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The WonderWeb Library of Foundational Ontologies
Preliminary Report

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[1] National Research Council, Institute of Cognitive Sciences and Technology. The ontology group formerly at LADSEB-CNR has now joined this new institute. The rest of LADSEB-CNR has joined another new institute, ISIB-CNR (Institute for Biomedical Engineering). Formal changes to the WonderWeb's contract are in progress.

WonderWeb Project

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15-08-2002	V2.0	1. New author added (Stefano Borgo) 2. Adjustements to the main taxonomy: a. The endurant/perdurant distinction does not involve qualities b. ‘Arbitrary collection’ replaced with ‘Arbitrary sum’ of endurants c. ‘Relevant part’ and ‘Place’ removed from the taxonomy (only informal discussion) 3. Parthood not defined for qualities; axiomatization of qualities improved. 4. Axiomatization and theorems extensivelly checked and revised 5. Comments on pseudo-second order quantification on universals revised 6. Function symbols replaced by relation symbols (thanks to Pawel Garbacz) 7. Informal presentation improved 8. Axiomatization of occurrences improved 9. Many others!

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1 Introduction

Ontologies are the basic infrastructure for the Semantic Web. Everybody agrees on this, as the very idea of the Semantic Web hinges on the possibility to use shared vocabularies for describing resource content and capabilities, whose semantics is described in a (reasonably) unambiguous and machine-processable form. Describing this semantics, i.e. what is sometimes called the *intended meaning* of vocabulary terms, is exactly the job ontologies do for the Semantic Web.

But what *kinds* of ontologies do we need? This is still an open issue. Some people believe that *upper level* ontologies are important, others think they are a waste of time, and prefer to concentrate on *lightweight* ontologies, focusing on the minimal terminological structure (often just a taxonomy) which fits the needs of a specific community.

The point is that ontologies can be used in different ways within the Semantic Web. On one hand, for instance, they can be used for *semantic access* to a specific resource; in this case the intended meaning of a single term is more or less known in advance, and the ontology can be limited to those structural relationships among terms which are relevant for the query (in many cases, taxonomic relationships are enough).

On the other hand, ontologies can be used to *negotiate meaning*, either for enabling effective cooperation between multiple artificial agents, or for *establishing consensus* in a mixed society where artificial agents cooperate with human beings. This is a completely different task for ontologies, which requires the explicit representation of *ontological commitment* in terms of a rich axiomatization. The axiomatization's purpose is to exclude terminological and conceptual ambiguities, due to unintended interpretations. In general, meaning negotiation is of course an extremely hard task (both conceptually and computationally), but it only needs to be undertaken *once*, before a cooperation process starts. The quality of a meaning negotiation process may drastically affect the *trust* in a service offered by the Semantic Web, but not the computational performance of the service itself. For example, a product procurement process involving multiple agents with distributed lightweight ontologies may be carried out in an efficient way by using simple terminological services, but the risk of semantic mismatch can be minimized only if the agents share a (more or less minimal) common ontology.

1.1 The WonderWeb Foundational Ontologies Library

In WonderWeb, we use the term "foundational ontologies" for the ontologies of the second kind above, ultimately devoted to facilitate mutual understanding. Our vision is to have *a library* of such ontologies, reflecting different commitments and purposes, rather than a single monolithic module. Indeed, we believe that the most important challenge for the Semantic Web is not so much the agreement on a monolithic set of ontological categories, but rather the careful isolation of the fundamental ontological options and their formal relationships. In our view, each module in this library should be described in terms of such fundamental options. Rationales and alternatives underlying the different ontological choices should be made as explicit as possible, in order to form a network of different but systematically related modules which the various Semantic Web applications can commit to, according to their ontological assumptions. In this view, making people (and computers) *understand one another* (and possibly understanding the reasons of ontological disagreement) is more important than enforcing interoperability by the adoption of a single ontology.

In short, the main goals of the WonderWeb Foundational Ontologies Library (WFOL, see Figure 1) are to serve as:

- a starting point for building new ontologies. One of the most important and critical questions when starting a new ontology is determining what things there are in the domain to be modeled. Adopting a high level view provides an enormous jump start in answering this question;

- a reference point for easy and rigorous comparisons among different ontological approaches;
- a foundational framework for analyzing, harmonizing and integrating existing ontologies and metadata standards (by manually mapping existing categories into the categories assumed by some module(s) in the library).

In addition, we intend the library to be:

- *minimal* – as opposed to other comprehensive ontology efforts, we intend the library to be as general as possible, including only the most reusable and widely applicable upper-level categories;
- *rigorous* – where possible, the ontologies in the libraries will be characterized by means of rich axiomatizations, and the formal consequences (theorems) of such characterizations will be explored in detail;
- *extensively researched* – each module in the library will be added only after careful evaluation by experts and consultation with canonical works. The basis for ontological choices will be documented and referenced.

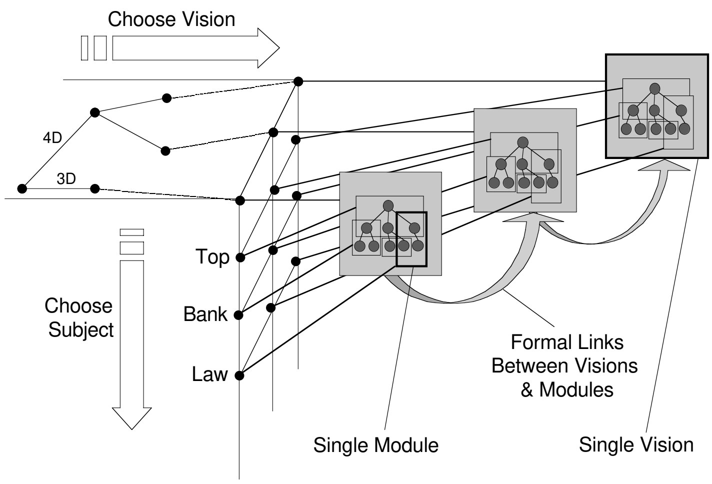

Figure 1. The WonderWeb Foundational Ontologies Library. The tree to the left describes a "roadmap" of ontological choices. Grey squares to the right correspond to ontologies (possibly) developed according to such choices. In turn, these are organized in modules according to domain specificity.

1.2 OWL and WFOL

Among other things, the WonderWeb project is committed to develop a layered language architecture for representing ontologies in the Semantic Web, based on existing standards such as RDF and DAML+OIL. OWL (Ontology Web Language) is a recent name intended to replace DAML+OIL. It is intended to be used as a language for representing and querying *ontologies* on the Web, and it is being carefully design in order to offer the best possible tradeoff between expressivity and computational efficiency, while guaranteeing at the same time important logical properties such as inferential completeness. The result is however a logical language whose expressivity is much lower than first-order logic.

Using such a language for specifying foundational ontologies would be non-sensical: because of their very goals and nature, these ontologies need an expressive language, in order to suitably characterize their intended models. On the other hand, as we have noted above, their computational requirements are less stringent, since they only need to be accessed for meaning negotiation, not for terminological services where the intended meaning of terms is already agreed upon.

The strategy we have devised to solve this expressivity problem is the following:

1. Describe a foundational ontology on paper, using a full first-order logic with modality;
2. Isolate the part of the axiomatization that can be expressed in OWL, and implement it;
3. Add the remaining part in the form of KIF[1] comments attached to OWL concepts.

1.3 Paper structure

In this paper we present DOLCE, the first module of the WFOL. It is described using first-order logic, according to the point 1 above. In the next section we introduce informally the specific assumptions adopted for this module, along with the basic categories, functions, and relations. In Section 3 we present a rich axiomatic characterization, aimed at clarifying our assumptions and illustrate their formal consequences (theorems).

2 DOLCE: a Descriptive Ontology for Linguistic and Cognitive Engineering

2.1 Basic assumptions

The first module of our foundational ontologies library is a Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE). According to the vision introduced above, we do *not* intend DOLCE as a candidate for a "universal" standard ontology. Rather, it is intended to act as starting point for comparing and elucidating the relationships with other future modules of the library, and also for clarifying the hidden assumptions underlying existing ontologies or linguistic resources such as WordNet.
As reflected by its acronym, DOLCE has a clear *cognitive bias*, in the sense that it aims at capturing the ontological categories underlying natural language and human commonsense. We believe that such bias is very important for the Semantic Web (especially if we recognize its intrinsic social nature [Castelfranchi 2001]). We do not commit to a strictly referentialist metaphysics related to the intrinsic nature of the world: rather, the categories we introduce here are thought of as cognitive artifacts ultimately depending on human perception, cultural imprints and social conventions (a sort of "cognitive" metaphysics). We draw inspiration here from Searle's notion of "deep background" [Searle 1983], which represents the set of skills, tendencies and habits shared by humans because of their peculiar biological make up, and their evolved ability to interact with their ecological niches. The consequences of this approach are that our categories are at the so-called *mesoscopic* level [Smith 1995], and they do not claim any special robustness against the state of the art in scientific knowledge: they are just *descriptive* notions that assist in making *already formed* conceptualizations explicit. They do not provide therefore a *prescriptive* (or "revisionary" [Strawson 1959]) framework to conceptualize entities. In other words, our categories describe entities in an *ex post* way, reflecting more or less the surface structures of language and cognition.

DOLCE is an ontology of *particulars*, in the sense that its domain of discourse is restricted to them. The fundamental ontological distinction between *universals* and *particulars* can be informally understood by taking the relation of *instantiation* as a primitive: particulars are entities which have no instances[2]; universals are entities that can have instances. Properties and relations (corresponding to predicates in a logical language) are usually considered as universals. We take the ontology of universals as formally separated from that of particulars. Of course, universals *do* appear in an ontology of particulars, insofar they are used to organize and characterize them: simply, since they are not in the domain of discourse, they are not themselves subject to being

[1] Indeed, we are considering the new language CL (cl.tamu.edu), which is an extension of KIF.
[2] More exactly, we should say that they *can't* have instances. This coincides with saying that they have no instances, since we include *possibilia* (possible instances) in our domain.

organized and characterized (e.g., by means of *metaproperties*). An ontology of unary universals has been presented in [Guarino and Welty 2000]. In this paper, we shall occasionally use notions (e.g., rigidity) taken from such work in our meta-language.

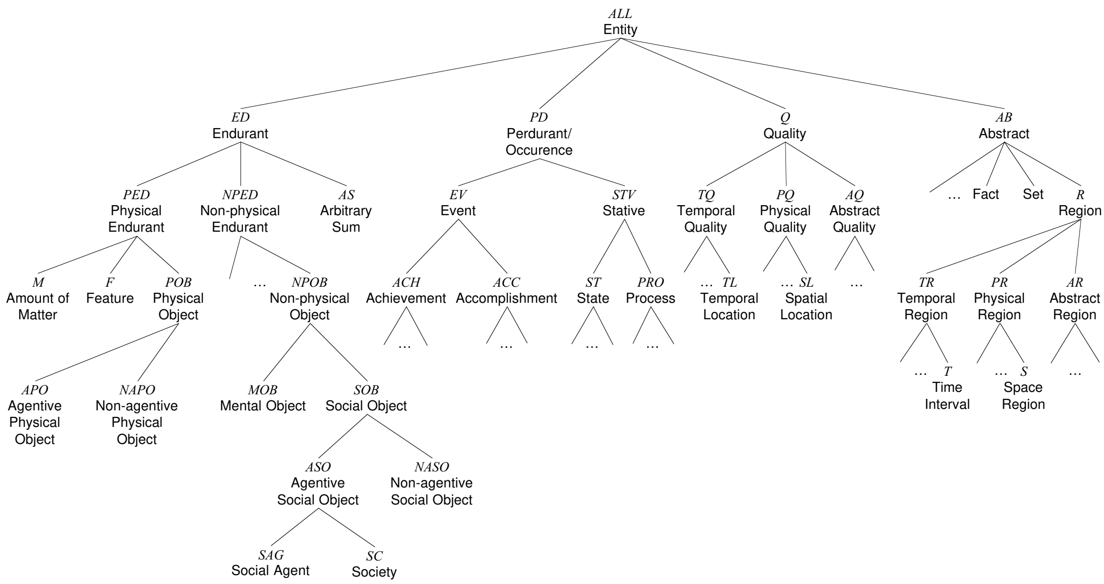

Figure 2. Taxonomy of DOLCE basic categories.

A basic choice we make in DOLCE is the so-called *multiplicative approach*: different entities can be *co-located* in the same space-time. The reason why we *assume* they are different is because we *ascribe* to them incompatible essential properties. The classical example is that of the vase and the amount of clay: necessarily, the vase does not survive a radical change in shape or topology, while, necessarily, the amount of clay does. Therefore the two things must be different, yet co-located: as we shall see, we say that the vase is *constituted* by an amount of clay, but it is not an amount of clay[1]. Certain properties a particular amount of clay happened to have when it was shaped by the vase-master are considered as essential for the *emergence* of a new entity. In language and cognition, we refer to this new entity as a genuine different thing: for instance, we say that a vase has a handle, but not that a piece of clay has a handle.
A similar multiplicative attitude concerns the introduction of categories which in principle could be reduced to others. For instance, suppose we want to explore whether or not having points in addition to regions (or vice versa) in one's ontology. It seems safe to assume the existence of both kind of entities, in order to study their formal relationships (and possibly their mutual reducibility), rather than committing on just one kind of entity in advance. Hence, when in doubt, we prefer to introduce new categories, since it is easy to explain their general behavior, while keeping at the same time the conceptual tools needed to account for their specific characteristics.

2.2 Basic categories

The taxonomy of the most basic categories of particulars assumed in DOLCE is depicted in Figure 2. They are considered as *rigid* properties, according to the OntoClean methodology that stresses the importance of focusing on these properties first. Some examples of "leaf" categories instances are illustrated in Table 1.

[1] One of the purposes of the OntoClean methodology [Guarino and Welty 2002, Guarino and Welty 2002] is to help the user evaluating ontological choices like this one.

"Leaf" Basic Category	Examples
Abstract Quality	*the value of an asset*
Abstract Region	*the (conventional) value of 1 Euro*
Accomplishment	*a conference, an ascent, a performance*
Achievement	*reaching the summit of K2, a departure, a death*
Agentive Physical Object	*a human person (as opposed to legal person)*
Amount of Matter	*some air, some gold, some cement*
Arbitrary Sum	*my left foot and my car*
Feature	*a hole, a gulf, an opening, a boundary*
Mental Object	*a percept, a sense datum*
Non-agentive Physical Object	*a hammer, a house, a computer, a human body*
Non-agentive Social Object	*a law, an economic system, a currency, an asset*
Physical Quality	*the weight of a pen, the color of an apple*
Physical Region	*the physical space, an area in the color spectrum, 80Kg*
Process	*running, writing*
Social Agent	*a (legal) person, a contractant*
Society	*Fiat, Apple, the Bank of Italy*
State	*being sitting, being open, being happy, being red*
Temporal Quality	*the duration of World War I, the starting time of the 2000 Olympics*
Temporal Region	*the time axis, 22 june 2002, one second*

Table 1. Examples of "leaf" basic categories.

