it can only look "as if" (because the physical dynamics merely provides an extrinsic perspective on the process) and that it explains the seeming increase of "mental-looking properties" emerging within the hierarchy of natural phenomena (because of the complexification that characterizes the transition from the physical to the biological). This is different from saying that there is meaning "inside" the organism, a claim which strikes us as dualist.

One way of justifying (ii) is rooted in the rejection of the claim that a mechanistic model could comprehensively account for biological phenomena, a claim which unfortunately seems to be the mainstream opinion of current physicalism. An argument against a mechanistic philosophy of nature was famously laid out in Kant's *Critique of the Power of Judgement* [52]; for a modern appreciation of the Kantian Critique in developmental and molecular biology see, e.g., [53]. The argument is usually based on the inability of theoretical frameworks to explain prototypical examples of biological mechanisms such as the seemingly intentional behavior during pattern formation or embryogenesis. We do not wish to enter the specific debates here. Instead, we wish to present some more principled reasons to doubt the claim that mechanistic descriptions are sufficient to exhaustively describe biological phenomena. This is, on purpose, *not* an empirical claim but relates to some concepts any philosophy of nature needs to be clear about:

1. Scientific concepts usually have a long history, and to a philosopher it seems puzzling that their genesis is sometimes overlooked in their conceptual analysis. Take the concept of entropy that is now very well known in the physical sciences (though often confusedly employed). Whereas many believe that entropy refers to an objective property of thermodynamic systems (but see for example E.T. Jaynes [54] who argued that entropy is an "anthropomorphic concept"), the inventor of the term "entropy", Rudolf Clausius, purposely conceived it to refer to a natural process that derives from our everyday experiences in and outside the laboratory. ("Entropy" derives from the Greek word εν-τϱοπη meaning "content of transformation". [55]) It could even be argued that all scientific concepts such as "energy", "force" or "field" have their genesis in a multitude of subjective experiences that led to an inter-subjectively true description of the world (cf. [56]). This suggests that, in fact, apparently objective descriptions are not necessarily about the "true states of the world out there" but result from a generalization of concrete experiences.
2. One of these concepts, the concept of *probability*, is still in need of clarification. Objectivists conceive of probability as (ignorance about) a property of the system under study and compete with subjectivists that tie probability to the degree of belief of an observer (see, e.g., the overviews in [57,58]). Objectivists would need to show that their concept of probabilities is really free from any reference to (subjective) belief; subjectivists would need to demonstrate the explanatory benefit of their position. Settling this dispute is beyond the present state of play in logic. Until it

is settled, however, we need to be careful when interpreting theoretical frameworks that explain a system's behavior primarily in terms of probability.

3. Biological systems (such as, but not limited to, the brain) are often described as probabilistic systems under thermodynamic constraints. Generalizations about the workings of such systems are subject to the caveats that pertain to thermodynamics and probabilities. In particular, this pertains to any explanation in biology cast in terms of information-theory. If it is the case that the concept of probability *logically necessitates* a subjectivist approach, both observational *and* theoretical statements must not be regarded as being about some "objective truth out there". It then follows that generalized biological theories too must not lightheartedly be regarded as being "objective" (in the same sense), and a description purely in terms of physical concepts would not exhaustively describe a system's behavior.

The above indicates that some of the concepts we employ in scientific theorizing might indicate an irreducibly subjective (and as a corollary: phenomenal) ontological counterpart, in particular the concept of probability as applied to systems dealing with uncertainty. This also pertains to other "more biological" concepts such as "function" or "purpose", which hinge on the status of more primitive concepts such as causation, probability or chance. This therefore defines another area where conceptual work in philosophy is relevant for the scientific enterprise. A new philosophy of nature would probably lead to very different conceptions than those of physicalism.

We can summarize this subsection by saying that a minimal account of "phenomenal meaning" seems to be necessary for understanding biological phenomena expressed in the language of information-theory. We henceforth shall say that "information is meaningful" to a particular organism, noting that we thereby do not claim that organisms resemble "little persons". The notion "information is meaningful" arises naturally from regarding experiencing as primitive concept in our ontology, together with the onto-epistemic thesis that experiencing gets objectified in nature. We could also justify this by pointing to a deficiency of the "received view" of physicalism, according to which purely mechanical (literally meaningless) descriptions supposedly afford exhaustive explanations of biological phenomena—a claim which should be rejected eventually.

