ECONOMIC OPPORTUNITY AND EVOLUTION:
BEYOND LANDSCAPES AND BOUNDED RATIONALITY

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ABSTRACT

The nature of economic opportunity has recently received significant attention in entrepreneurship, organization science and strategy. The notion of boundedly rational search on an (NK) opportunity landscape has been particularly relevant to these conversations and debates. We argue that the focus on bounded rationality and search is highly problematic for the fields of entrepreneurship and strategy and does not allow us to explain the origins of economic novelty. We contrast the NP problem with the frame problem to illustrate our point, and highlight the role of adjacent possibilities and novel affordances. We discuss the entrepreneurial and economic implications of these arguments by building on unique insights from biology, the natural and computational sciences.

Keywords: entrepreneurship; economic opportunity; novelty; strategy

INTRODUCTION

The origins of novelty and the nature of economic opportunity have recently received significant attention in entrepreneurship, organization science, and strategy. The notion of boundedly rational search (Simon, 1955, 1956)—on a strategy landscape or 'phase space'—represents a particularly powerful and influential metaphor and tool for thinking about the nature of economic activity.[1] For example, NK modeling has been used to study how firms search locally or globally for peaks or opportunities within landscapes (Levinthal, 1997; Winter, Cattani, and Dorsch, 2007). Some have argued that behavior and 'rationality' on this landscape is a process (Levinthal, 2011; also see March, 1994; Simon, 1978), thus emphasizing mechanisms such as experiential learning and environmental feedback—while yet others have recently focused on how novelty and opportunity might emerge via distant, cognitive leaps on a landscape (e.g., Gavetti, 2012; cf. Holyoak and Thagard, 1996). The discussion has centered on how economic actors navigate and map these opportunity landscapes, given uncertainty and such factors as the resources of the economic actors, the cognition or biases of the decision makers, the dynamism of the environment, or competition and past experience. It is important to note—given the arguments in this article—that the origins of the landscape metaphor and associated tools such as NK modeling can be traced back to computational and evolutionary biology (see Kauffman and Levin, 1987; Kauffman and Weinberger, 1989).[2] Furthermore, it is also quite significant that Herbert Simon's (1955, 1956) path-breaking arguments about bounded rationality were

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[1] As we will later discuss, phase spaces and various combinatorial landscapes have been central in a number of disciplines, including physics, biology, and chemistry (see Reidys and Stadler, 2002). To learn about the history and basic mathematics behind phase spaces, see Nolte, 2010.

[2] Links between biology and economics are deep, going back to Darwin and Malthus (Mayr, 1977). For a history of the extensive links between biology and economics, see Hodgson, 2005.

explicitly tied to biological intuition and mechanisms about organisms searching, calculating, and optimizing behavior in environments.[3]

The metaphor and very nature of an opportunity landscape have recently been challenged and debated, particularly in the context of explaining entrepreneurship, strategy, and novelty in economic settings. For example, Winter (2012: 291) has raised questions about the notion of an opportunity landscape—specifically vis-à-vis Gavetti's (2012) arguments—and provocatively asks 'why [should we even] theorize opportunity?' Winter (2012) argues that 'serendipity' and 'contextual factors' play an important role in the emergence of novelty and in the discovery of profitable opportunities (also see Denrell, Fang, and Winter, 2003). Importantly, scholars in entrepreneurship have also raised concerns that relate to the landscape metaphor, specifically in recent debates about the subjective versus objective nature of economic opportunities—whether opportunities are 'created' and enacted versus 'discovered' (e.g., Alvarez and Barney, 2007; Alvarez, Barney, and Anderson, 2013; Eckhardt and Shane, 2012).

These debates raise important questions about the origins of novelty and the very nature of economic and entrepreneurial activity. Given that scholars have extensively focused on search and landscapes both as a metaphor and tool (such as NK modeling), we explicitly revisit the underlying assumptions embedded in these approaches and more generally revisit the idea of bounded rationality and organism-environment relations, particularly as these apply to entrepreneurship and novel economic activity.[4] We first discuss Herbert Simon's foundational notion of bounded rationality and argue that the focus on search and computational complexity

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[3] Importantly, these arguments also provide the foundations for the field of artificial intelligence (Newell, Shaw, and Simon, 1958; Newell and Simon, 1959; for an overview, see Russell and Norvig, 2009).
[4] We have explicitly not defined what novelty is, particularly since seemingly more minor innovations might, in fact, enable (and thus be central to) subsequent, larger innovations and forms of novelty. Thus, our focus in this article can be seen as an effort to emphasize the *process* and *emergence* of novelty, rather than an effort to pinpoint, capture, or label something as novel at any one point in time.

has led the field astray. We focus on the rationality-related and biological and computational assumptions made by extant theories that focus on search in landscapes. We argue that much of the entrepreneurial, strategy, and organizational literature is built on overly computational, calculation- and algorithm-oriented conceptions of activity and behavior and that these approaches suffer from critical deficiencies. We address the weaknesses of these search- and landscape-focused views, particularly vis-à-vis explaining novelty, by highlighting arguments from the disciplines from which these approaches stem: biology, physics, and computer science. While scholars have defined economic activity by computational limitation and complexity (for example, focusing on 'NP-completeness'—e.g., Levinthal, 2011; Rivkin, 2000; cf. Weinberger, 1996), we argue that the real problem in explaining novelty and entrepreneurial activity instead is the 'frame problem'—and, thus, we provide the preliminary foundations of a theory to explain the origins of novelty in economic settings.