Endurants and Perdurants

DOLCE is based on a fundamental distinction between *enduring* and *perduring* entities, i.e. between what philosophers usually call *continuants* and *occurrents* [Simons 1987], a distinction still strongly debated both in the philosophical literature [Varzi 2000] and within ontology standardization initiatives[1]. Again, we must emphasise that this distinction is motivated by our cognitive bias, and we do not commit to the fact that both these kinds of entity "do really exist".

Classically, the difference between enduring and perduring entities (which we shall also call *endurants* and *perdurants*) is related to their behavior in time. Endurants are *wholly* present (i.e., all their proper parts are present) at any time they are present. Perdurants, on the other hand, just extend in time by accumulating different temporal parts, so that, at any time they are present, they are only *partially* present, in the sense that some of their proper temporal parts (e.g., their previous or future phases) may be not present. E.g., the piece of paper you are reading now is wholly present, while some temporal parts of your reading are not present any more. Philosophers say that endurants are entities that *are in time*, while lacking however temporal parts (so to speak, all their parts flow with them in time). Perdurants, on the other hand, are entities that *happen in time*, and can have temporal parts (all their parts are fixed in time)[2].

Hence endurants and perdurants can be characterised by whether or not they can exhibit change in time. Endurants can "genuinely" change in time, in the sense that the very same endurant as a whole can have incompatible properties at different times; perdurants

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[1] See for instance the extensive debate about the "3D" vs. the "4D" approach at suo.ieee.org, or the SNAP/SPAN opposition sketched at ontology.buffalo.edu/bfo

[2] Time-snapshots of perdurants (i.e., in our time structure, perdurants whose temporal location is atomic, and which lack therefore proper temporal parts) are a limit case in this distinction. We consider them as perdurants since we assume that their temporal location is fixed (a time-snapshot at a different time would be a different time-snapshot).

cannot change in this sense, since none of their parts keeps its identity in time. To see this, suppose that an endurant say "this paper" has a property at a time *t* "it's white", and a different, incompatible property at time *t'* "it's yellow": in both cases we refer to the whole object, without picking up any particular part of it. On the other hand, when we say that a perdurant "running a race" has a property at *t* "running fast" (say during the first five minutes) and an incompatible property at *t'* "running slow" (say toward the end of the race) there are always two different parts exhibiting the two properties.
Another way of characterizing endurants and perdurants – quite illuminating for our purposes – has been proposed recently by Katherine Hawley: something is an endurant iff (i) it exists at more than one moment and (ii) statements about what parts it has must be made relative to some time or other [Hawley 2001]. In other words, the distinction is based on the different nature of the parthood relation when applied to the two categories: endurants need a time-indexed parthood, while perdurants do not. Indeed, a statement like "this keyboard is part of my computer" is incomplete unless you specify a particular time, while "my youth is part of my life" does not require such specification.
In DOLCE, the main relation between endurants and perdurants is that of *participation*: an endurant "lives" in time by *participating* in some perdurant(s). For example, a person, which is an endurant, may participate in a discussion, which is a perdurant. A person's life is also a perdurant, in which a person participates throughout its all duration.
In the following, we shall take the term *occurrence* as synonym of *perdurant*. We prefer this choice to the more common *occurrent*, which we reserve for denoting a type (a *universal*), whose instances are occurrences (*particulars*).

Qualities and quality regions

Qualities can be seen as the basic entities we can perceive or measure: shapes, colors, sizes, sounds, smells, as well as weights, lengths, electrical charges… 'Quality' is often used as a synonymous of 'property', but this is not the case in DOLCE: qualities are particulars, properties are universals. Qualities *inhere* to entities: every entity (including qualities themselves) comes with certain qualities, which exist as long as the entity exists.[1] Within a certain ontology, we assume that these qualities belong to a finite set of *quality types* (like color, size, smell, etc., corresponding to the "leaves" of the quality taxonomy shown in Figure 2), and are characteristic for (*inhere in*) specific individuals: no two particulars can have the same quality, and each quality is *specifically constantly dependent* (see below) on the entity it inheres in: at any time, a quality can't be present unless the entity it inheres in is also present. So we distinguish between a quality (e.g., the color of a specific rose), and its "value" (e.g., a particular shade of red). The latter is called *quale*, and describes the position of an individual quality within a certain *conceptual space* (called here *quality space*) [Gärdenfors 2000]. So when we say that two roses have (exactly) the same color, we mean that their color qualities, which are distinct, have the same position in the color space, that is they have the same *color quale*.

1. *This rose is red*
2. *Red is a color*
3. *This rose has a color*
4. *The color of this rose turned to brown in one week*
5. *The rose's color is changing*
6. *Red is opposite to green and close to brown*

Table 2. Some linguistic examples motivating the introduction of individual qualities.

This distinction between qualities and qualia is inspired by [Goodman 1951] and the so-called *trope theory* [Campbell 1990] (with some differences that are not discussed here[2]).

[1] We do not consider, for the time being, the possibility of a quality that intermittently inheres to something (for instance, an object that ceases to have a color while becoming transparent).
[2] An important difference is that standard trope theories explain a qualitative change in terms of a substitution of tropes (an old trope disappears and a new one is created). We assume instead that

Its intuitive rationale is mainly due to the fact that natural language – in certain constructs – often seems to make a similar distinction (Table 2). For instance, in cases 4 and 5 of Table 2, we are not speaking of a certain shade of red, but of something else that keeps its identity while its 'value' changes.
On the other hand, in case 6 we are not speaking of qualities, but rather of regions within quality spaces. The specific shade of red of our rose – its color quale – is therefore a point (or an atom, mereologically speaking) in the color space.[1]
Each quality type has an associated quality space with a specific structure. For example, lengths are usually associated to a metric linear space, and colors to a topological 2D space. The structure of these spaces reflects our perceptual and cognitive bias: this is another important reason for taking the notion of "quale", as used in philosophy of mind, to designate quality regions, which roughly correspond to qualitative sensorial experiences of humans[2].
In this approach, we can explain the relation existing between 'red' intended as an adjective (as in "this rose is red") and 'red' intended as a noun (as in "red is a color"): the rose is red because its color is located in the red region within the color space (more exactly, its color quale is a part of that region). Moreover, we can explain the difference between "this rose is red" and "the color of this rose is red" by interpreting "red" as synonymous of *red-thing* in the first case, and of *red-color* in the latter case (Figure 3).

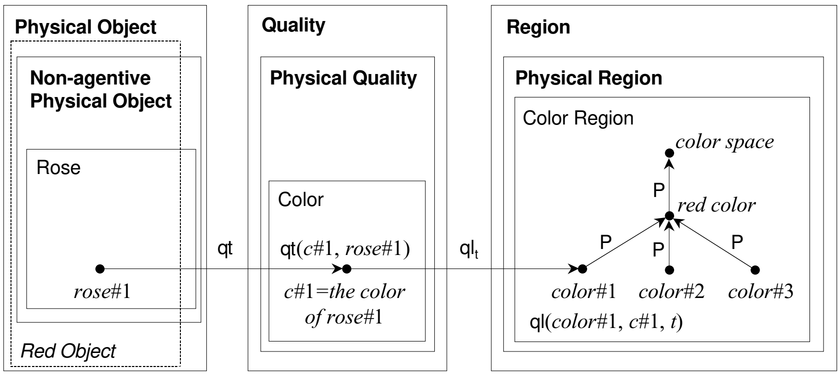

Figure 3. Qualities and quality regions.

Space and time locations as special qualities

In our ontology, space and time locations are considered as individual qualities like colors, weights, etc. Their corresponding qualia are called *spatial* (*temporal*) *regions*. For example, the spatial location of a physical object belongs to the quality type *space*, and its quale is a region in the geometric space. Similarly for the temporal location of an occurrence, whose quale is a region in the temporal space. This allows an homogeneous approach that remains neutral about the properties of the geometric/temporal space adopted (for instance, one is free to adopt linear, branching, or even circular time).

Direct and indirect qualities

We distinguish in DOLCE two kinds of quality inherence: *direct* and *indirect* inherence. The main reason for this choice comes from the symmetric behavior of perdurants and endurants with respect to their temporal and spatial locations: perdurants have a well-defined temporal location, while their spatial location seems to come indirectly from the spatial location of their participants; similarly, most endurants (what we call *physical endurants*, see below) have a clear spatial location, while their temporal location comes

qualities persist in time during a qualitative change (note however that they are not endurants, since the parthood relation is not defined for them).
[1] The possibility of talking of qualia as particulars rather than reified properties is another advantage of our approach.
[2] We also allow for non-sensorial "qualia" such as "a 1 Euro value" (fixed by social conventions and independent from perception)

indirectly from the that of the perdurants they participate in.
Another argument for this distinction concerns complex qualities like colors, which – according to Gardenfors – exhibit multiple *dimensions* (hue, luminosity, etc.). We model this case by assuming that such dimensions are qualities of qualities: the quality *color of rose#1* has a specific hue that directly inheres to it, and indirectly inheres to *rose#1*.

Parts of qualities

As a final comment, we must observe that no parthood relation (neither temporal nor atemporal) is defined for qualities in the DOLCE ontology. This seems to us a safe choice, since apparently we do not need to reason about parts of qualities (while we certainly do need to reason on parts of quality regions). So we do not have to commit on a single kind of parthood relationship for them (maybe some of them need a temporal parthood, while others do not). Since no parthood is defined, qualities are neither endurants nor perdurants, although their persistence conditions may be similar, in certain cases, to those of endurants or perdurants.

Abstract entities

The main characteristic of abstract entities is that they do not have spatial nor temporal qualities, and they are not qualities themselves. The only class of abstract entities we consider in the present version of DOLCE is that of *quality regions* (or simply *regions*). *Quality spaces* are special kinds of quality regions, being mereological sums of all the regions related to a certain quality type. The other examples of abstract entities reported in Figure 2 (sets and facts) are only indicative.

2.3 Basic functions and relations

According to the general methodology introduced in [Gangemi *et al.* 2001], before discussing the DOLCE *backbone* properties, we have first to introduce a set of *basic primitive relations*, suitable to characterize our ontological commitments as neutrally as possible. We believe that these relations should be, as much as possible,

- general enough to be applied to multiple domains;
- such that they do not rest on questionable ontological assumptions about the ontological nature of their arguments;
- sufficiently intuitive and well studied in the philosophical literature;
- hold as soon as their relata are given, without mediating additional entities.

In the past, we adopted the term *formal relation* (as opposite to *material relation*) for a relation that can be applied to *all* possible domains. Recently, however, [Degen *et al.* 2001] proposed a different notion of formal relation: "A relation is *formal* if it holds as soon as its relata are given. Formal relations are called equivalently *immediate relations*, since they hold of their relata without mediating additional individuals"[1]. The notion of *basic primitive relation* proposed above combines together the two notions. Roughly, a basic primitive relation is an immediate relation that spans multiple application domains.
The axioms constraining the arguments of primitive relations and functions are reported in Table 3, and summarized in Figure 4.

[1] The notion of 'immediate relation' seems to be equivalent to what Johansson called *ground relation* [Johansson 1989]. According to Johansson, a ground relation "is derivable from its relata". We understand that the very existence of the arguments is *sufficient* to conclude whether the relation holds or not. This notion seems also equivalent to that of "internal relation".

Parthood: "*x is part of y*" $\mathsf{P}(x, y) \rightarrow (AB(x) \vee PD(x)) \wedge (AB(y) \vee PD(y))$
Temporary Parthood: "*x is part of y during t*" $\mathsf{P}(x, y, t) \rightarrow (ED(x) \wedge ED(y) \wedge T(t))$
Constitution: "*x constitutes y during t*" $\mathsf{K}(x, y, t) \rightarrow ((ED(x) \vee PD(x)) \wedge (ED(y) \vee PD(y)) \wedge T(t))$
Participation: "*x participates in y during t*" $\mathsf{PC}(x, y, t) \rightarrow (ED(x) \wedge PD(y) \wedge T(t))$
Quality: "*x is a quality of y*" $\mathsf{qt}(x, y) \rightarrow (Q(x) \wedge (Q(y) \vee ED(y) \vee PD(y)))$
Quale: "*x is the quale of y* (*during t*)" $\mathsf{ql}(x, y) \rightarrow (TR(x) \wedge TQ(y))$ $\mathsf{ql}(x, y, t) \rightarrow ((PR(x) \vee AR(x)) \wedge (PQ(y) \vee AQ(y)) \wedge T(t))$

Table 3. Basic axioms on argument restrictions of primitives.

Parthood and Temporary Parthood

The endurants/perdurants distinction introduced in the previous section provides evidence for the general necessity of having two kinds of parthood relations: a-temporal and time-indexed parthood. The latter will hold for endurants, since for them it is necessary to know *when* a specific parthood relationship holds. Consider for instance the classical example of Tibbles the cat [Simons 1987]: Tail is part of Tibbles before the cut but not after it. Formally, we can write *P*(Tail, Tibbles, *before*(cut)) and ¬*P*(Tail, Tibbles, *after*(cut)). Atemporal parthood, on the other hand, will be used for entities which do not properly change in time (occurrences and abstracts). In the present version, parthood will not be defined for qualities.

With respect to time-indexed parthood, two useful notions can be defined. We shall say that an endurant is *mereologically constant* iff all its parts remains the same during its life, and *mereologically invariant* iff they remain the same across all possible worlds. For example, we usually take ordinary material objects as mereologically variable, because during their life they can lose or gain parts. On the other hand, amounts of matter are taken as mereologically invariant (all their parts are *essential parts*).

Dependence and Spatial Dependence

There are basically two approaches to characterizing the notion of ontological dependence:

- non-modal accounts (cf. [Fine and Smith 1983] and [Simons 1987] , pp. 310-318)
- modal accounts (cf. [Simons 1987]).