4.3. Meaning and Awareness

How could this lead to a model of awareness? When discussing a potential "referential nucleus" for consciousness studies, [59] noted that, while the presence of perception-action cycles might indicate the presence of experience, the ascription of awareness to such systems might nevertheless be precluded by an apparent lack of reportable 1st-personal content. Thus, any empirically accessible conception of awareness should involve such contents. This seems consistent with ideas coming under the heading of "global workspace" theory [24] where awareness supposedly derives from accessibility of neuronally encoded information, which ultimately leads to subjective reports. This framework has recently been developed into a neuro-computational direction [60]. Some might doubt, however, that the notion of computation is more than a convenient fiction by which one represents the system's dynamics (from a scientist's 3rd-person perspective), rather than referring to the idea that certain complex biological systems actually do take a 1st-person perspective on their environment. In other words, it does not become intelligible how the consistency requirement as sketched in Section 2.3 would hold for such an explanation.

The things that organisms perceive are not detached Cartesian ideas but the inferred objects and structures that constitute the organism's *experienced world*. A good example that lets one see the difference between descriptions of mere behavior and awareness is provided by a discussion of "time consciousness". Many organisms are able to vary their action according to temporal cues they get from their environment. Yet, this does not imply that they represent time from a 1st personal perspective; rather their action is simply coded to an external periodic pattern (expressed, e.g., in circadian rhythms [61]). While the latter is sometimes understood in terms of an intricate mechanism pertaining to biological homeostasis, this is different from the "time consciousness" of a personal subject, which (phenomenally) experiences an enduring "now". The canonical phenomenological discussion of this is due to Edmund Husserl [62]: Awareness is structured according to temporal patterns (according to Husserl these are the "temporal moments" of "retention", "primal impression" and "protention"), which lets the organism see distinguishable objects that appear in consciousness. Similarly, this might hold for the representation of space in terms of spatial patterns.

How could a merely computational mechanism account for this difference? Our concept of experiencing comes to help. While we do acknowledge the role of computational mechanisms in generating reportable (or otherwise accessible) content, we add that the information thereby processed is already meaningful. Making it available to the system could make intelligible how biological systems become aware by computing over "meaningful information" and thus create the rich phenomenal structure such as the one coming under the header of "time consciousness".

The important meta-theoretical constraints are (i) that such reportable content could be identified, in some non-trivial sense, with 1st-personal descriptions and (ii) these descriptions are consistent with the overall biological dynamics. (We have suggested earlier that the consistency requirement should be taken as referring to the interaction of an organism with its environment and not merely to the functional organization of its nervous system.) At this point, it is good to remind ourselves that we have defined experiencing itself to be subject to two different and dual descriptions – a phenomenal one and a physical one. We have thus good reason to assume that the problem of awareness might be resolvable when accepting the conceptual innovations proposed in this article.

5. Discussion

A novel philosophy of nature should overcome the impasse of our current naturalist world view. In physicalism, this is the inability to account for subjective experience, in particular consciousness in all its forms, as natural property of the world. We therefore put our focus on this question and pointed at novel concepts that should be incorporated into natural philosophy. Unsatisfied with "emergentist" solutions to the problem of consciousness, we proposed that experience should figure as primitive concept in the theory.

The conceptual inadequacy to account for consciousness in physicalist terms can readily be seen when looking at two widespread "working definitions" of consciousness that are frequently found throughout the literature. After briefly stating them in Section 2 "Working definitions of consciousness", we noted that both seem to reduce the phenomenon of consciousness to either its physical or its subjective aspect. In contrast to this, we have put forward a "consistency requirement" which demands that any account of consciousness as natural property should treat it as perspectival entity that defies mutual reduction. Such consistency will likely be given by appealing to a more fundamental ontological primitive.

We then elaborated on a philosophical alternative to physicalism in Section 3 "Experiencing", according to which "experiencing" refers to the structured process of interaction of an agent with its world. Experiencing refers to an a-personal process in nature and can be studied under different aspects. One of these aspects pertains to the subjective perspective of the agent, which is irreducibly phenomenal for that (and only for that) particular agent. A second perspective on this process corresponds to the physical (or "objective") aspect of experiencing. Furthermore, experiencing is assumed to be an a-personal phenomenon, marking a clear distinction between experiencing and any notion of awareness. The latter should then be understood to "arise" from a hierarchy of objectivations of experiencing in sufficiently complex organisms, making intelligible how a 1st-personal perspective arises from experiencing. The consistency requirement serves as constraint on such theories.