In all, we argue that entrepreneurial and economic activity is not computation, calculation or boundedly rational search. Our focus, instead, is on the unprestatable but nonetheless scientifically explicable nature of the phase or strategy space within which novel entrepreneurial activity takes place. We highlight parallels between evolution in the biological and economic spheres, respectively (cf. Kauffman, 1993). Economic actions—including behaviors, products, and capabilities—yield constant flows of emergent possibilities that cannot be meaningfully listed, let alone 'rationally' considered, searched, or compared. Both in economics, particularly in entrepreneurial settings, as in nature, there is no effective procedure or algorithm that can list the opportunities available for organisms, and this non-algorithmicity means that the emergent possibilities cannot be prestated. Thus the very idea of search on a landscape or phase space and the notion of bounded rationality—despite its foundational and even sacred status in

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organizational research—are highly problematic for explaining novelty and entrepreneurial activity. However, this does not leave us outside the bounds of science. As we will discuss, explaining the origins of economic opportunities and novelty is nonetheless possible.

BOUNDED RATIONALITY AND COMPUTATION IN UNCERTAIN ENVIRONMENTS

The notion of 'bounded rationality' has been central in advancing our understanding of economic activity. Herbert Simon's (1959: 99) goal in introducing bounded rationality was 'to replace the global rationality of economic man with a kind of rational behavior that is compatible with the access to information and the computational capacities that are actually possessed by organisms, including man, in the kinds of environments in which such organisms exist.' Rather than assuming that organisms, such as economic actors, are perfectly rational (that is, globally aware of all the possibilities and able to comparatively compute them and decide optimally), Simon emphasized the search for possibilities and the localness and limits of rationality. Bounded rationality has subsequently become a central assumption of many economic and organizational theories, including transaction cost economics (Williamson, 1991), the behavioral theory of the firm (March and Simon, 1958), and evolutionary economics (Nelson and Winter, 1982; also see Aldrich, 1999). The notion of bounded rationality indeed provides a much-needed contrast with and advance over models that assume perfect rationality and explicitly focus on the efficiency of markets (Arrow and Debreu, 1954). The assumption behind efficient markets, in its extreme form, is that all possible goods and services—in effect, all possible futures—can be prestated and listed and that all of this can be comparatively calculated and traded by economic actors.[5]

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[5] Here we are highlighting a very specific, extreme conception of markets. We certainly recognize that alternative conceptions exist, including the behavioral ones we discuss. For example, the non-equilibrium models of Hayek (1945; also see Kirzner, 1982) provide one example.

Simon's notion of bounded rationality is anchored on biological and computational language, mechanisms, and metaphors. For example, Simon's original articles focus on 'organisms including man, in the kinds of environments in which such organisms exist' (1955: 99). Thus the argument is meant to be general—to include man—and to highlight how organisms search and operate in complex environments. Not just the language is biological, but so are the examples. Simon's most extensive illustration of bounded rationality focuses on how an animal searches for randomly distributed food in an environment or 'behavior space' (1956). The basics of a behavioral model of boundedly rational search were, thus, developed early on. Note that this intuition is also quite closely linked with mathematical models of animal foraging and optimization in patchy environments (e.g., Pyke, Pulliam, and Charnov, 1977).[6]

The advantage of Simon's approach, as a response to neoclassical, rational choice models, was that it could be mathematized and formalized in powerful ways. Organisms are seen as algorithmic computers (Turing machines) that process information via programs, within the bounds of their capability or experience. Simon drew direct links between the way humans and computers solve problems, which is readily evident by the focus on concepts such as memory and storage capacity, programs, information processing, effectors, and receptors (see Newell *et al.*, 1958; cf. Simon, 1956, 1969). Again, Simon provided a much-needed alternative to perfectly rational conceptions of agents. The overly rational or even omniscient organism, or economic actor, was replaced by one who was boundedly rational: had computational limitations and needed to search for solutions, given limited access to information about alternatives. Note that these concepts—of search and problem solving in environments, effectors and receptors,

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[6] The organizational and economic sciences continue to make extensive use of biological tools, concepts, and mechanisms. For example, beyond Simon's notion of bounded rationality, fields such as organizational ecology have borrowed and focused on concepts quite familiar to us from biology—such as population-level dynamics, resource partitioning, niches, carrying capacity, and fitness and selection (Hannan and Freeman, 1993, for an overview of these concepts see Carroll, 1984; Singh and Lumsden, 1990).

learning—also provide the very foundations of the field of artificial intelligence (see Russell and Norvig, 2009).