Non-modal approaches treat the dependence relation as a quasi-mereological primitive whose formal properties are characterized by axioms. However, as Simons has justly observed, such axiomatizations cannot rule out non-intended interpretations that are purely topological in nature. The only way to save them is actually to link them with modal accounts.
In a modal approach, dependence of an entity *x* on an entity *y* might be defined as follows: *x* depends on *y* iff, necessarily, *y* is present whenever *x* is present. Such a definition seems to be in harmony both with commonsense intuition as well as philosophical tradition (Aristotle, Husserl), despite the fact that there are some cases where, as Kit Fine has shown, this characterization is vacuous. Indeed, according to the definition, everything is trivially dependent on necessarily existing or always present

objects. However, Simons has shown that it is possible to exclude such vacuous examples and while this move might be philosophically dubious, it makes perfect sense in an engineering approach to ontologies of everyday contingent objects.
Our concept of dependence involves the notion of presence in time as well as modality. We mainly use two variants of dependence, adapted from [Thomasson 1999]: *specific* and *generic constant dependence*. The former is defined both for particulars and properties, while the latter only for properties. A particular *x* is *specifically constantly dependent* on another particular *y* iff, at any time *t*, *x* can't be present at *t* unless *y* is also present at *t*. For example, a person might be specifically constantly dependent on its brain. This notion is naturally extended to properties by defining that a property ϕ is specifically constantly dependent on a property ψ iff every ϕer is specifically constantly dependent on a ψer. A property ϕ is *generically constantly dependent* on a property ψ iff, for any instance *x* of ϕ, at any time *t*, *x* can't be present at *t*, unless a certain instance *y* of ψ is also present at *t*. For example, a person might be generically constantly dependent on having a heart.
We define spatial dependence as a particular kind of dependence which is grounded not only in time (presence), but also in space. The definitions are as above with the further requirement that *y* has to be spatially co-localised with *x* in addition of being co-present. This notion is defined both for endurants and perdurants.

Constitution

Constitution has been extensively discussed in the philosophical literature:

- Doepke (cit. in [Simons 1987] p.238) "*x* constitutes *y* at time *t* iff *x* could be a substratum of *y*'s destruction."
- Simons (cit. in [Simons 1987] p.239) "When *x* constitutes *y*, there are certain properties of *x* which are *accidental* to *x*, but essential to *y*. (…) Where the essential properties concern the type and disposition of parts, this is often a case of composition, but in other cases, such as that of body/person, it is not."

Constitution is not Identity – Consider the following classical example. I buy a portion of clay (*LUMPL*) at 9am. At 2pm I made a statue (*GOLIATH*) out of *LUMPL* and I put *GOLIATH* on a table. At 3pm I replace the left hand of *GOLIATH* with a new one and I throw the old hand in the dustbin. There are three reasons to support the claim that *LUMPL* is not *GOLIATH*:

(*i*) *Difference in histories*
LUMPL is present a 9am, but *GOLIATH* is not [Thomson 1998]

(*ii*) *Difference in persistence conditions*
At 3pm *GOLIATH* is wholly present on the table, but *LUMPL* is not wholly present on the table (a statue can undergo replacements of certain parts, but not an amount (portion) of matter, i.e. all parts of *LUMPL* are essential but not all parts of *GOLIATH* are essential [Thomson 1998]. *LUMPL* can survive a change of shape, *GOLIATH* not.

(*iii*) *Difference in essential relational properties*
It is metaphysically possible for *LUMPL*, but not for *GOLIATH*, to exist in the absence of an artworld or an artist or anybody's intentions [Baker 2000].

Participation

The usual intuition about participation is that there are endurants "involved" in an occurrence. Linguistics has extensively investigated the relation between occurrences and their participants in order to classify verbs and verbal expressions. Fillmore's Case Grammar [Fillmore 1984] and its developments (Construction Grammar, FrameNet) is one of the best attempts at building a systematic model of language-oriented participants. On the other hand, the first systematic investigation goes back at least to Aristotle, that defined four "causes" (aitiai), expressing the initiator, the destination, the instrument, and

the substrate or host of an event. Sowa further specified subsets of aitiai on the basis of properties borrowed from linguistics (cfr. [Sowa 1999]).
In an ontology based on a strict distinction between endurants and perdurants, participation cannot be simply parthood; the participating endurants are not parts of the occurrences: only occurrences can be parts of other occurrences. Moreover, the primitive participation we introduce is time-indexed, in order to account for the varieties of participation in time (temporary participation, constant participation).

Quality inherence and quality value

Finally, three primitive relations are introduced in order to account for qualities: a generalized (direct or indirect) primitive relation[1], holding between a quality and what it inheres to, and two kinds of "quale" relations (time-indexed and atemporal), holding between a quality and its quale, according to whether the entity to which the quality inheres can change in time or not.

2.4 Further distinctions

Let us discuss in the following some further distinctions we make within our basic categories, defined with the help of the functions and relations introduced in the previous section.

Physical and non-physical endurants

Within endurants, we distinguish between *physical* and *non-physical endurants*, according to whether they have direct spatial qualities. Within physical endurants, we distinguish between *amounts of matter*, *objects*, and *features*. This distinction is mainly based on the notion of unity we have discussed and formalized in [Gangemi *et al.* 2001][2]. In principle, the general structure of such distinction is supposed to hold also for non-physical endurants: nevertheless, we direct fully exploit it only for physical endurants, since the characteristics of non-physical features have not been considered yet.

Amounts of matter

The common trait of *amounts of matter* is that they are endurants with no unity (according to [Gangemi *et al.* 2001], none of them is an essential whole). Amounts of matter – "stuffs" referred to by mass nouns like "gold", "iron", "wood", "sand", "meat", etc. – are mereologically invariant, in the sense that they change their identity when they change some parts.

Objects

The main characteristic of objects is that they are endurants with unity. However, they have no *common* unity criterion, since different subtypes of objects may have different unity criteria. Differently from aggregates, (most) objects change some of their parts while keeping their identity, they can have therefore *temporary parts*. Often objects (indeed, all endurants) are ontologically independent from occurrences (discussed below). However, if we admit that every object has a life, it is hard to exclude a mutual specific constant dependence between the two. Nevertheless, we may still use the notion of dependence to (weakly) characterize objects as being not specifically constantly dependent *on other objects*.

Features

Typical examples of features are "parasitic entities" such as holes, boundaries, surfaces, or stains, which are generically constantly dependent on physical objects[3] (their hosts). All

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[1] Direct inherence can be easily defined in terms of indirect inherence. The viceversa seem to be more problematic, since it would involve a recursive definition.
[2] In this preliminary report, such formalization has not been included in the axiomatization presented below.
[3] We may think that features are specifically constantly dependent on their host, but an example like "a whirlpool" is very critical in this sense. Notice that we are not considering as features entities that are

features are essential wholes, but, as in the case of objects, no common unity criterion may exist for all of them. However, typical features have a topological unity, as they are singular entities. Some features may be *relevant parts* of their host, like a bump or an edge, or *places* like a hole in a piece of cheese, the underneath of a table, the front of a house, which are not parts of their host.
It may be interesting to note that we do not consider body parts like heads or hands as features: the reason is that we assume that a hand can be detached from its host (differently from a hole or a bump), and we assume that in this case it retains its identity. Should we reject this assumption, then body parts would be features.

Non-physical endurants and the agentive/non-agentive distinction

Within Physical Objects, a special place have those those to which we ascribe *intentions, beliefs,* and *desires*. These are called *Agentive*, as opposite to *Non-agentive*. Intentionality is understood here as the capability of heading for/dealing with objects or states of the world[1]. This is an important area of ontological investigation we haven't properly explored yet, so our suggestions are really very preliminary.
In general, we assume that agentive objects are *constituted* by non-agentive objects: a person is constituted by an organism, a robot is constituted by some machinery, and so on. Among non-agentive physical objects we have for example houses, body organs, pieces of wood, etc.
Non-physical Objects are divided into *Social Objects and Mental Objects* according to whether or not they are are generically dependent a community of agents. A private experience, for istance, is an example of a mental object.
Social Objects are further divided into *Agentive* and *Non-agentive*. Examples of Agentive Social Objects are *social agents* like "the president of United States": we may think that the latter, besides depending generically on a community of US citizens, depends also generically on "George Bush *qua* legal person" (since the president can be substituted), which in turn depends specifically on "George Bush *qua* human being". Social agents are *not* constituted by agentive physical objects (although they depend on them), while they can constitute *societies,* like the CNR, Mercedes-Benz, etc. Examples of *Non-Agentive Social Objects* are laws, norms, shares, peace treaties ecc., which are generically dependent on societies.

Kinds of perdurants

Perdurants (also called occurrences) comprise what are variously called events, processes, phenomena, activities and states. They can have temporal parts or spatial parts. For instance, the first movement of (an execution of) a symphony is a temporal part of it. On the other side, the play performed by the left side of the orchestra is a spatial part. In both cases, these parts are occurrences themselves. We assume that objects cannot be parts of occurrences, but rather they *participate* in them.
In DOLCE we distinguish among different kinds of occurrences mainly on the basis of two notions, both extensively discussed in the linguistic and philosophic literature: *homeomericity* and *cumulativity*. The former is discussed for instance in [Casati and Varzi 1996]; the latter has been introduced in [Goodman 1951, pp. 49-51], and refined in [Pelletier 1979].
Intuitively, we say that an occurrence is homeomeric if and only if all its temporal parts are described *by the very expression* used for the whole occurrence. Every temporal part of the occurrence "John sitting here" is still described by "John sitting here". But if we consider "a walk from *Ponte dei Sospiri* in Venice to *Piazza S. Marco*", there are no parts of such an event which constitute a walk from these two places. In linguistic as well as in philosophical terminology, the notion of the *homeomericity* of an occurrence is often introduced with respect to a property characteristic of (or *exemplified by*) the occurrence itself. If such property holds for all the temporal parts of the occurrence, then the occurrence is homeomeric. In our axiomatization, this presupposes a finite list of

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dependent on mental-objects.
[1] See for example [Searle 1983].

occurrence-types (*occurrents*) which have to be declared in advance.
An occurrence-type is *stative* or *eventive* according to whether it holds of the mereological sum of two of its instances, *i.e.* if it is *cumulative* or not. A *sitting* occurrence is stative since the sum of two sittings is still a sitting occurrence. Within stative occurrences, we distinguish between *states* and *processes* according to homeomericity: *sitting* is classified as a state but *running* is classified as a process, since there are (very short) temporal parts of a running that are not themselves runnings.
Finally, eventive occurrences (*events*) are called *achievements* if they are atomic, otherwise they are *accomplishments*.

Kinds of quality

We assume that qualities belong to disjoint quality types according to kinds of entity they directly inhere to. That is, *temporal qualities* are those that directly inhere to perdurants, *physical qualities* those that directly inhere to physical endurants, and *abstract qualities* those that directly inhere to non-physical perdurants (Figure 4). We are aware that, unfortunately, this terminology is very problematic: for instance, it should be clear that abstract qualities are *not* abstracts, since they have a temporal location. Better suggestions are welcome.

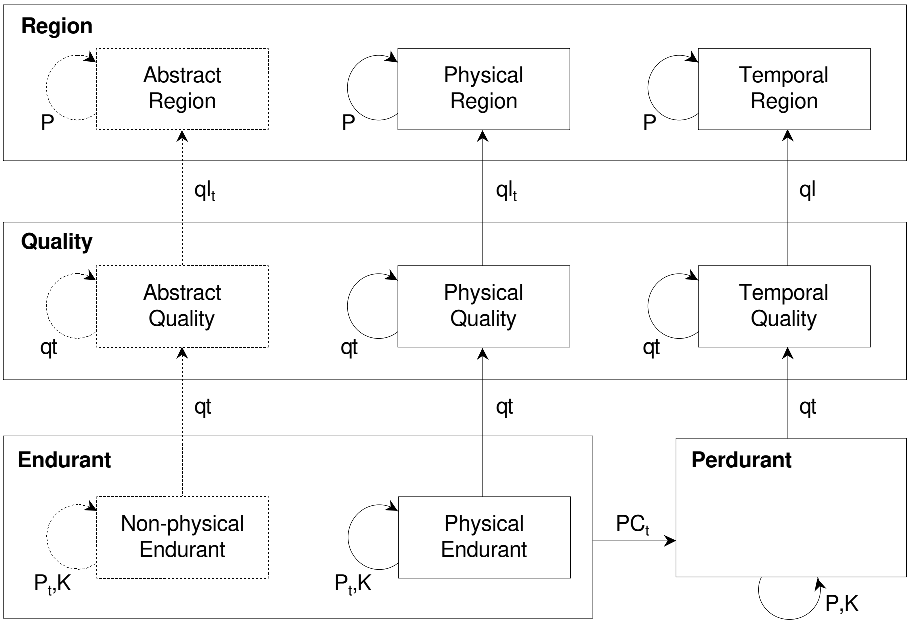

Figure 4. Primitive relations between basic categories.[1]

[1] The dotted lines to the left indicate that we are less confident with what concerns non-physical endurants.

3 Formal Characterization

3.1 Notation and introductory notes

Notation – In the following, we shall adopt the conventions below for variable and constant symbols:

Constants denoting Particulars: a, b, c, …
Variables ranging on Particulars: x, y, z, …
Constants denoting Universals: T, R, Q, …
Variables ranging on Universals: ϕ, ψ, φ, …

Modality and Time – In this module we shall adopt the simplest quantified modal logic, namely S5 plus the Barcan Formula [Hughes and Cresswell 1996]. This means that we assume a *possibilist* view including in the domain of quantification all *possibilia* – all possible entities – independently of their actual existence [Lewis 1983], and that we quantify over a constant domain in every possible world (recall that all axioms and theorems are necessarily true even if the necessity box $\Box$ is not present in front of the formulas). In addition, we assume an *eternalist* view of time, including in the domain of quantification all past, present and future entities/intervals.

Universals – In some cases we shall quantify over properties, and hence one might believe we have to adopt a second-order logic. However, for our purpose, we need to quantify only over a finite list of predicates, those that are explicitly introduced in the present theory or in any theory that specializes (commits to) the present one. We follow therefore the strategy proposed by the Common Logic working group[1], which is to view, under suitable conditions, a second-order axiom (or definition) as syntactic sugar for a finite list of first-order axioms (definitions). Formally:

- all variables ϕ, ψ, φ, … range on a finite set (Π) of explicitly introduced universals;
- the subclass of Π, that corresponds to the categories introduced Figure 2, is called Π_X and it is identified by means of the (meta)predicate X: $X(\phi)$ iff $\phi \in \Pi_X$;
- existential quantifiers on universals, $\exists\phi(\phi(x))$, correspond to $\bigvee_{\psi \in \Pi}(\psi(x))$;
- universal quantifiers on universals, $\forall\phi(\phi(x))$ correspond to $\bigwedge_{\psi \in \Pi}(\psi(x))$;

More explicitly, in DOLCE we consider:

Π_X = {*ALL*, *AB*, *R*, *TR*, *T*, *PR*, *S*, *AR*, *Q*, *TQ*, *TL*, *PQ*, *SL*, *AQ*, *ED*, *PED*, *M*, *F*, *POB*, *APO*, *NAPO*, *NPED*, *NPOB*, *MOB*, *SOB*, *ASO*, *SAG*, *SC*, *NASO*, *AS*, *PD*, *EV*, *ACH*, *ACC*, *STV*, *ST*, *PRO*};

We can introduce some useful notions regarding universals:

(D1) $\mathsf{RG}(\phi) =_{df} \Box\forall x(\phi(x) \rightarrow \Box\phi(x))$ (ϕ *is Rigid*)
(D2) $\mathsf{NEP}(\phi) =_{df} \Box\exists x(\phi(x))$ (ϕ *is Non-Empty*)
(D3) $\mathsf{DJ}(\phi, \psi) =_{df} \Box\neg\exists x(\phi(x) \wedge \psi(x))$ (ϕ *and* ψ *are Disjoint*)
(D4) $\mathsf{SB}(\phi, \psi) =_{df} \Box\forall x(\psi(x) \rightarrow \phi(x))$ (ϕ *Subsumes* ψ)
(D5) $\mathsf{EQ}(\phi, \psi) =_{df} \mathsf{SB}(\phi, \psi) \wedge \mathsf{SB}(\psi, \phi)$ (ϕ *and* ψ *are Equal*)
(D6) $\mathsf{PSB}(\phi, \psi) =_{df} \mathsf{SB}(\phi, \psi) \wedge \neg\mathsf{EQ}(\phi, \psi)$ (ϕ *Properly Subsumes* ψ)
(D7) $\mathsf{L}(\phi) =_{df} \Box\forall\psi(\mathsf{SB}(\phi, \psi) \rightarrow \mathsf{EQ}(\phi, \psi))$ (ϕ *is a Leaf*)
(D8) $\mathsf{SBL}(\phi, \psi) =_{df} \mathsf{SB}(\phi, \psi) \wedge \mathsf{L}(\psi)$ (ψ *is a Leaf Subsumed by* ϕ)

[1] See cl.tamu.edu.