This is the broad outline. Yet, there are many issues which still need to be addressed in more detail, for example, how the mechanism of complexification of experiencing works or how experiencing is related to biology more generally. We have discussed a model in Section 4 "The biology of meaning", which illustrates how the process of experiencing could be regarded as being objectified in a biological setting. Information processing in biological systems was argued to be meaningful.

However, the biological system does not correspond to a "person" in any substantial sense of the word. The model is formally consistent with recent trends in theoretical biology, for example, Friston's cognitive-biological approach [63], which could aptly be named "the physics of belief", since the mathematical description of the dynamical system appears to be a functional on "beliefs" (a "Lagrangian" according to [64], that is, a functional on probabilities derivable from the internal states of a network). This type of "belief" is a-personal. Furthermore, our approach is not about specific "causal powers" [13] of the brain but about natural tendencies of self-organizing biological systems *tout court* and lends itself to a very different interpretation, more in line with naturalized phenomenology and models of dynamical agent-environment couplings. Of course, the brain has an important role to play in the process of generating awareness, but it is not the role of "magically" creating phenomenology. Rather, the brain seems to afford a particularly efficient way of systematically correlating and processing a vast amount of (sensory and endogenous) inputs that result in suitable (behavioral) output. The brain, on our view, should be thought of as processing information that is literally meaningful to the organism by regulating an organism's self-sustaining and adaptive behavior.

The transition from simple information-processing to complex representation furthermore indicates how personalist human psychology might be related to an a-personal precursor phenomenon embodied in biological systems. Personalist psychology could be regarded as a scaled-up and evolutionarily constrained result of natural biological processes. Our approach has much in common with the cell-theory of life: The minds of complex (psychological) agents arise from the minds of simpler (biological) agents. However, the mind is not emergent, it is fundamental and objectifies itself in nature.

The model promises to be productive for the scientific project. We have illustrated this along the (seemingly hopeless) problem of consciousness. If true, is this enough reason to abandon physicalism? One could be skeptical. Nothing could directly verify (or falsify) physicalism, as long as physicalism has the last say on what does or does not count as substantial anomaly to the framework. The best one could do is show how certain assumptions eventually lead to self-contradicting consequences. The reason to reject physicalism (or any other philosophical view) is usually not to be found in an *experimentum crucis* but derives from its inability or inadequacy to account for the experiences we make inside and outside of our laboratories. It is thus the task of natural philosophy to make experience intelligible again.

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philosophies

Book Review

In Praise of and a Critique of Nicholas Maxwell's *In Praise of Natural Philosophy: A Revolution for Thought and Life*

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"Where is the wisdom we have lost in knowledge?

Where is the knowledge we have lost in information?"—T.S. Eliot

Nicholas Maxwell [1] makes an excellent point in his book *In Praise of Natural Philosophy: A Revolution for Thought and Life*, which I am happy to support with some reservations. The separation of natural philosophy into the various disciplines of science and philosophy has provided both a service and a disservice.

The service is that specializing and narrowing the scope of study in the sciences has led to a better understanding of nature. It also has led to the extension of the methodology of science to the study of the social interactions of humans, known as the social sciences. The specialization of philosophy has led to a better understanding of the various disciplines of science and social science, as well many of the topics that natural philosophy has dealt with such as ethics and values.

The disservice of the separation of natural philosophy into science and philosophy and the narrowing of the scope of study involves the problems of specialization and the loss of context. "Philosophers are people who know less and less about more and more, until they know nothing about everything. Scientists are people who know more and more about less and less, until they know everything about nothing". This quote, ascribed to Konrad Lorenz, in a certain sense captures some of the concerns of Nicholas Maxwell.

There is another dimension to the concerns of Maxwell that stems from the way that science is practiced, namely, that science is value-free and objective for it to be universal and solely evidence-based. An historic example of why this is important is the objections that the Roman Catholic Church had to the Copernican heliocentric theory of the solar system, which in some way slowed the progress of the Scientific Revolution.

The Church had no objections to the practice of science up to the publication of Copernicus's revolutionary theory of helio-centricism. In fact, many of the earliest scientists were priests and churchmen, as the following lists indicates.

Robert Grosseteste (1175–1273), Bishop of Lincoln, England, who studied optics and geometry, introduced the idea of controlled experiments and suggested that the laws of physics pertained to both matter on Earth and in the heavens.

Roger Bacon (1219/20–1292), Franciscan Friar, father of the scientific method, mathematician and astronomer who researched optics, alchemy (discovered gun powder), and agronomy; he was also a reformer of the calendar that was the forerunner of the Gregorian calendar.