Our understanding of economic activity continues to be strongly influenced by the notion of bounded rationality and by direct analogies and tools from the biological and computational sciences. As discussed at the outset, NK modeling was originally developed in evolutionary and computational biology (Kauffman and Levin, 1987; Kauffman and Weinberger, 1989), and this tool is now frequently used in strategy and organization science (e.g., Levinthal, 1997; also see Gavetti, Levinthal, and Rivkin, 2005; Levinthal and Warglien, 1999; Rivkin, 2000; Rivkin and Siggelkow, 2007; Siggelkow and Rivkin, 2005; Winter *et al*., 2007). This work has indeed generated many important insights about how firms and economic actors behave and search and find profitable opportunities in landscapes. The most basic mechanism for exploring the landscape has focused on experiential learning, where focal actors learn and adapt as they experience and sample the landscape itself and receive behavioral feedback from the environment (cf. Levinthal, 1997). This research has, for example, focused on the problem of getting stuck on suboptimal, local peaks. The contrast between local exploitation versus more global exploration on landscapes has also been a central metaphor for understanding the trade-offs that firms make (e.g., Levinthal and March, 1993; Rivkin and Siggelkow, 2007). These approaches can broadly be classified as part of evolutionary economics, as well as a more general behavioral program of research in organization science and strategic management (for an overview, see Gavetti *et al*., 2012).

There are also some important tensions within this program of research, particularly vis-à-vis the respective emphasis that ought to be placed on the nature or 'rationality' of an organism itself versus how much emphasis ought to be placed on the environment (cf. Felin, 2012).

Gavetti (2012) has recently argued that an emphasis should be placed on cognitive leaps—associational or analogical leaps that economic actors make on landscapes (cf. Holyoak and Thagard, 1996). The focus is on finding ways to capture the crude but 'forward-looking' representations that economic actors have about operating on uncertain opportunity landscapes (cf. Gavetti and Levinthal, 2000. This, more organism-centric approach strives to place some emphasis on agency and cognition in response to the seemingly more deterministic approaches that characterize evolutionary economics. However, these approaches remain linked with a behavioral logic (given the focus, for example, on the mechanism of association or analogy) that says little about the organism itself (Felin and Foss, 2011). Furthermore, Winter (2012) responds to Gavetti's general emphasis on (more rational) cognitive search on landscapes and argues that serendipity and contextual factors play a central role. One of the central tensions in this discussion is how much rationality to afford organisms and economic actors—and, in fact, what we even mean by the notion of rationality—and the role of organisms or actors versus randomness, serendipity, and luck.

It is worth making a specific note of the fact that much of this discussion—and large swaths of evolutionary economics and organization science more generally—is based on a *one-to-one* borrowing of theories, mechanisms, and tools from the biological and computational sciences. The links between economics and biology have indeed been quite tight, going back to Darwin and Malthus (see Mayr, 1977). For example, evolutionary economics has been an effort to generalize the basic framework of Darwinism and the emphasis on environmental selection (for a recent overview, see Hodgson and Knudsen, 2011). Similarly, the mechanisms and tools in artificial intelligence and biology are also quite readily apparent in much strategy and organizational work, a focus on the computational and algorithmic aspects of behavior, search,

and decision making. In all of the above, the notion of a phase space or landscape has been central: a representation of all possible actions for organisms and their exploration of these landscapes through search, calculation, comparison, and various behavioral mechanisms.

While the links between biology and economics have been fruitful, we argue that bounded rationality and the landscape notion and associated tools utilizing various forms of search, such as NK modeling, are problematic for explaining novelty. We build on arguments from the biological, natural, and computational sciences to make our point.

WHAT IS THE NATURE OF THE PROBLEM? FROM NP TO FRAME

How, specifically, should the 'problem' of explaining entrepreneurial activity, opportunities, and novelty be conceptualized? We argue that the extant focus on computation and algorithmic search, calculation, and behavior—anchored on bounded rationality—is problematic. While bounded rationality rightly amends models of global rationality by setting limits on both what can be considered and the abilities of actors to process all the relevant information, different foundations are, nonetheless, needed. Specifically, we hope to amend the focus on bounded rationality and computational complexity to also consider the generative and productive aspects, beyond search and calculation, manifest in entrepreneurial and strategy activity.

In existing work, economic actors, entrepreneurs, and firms are treated as algorithmic information processors. Economic actors and firms are, in effect, seen as computers (or Turing machines). To illustrate, strategy scholars and organization scientists have specifically focused on bounded rationality in the form of the unfeasible computability of all choices and their interactions. Some have linked the complexities associated with economic calculation and behavior with the 'NP' problem in computer science (e.g., Levinthal, 2011; Rivkin, 2000):

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problems that may be computable but only in too long (exponential) a time, due to complexities.[7] The setting of NK landscapes indeed is optimal for studying the NP-complete problem (cf. Weinberger, 1996). But the very premise of NP-completeness does not match the context of economic and entrepreneurial activity, just as it doesn't match it in the context of biological activity (cf. Longo, 2012).[8] Approaches that focus on computation presume that solutions preexist—the landscape is given and needs to be searched (or calculated)—and that all options are somehow listable and comparable. Thus the economic problem is framed as one where all solutions are listable, searchable, and comparable, though where the processing or comparison of potential solutions occurs in bounded fashion. This boundedness focuses on the limits of calculation and the impossibility of considering all possibilities, for example, as illustrated by the combinatorial interactions of various decision elements (proxied by K in NK work). References to the NP problem suggest that the central economic problem is one of information processing, computation, and cognitive limitation. The landscape itself is seen as a given, and the economic problem is algorithmic. Existing models then presume that a satisficing and, thus more limitedly 'rational,' solution can be calculated (or learned over time) within the limitations of the computational power of the agent involved. We find this problematic.