(D9) $\mathsf{PSBL}(\phi, \psi) =_{df} \mathsf{PSB}(\phi, \psi) \wedge \mathsf{L}(\psi)$ (ψ *is a Leaf Properly Subsumed by* ϕ)
(D10) $\mathsf{L}_X(\phi) =_{df} \mathsf{X}(\phi) \wedge \Box\forall\psi((\mathsf{SB}(\phi, \psi) \wedge \mathsf{X}(\phi)) \rightarrow \mathsf{EQ}(\phi, \psi))$ (ϕ *is a Leaf in* Π^X)
(D11) $\mathsf{SBL}_X(\phi, \psi) =_{df} \mathsf{SB}(\phi, \psi) \wedge \mathsf{L}_X(\psi)$
(D12) $\mathsf{PSBL}_X(\phi, \psi) =_{df} \mathsf{PSB}(\phi, \psi) \wedge \mathsf{L}_X(\psi)$
(D13) $\mathsf{PT}(\psi, \phi_1, \ldots, \phi_n) =_{df} \mathsf{DJ}(\phi_i, \phi_j)$ for $1 \leq i \neq j \leq n \wedge$
$\Box\forall x(\psi(x) \leftrightarrow (\phi_1(x) \vee \ldots \vee \phi_n(x)))$ ($\phi_1, \ldots, \phi_n$ *is a Partition of* ψ)

All predicates in Π are assumed to be non-empty; all predicates in Π_X are assumed to be rigid, i.e.:

$\forall\phi(\mathsf{NEP}(\phi))$
$\forall\phi(\mathsf{X}(\phi) \rightarrow \mathsf{RG}(\phi))$

Moreover, all the taxonomy branches shown in Figure 2 are considered as partitions (except for partially specified branches, where dots are shown), i.e. for example:

$\mathsf{PT}(ALL, AB, Q, ED, PD)$, $\mathsf{PT}(R, TR, PR, AR)$, $\mathsf{PT}(ED, PED, NEPD, AS)$, …
$\mathsf{SB}(AB, R)$, $\mathsf{SB}(TQ, TL)$, $\mathsf{SB}(PQ, SL)$, …

3.2 Definitions

Mereological Definitions

(D14) $\mathsf{PP}(x, y) =_{df} \mathsf{P}(x, y) \wedge \neg\mathsf{P}(y, x)$ (*Proper Part*)
(D15) $\mathsf{O}(x, y) =_{df} \exists z(\mathsf{P}(z, x) \wedge \mathsf{P}(z, y))$ (*Overlap*)
(D16) $\mathsf{At}(x) =_{df} \neg\exists y(\mathsf{PP}(y, x))$ (*Atom*)
(D17) $\mathsf{AtP}(x, y) =_{df} \mathsf{P}(x, y) \wedge \mathsf{At}(x)$ (*Atomic Part*)
(D18) $x + y =_{df} \iota z\forall w(\mathsf{O}(w, z) \leftrightarrow (\mathsf{O}(w, x) \vee \mathsf{O}(w, y)))$ (*Binary Sum*)
(D19) $\sigma x\phi(x) =_{df} \iota z\forall y(\mathsf{O}(y, z) \leftrightarrow \exists w(\phi(w) \wedge \mathsf{O}(y, w)))$[1] (*Sum of* ϕ*'s*)

(D20) $\mathsf{PP}(x, y, t) =_{df} \mathsf{P}(x, y, t) \wedge \neg\mathsf{P}(y, x, t)$ (*Temporary Proper Part*)
(D21) $\mathsf{O}(x, y, t) =_{df} \exists z(\mathsf{P}(z, x, t) \wedge \mathsf{P}(z, y, t))$ (*Temporary Overlap*)
(D22) $\mathsf{At}(x, t) =_{df} \neg\exists y(\mathsf{PP}(y, x, t))$ (*Temporary Atom*)
(D23) $\mathsf{AtP}(x, y, t) =_{df} \mathsf{P}(x, y, t) \wedge \mathsf{At}(x, t)$ (*Temporary Atomic Part*)
(D24) $x \equiv_t y =_{df} \mathsf{P}(x, y, t) \wedge \mathsf{P}(y, x, t)$ (*Coincidence*)
(D25) $\mathsf{CP}(x, y) =_{df} \exists t(\mathsf{PR}(y, t)) \wedge \forall t(\mathsf{PR}(y, t) \rightarrow \mathsf{P}(x, y, t))$ (*Constant Part*)
(D26) $x +' y =_{df} \iota z\forall w,t(\mathsf{O}(w, z, t) \leftrightarrow (\mathsf{O}(w, x, t) \vee \mathsf{O}(w, y, t)))$
(D27) $\sigma' x\phi(x) =_{df} \iota z\forall y,t(\mathsf{O}(y, z, t) \leftrightarrow \exists w(\phi(w) \wedge \mathsf{O}(y, w, t)))$[2]

Quality

(D28) $\mathsf{dqt}(x, y) =_{df} \mathsf{qt}(x, y) \wedge \neg\exists z(\mathsf{qt}(x, z) \wedge \mathsf{qt}(z, y))$ (*Direct Quality*)
(D29) $\mathsf{qt}(\phi, x, y) =_{df} \mathsf{qt}(x, y) \wedge \phi(x) \wedge \mathsf{SBL}_X(Q, \phi)$ (*Quality of type* ϕ)

Temporal and Spatial Quale

(D30) $\mathsf{ql}_{T,PD}(t, x) =_{df} PD(x) \wedge \exists z(\mathsf{qt}(TL, z, x) \wedge \mathsf{ql}(t, z))$
(D31) $\mathsf{ql}_{T,ED}(t, x) =_{df} ED(x) \wedge t = \sigma t'(\exists y(\mathsf{PC}(x, y, t))$
(D32) $\mathsf{ql}_{T,TQ}(t, x) =_{df} TQ(x) \wedge \exists z(\mathsf{qt}(x, z) \wedge \mathsf{ql}_{T,PD}(t, z))$
(D33) $\mathsf{ql}_{T,PQ\vee AQ}(t, x) =_{df} (PQ(x) \vee AD(x)) \wedge \exists z(\mathsf{qt}(x, z) \wedge \mathsf{ql}_{T,ED}(t, z))$
(D34) $\mathsf{ql}_{T,Q}(t, x) =_{df} \mathsf{ql}_{T,TQ}(t, x) \vee \mathsf{ql}_{T,PQ\vee AQ}(t, x)$
(D35) $\mathsf{ql}_T(t, x) =_{df} \mathsf{ql}_{T,ED}(t, x) \vee \mathsf{ql}_{T,PD}(t, x) \vee \mathsf{ql}_{T,Q}(t, x)$ (*Temporal Quale*)

[1] In this case the property ϕ do not belong in general to Π, but is a generic property definable in the language of *DOLCE*.
[2] This definition may be problematic if ϕ depends on time. However, in the following, we apply it only to atemporal properties.

(D36) $\mathrm{ql}_{S,PED}(s, x, t) =_{df} PED(x) \wedge \exists z(\mathrm{qt}(SL, z, x) \wedge \mathrm{ql}(s, z, t))$

(D37) $\mathrm{ql}_{S,PQ}(s, x, t) =_{df} PQ(x) \wedge \exists z(\mathrm{qt}(x, z) \wedge \mathrm{ql}_{S,PED}(s, z, t))$

(D38) $\mathrm{ql}_{S,PD}(s, x, t) =_{df} PD(x) \wedge \exists z(\mathrm{mppc}(z, x, t) \wedge \mathrm{ql}_{S,PED}(s, z, t))$

(D39) $\mathrm{ql}_{S}(s, x, t) =_{df} \mathrm{ql}_{S,PED}(s, x, t) \vee \mathrm{ql}_{S,PQ}(s, x, t) \vee \mathrm{ql}_{S,PD}(s, x, t)$ (*Spatial Quale*)

Note – The *temporal quale* function is not defined in the case of abstract entities. The *spatial quale* function is not defined in the case of non-physical endurants, abstract qualities, non-physical perdurants (i.e. perdurants that have only non-physical participants))[1], and abstract entities.

Being present

(D40) $\mathrm{PR}(x, t) =_{df} \exists t'(\mathrm{ql}_{T}(t', x) \wedge \mathrm{P}(t, t'))$ (*Being Present at t*)

(D41) $\mathrm{PR}(x, s, t) =_{df} \mathrm{PR}(x, t) \wedge \exists s'(\mathrm{ql}_{S}(s', x, t) \wedge \mathrm{P}(s, s'))$ (*Being Present in s at t*)

Inclusion and Coincidence

(D42) $x \subseteq_{T} y =_{df} \exists t,t'(\mathrm{ql}_{T}(t, x) \wedge \mathrm{ql}_{T}(t', y) \wedge \mathrm{P}(t, t'))$ (*Temporal Inclusion*)

(D43) $x \subset_{T} y =_{df} \exists t,t'(\mathrm{ql}_{T}(t, x) \wedge \mathrm{ql}_{T}(t', y) \wedge \mathrm{PP}(t, t'))$ (*Proper Temporal Inclusion*)

(D44) $x \subseteq_{S,t} y =_{df} \exists s,s'(\mathrm{ql}_{S}(s, x, t) \wedge \mathrm{ql}_{S}(s', y, t) \wedge \mathrm{P}(s, s'))$ (*Temporary Spatial Inclusion*)

(D45) $x \subset_{S,t} y =_{df} \exists s,s'(\mathrm{ql}_{S}(s, x, t) \wedge \mathrm{ql}_{S}(s', y, t) \wedge \mathrm{PP}(s, s'))$ (*Temp. Proper Sp. Inclusion*)

(D46) $x \subseteq_{ST} y =_{df} \exists t(\mathrm{PR}(x, t)) \wedge \forall t(\mathrm{PR}(x, t) \rightarrow x \subseteq_{S,t} y)$ (*Spatio-temporal Inclusion*)

(D47) $x \subseteq_{ST,t} y =_{df} \mathrm{PR}(x, t) \wedge \forall t'(\mathrm{AtP}(t', t) \rightarrow x \subseteq_{S,t'} y)$ (*Spatio-temp. Incl. during t*)

(D48) $x \approx_{T} y =_{df} (x \subseteq_{T} y \wedge y \subseteq_{T} x)$ (*Temporal Coincidence*)

(D49) $x \approx_{S,t} y =_{df} (x \subseteq_{S,t} y \wedge y \subseteq_{S,t} x)$ (*Temporary Spatial Coincidence*)

(D50) $x \approx_{ST} y =_{df} (x \subseteq_{ST} y \wedge y \subseteq_{ST} x)$ (*Spatio-temporal Coincidence*)

(D51) $x \approx_{ST,t} y =_{df} \mathrm{PR}(x, t) \wedge \forall t'(\mathrm{AtP}(t', t) \rightarrow x \approx_{S,t'} y)$ (*Spatio-temp. Coinc. during t*)

(D52) $x \bigcirc_{T} y =_{df} \exists t,t'(\mathrm{ql}_{T}(t, x) \wedge \mathrm{ql}_{T}(t', y) \wedge \mathrm{O}(t, t'))$ (*Temporal Overlap*)

(D53) $x \bigcirc_{S,t} y =_{df} \exists s,s'(\mathrm{ql}_{S}(s, x, t) \wedge \mathrm{ql}_{S}(s', y, t) \wedge \mathrm{O}(s, s'))$ (*Temporary Spatial Overlap*)

Perdurant

(D54) $\mathrm{P}_{T}(x, y) =_{df} PD(x) \wedge \mathrm{P}(x, y) \wedge \forall z((\mathrm{P}(z, y) \wedge z \subseteq_{T} x) \rightarrow \mathrm{P}(z, x))$ (*Temporal Part*)

(D55) $\mathrm{P}_{S}(x, y) =_{df} PD(x) \wedge \mathrm{P}(x, y) \wedge x \approx_{T} y$ (*Spatial Part*)

(D56) $\mathrm{NEP}_{S}(\phi) =_{df} \mathrm{SB}(PD, \phi) \wedge \Box\exists x,y(\phi(x) \wedge \phi(y) \wedge \neg\mathrm{P}(x, y) \wedge \neg\mathrm{P}(y, x))$
(ϕ *is Strongly Non-Empty*)

(D57) $\mathrm{CM}(\phi) =_{df} \mathrm{SB}(PD, \phi) \wedge \Box\forall x,y((\phi(x) \wedge \phi(y)) \rightarrow \phi(x + y))$ (ϕ *is Cumulative*)

(D58) $\mathrm{CM}^{\sim}(\phi) =_{df} \mathrm{SB}(PD, \phi) \wedge \Box\forall x,y((\phi(x) \wedge \phi(y) \wedge \neg\mathrm{P}(x, y) \wedge \neg\mathrm{P}(y, x)) \rightarrow \neg\phi(x + y))$
(ϕ *is Anti-Cumulative*)

(D59) $\mathrm{HOM}(\phi) =_{df} \mathrm{SB}(PD, \phi) \wedge \Box\forall x,y((\phi(x) \wedge \mathrm{P}_{T}(y, x)) \rightarrow \phi(y))$ (ϕ *is Homeomerous*)

(D60) $\mathrm{HOM}^{\sim}(\phi) =_{df} \mathrm{SB}(PD, \phi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\mathrm{P}_{T}(y, x) \wedge \neg\phi(y)))$ (ϕ *is Anti-Homeom.*)

(D61) $\mathrm{AT}(\phi) =_{df} \mathrm{SB}(PD, \phi) \wedge \Box\forall x(\phi(x) \rightarrow \mathrm{At}(x))$ (ϕ *is Atomic*)

(D62) $\mathrm{AT}^{\sim}(\phi) =_{df} \mathrm{SB}(PD, \phi) \wedge \Box\forall x(\phi(x) \rightarrow \neg\mathrm{At}(x))$ (ϕ *is Anti-Atomic*)

Participation

(D63) $\mathrm{PC}_{C}(x, y) =_{df} \exists t(\mathrm{PR}(y, t)) \wedge \forall t(\mathrm{PR}(y, t) \rightarrow \mathrm{PC}(x, y, t))$ (*Constant Participation*)

(D64) $\mathrm{PC}_{T}(x, y, t) =_{df} PD(x) \wedge \forall z((\mathrm{P}(z, y) \wedge \mathrm{PR}(z, t)) \rightarrow \mathrm{PC}(x, z, t))$
(*Temporary Total Particip.*)

(D65) $\mathrm{PC}_{T}(x, y) =_{df} \exists t(\mathrm{ql}_{T}(t, y) \wedge \mathrm{PC}_{T}(x, y, t))$ (*Total Participation*)

(D66) $\mathrm{mpc}(x, y) =_{df} x = \sigma' z(\mathrm{PC}_{T}(z, y))$ (*Maximal Participant*)

(D67) $\mathrm{mppc}(x, y) =_{df} x = \sigma' z(\mathrm{PC}_{T}(z, y) \wedge PED(z))$ (*Maximal Physical Participant*)

[1] In order to generalize the spatial quale function in the case of non-physical entities we need a function that specify (for each temporal interval) the physical endurant on which a non-physical endurant depends.