William of Ockham (1287–1347), an English Franciscan monk, was a logician, a physicist, and a theologian; he was most famous for his argument for logical simplicity (parsimony) known as Ockham's Razor.

Jean Buridan (1295–1363) was a French priest who formulated the notion of impetus, which was the forerunner of inertia initially discovered by Galileo and incorporated into Newton's Laws of Motion as the First Law.

Albert of Saxony (1320–90), Bishop of Halberstadt, contributed to logic and physics.

Nicholas of Oresme (1320–82), Bishop of Lisieux, wrote on economics, mathematics, physics, astronomy, and theology. As a forerunner of Copernicus, he entertained the notion that the Earth was in motion about the Sun but concluded he did not have enough evidence to assert that that was the case.

Nicholas Copernicus (1473–1543) was a priest, one of four candidates for Bishop of Warmia; he studied for and earned a doctorate in Canon Law in Bologna. Copernicus sensed that his revolutionary theory of heliocentrism would be met with resistance by the Church and therefore did not consent to the publication of *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*) until the end of his life, receiving the printer's proofs of his book while he was on his death bed.

Copernicus's concerns were well founded, as the Church attempted to suppress the Copernican theory including the work of Galileo's as well. This is what I believe ultimately led to the division between science and philosophy, even though Newton still used the term natural philosophy but made it clear that his mechanics was strictly evidence-based.

Because of the unfortunate suppression of Copernican theory, scientists developed an aversion to anything that dealt with religion or values as being out of bounds for science. The only value embraced by science was its demand that all science be evidence-based. Maxwell has critiqued this central value of science by suggesting that there is no evidence that evidence-based science leads to truth.

> Physics makes a persistent, substantial metaphysical (i.e. untestable) assumption about the nature of the universe: it is such that, at the very least, no seriously disunified, non-explanatory theory is true. The universe is (more or less) physically comprehensible (i.e., such that physical explanations for phenomena exist to be discovered). Thus, physics does make a persistent assumption about the universe independent of evidence—even, in a certain sense, in violation of evidence—and that means standard empiricism is false.

In his attempt to rescue natural philosophy, Maxwell suggests that the basic principle, which led to so much understanding of our universe, is not valid. This is where Maxwell's criticism goes too far for me. The evidence that evidence-based science is appropriate is that it has led to a better understanding of the world in which we live and has led directly to developments that have improved the well-being of humankind. This is my critique of Maxwell.

My praise for Maxwell is that he underscores what is missing in science, namely, its inability, given its modus operandum, to deal with values and the impacts of science and science-based technology. Here, Maxwell strikes a responsive chord with me. Additionally, this is where the integration or partnership of science with philosophy that Maxwell calls for makes a lot of sense and earns my praise. I would suggest, however, that rather than going back to what was natural philosophy, we need to move forward and explore new ways of integrating science and philosophy.

Philosophy literally means the love of wisdom, and perhaps this is the missing ingredient in both sciences and philosophies. As the term science is derived from the Latin term scientia, meaning knowledge, what Maxwell is calling for is an integration of knowledge with wisdom. In my work in the field of knowledge management, I came up with the following relationship of data, information, knowledge, and wisdom:

- Data are the pure and simple facts without any particular structure or organization, the basic atoms of information,
- Information is structured data, which adds meaning to the data and gives it context and significance,
- Knowledge is the ability to use information strategically to achieve one's objectives, and

- Wisdom is the capacity to choose objectives, so they are consistent with one's values and within a larger social context [2].

To integrate the knowledge of the scientists with the love of wisdom of the philosophers will not be any easy task. The only way to achieve such an integration is to organize dialogues of scientists and philosophers. This is something that I have been organizing at the University of Toronto at St. Michael's College and the School of the Environment, both of which I am cross-appointed to. The dialogues between theologians and environmental scientists have focused on discussing global warming and climate change in the context of Pope Francis's encyclical Laudato si'. Lest the reader thinks that this activity was strictly organized from the perspective of Roman Catholicism, I will mention that I am a Jewish physicist concerned with the impending disaster that will surely be the result of climate change. It is too late to avert this crisis with a sustainability strategy. The only hope to minimize the damage will be with a resiliency strategy. This will require the integration of the knowledge of science with the wisdom that only philosophy or philosophical thinking is capable of producing. If this can be achieved, not only will we minimize the damage that climate change will create, but it will also be a step in the direction of resurrecting the natural philosophy that Maxwell is calling for.

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