Note that the exercise of computing solutions has some striking similarities with neoclassical economics and rational choice approaches, namely, the emphasis on computation. While equilibrium-oriented models focus on the simultaneous and instantaneous nature of this economic calculation, evolutionary and computational approaches, in turn, focus on the temporal, cognitive, bounded, and search-related aspects of the climb to an optimum. We certainly find the latter conceptualization more convincing. But it also, particularly vis-à-vis

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[7] For an additional example of this type of complexity in economic settings, see Axtell, 2005.
[8] We are, of course, not the only ones to highlight problems with input-output models and Turing-type, mechanistic conceptions of cognitive activity (for example, see Wheeler, 2005).

explaining novelty in economic settings, deserves scrutiny. Specifically, references to the NP problem, calculation, and search mis-specify what the economic problem entails. While complexity undoubtedly is involved in economic decision making, the problem is *not* one where all (or even just some) solutions are somehow listed, listable, calculable, or comparable, but rather one of how we can account for the emergence of these solutions in the first place. The shift, then, if we seek to retain the landscape metaphor, is one of understanding how portions of the landscape—hidden to our view—emerge in the first place.

The central problem of economic and entrepreneurial activity, then, is not equivalent to the NP problem or to the problem of search on a landscape. Rather, if comparisons or metaphors between economic and computational problems are sought, then we should instead focus on the 'frame problem' (originally introduced by McCarthy and Hayes, 1969; for a broader sense of the frame problem, see Dennett, 1984).[9] Put simply, the frame problem focuses us on the problematic nature of explaining the full task set of activities and *possible* functionalities and uses for operating in the world (or some situation or environment, whether real or artificial). The problem is that there is no full account or set of algorithms that can be given about all possible actions, uses, and functions. The shift here is also one of needing to move from an emphasis on the exogenous environment to the endogenous nature, growth, and enabling constraints provided by an organism and nature (cf. Felin, 2012).

To illustrate the incapacity to solve the frame problem algorithmically, consider the familiar screwdriver (cf. Longo, Montevil, and Kauffman, 2012). Suppose we try to list all its

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[9] The technical details associated with the frame problem in computer science are far beyond the scope of this article. For a broader conception of the frame problem, more conducive with our discussion, see Dreyfus, 2007. In short, Dreyfus highlights how the frame problem focuses on 'which facts are relevant in a given situation' (something that computers cannot meaningfully bootstrap), the problem of the situation-specific nature of frames, and the problem of how to account for operating in a changing world. This broader conception of the frame problem is the one that we have in mind.

uses alone or with other objects or processes: screw in a screw, wedge open a door, open a can of paint, tie to a stick as a fish spear, rent to locals and take 5 percent of the catch, kill an assailant, and so forth. As we will argue below with reference to biology (or to phenotypes, as forms and functions of the living), the number of uses of a screwdriver (as forms and functions of uses and activities) are both indefinite and unorderable. No effective procedure or algorithm can list all uses, let alone possible future uses. This means, *a fortiori*, that the frame problem is not solvable algorithmically. However, as we will discuss, evolution in nature 'solves' the frame problem non-algorithmically. Because we cannot list all the uses of evolving cellular or molecular screwdrivers, we cannot prestate all the possibilities and, thus, do *not* (and cannot) know the sample space of the process and, therefore, can make no probability statements in any known way. Not only do we not know what will happen—we also do not know what *can* happen. Yet, we argue, it is from the unprestatable uses of screwdrivers in general that economic novelty emerges.

In the economy, the landscape metaphor and associated computational tools require every observable in a given environment (i.e., the possible 'space' or landscape) to somehow be listed and classified and assigned its proper uses and functionalities, whether in a global or more narrow, bounded sense. Thus, the assumption—to put this in more practical terms—is that every object 'is-a,' 'has-a,' 'needs-a.' But this list of possible 'affordances' is not fully prestatable for operating in the world, other than for extremely limited circumstances. The problem is not only one of comparison amongst the best uses and functions of objects and spaces, but even the very generation of the full list is not algorithmically feasible. To put this differently, as discussed by Gibson (1986: 134), 'to perceive an affordance is not to classify an object.' The problem is not one of informational complexity and computational limitation (the NP problem), though these

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also play a role in certain types of activity and behavior. Rather, the problem is that the landscape is not predefinable. The problem, then, shifts to a need to explain the origins of uses and functions, particularly new ones. Of course, an artificial agent might be given tools to generate hypotheses about possible uses and functionalities, via mechanisms such as trial-and-error or association. But these are scarcely sufficient for explaining economic or entrepreneurial novelty (cf. Felin and Zenger, 2009). Outcomes are only as good as the intelligence of the interpreter. This matters, since presently the mechanisms used in artificial intelligence are precisely the same as those used in our study of human and economic behavior.

We might parenthetically note that scholars have long been optimistic about the potential of artificial intelligence and computers to surpass the ability of humans. But the inability of computers to solve the frame problem captures the very crux of the difference between mechanistic or computational conceptions of behavior, versus approaches that more readily account for the capability of disparate organisms, including humans. It is hard to ascribe any kind of creativity or novelty to artificial agents and computers (Dreyfus, 1992). This problem, related to the generation of novelty, was even anticipated by the very early pioneers of artificial intelligence, such as Ada Lovelace. She argued that 'the Analytical Engine has no pretensions whatever to originate anything. It can do whatever we know how to order it to perform. It can follow analysis, but it has no power of anticipating any analytical relations or truths. Its province is to assist us in making available what we are already acquainted with' (Lovelace, 1843: 722).