(D68) $\mathsf{lf}(x, y) =_{df} x = \sigma z(\mathsf{PC_T}(y, z))$ (*x is the Life of y*)

Dependence

(see Figure 5 for a summary of dependence relations between the basic categories)

(D69) $\mathsf{SD}(x, y) =_{df} \Box(\exists t(\mathsf{PR}(x, t)) \wedge \forall t(\mathsf{PR}(x, t) \rightarrow \mathsf{PR}(y, t)))$ (*Specific Const. Dep.*)
(D70) $\mathsf{SD}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathsf{SD}(x, y)))$ (*Specific Const. Dep.*)
(D71) $\mathsf{GD}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t(\mathsf{PR}(x, t)) \wedge \forall x,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, t)) \rightarrow \exists y(\psi(y) \wedge \mathsf{PR}(y, t))))$ (*Generic Const. Dep.*)
(D72) $\mathsf{D}(\phi, \psi) =_{df} \mathsf{SD}(\phi, \psi) \vee \mathsf{GD}(\phi, \psi))$ (*Constant Dependence*)
(D73) $\mathsf{OD}(\phi, \psi) =_{df} \mathsf{D}(\phi, \psi) \wedge \neg\mathsf{D}(\psi, \phi)$ (*One-sided Constant Dependence*)
(D74) $\mathsf{OSD}(\phi, \psi) =_{df} \mathsf{SD}(\phi, \psi) \wedge \neg\mathsf{D}(\psi, \phi)$ (*One-sided Specific Constant Dependence*)
(D75) $\mathsf{OGD}(\phi, \psi) =_{df} \mathsf{GD}(\phi, \psi) \wedge \neg\mathsf{D}(\psi, \phi)$ (*One-sided Generic Constant Dependence*)
(D76) $\mathsf{MSD}(\phi, \psi) =_{df} \mathsf{SD}(\phi, \psi) \wedge \mathsf{SD}(\psi, \phi)$ (*Mutual Specific Constant Dependence*)
(D77) $\mathsf{MGD}(\phi, \psi) =_{df} \mathsf{GD}(\phi, \psi) \wedge \mathsf{GD}(\psi, \phi)$ (*Mutual Generic Constant Dependence*)

Note – Since regions are not present in time, the definition of dependence does not make sense for them.

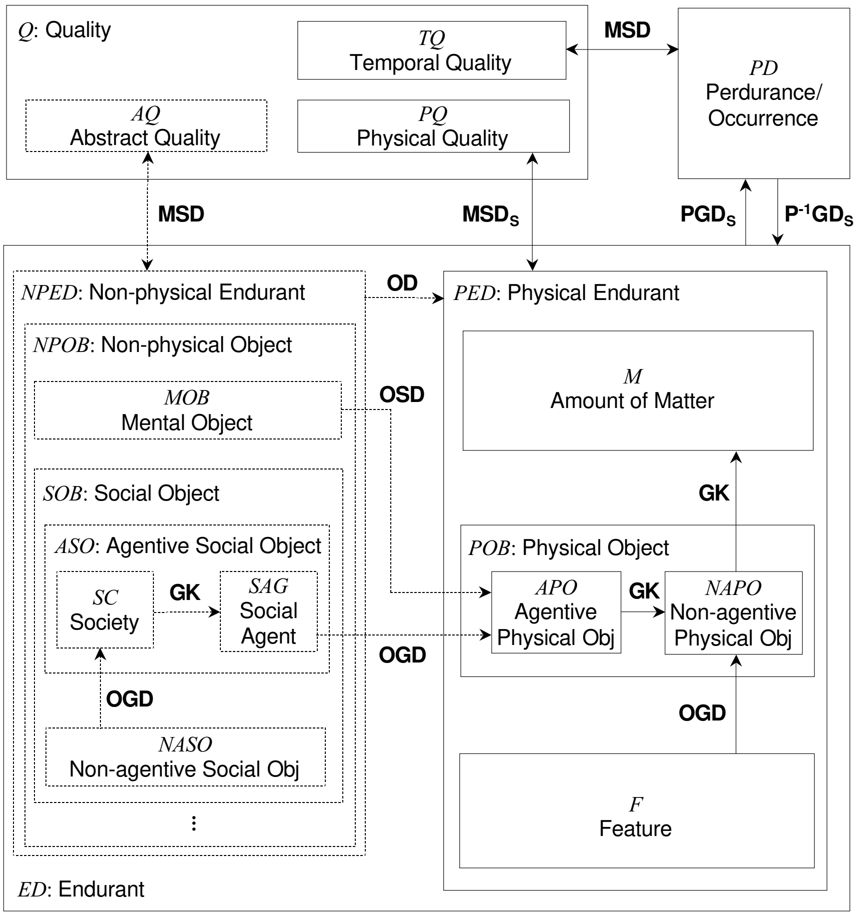

Figure 5. Constitution and (spatial) dependence relations between basic categories.

Spatial Dependence

(see Figure 5 for a summary of spatial dependence relations between the basic categories)

(D78) $\mathsf{SD_S}(x, y) =_{df} \Box(\exists t,s(\mathsf{PR}(x, s, t)) \wedge \forall s,t(\mathsf{PR}(x, s, t) \rightarrow \mathsf{PR}(y, s, t)))$
(*Specific Spatial Dependence*)

(D79) $\mathsf{PSD_S}(x, y) =_{df} \Box(\exists t,s(\mathsf{PR}(x, s, t)) \wedge \forall s,t(\mathsf{PR}(x, s, t) \rightarrow \exists s'(\mathsf{PP}(s', s) \wedge \mathsf{PR}(y, s', t))))$
(*Partial Specific Spatial Dependence*)

(D80) $\mathsf{P^{-1}SD_S}(x, y) =_{df} \Box(\exists t,s(\mathsf{PR}(x,s,t)) \wedge \forall s,t(\mathsf{PR}(x, s, t) \rightarrow \exists s'(\mathsf{PP}(s, s') \wedge \mathsf{PR}(y, s', t))))$
(*Inverse Partial Specific Spatial Dependence*)

(D81) $\mathsf{SD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathsf{SD_S}(x, y)))$

(D82) $\mathsf{PSD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathsf{PSD_S}(x, y)))$

(D83) $\mathsf{P^{-1}SD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathsf{P^{-1}SD_S}(x, y)))$

(D84) $\mathsf{GD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t,s(\mathsf{PR}(x, s, t)) \wedge$
$\forall x,s,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, s, t)) \rightarrow \exists y(\psi(y) \wedge \mathsf{PR}(y, s, t))))$
(*Generic Spatial Dependence*)

(D85) $\mathsf{PGD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t,s(\mathsf{PR}(x, s, t)) \wedge$
$\forall x,s,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, s, t)) \rightarrow \exists y,s'(\psi(y) \wedge \mathsf{PP}(s', s) \wedge \mathsf{PR}(y, s', t))))$
(*Partial Generic Spatial Dependence*)

(D86) $\mathsf{P^{-1}GD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t,s(\mathsf{PR}(x, s, t)) \wedge$
$\forall x,s,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, s, t)) \rightarrow \exists y,s'(\psi(y) \wedge \mathsf{PP}(s, s') \wedge \mathsf{PR}(y, s', t))))$
(*Inverse Partial Generic Spatial Dependence*)

(D87) $\mathsf{DGD_S}(\phi, \psi) =_{df} \mathsf{GD_S}(\phi, \psi) \wedge \neg\exists\varphi(\mathsf{GD_S}(\phi, \varphi) \wedge \mathsf{GD_S}(\varphi, \psi))$
(*Direct Generic Spatial Dependence*)

(D88) $\mathsf{SD_S}(x, y, t) =_{df} \mathsf{SD_S}(x, y) \wedge \mathsf{PR}(x, t)$ (*Temporary Specific Spatial Dependence*)

(D89) $\mathsf{GD_S}(x, y, t) =_{df} \exists\phi,\psi(\phi(x) \wedge \psi(y) \wedge \mathsf{GD_S}(\phi, \psi) \wedge x \approx_{S,t} y)$ (*Temp. Gen. Sp. Dep.*)

(D90) $\mathsf{DGD_S}(x, y, t) =_{df} \exists\phi,\psi(\phi(x) \wedge \psi(y) \wedge \mathsf{DGD_S}(\phi, \psi) \wedge x \approx_{S,t} y)$
(*Temp. Direct Sp. Dep.*)

(D91) $\mathsf{OSD_S}(\phi, \psi) =_{df} \mathsf{SD_S}(\phi, \psi) \wedge \neg\mathsf{D}(\psi, \phi)$ (*One-sided Specific Spatial Dependence*)

(D92) $\mathsf{OGD_S}(\phi, \psi) =_{df} \mathsf{GD_S}(\phi, \psi) \wedge \neg\mathsf{D}(\psi, \phi)$ (*One-sided Generic Spatial Dependence*)

(D93) $\mathsf{MSD_S}(\phi, \psi) =_{df} \mathsf{SD_S}(\phi, \psi) \wedge \mathsf{SD_S}(\psi, \phi)$ (*Mutual Specific Spatial Dependence*)

(D94) $\mathsf{MGD_S}(\phi, \psi) =_{df} \mathsf{GD_S}(\phi, \psi) \wedge \mathsf{GD_S}(\psi, \phi)$ (*Mutual Generic Spatial Dependence*)

Note – If $\mathsf{DGD_S}(\phi, \psi)$ holds, this does not imply that there could not be another φ such that $\mathsf{DGD_S}(\varphi, \psi)$ also holds. That is, we do not exclude at the moment the possibility of two different properties which are generically directly spatially dependent on a given property. If we allow this, then we have no proper stratification with respect to spatial dependence, in the sense that there is no total order between the strata. In order to guarantee the latter, we would need axioms like the following (a similar argument can be made for constitution):

$(\mathsf{DGD_S}(\phi, \psi) \wedge \mathsf{DGD_S}(\varphi, \psi)) \rightarrow \varphi = \phi$
$(\mathsf{DGD_S}(\phi, \psi) \wedge \mathsf{DGD_S}(\phi, \varphi)) \rightarrow \varphi = \psi$

Constitution

(see Figure 5 for a summary of constitution relations between the basic categories))

(D95) $\mathsf{DK}(x, y, t) =_{df} \mathsf{K}(x, y, t) \wedge \neg\exists z(\mathsf{K}(x, z, t) \wedge \mathsf{K}(z, y, t))$ (*Direct Constitution*)

(D96) $\mathsf{SK}(x, y) =_{df} \Box(\exists t(\mathsf{PR}(x, t)) \wedge \forall t(\mathsf{PR}(x, t) \rightarrow \mathsf{K}(y, x, t)))$
(*x is Constantly Specifically Constituted by y*)

(D97) $\mathsf{SK}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathsf{SK}(x, y)))$
(ϕ *is Constantly Specifically Constituted by* ψ)

(D98) $\mathsf{GK}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t(\mathsf{PR}(x, t)) \wedge$
$\forall x,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, t)) \rightarrow \exists y(\psi(y) \wedge \mathsf{K}(y, x, t))))$
(ϕ *is Constantly Generically Constituted by* ψ)

(D99) $\mathsf{K}(\phi, \psi) =_{df} \mathsf{SK}(\phi, \psi) \vee \mathsf{GK}(\phi, \psi))$ (ϕ *is Constituted by* ψ)
(D100) $\mathsf{OSK}(\phi, \psi) =_{df} \mathsf{SK}(\phi, \psi) \wedge \neg\mathsf{K}(\psi, \phi)$ (ϕ *is One-sided Cons. Specif. Const. by* ψ)
(D101) $\mathsf{OGK}(\phi, \psi) =_{df} \mathsf{GK}(\phi, \psi) \wedge \neg\mathsf{K}(\psi, \phi)$ (ϕ *is One-sided Cons. Generic. Const. by* ψ)
(D102) $\mathsf{MSK}(\phi, \psi) =_{df} \mathsf{SK}(\phi, \psi) \wedge \mathsf{SK}(\psi, \phi)$ (*Mutual Specific Constitution*)
(D103) $\mathsf{MGK}(\phi, \psi) =_{df} \mathsf{GK}(\phi, \psi) \wedge \mathsf{GK}(\psi, \phi)$ (*Mutual Generic Constitution*)

3.3 Characterization of functions and relations

Parthood

We shall adopt for atemporal parthood the axioms of atomic General Extensional Mereology (GEM), with the classical definitions of overlap, proper part, atom, etc.

Argument Restrictions
(A1) $\mathsf{P}(x, y) \rightarrow (AB(x) \vee PD(x)) \wedge (AB(y) \vee PD(y))$
(A2) $\mathsf{P}(x, y) \rightarrow (PD(x) \leftrightarrow PD(y))$
(A3) $\mathsf{P}(x, y) \rightarrow (AB(x) \leftrightarrow AB(y))$
(A4) $(\mathsf{P}(x, y) \wedge \mathsf{SB}(R, \phi) \wedge \mathsf{X}(\phi)) \rightarrow (\phi(x) \leftrightarrow \phi(y))$
Ground Axioms
(A5) $(AB(x) \vee PD(x)) \rightarrow \mathsf{P}(x, x)$
(A6) $(\mathsf{P}(x, y) \wedge \mathsf{P}(y, x)) \rightarrow x = y$
(A7) $(\mathsf{P}(x, y) \wedge \mathsf{P}(y, z)) \rightarrow \mathsf{P}(x, z)$
(A8) $((AB(x) \vee PD(x)) \wedge \neg\mathsf{P}(x, y)) \rightarrow \exists z(\mathsf{P}(z, x) \wedge \neg\mathsf{O}(z, y))$
(A9) $(\exists x\phi(x) \wedge (\forall x(\phi(x) \rightarrow AB(x)) \vee \forall x(\phi(x) \rightarrow PD(x)))) \rightarrow \exists y(y = \sigma x\phi(x))$

Temporary Parthood

We drop antisymmetry and we slightly modify the axioms for P by introducing the *infinite sum* defined in (D27).

Argument restrictions
(A10) $\mathsf{P}(x, y, t) \rightarrow (ED(x) \wedge ED(y) \wedge T(t))$
(A11) $\mathsf{P}(x, y, t) \rightarrow (PED(x) \leftrightarrow PED(y))$
(A12) $\mathsf{P}(x, y, t) \rightarrow (NPED(x) \leftrightarrow NPED(y))$
Ground Axioms
(A13) $(\mathsf{P}(x, y, t) \wedge \mathsf{P}(y, z, t)) \rightarrow \mathsf{P}(x, z, t)$
(A14) $(ED(x) \wedge ED(y) \wedge \mathsf{PR}(x, t) \wedge \mathsf{PR}(y, t) \wedge \neg\mathsf{P}(x, y, t)) \rightarrow \exists z(\mathsf{P}(z, x, t) \wedge \neg\mathsf{O}(z, y, t))$
(A15) $(\exists x\phi(x) \wedge \forall x(\phi(x) \rightarrow ED(x))) \rightarrow \exists y(y = \sigma' x\phi(x))$
Links With Other Primitives
(A16) $(ED(x) \wedge \mathsf{PR}(x, t)) \rightarrow \mathsf{P}(x, x, t)$
(A17) $\mathsf{P}(x, y, t) \rightarrow (\mathsf{PR}(x, t) \wedge \mathsf{PR}(y, t))$
(A18) $\mathsf{P}(x, y, t) \rightarrow \forall t'(\mathsf{P}(t', t) \rightarrow \mathsf{P}(x, y, t'))$
(A19) $(PED(x) \wedge \mathsf{P}(x, y, t)) \rightarrow x \subseteq_{S,t} y$

Debatable axiom:
(AP=) $(\mathsf{CP}(x, y) \wedge \mathsf{CP}(y, x)) \rightarrow x = y$

Note – With the introduction of (A15) we are accepting the existence of intermittent objects. Consider for example the sum of two objects that are temporally extended in disjoint intervals. In this case we have a theorem like $\mathsf{PR}(c_1 + c_2, t) \leftrightarrow \mathsf{PR}(c_1, t) \vee \mathsf{PR}(c_2, t)$. Alternatively, we could define a different sum of temporally co-extensional endurants. (cf. [Simons 1987] and [Thomson 1998]).
Note – The unicity of the product is guaranteed only if (AP=) is introduced.
Note – We can alternatively consider $\mathsf{P}(x, y, t)$ as defined only on temporal atoms, by substituting (A18) wiht $\mathsf{P}(x, y, t) \rightarrow \mathsf{At}(t)$.
Note – It may be interesting to study the cases where the law of substitution restricted to coincident entities is valid. In other words, we may want to study the circumstances

where, given a temporary n+1-ary relation between particulars $\mathsf{Rel}(x_1, \ldots, x_n, t)$, then $(\mathsf{Rel}(x_1, \ldots, x_n, t) \wedge x_1 \equiv_t y_1 \wedge \ldots \wedge x_n \equiv_t y_n) \rightarrow \mathsf{Rel}(y_1, \ldots, y_n, t)$.
Note – Clearly, extensionality does not hold for temporary parthood. That is, *having the same parts* does not imply *being the same*. Nevertheless, we have still to decide whether or not *having the same proper parts* means *being coincident*: $\mathsf{P}(x, y, t) \leftrightarrow \forall z(\mathsf{PP}(z, x, t) \rightarrow \mathsf{P}(z, y, t))$.

Constitution

Argument restrictions
(A20) $\mathsf{K}(x, y, t) \rightarrow ((ED(x) \vee PD(x)) \wedge (ED(y) \vee PD(y)) \wedge T(t))$
(A21) $\mathsf{K}(x, y, t) \rightarrow (PED(x) \leftrightarrow PED(y))$
(A22) $\mathsf{K}(x, y, t) \rightarrow (NPED(x) \leftrightarrow NPED(y))$
(A23) $\mathsf{K}(x, y, t) \rightarrow (PD(x) \leftrightarrow PD(y))$
Ground Axioms
(A24) $\mathsf{K}(x, y, t) \rightarrow \neg\mathsf{K}(y, x, t)$
(A25) $(\mathsf{K}(x, y, t) \wedge \mathsf{K}(y, z, t)) \rightarrow \mathsf{K}(x, z, t)$
Links with other Primitives
(A26) $\mathsf{K}(x, y, t) \rightarrow (\mathsf{PR}(x, t) \wedge \mathsf{PR}(y, t))$
(A27) $\mathsf{K}(x, y, t) \leftrightarrow \forall t'(\mathsf{P}(t', t) \rightarrow \mathsf{K}(x, y, t'))$
(A28) $(\mathsf{K}(x, y, t) \wedge PED(x)) \rightarrow x \approx_{S,t} y$
(A29) $(\mathsf{K}(x, y, t) \wedge \mathsf{P}(y', y, t)) \rightarrow \exists x'(\mathsf{P}(x', x, t) \wedge \mathsf{K}(x', y', t))$
Links between Categories
(A30) $\mathsf{GK}(NAPO, M)$
(A31) $\mathsf{GK}(APO, NAPO)$
(A32) $\mathsf{GK}(SC, SAG)$

General Properties
(T1) $\neg\mathsf{K}(x, x, t)$
(T2) $\mathsf{SK}(\phi, \psi) \rightarrow \mathsf{SD}(\phi, \psi)$
(T3) $\mathsf{GK}(\phi, \psi) \rightarrow \mathsf{GD}(\phi, \psi)$
(T4) $(\mathsf{SK}(\phi, \psi) \wedge \mathsf{SK}(\psi, \varphi) \wedge \mathsf{DJ}(\phi, \varphi)) \rightarrow \mathsf{SK}(\phi, \varphi)$
(T5) $(\mathsf{GK}(\phi, \psi) \wedge \mathsf{GK}(\psi, \varphi) \wedge \mathsf{DJ}(\phi, \varphi)) \rightarrow \mathsf{GK}(\phi, \varphi)$

Debatable Axioms
$\mathsf{SK}(x, y) \rightarrow \neg\mathsf{D}(y, x)$
$\mathsf{SK}(\phi, \psi) \rightarrow \neg\mathsf{D}(\psi, \phi)$
$\mathsf{GK}(\phi, \psi) \rightarrow \neg\mathsf{D}(\psi, \phi)$
$\mathsf{K}(x, y, t) \rightarrow (\mathsf{AtP}(z, x, t)) \leftrightarrow \mathsf{AtP}(z, y, t))$

Note – This last axiom is rather strong, but it is also very informative on the distinction between spatial dependence and constitution.

Participation

Argument restrictions
(A33) $\mathsf{PC}(x, y, t) \rightarrow (ED(x) \wedge PD(y) \wedge T(t))$
Existential Axioms
(A34) $(PD(x) \wedge \mathsf{PR}(x, t)) \rightarrow \exists y(\mathsf{PC}(y, x, t))$
(A35) $ED(x) \rightarrow \exists y,t(\mathsf{PC}(x, y, t))$
Links with other Primitives
(A36) $\mathsf{PC}(x, y, t) \rightarrow (\mathsf{PR}(x, t) \wedge \mathsf{PR}(y, t))$
(A37) $\mathsf{PC}(x, y, t) \leftrightarrow \forall t'(\mathsf{P}(t', t) \rightarrow \mathsf{PC}(x, y, t'))$

Ground Properties
(T6) $\neg\mathsf{PC}(x, x, t)$

(T7) $\mathsf{PC}(x, y, t) \rightarrow \neg\mathsf{PC}(y, x, t)$

Note – We consider also non-physical endurants as participants.

Quality

Argument restrictions:
(A38) $\mathsf{qt}(x, y) \rightarrow (Q(x) \wedge (Q(y) \vee ED(y) \vee PD(y)))$
(A39) $\mathsf{qt}(x, y) \rightarrow (TQ(x) \leftrightarrow (TQ(y) \vee PD(y)))$
(A40) $\mathsf{qt}(x, y) \rightarrow (PQ(x) \leftrightarrow (PQ(y) \vee PED(y)))$
(A41) $\mathsf{qt}(x, y) \rightarrow (AQ(x) \leftrightarrow (AQ(y) \vee NPED(y)))$
Ground Axioms:
(A42) $(\mathsf{qt}(x, y) \wedge \mathsf{qt}(y, z)) \rightarrow \mathsf{qt}(x, z)$
(A43) $(\mathsf{dqt}(x, y) \wedge \mathsf{dqt}(x, y')) \rightarrow y = y'$
(A44) $(\mathsf{qt}(\phi, x, y) \wedge \mathsf{qt}(\phi, x', y)) \rightarrow x = x'$
(A45) $(\mathsf{qt}(\phi, x, y) \wedge \mathsf{qt}(\psi, y, z)) \rightarrow \mathsf{DJ}(\phi, \psi)$
Existential Axioms:
(A46) $TQ(x) \rightarrow \exists! y(\mathsf{qt}(x, y) \wedge PD(y))$
(A47) $PQ(x) \rightarrow \exists! y(\mathsf{qt}(x, y) \wedge PED(y))$
(A48) $AQ(x) \rightarrow \exists! y(\mathsf{qt}(x, y) \wedge NPED(y))$
(A49) $PD(x) \rightarrow \exists y(\mathsf{qt}(TL, y, x))$
(A50) $PED(x) \rightarrow \exists y(\mathsf{qt}(SL, y, x))$
(A51) $NPED(x) \rightarrow \exists \phi, y(\mathsf{SBL}(AQ, \phi) \wedge \mathsf{qt}(\phi, y, x))$

(T8) $\neg\mathsf{qt}(x, x)$

Note – Maybe it is interesting to make explicit, for each kind of entity, which are the types of quality they necessarily possess.

Quale

Immediate Quale

Argument restrictions:
(A52) $\mathsf{ql}(x, y) \rightarrow (TR(x) \wedge TQ(y))$
(A53) $(\mathsf{ql}(x, y) \wedge TL(y)) \rightarrow T(x)$
Basic Axioms:
(A54) $(\mathsf{ql}(x, y) \wedge \mathsf{ql}(x', y)) \rightarrow x = x'$
Existential Axioms:
(A55) $TQ(x) \rightarrow \exists y(\mathsf{ql}(y, x))$
(A56) $(\mathsf{L}_X(\phi) \wedge \phi(x) \wedge \phi(y) \wedge \mathsf{ql}(r, x) \wedge \mathsf{ql}(r', y)) \rightarrow \exists\psi(\mathsf{L}_X(\psi) \wedge \psi(r) \wedge \psi(r'))$
(A57) $(\mathsf{L}_X(\phi) \wedge \phi(x) \wedge \neg\phi(y) \wedge \mathsf{ql}(r, x) \wedge \mathsf{ql}(r', y)) \rightarrow \neg\exists\psi(\mathsf{L}_X(\psi) \wedge \psi(r) \wedge \psi(r'))$

Temporary Quale

Argument restrictions:
(A58) $\mathsf{ql}(x, y, t) \rightarrow ((PR(x) \vee AR(x)) \wedge (PQ(y) \vee AQ(y)) \wedge T(t))$
(A59) $\mathsf{ql}(x, y, t) \rightarrow (PR(x) \leftrightarrow PQ(y))$
(A60) $\mathsf{ql}(x, y, t) \rightarrow (AR(x) \leftrightarrow AQ(y))$
(A61) $(\mathsf{ql}(x, y, t) \wedge SL(y)) \rightarrow S(x)$
Existential Axioms:
(A62) $((PQ(x) \vee AQ(x)) \wedge \mathsf{PR}(x, t)) \rightarrow \exists y(\mathsf{ql}(y, x, t))$
(A63) $(\mathsf{L}_X(\phi) \wedge \phi(x) \wedge \phi(y) \wedge \mathsf{ql}(r, x, t) \wedge \mathsf{ql}(r', y, t)) \rightarrow \exists\psi(\mathsf{L}_X(\psi) \wedge \psi(r) \wedge \psi(r'))$
(A64) $(\mathsf{L}_X(\phi) \wedge \phi(x) \wedge \neg\phi(y) \wedge \mathsf{ql}(r, x, t) \wedge \mathsf{ql}(r', y, t)) \rightarrow \neg\exists\psi(\mathsf{L}_X(\psi) \wedge \psi(r) \wedge \psi(r'))$
Link with Parthood and extension:
(A65) $\mathsf{ql}(x, y, t) \rightarrow \mathsf{PR}(y, t)$
(A66) $\mathsf{ql}(x, y, t) \leftrightarrow \forall t'(\mathsf{P}(t', t) \rightarrow \mathsf{ql}(x, y, t'))$

Dependence and Spatial Dependence

Links between categories

(A67) $\mathsf{MSD}(TQ, PD)$
(A68) $\mathsf{MSD_S}(PQ, PED)$
(A69) $\mathsf{MSD}(AQ, NPED)$
(A70) $\mathsf{OGD}(F, NAPO)$
(A71) $\mathsf{OSD}(MOB, APO)$
(A72) $\mathsf{OGD}(SAG, APO)$
(A73) $\mathsf{OGD}(NASO, SC)$
(A74) $\mathsf{OD}(NPED, PED)$

General properties

(T9) $(\mathsf{SD}(\phi, \psi) \wedge \mathsf{SD}(\psi, \varphi) \wedge \mathsf{DJ}(\phi, \varphi)) \rightarrow \mathsf{SD}(\phi, \varphi)$
(T10) $(\mathsf{GD}(\phi, \psi) \wedge \mathsf{GD}(\psi, \varphi) \wedge \mathsf{DJ}(\phi, \varphi)) \rightarrow \mathsf{GD}(\phi, \varphi)$
(T11) $(\mathsf{SD}(\phi, \psi) \wedge \mathsf{GD}(\psi, \varphi) \wedge \mathsf{DJ}(\phi, \varphi)) \rightarrow \mathsf{GD}(\phi, \varphi)$
(T12) $(\mathsf{GD}(\phi, \psi) \wedge \mathsf{SD}(\psi, \varphi) \wedge \mathsf{DJ}(\phi, \varphi)) \rightarrow \mathsf{GD}(\phi, \varphi)$
(T13) $\mathsf{SD_S}(\phi, \psi) \rightarrow \mathsf{SD}(\phi, \psi)$
(T14) $\mathsf{GD_S}(\phi, \psi) \rightarrow \mathsf{GD}(\phi, \psi)$

Being Present

(T15) $(ED(x) \vee PD(x) \vee Q(x)) \rightarrow \exists t(\mathsf{PR}(x, t))$
(T16) $((PED(x) \vee PQ(x)) \wedge \mathsf{PR}(x, t)) \rightarrow \exists s(\mathsf{PR}(s, x, t))$
(T17) $(\mathsf{PR}(x, t) \wedge \mathsf{P}(t', t)) \rightarrow \mathsf{PR}(x, t')$
(T18) $\mathsf{PR}(s, x, t) \rightarrow \mathsf{PR}(x, t)$

3.4 Characterization of Categories

In order to resume all the properties of categories, we shall report in this section also some axioms or theorems introduced in the previous sections. We shall mark such axioms/theorems with an asterisk.