The desire to capture biological and human activity, including entrepreneurial and economic activity, in computational or mechanistic form is tempting and seemingly scientific (lending itself to various types of formalization and tools), and it represents a more general ethos of trying to unify the sciences through computational reduction or broader, environmentally

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oriented models of behavior (such as NK landscapes). Work such as Jacques Loeb's

(1912) *Mechanistic Conception of Life* capture this intuition: a heroic attempt to build a general

theory focused on environmental inputs, stimulus-response relationships, and selection. These

mechanistic conceptions and the focus on computational observables also have links to

prominent theories and approaches in psychology (Skinner, 1938) and physics (Mach, 1897). But

environment-oriented conceptions of evolutionary economics suffer from similar problems

(Felin and Foss, 2011). While these approaches are influential, they are overly deterministic and

unable to explain the emergence of variety.

THE ORIGINS OF VARIETY AND NOVELTY: INSIGHTS FROM BIOLOGY

Where, then, does variety and novelty—whether in the biological or economic sphere—originate

from? Perhaps the best place to start is with reference to extant biological arguments that deal

with similar questions about the origins of variety and novelty in nature. Evolutionary models

that focus on selection require a counterpart to explain where the selection set comes from. In

other words, whether biology or economics, we need to not just explain the survival of the fittest

but also the 'arrival' of the fittest (cf. Fontana and Buss, 1995). Radical and emergent

heterogeneity in nature is not explainable by appealing to the mechanism of selection alone (cf.

Kauffman, 1993), despite efforts to do so.[10] As areas such as evolutionary economics are

attempting to build on a general theory of evolution[11] and these efforts have heavily influenced

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[10] Within the domain of biology and nature, the arrival of variety has led scholars to focus on various factors. For example, scholars have highlighted such factors as niche construction (Odling-Smee, Laland, and Feldman, 2003), speciation and punctuated equilibria (Gould and Eldredge, 1977), exaptation (Gould and Vrba, 1982), epigenetics (Waddington, 1942), ontogeny (Gould, 1977), and morphogenesis or the growth of form (Thompson, 1917; Turing, 1952). In a later section we revisit extant work in economics that touches on these issues.

[11] In terms of 'general' Darwinism and the importance of selection as a mechanism, Winter (1987: 617; also see Aldrich *et al.*, 2008; Murmann *et al.,* 2003) has argued that 'natural selection and evolution should not be viewed as concepts developed for the specific purposes of biology and possibly appropriable for the specific purposes of economics, but rather as elements of the framework of a new conceptual structure that biology, economics and other social sciences can comfortably share.'

We believe Darwin's first principle, descent with modification (and associated development and growth), a key

work in strategy and entrepreneurship, it is important to highlight both sides of the argument: survival as well as arrival and development.

Our argument, building on extant biology, is that there are selection-independent mechanisms that generate novelty in the biosphere. Or put differently, the origins and development of organisms and selected-for sets also requires careful attention. Recall that Darwin's *Origin of Species* is founded on two principles: descent with modification and selection. The first is as revolutionary as the second. It stresses the idea that organisms, beginning with unicellular ones, proliferate *with variation* under all circumstances. This radically changes the previous 'evolutionist' perspective of Buffon and Lamarck, as variation was supposed to be induced by the environment. Then, of course, Darwinian selection, *as the exclusion of the incompatible*, applies.

To illustrate, consider the emergence of the swim bladder (Longo *et al.*, 2012). Swim bladders help fish maintain neutral buoyancy via the ratio of water to air in the bladder (cf. Perry *et al*., 2001). This functionality, a Darwinian preadaptation, emerged from lungfish as some water seeped into lungs. Sacs in the lungs were partially filled with air and with water, poised to evolve into swim bladders. The possibility of developing this new and emergent functionality existed *a priori*, but was not a necessity: life could continue without it for that particular fish. But the novel functionality was an 'adjacent possibility' once lungfish existed, but not before a mutation or other forms of inheritance made that possibility *actual* as well as *heritable.* In other words, the bladder represents a preadaptation that as an adjacent possibility emerges without selection 'acting' to achieve the possibility. It is a possibility enhanced by reproduction with heritable variation. So, both new functionalities and niches may emerge, possibly originating at

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component of variability and diversity in evolution, should also be given a similarly fundamental role.

molecular level (mutations). These new observable phenotypes are, thus, totally unpredictable: they may even depend on a quantum event in a germinal cell (Buiatti and Longo, 2013).[12]

Organisms in nature constantly develop surprising functional capabilities and uses that are not prestatable. The swim bladder, once it has evolved, may constitute an adjacent possible empty niche where, for example, bacterium may evolve to live. Once evolved, the swim bladder alters the adjacent possible evolution of the biosphere. But what is the role of natural selection here? Selection surely plays a role in the evolution of a population of lungfish to craft a working swim bladder by excluding incompatible ones. And once the swim bladder exists, it constitutes an adjacent possible empty niche, or 'opportunity' altering the future possible evolution of the biosphere via the worm or bacterium that, in turn, might evolve to live in swim bladders. But critically, selection did not 'act' to achieve the swim bladder. This means something fundamental: without selection acting to do so, evolution is creating its own future possibilities and opportunities, by the first of Darwin's principles. Note that no fixed, known physical theory (or conceptualization of 'phase space') can list all biological possibilities. The forms of randomness proper to biological dynamics include both classical and quantum randomness (which happen not to be unified in one theory). They also include the unpredictable interactions between these two different forms of randomness as well as between different levels of organization—within a cell, a multicellular organisms, and an ecosystem (see Buiatti and Longo, 2013).