Region

(A4)* $(\mathsf{P}(x, y) \wedge \mathsf{SB}(R, \phi) \wedge \mathsf{X}(\phi)) \rightarrow (\phi(x) \leftrightarrow \phi(y))$
(A59)* $\mathsf{ql}(x, y, t) \rightarrow (PR(x) \leftrightarrow PQ(y))$
(A60)* $\mathsf{ql}(x, y, t) \rightarrow (AR(x) \leftrightarrow AQ(y))$
(A62)* $((PQ(x) \vee AQ(x)) \wedge \mathsf{PR}(x, t)) \rightarrow \exists y(\mathsf{ql}(y, x, t))$

Debatable Axioms

(??) $\Diamond\exists x(R(x) \rightarrow \neg\exists y,t(\mathsf{ql}(x, y, t)))$ *or*
(??) $\Box\forall x,t(R(x) \rightarrow (\exists y(\mathsf{ql}(x, y, t))$

Quality

(A38)* $\mathsf{qt}(x, y) \rightarrow (Q(x) \wedge (Q(y) \vee ED(y) \vee PD(y)))$
(A39)* $\mathsf{qt}(x, y) \rightarrow (TQ(x) \leftrightarrow (TQ(y) \vee PD(y)))$
(A40)* $\mathsf{qt}(x, y) \rightarrow (PQ(x) \leftrightarrow (PQ(y) \vee PED(y)))$
(A41)* $\mathsf{qt}(x, y) \rightarrow (AQ(x) \leftrightarrow (AQ(y) \vee NPED(y)))$
(A46)* $TQ(x) \rightarrow \exists! y(\mathsf{qt}(x, y) \wedge PD(y))$
(A47)* $PQ(x) \rightarrow \exists! y(\mathsf{qt}(x, y) \wedge PED(y))$
(A48)* $AQ(x) \rightarrow \exists! y(\mathsf{qt}(x, y) \wedge NPED(y))$
(A67)* $\mathsf{MSD}(TQ, PD)$
(A68)* $\mathsf{MSD_S}(PQ, PED)$
(A69)* $\mathsf{MSD}(AQ, NPED)$
(T15)* $(ED(x) \vee PD(x) \vee Q(x)) \rightarrow \exists t(\mathsf{PR}(x, t))$

Perdurant

(A2)* $\mathsf{P}(x, y) \rightarrow (PD(x) \leftrightarrow PD(y))$
(A39)* $\mathsf{qt}(x, y) \rightarrow (TQ(x) \leftrightarrow (TQ(y) \vee PD(y)))$
(A46)* $TQ(x) \rightarrow \exists! y(\mathsf{qt}(x, y) \wedge PD(y))$
(A49)* $PD(x) \rightarrow \exists y(\mathsf{qt}(TL, y, x))$
(A34)* $(PD(x) \wedge \mathsf{PR}(x, t)) \rightarrow \exists y(\mathsf{PC}(y, x, t))$
(T15)* $(ED(x) \vee PD(x) \vee Q(x)) \rightarrow \exists t(\mathsf{PR}(x, t))$
Conditions on Perdurant's Leaves
(A75) $\mathsf{PSBL}(ACH, \phi) \rightarrow (\mathsf{NEP_S}(\phi) \wedge \mathsf{CM}^{\sim}(\phi) \wedge \mathsf{AT}(\phi))$
(A76) $\mathsf{PSBL}(ACC, \phi) \rightarrow (\mathsf{NEP_S}(\phi) \wedge \mathsf{CM}^{\sim}(\phi) \wedge \mathsf{AT}^{\sim}(\phi))$
(A77) $\mathsf{PSBL}(ST, \phi) \rightarrow (\mathsf{NEP_S}(\phi) \wedge \mathsf{CM}(\phi) \wedge \mathsf{HOM}(\phi))$
(A78) $\mathsf{PSBL}(PRO, \phi) \rightarrow (\mathsf{NEP_S}(\phi) \wedge \mathsf{CM}(\phi) \wedge \mathsf{HOM}^{\sim}(\phi))$
Existential Axioms
(A79) $\exists\phi(\mathsf{PSBL}(ACH, \phi))$
(A80) $\exists\phi(\mathsf{PSBL}(ACC, \phi))$
(A81) $\exists\phi(\mathsf{PSBL}(ST, \phi))$
(A82) $\exists\phi(\mathsf{PSBL}(PRO, \phi))$

Debatable Axioms
(??) $(PD(x) \wedge PD(y) \wedge x \subseteq_{\mathrm{T}} y) \rightarrow \exists z(z \approx_{\mathrm{T}} x \wedge z \subseteq_{\mathrm{ST}} y)$

Endurant

(A35)* $ED(x) \rightarrow \exists y,t(\mathsf{PC}(x, y, t))$
(T15)* $(ED(x) \vee PD(x) \vee Q(x)) \rightarrow \exists t(\mathsf{PR}(x, t))$

Physical endurant

(A11)* $\mathsf{P}(x, y, t) \rightarrow (PED(x) \leftrightarrow PED(y))$
(A21)* $\mathsf{K}(x, y, t) \rightarrow (PED(x) \leftrightarrow PED(y))$
(A40)* $\mathsf{qt}(x, y) \rightarrow (PQ(x) \leftrightarrow (PQ(y) \vee PED(y)))$
(A47)* $PQ(x) \rightarrow \exists! y(\mathsf{qt}(x, y) \wedge PED(y))$
(A50)* $PED(x) \rightarrow \exists y(\mathsf{qt}(SL, y, x))$
(A74)* $\mathsf{OD}(NPED, PED)$

Debatable Axioms
(??) $(PED(x) \wedge PED(y) \wedge \Box(x \approx_{\mathrm{ST}} y)) \rightarrow x = y$

Amount of Matter

(A30)* $\mathsf{GK}(NAPO, M)$

Physical Object

(A31)* $\mathsf{GK}(APO, NAPO)$
(A30)* $\mathsf{GK}(NAPO, M)$
(A70)* $\mathsf{OGD}(F, NAPO)$
(A71)* $\mathsf{OSD}(MOB, APO)$
(A72)* $\mathsf{OGD}(SAG, APO)$

Feature

(A70)* $\mathsf{OGD}(F, NAPO)$

Non-physical Endurant

(A12)* $\mathsf{P}(x, y, t) \rightarrow (NPED(x) \leftrightarrow NPED(y))$
(A22)* $\mathsf{K}(x, y, t) \rightarrow (NPED(x) \leftrightarrow NPED(y))$
(A41)* $\mathsf{qt}(x, y) \rightarrow (AQ(x) \leftrightarrow (AQ(y) \vee NPED(y)))$
(A48)* $AQ(x) \rightarrow \exists! y(\mathsf{qt}(x, y) \wedge NPED(y))$
(A51)* $NPED(x) \rightarrow \exists\phi,y(\mathsf{SBL}(AQ, \phi) \wedge \mathsf{qt}(\phi, y, x))$

(A74)* OD(*NPED*, *PED*)

Mental Object

(A71)* OSD(*MOB*, *APO*)

Social Object

(A73)* OGD(*NASO*, *SC*)
(A32)* GK(*SC*, *SAG*)
(A71)* OSD(*MOB*, *APO*)
(A72)* OGD(*SAG*, *APO*)

4 Conclusions and future work

The purpose of this preliminary report is mainly to establish a basis for further discussions within the WonderWeb project, and to get feedbacks both from potential users of the Foundational Ontologies Library as well as from research groups and institutions active in the area of upper level ontologies[1]. Besides incorporating such feedbacks, our future work will include:

- Clearly marking and isolating the "branching points" corresponding to specific ontological choices.
- Encoding the axiomatization in KIF or CL, and using existing proof-checkers for testing its consistency.
- Establishing a link with WordNet's categories.
- Encoding part of this axiomatization in OWL.
- Using DOLCE (among other things) as the basis for the elaboration of a domain ontology on information and information processing.

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[1] Among those who have already expressed preliminary interest to DOLCE we may mention: the University of Amsterdam, the GOL project at the University of Leipzig, the Princeton WordNet's group, the University of Leeds, the FAO project on Agricultural Ontology Service, OntologyWorks Inc., the OntoText Lab,

5 Glossary of Basic Categories

AB	Abstract
ACC	Accomplishment
ACH	Achievement
ALL	Entity
APO	Agentive Physical Object
AQ	Abstract Quality
AR	Abstract Region
AS	Arbitrary Sum
ASO	Agentive Social Object
ED	Endurant
EV	Event
F	Feature
M	Amount of Matter
MOB	Mental Object
NAPO	Non-agentive Physical Object
NASO	Non-agentive Social Object
NPED	Non-physical Endurant
NPOB	Non-physical Object
PD	Perdurant Occurrence
PED	Physical Endurant
POB	Physical Object
PQ	Physical Quality
PR	Physical Region
PRO	Process
Q	Quality
R	Region
S	Space region
SAG	Social Agent
ED	Endurant
SC	Society
SL	Spatial Location
SOB	Social Object
ST	State
STV	Stative
T	Time interval
TL	Temporal Location
TQ	Temporal Quality
TR	Temporal Region

Abstract	*AB*
Abstract Quality	*AQ*
Abstract Region	*AR*
Accomplishment	*ACC*
Achievement	*ACH*
Agentive Physical Object	*APO*
Agentive Social Object	*ASO*
Amount of Matter	*M*
Arbitrary Sum	*AS*
Endurant	*ED*
Entity	*ALL*
Event	*EV*
Feature	*F*
Mental Object	*MOB*
Non-agentive Physical Object	*NAPO*
Non-agentive Social Object	*NASO*
Non-physical Endurant	*NPED*
Non-physical Object	*NPOB*
Occurrence	*PD*
Perdurant	*PD*
Physical Endurant	*PED*
Physical Object	*POB*
Physical Quality	*PQ*
Physical Region	*PR*
Process	*PRO*
Quality	*Q*
Region	*R*
Social Agent	*SAG*
Social Object	*SOB*
Society	*SC*
Space region	*S*
Spatial Location	*SL*
State	*ST*
Stative	*STV*
Endurant	*ED*
Temporal Location	*TL*
Temporal Quality	*TQ*
Temporal Region	*TR*
Time interval	*T*

6 Glossary of Definitions

Symbol	Description and Definition	def. n.	p.
$\mathsf{At}(x)$	*Atom* $\mathsf{At}(x) =_{df} \neg\exists y(\mathsf{PP}(y, x))$	(D16)	20
$\mathsf{At}(x, t)$	*Temporary Atom* $\mathsf{At}(x, t) =_{df} \neg\exists y(\mathsf{PP}(y, x, t))$	(D22)	20
$\mathsf{AT}(\phi)$	*Atomicity* $\mathsf{AT}(\phi) =_{df} \mathsf{SB}(PD, \phi) \wedge \Box\forall x(\phi(x) \rightarrow \mathsf{At}(x))$	(D61)	21
$\mathsf{AT}^{\sim}(\phi)$	*Anti-Atomicity* $\mathsf{AT}^{\sim}(\phi) =_{df} \mathsf{SB}(PD, \phi) \wedge \Box\forall x(\phi(x) \rightarrow \neg\mathsf{At}(x))$	(D62)	21
$\mathsf{AtP}(x, y)$	*Atomic Part* $\mathsf{AtP}(x, y) =_{df} \mathsf{P}(x, y) \wedge \mathsf{At}(x)$	(D17)	20
$\mathsf{AtP}(x, y, t)$	*Temporary Atomic Part* $\mathsf{AtP}(x, y, t) =_{df} \mathsf{P}(x, y, t) \wedge \mathsf{At}(x, t)$	(D23)	20
$\mathsf{CM}(\phi)$	*Cumulativity* $\mathsf{CM}(\phi) =_{df} \mathsf{SB}(PD, \phi) \wedge \Box\forall x,y((\phi(x) \wedge \phi(y)) \rightarrow \phi(x + y))$	(D57)	21
$\mathsf{CM}^{\sim}(\phi)$	*Anti-Cumulativity* $\mathsf{CM}^{\sim}(\phi) =_{df} \mathsf{SB}(PD, \phi) \wedge$ $\Box\forall x,y((\phi(x) \wedge \phi(y) \wedge \neg\mathsf{P}(x, y) \wedge \neg\mathsf{P}(y, x)) \rightarrow \neg\phi(x + y))$	(D58)	21
$\mathsf{CP}(x, y)$	*Constant Part* $\mathsf{CP}(x, y) =_{df} \exists t(\mathsf{PR}(y, t)) \wedge \forall t(\mathsf{PR}(y, t) \rightarrow \mathsf{P}(x, y, t))$	(D25)	20
$\mathsf{D}(\phi, \psi)$	*Constant Dependence* $\mathsf{D}(\phi, \psi) =_{df} \mathsf{SD}(\phi, \psi) \vee \mathsf{GD}(\phi, \psi))$	(D72)	22
$\mathsf{DGD_S}(x, y, t)$	*Temporary Direct Spatial Dependence* $\mathsf{DGD_S}(x, y, t) =_{df} \exists\phi,\psi(\phi(x) \wedge \psi(y) \wedge \mathsf{DGD_S}(\phi, \psi) \wedge x \approx_{S,t} y)$	(D90)	23
$\mathsf{DGD_S}(\phi, \psi)$	*Direct Generic Spatial Dependence* $\mathsf{DGD_S}(\phi, \psi) =_{df} \mathsf{GD_S}(\phi, \psi) \wedge \neg\exists\varphi(\mathsf{GD_S}(\phi, \varphi) \wedge \mathsf{GD_S}(\varphi, \psi))$	(D87)	23
$\mathsf{DJ}(\phi, \psi)$	*ϕ and ψ are Disjoint classes* $\mathsf{DJ}(\phi, \psi) =_{df} \Box\neg\exists x(\phi(x) \wedge \psi(x))$	(D3)	19
$\mathsf{DK}(x, y, t)$	*Direct Constitution* $\mathsf{DK}(x, y, t) =_{df} \mathsf{K}(x, y, t) \wedge \neg\exists z(\mathsf{K}(x, z, t) \wedge \mathsf{K}(z, y, t))$	(D95)	23
$\mathsf{dqt}(x, y)$	*Direct Quality* $\mathsf{dqt}(x, y) =_{df} \mathsf{qt}(x, y) \wedge \neg\exists z(\mathsf{qt}(x, z) \wedge \mathsf{qt}(z, y))$	(D28)	20
$\mathsf{EQ}(\phi, \psi)$	*ϕ and ψ are Equal* $\mathsf{EQ}(\phi, \psi) =_{df} \mathsf{SB}(\phi, \psi) \wedge \mathsf{SB}(\psi, \phi)$	(D5)	19
$\mathsf{GD}(\phi, \psi)$	*Generic Constant Dependence* $\mathsf{GD}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t(\mathsf{PR}(x, t)) \wedge$ $\forall x,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, t)) \rightarrow \exists y(\psi(y) \wedge \mathsf{PR}(y, t)))$	(D71)	22
$\mathsf{GD_S}(x, y, t)$	*Temporary Generic Spatial Dependence* $\mathsf{GD_S}(x, y, t) =_{df} \exists\phi,\psi(\phi(x) \wedge \psi(y) \wedge \mathsf{GD_S}(\phi, \psi) \wedge x \approx_{S,t} y)$	(D89)	23
$\mathsf{GD_S}(\phi, \psi)$	*Generic Spatial Dependence* $\mathsf{GD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t,s(\mathsf{PR}(x, s, t)) \wedge$ $\forall x,s,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, s, t)) \rightarrow \exists y(\psi(y) \wedge \mathsf{PR}(y, s, t))))$	(D84)	23
$\mathsf{GK}(\phi, \psi)$	*ϕ is Constantly Generic Constituted by ψ* $\mathsf{GK}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t(\mathsf{PR}(x, t)) \wedge$ $\forall x,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, t)) \rightarrow \exists y(\psi(y) \wedge \mathsf{K}(y, x, t)))$	(D98)	23
$\mathsf{HOM}(\phi)$	*Homeomericity* $\mathsf{HOM}(\phi) =_{df} \mathsf{SB}(PD, \phi) \wedge \Box\forall x,y((\phi(x) \wedge \mathsf{P_T}(y, x)) \rightarrow \phi(y))$	(D59)	21