The emergence of new, unprestatable functions and new, unprestatable opportunities is constant and continual. The phase space of the evolution of organisms and phenotypes—if it even can be called a phase space or landscape—is never fixed. It is radically emergent. There are

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[12] Another example (see Gould and Vrba, 1982) is the formation of the vertebrate's ear bones. They derive, by 'exaptation' (*ex post* adaptation), from the double jaw of some vertebrate some 200 millions years ago. A typical case of Gould's contingency: there was no need for animals to have ears. Features emerge via a process of random cascades of mutations and many other explorations, possibly excluded by selection. The animals' interactions and, thus, the ecosystem were changed by this new phenotype.

adjacent possibilities and niches for each trait, function, or capability of an organism and new

organisms may be —in the terminology of Longo *et al*. (2012)—'enabled.' It is not possible to

map all of these possible adjacencies, just as all the uses of a screwdriver are not algorithmically

listable, nor are all the opportunities that arise listable or prestatable. Moreover, all that must

occur in evolution is that some molecular screwdriver in an evolving organism 'finds a use' that

enhances the fitness of the organism and that there be heritable variation for that use. Natural

selection might then positively select for this newly adapted use. This *is* the arrival of the fitter,

missing in selection-oriented approaches. Moreover, the unprestatable new use further alters the

phase space of evolution in unprestatable ways, precluding our ability to write laws of motion for

that evolution.

One way to think about the emergence of novelty is that there is a constant 'empty' set of

possibilities that are adjacent to the existing phase space. The problem of specifying the phase

space of possibilities is closely linked with our previous discussion of the algorithmic incapacity

to list affordances and uses. Any product, skill, or function represents a latent but unprestatable

set of uses. The aforementioned screwdriver—a seemingly trivial object—illustrates the point.

Since the number of uses of screwdrivers is indefinite and unorderable, it simply is not

possible, *a priori*, to use any effective procedure to list all the possible uses. The same goes for

the possible functionality for any other product, characteristic, capability, or skill. As these

examples illustrate, our goal is not to try to make predictions about why *a particular*—of many

possible—novel use or functionality might emerge in the first place. Rather, our goal is to

highlight the unprestatability of all the possibilities. Thus, our approach is, in fact,

complementary with existing evolutionary arguments, where the mechanisms for generating

particular novelties might also emerge through random experimentation or trial and error. That

said, randomness in evolution—whether economic or biological—is not randomness in the sense of 'noise' and is not measurable by probability theory, but rather it is at the origin of possible variability and diversity and, thus, it contributes, in biology, to organisms, populations, and ecosystem's structural stability (Longo *et al.*, 2012; Buiatti and Longo, 2013).

It is also important to note that the evolving organism in its actual niche achieves 'task closure' allowing it to reproduce, via causal pathways that pass through the environment. However, these pathways cannot be prestated non-circularly with respect to the evolving organism in its actual niche. In short, we cannot prestate the niche of an evolving organism, it is revealed only if the organism is successful, that is, by selection acting at the level of the *whole* organism.

This distinction touches on a key point about the need to distinguish *developmental* constraints (and enablement) from *selective* constraints (Maynard Smith *et al.*, 1985). Our emphasis is on the former. While variation and selection emphasize randomness, we emphasize the changing constraints that make further development possible. Constraints, such as the swim bladder, are 'enabling.' Development is not deterministic, but allows for adjacencies to be explored by variation at some other level (e.g., the changing bacterium). Enabling constraints suggest not just limitations but also evolutionary growth toward possibilities and opportunities. [13]

A further problem with focusing on selection alone—as a prestated, searchable landscape would suggest—is that particular traits or functions are rarely, if ever, selected for. Rather, *whole* organisms are. Thus, not only is it hard to specify which functions or traits were selected for, but it is also hard to specify the latent set of possible future traits and functions accompanying the 'selected' one(s). Whole organisms can be seen as complex bundles of parts,

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[13] The poet Wallace Stevens, in the last poem published during his lifetime (titled *July Mountain*) captures a similar notion by referring to 'an always incipient cosmos.'

latent traits, and possibilities and, thus, even after selection 'we cannot [pre-list] the newly relevant functional features of its parts revealed by selection' (Longo *et al*., 2012: 2). Organizations represent similar types of wholes. As we discuss next, there are indeed important links between organisms and environments, as well as notions of phase spaces and landscapes, particularly in terms of how these ideas apply to understanding novelty in economic settings.

REVISITING THE PHASE SPACE AND LANDSCAPE

Our arguments here have profound implications for the notion of 'phase space'—a representation of the set of all possible actions, strategies, or states—and associated modeling such as combinatorial landscapes (cf. Kauffman and Weinberger, 1989). These, again, have been a central metaphor in the fields of strategy, entrepreneurship, and organization science (Levinthal, 1997). The notion of phase space originates from the physical sciences and the pioneering work of Ludwig Boltzmann and the efforts in statistical mechanics (as well as thermodynamics, and later, quantum mechanics) to specify the full set of possible states that a particle or system can take. Boltzmann argued that even highly complex, non-reducible systems were 'ergodic,' that is, they randomly but uniformly explored all the possibilities in a given phase space. As a consequence, their *average* performance and behavior was predictable given sufficient historical information.

The problem in biological evolution, compared to thermodynamics, is that this phase space cannot be specified even on average (Longo *et al*., 2012). In Newtonian and Laplacian physics, which are given in a fixed phase space, we can determine and predict motion and direction. But the biological sphere does not lend itself to such physical models given the aforementioned latent functionalities of organisms. Specifically, there are several concerns with the notion of phase space. As mentioned earlier, in the biological sphere, organisms are selected as wholes.

Organisms naturally embody myriad functionalities and uses that cannot be prestated or captured, which range from quantum to classical to 'inter-level' interactions between the organism and ecosystem. Even retrospective imputation of a selected-for trait or phenotype can be difficult, if not impossible.

The argument that the phase space is not prestatable might be seen as an argument for unrestricted randomness or ergodicity as the exploration of all possibilities. However, the very notion of development, as the counterpart of selection, suggests that there are possible trajectories, or 'evolvability' (cf. Wagner and Altenberg, 1996), within organisms. Evolution is not fully random in any extreme sense: its randomness is highly canalized. Biological entities can be said to be 'poised' for a large set of possible adaptations (cf. Bailly and Longo, 2011; Mora and Bialek, 2011; also see Kauffman, 2012). The set of adjacent possible directions, of course, is extremely large, though not infinite—that is, within the limits, constraints, and enablement of the nature of the organism in question. Scholars of course have tried to capture the developmental portions of the evolution of organisms mathematically, for example, in an effort to map the 'topology of the possible' (Fontana and Schuster, 1998; Stadler *et al*., 2001). Certainly a new set of mathematical and empirical tools is needed to capture the richness of the emergent, unprestatable biological sphere and associated evolution, including economic evolution.

But, the bottom line is that extant notions of phase spaces and landscapes import certain assumptions from physics and the mathematical sciences that are rather problematic in the context of both biological and economic evolution. In addition to the aforementioned problems, phase spaces also assume symmetries, invariance, and that conservation laws are upheld (cf. Sethna, 2006). However, these assumptions do not hold in the case of biological evolution, let alone in economic or entrepreneurial settings. Biological evolution represents continual changes

to symmetry as the trajectories of organisms evolve. In physics, the observables yield the phase space and possible trajectories. That is, the mathematical construction of the phase space is based on invariants (e.g., momentum and energy conservation) and invariant-preserving transformations that allow us to analyze trajectories (momentum x position or energy x time in the two cases above). However, biological evolution cannot be captured by observables alone since the relevant observables (phenotypes and organisms) and pertinent variables shift constantly.

As we have already hinted, the problem of a prespecified phase space or landscape can also be looked at by highlighting quantum effects. Quantum physics highlights how it is highly problematic to identify the position of a particle or system—its state is indeterministic. Changes can be random, nonlocal, and acausal. The whole notion of quantum effects raises hairy questions about the precise nature and state of things (particles versus waves), as well as measurement problems. The question is whether the outcome of any single quantum measurement can be calculated, for if not, that outcome is not entailed. The notion of observables and spatial location—at the very heart of a phase space or landscape—then is problematized given quantum non-locality. As closely analyzed by Buiatti and Longo (2013), these acausal quantum events may have a major role in intracellular dynamics and may affect biological evolution.

In all, our arguments raise profound problems with the use of phase spaces and landscapes, whether as a metaphor or as a tool for understanding the evolution and development of organisms in biological *and* economic spheres. That said, there are some, more narrow, settings where it is possible to list all available options or to simulate the search for optimal outcomes. But, the context of entrepreneurial and strategic activity is not one of these settings. If we are

seeking to explain the emergence of novelty and newness, whether in biological or economic settings, then focusing on phase spaces and landscapes will only lead us astray.

DISCUSSION AND CONCLUSION

Our central point is this: entrepreneurial and economic activity is not boundedly rational search or computation. The focus on factors such as bounded rationality, calculation, and search on phase spaces and landscapes is inappropriate for understanding the emergence of entrepreneurial and economic novelty. We have sought to make this point by highlighting how the specific theories, metaphors, and methodologies—imported from the natural and biological sciences—are inappropriate for explaining both biological and economic novelty. Thus, evolutionary and computational arguments of the nature of economic and entrepreneurial activity need to move beyond landscape and phase space-type assumptions, as well as search-laden, computational metaphors toward alternative explanations of novelty and heterogeneity. For example, rather than emphasizing the NP problem or the computational limitations (as instantiations of bounded rationality) of economic actors, we think the frame problem offers a more realistic future focus for explaining the emergence of novelty in the economic sphere. After all, understanding the emergence of novel uses and functionalities is at the heart of economic and entrepreneurial activity. Furthermore, we have discussed the need to explain the arrival and development of the fittest, rather than merely survival, and to focus on the emergent, poised possibility space of novel entrepreneurial activities.

Some of issues raised in this article have, of course, been touched on by others. For example, Alvarez and Barney (2007) argue that entrepreneurial opportunities are not meaningfully discovered in some objective way; rather, that they are created. Their emphasis is on the discovery-creation dichotomy and the social construction of opportunities. Our emphasis,

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instead, is on the problematic nature of concepts such as bounded rationality and the associated computational and calculation or search-oriented logic. Yet others have highlighted specific evolutionary mechanisms that focus more on the emergence of variation, which we emphasize, rather than focusing on selection. For example, Adner and Levinthal (2002) discuss punctuated equilibria in the context of the 'speciation' of technologies, where surprising new uses and functionalities emerge for technologies intended for different purposes and contexts. And Cattani (2005, 2006) offers an apt example of 'preadaptation,' where a firm's capabilities in glass manufacturing led to surprising new innovations in fiber optics technology. However, work in the domain of evolutionary economics, entrepreneurship, and strategy continues to be heavily focused on the environment, search and selection-type mechanisms (Felin, 2012). Evolutionary economics continues to be strongly linked to an environmental selection logic. To provide but one example, in their recent review of evolutionary theories across the sciences (and their calls for a Generalized Darwinism), Hodgson and Knudsen (2011) only briefly mention 'ontogeny' and related concepts (e.g., 'exaptation,'), but no theory is explicitly developed as it relates to the emergence of novelty in entrepreneurial or economic settings. Also, Giovanni Dosi briefly refers to a need to develop 'constructive' evolutionary models (see Cohen *et al*., 1996, footnote on page 678). But beyond footnotes and brief references, scholars need to move toward more substantive development of models that focus on organism- and development-related origins of novelty in economic and entrepreneurial settings. Landscape metaphors and associated methodologies and tools are irreparably constrained in terms of their ability to actually explain novel entrepreneurial and economic activity, despite the continuing efforts to try to do so (e.g., Gavetti, 2012). Thus, the development side of evolutionary arguments related to entrepreneurship and the economic sciences, given the extant focus on search and environments (whether populations, selection, or

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prespecified phase spaces), has received little attention. The effort in our article has been to bring endogeneity, development, and novelty center stage and to highlight how insights from the biological and natural sciences might directly inform our understanding of the nature of entrepreneurship, novel economic opportunity, and emergence of heterogeneity.

An emphasis on development also suggests a need to understand the *unique* comparative nature and capabilities of organisms, rather than solely privileging universal mechanisms such as environmental selection (e.g., Winter, 2011; cf. Felin and Foss, 2012). A focus on the environment causes us to lose sight of important individual- and lower-level details and heterogeneity. In other words, the endogenous nature and capabilities associated with entrepreneurial actors, whether individual or aggregate, deserves attention. This means a shift in the level of analysis—a need to understand the unique characteristics and nature of particular actors and the emergent, collective forms that entrepreneurial activities might take. A focus on lower levels of analysis (individuals, interaction, aggregation, and emergence), however does not suggest that higher levels of analysis should be ignored. Rather, scholars should attend to the coevolution of lower and higher levels. That said, references to higher levels (context and environment) often create black boxes that obscure rather than clarify. The vast, organism-level heterogeneity and possibility that lurks directly beneath blanket ascriptions of environmental importance needs to be carefully unpacked (Felin, 2012). Thus, there is an opportunity to draw insights about capabilities and the emergence of novelty from more comparative and organism-centric fields such as ethology.

In all, the purpose of this article has been to address recent theories and debates about the nature of entrepreneurial activity and economic opportunity and to highlight the crude beginnings of an alternative. We first discuss the current focus on computational and algorithmic

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approaches to economic activity, as manifest by the use of limited biological metaphors and tools associated with search on a landscape or phase space. We highlight how the notion of bounded rationality—central to key theories in entrepreneurship, strategy, and organization science—is anchored on a computational view of search behavior and, thus, is not able to explain the emergence of novelty nor properly account for entrepreneurial activity. Extant approaches prespecify the phase space or economic landscape and then highlight the computational boundaries and limitations of actors. While this approach improves on extreme versions of efficient market-type arguments that focus on the omniscience of economic actors, the focus on bounded search also features some critical deficiencies. For example, the focus on the NP problem and more general notions of bounded rationality direct our attention to calculation, computational limitation, and insufficiency rather than emergent novelty. We argue that the frame problem more readily captures the central question for explaining the emergence of novelty, both in nature as well as in entrepreneurial or economic settings. We provide examples from biology (lungfish), as well as common-day surroundings (screwdrivers), to highlight how novel uses and functionalities emerge—ones that cannot be prestated or listed. Overall, we argue that computational and algorithmic tools and metaphors and, more generally, the use of mathematically pre-given phase spaces, mis-specify rather than clarify our understanding of novelty. We argue that entrepreneurial activity, emergent novelty, and heterogeneity are best captured by focusing more carefully on the endogenous nature of organisms, including economic actors, and by focusing on the constraints that enable the emergence of future adjacent possibilities.

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