Symbol	Description and Definition	def. n.	p.
$\text{HOM}^{\sim}(\phi)$	*Anti-Homeomericity* $\text{HOM}^{\sim}(\phi) =_{df} \text{SB}(PD, \phi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\text{P}_{\text{T}}(y, x) \wedge \neg\phi(y))$	(D60)	21
$\text{K}(\phi, \psi)$	*ϕ is Constantly Constituted by ψ* $\text{K}(\phi, \psi) =_{df} \text{SK}(\phi, \psi) \vee \text{GK}(\phi, \psi))$	(D99)	24
$\text{L}(\phi)$	*Leaf* $\text{L}(\phi) =_{df} \Box\forall\psi(\text{SB}(\phi, \psi) \rightarrow \text{EQ}(\phi, \psi))$	(D7)	19
$\text{L}_{\text{X}}(\phi)$	*Leaf in Π_{X}* $\text{L}_{\text{X}}(\phi) =_{df} \text{X}(\phi) \wedge \Box\forall\psi((\text{SB}(\phi, \psi) \wedge \text{X}(\phi)) \rightarrow \text{EQ}(\phi, \psi))$	(D10)	20
$\text{lf}(x, y)$	*Life* $\text{lf}(x, y) =_{df} x = \sigma z(\text{PC}_{\text{T}}(y, z))$	(D68)	22
$\text{MGD}(\phi, \psi)$	*Mutual Generic Constant Dependence* $\text{MGD}(\phi, \psi) =_{df} \text{GD}(\phi, \psi) \wedge \text{GD}(\psi, \phi)$	(D77)	22
$\text{MGD}_{\text{S}}(\phi, \psi)$	*Mutual Generic Spatial Dependence* $\text{MGD}_{\text{S}}(\phi, \psi) =_{df} \text{GD}_{\text{S}}(\phi, \psi) \wedge \text{GD}_{\text{S}}(\psi, \phi)$	(D94)	23
$\text{MGK}(\phi, \psi)$	*Mutual Generic Constitution* $\text{MGK}(\phi, \psi) =_{df} \text{GK}(\phi, \psi) \wedge \text{GK}(\psi, \phi)$	(D103)	24
$\text{MSD}(\phi, \psi)$	*Mutual Specific Constant Dependence* $\text{MSD}(\phi, \psi) =_{df} \text{SD}(\phi, \psi) \wedge \text{SD}(\psi, \phi)$	(D76)	22
$\text{MSD}_{\text{S}}(\phi, \psi)$	*Mutual Specific Spatial Dependence* $\text{MSD}_{\text{S}}(\phi, \psi) =_{df} \text{SD}_{\text{S}}(\phi, \psi) \wedge \text{SD}_{\text{S}}(\psi, \phi)$	(D93)	23
$\text{MSK}(\phi, \psi)$	*Mutual Specific Constitution* $\text{MSK}(\phi, \psi) =_{df} \text{SK}(\phi, \psi) \wedge \text{SK}(\psi, \phi)$	(D102)	24
$\text{mpc}(x, y)$	*Maximal Participant* $\text{mpc}(x, y) =_{df} x = \sigma' z(\text{PC}_{\text{T}}(z, y))$	(D66)	21
$\text{mppc}(x, y)$	*Maximal Physical Participant* $\text{mppc}(x, y) =_{df} x = \sigma' z(\text{PC}_{\text{T}}(z, y) \wedge PED(z))$	(D67)	21
$\text{NEP}(\phi)$	*ϕ is Non-Empty* $\text{NEP}(\phi) =_{df} \Box\exists x(\phi(x))$	(D2)	19
$\text{NEP}_{\text{S}}(\phi)$	*ϕ is Strongly Non-Empty* $\text{NEP}_{\text{S}}(\phi) =_{df} \text{SB}(PD,\phi) \wedge \Box\exists x,y(\phi(x) \wedge \phi(y) \wedge \neg\text{P}(x, y) \wedge \neg\text{P}(y, x))$	(D56)	21
$\text{O}(x, y)$	*Overlap* $\text{O}(x, y) =_{df} \exists z(\text{P}(z, x) \wedge \text{P}(z, y))$	(D15)	20
$\text{O}(x, y, t)$	*Temporary Overlap* $\text{O}(x, y, t) =_{df} \exists z(\text{P}(z, x, t) \wedge \text{P}(z, y, t))$	(D21)	20
$\text{OD}(\phi, \psi)$	*One-sided Constant Dependence* $\text{OD}(\phi, \psi) =_{df} \text{D}(\phi, \psi) \wedge \neg\text{D}(\psi, \phi)$	(D73)	22
$\text{OGD}(\phi, \psi)$	*One-sided Generic Constant Dependence* $\text{OGD}(\phi, \psi) =_{df} \text{GD}(\phi, \psi) \wedge \neg\text{D}(\psi, \phi)$	(D75)	22
$\text{OGD}_{\text{S}}(\phi, \psi)$	*One-sided Generic Spatial Dependence* $\text{OGD}_{\text{S}}(\phi, \psi) =_{df} \text{GD}_{\text{S}}(\phi, \psi) \wedge \neg\text{D}(\psi, \phi)$	(D92)	23
$\text{OGK}(\phi, \psi)$	*ϕ is One-sided Constantly Generic Constituted by ψ* $\text{OGK}(\phi, \psi) =_{df} \text{GK}(\phi, \psi) \wedge \neg\text{K}(\psi, \phi)$	(D101)	24
$\text{OSD}(\phi, \psi)$	*One-sided Specific Constant Dependence* $\text{OSD}(\phi, \psi) =_{df} \text{SD}(\phi, \psi) \wedge \neg\text{D}(\psi, \phi)$	(D74)	22
$\text{OSD}_{\text{S}}(\phi, \psi)$	*One-sided Specific Spatial Dependence* $\text{OSD}_{\text{S}}(\phi, \psi) =_{df} \text{SD}_{\text{S}}(\phi, \psi) \wedge \neg\text{D}(\psi, \phi)$	(D91)	23

Symbol	Description and Definition	def. n.	p.
$\mathsf{OSK}(\phi, \psi)$	*ϕ is One-sided Constantly Specific Constituted by ψ* $\mathsf{OSK}(\phi, \psi) =_{df} \mathsf{SK}(\phi, \psi) \wedge \neg\mathsf{K}(\psi, \phi)$	(D100)	24
$\mathsf{P_S}(x, y)$	*Spatial Part* $\mathsf{P_S}(x, y) =_{df} PD(x) \wedge \mathsf{P}(x, y) \wedge x \approx_T y$	(D55)	21
$\mathsf{P_T}(x, y)$	*Temporal Part* $\mathsf{P_T}(x, y) =_{df} PD(x) \wedge \mathsf{P}(x, y) \wedge \forall z((\mathsf{P}(z, y) \wedge z \subseteq_T x) \rightarrow \mathsf{P}(z, x))$	(D54)	21
$\mathsf{PC_C}(x, y)$	*Constant Participation* $\mathsf{PC_C}(x, y) =_{df} \exists t(\mathsf{PR}(y, t)) \wedge \forall t(\mathsf{PR}(y, t) \rightarrow \mathsf{PC}(x, y, t))$	(D63)	21
$\mathsf{PC_T}(x, y, t)$	*Temporary Total Participation* $\mathsf{PC_T}(x, y, t) =_{df} PD(x) \wedge \forall z((\mathsf{P}(z, y) \wedge \mathsf{PR}(z, t)) \rightarrow \mathsf{PC}(x, z, t))$	(D64)	21
$\mathsf{PC_T}(x, y)$	*Total Participation* $\mathsf{PC_T}(x, y) =_{df} \exists t(\mathsf{ql_T}(t, y) \wedge \mathsf{PC_T}(x, y, t))$	(D65)	21
$\mathsf{PGD_S}(\phi, \psi)$	*Partial Generic Spatial Dependence* $\mathsf{PGD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t,s(\mathsf{PR}(x, s, t)) \wedge$ $\forall x,s,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, s, t)) \rightarrow$ $\exists y,s'(\psi(y) \wedge \mathsf{PP}(s', s) \wedge \mathsf{PR}(y, s', t))))$	(D85)	23
$\mathsf{PP}(x, y)$	*Proper Part* $\mathsf{PP}(x, y) =_{df} \mathsf{P}(x, y) \wedge \neg(x = y)$	(D14)	20
$\mathsf{PP}(x, y, t)$	*Temporary Proper Part* $\mathsf{PP}(x, y, t) =_{df} \mathsf{P}(x, y, t) \wedge \neg\mathsf{P}(y, x, t)$	(D20)	20
$\mathsf{PR}(x, t)$	*Being Present at t* $\mathsf{PR}(x, t) =_{df} \exists t'(\mathsf{ql_T}(t', x) \wedge \mathsf{P}(t, t'))$	(D40)	21
$\mathsf{PR}(x, s, t)$	*Being Present in s at t* $\mathsf{PR}(x, t) \wedge \exists s'(\mathsf{ql_S}(s', x, t) \wedge \mathsf{P}(s, s'))$	(D41)	21
$\mathsf{PSB}(\phi, \psi)$	*Proper Subsumption* $\mathsf{PSB}(\phi, \psi) =_{df} \mathsf{SB}(\phi, \psi) \wedge \neg\mathsf{EQ}(\phi, \psi)$	(D6)	19
$\mathsf{PSBL}(\phi, \psi)$	*ψ is a Leaf Properly Subsumed by ϕ* $\mathsf{PSBL}(\phi, \psi) =_{df} \mathsf{PSB}(\phi, \psi) \wedge \mathsf{L}(\psi)$	(D9)	20
$\mathsf{PSBL_X}(\phi, \psi)$	*ψ is a Leaf Properly Subsumed by ϕ in Π_X* $\mathsf{PSBL_X}(\phi, \psi) =_{df} \mathsf{PSB}(\phi, \psi) \wedge \mathsf{L_X}(\psi)$	(D12)	20
$\mathsf{PSD_S}(x, y)$	*Partial Specific Spatial Dependence between Particulars* $\mathsf{PSD_S}(x, y) =_{df} \Box(\exists t,s(\mathsf{PR}(x, s, t)) \wedge$ $\forall s,t(\mathsf{PR}(x, s, t) \rightarrow \exists s'(\mathsf{PP}(s', s) \wedge \mathsf{PR}(y, s', t))))$	(D79)	23
$\mathsf{PSD_S}(\phi, \psi)$	*Partial Specific Spatial Dependence* $\mathsf{PSD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathsf{PSD_S}(x, y)))$	(D82)	23
PT	*$\phi_1, \ldots, \phi_n$ is a Partition of ψ* $\mathsf{PT}(\psi, \phi_1, \ldots, \phi_n) =_{df} \mathsf{DJ}(\phi_i, \psi_j)$ for $1 \leq i \neq j \leq n \wedge$ $\Box\forall x(\psi(x) \leftrightarrow (\phi_1(x) \vee \ldots \vee \phi_n(x)))$	(D10)	20
$\mathsf{P^{-1}GD_S}(\phi, \psi)$	*Inverse Generic Partial Spatial Dependence* $\mathsf{P^{-1}GD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box(\forall x(\phi(x) \rightarrow \exists t,s(\mathsf{PR}(x, s, t)) \wedge$ $\forall x,s,t((\phi(x) \wedge \mathsf{At}(t) \wedge \mathsf{PR}(x, s, t)) \rightarrow$ $\exists y,s'(\psi(y) \wedge \mathsf{PP}(s, s') \wedge \mathsf{PR}(y, s', t))))$	(D86)	23
$\mathsf{P^{-1}SD_S}(x, y)$	*Inverse Partial Specific Spatial Dependence between particulars* $\mathsf{P^{-1}SD_S}(x, y) =_{df} \Box(\exists t,s(\mathsf{PR}(x, s, t)) \wedge \forall s,t(\mathsf{PR}(x, s, t) \rightarrow$ $\exists s'(\mathsf{PP}(s, s') \wedge \mathsf{PR}(y, s', t))))$	(D80)	23
$\mathsf{P^{-1}SD_S}(\phi, \psi)$	*Inverse Partial Specific Spatial Dependence* $\mathsf{P^{-1}SD_S}(\phi, \psi) =_{df} \mathsf{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathsf{P^{-1}SD_S}(x, y)))$	(D83)	23
$\mathsf{ql_S}(s, x, t)$	*Spatial Quale* $\mathsf{ql_S}(s, x, t) =_{df} \mathsf{ql_{S,PED}}(s, x, t) \vee \mathsf{ql_{S,PQ}}(s, x, t) \vee \mathsf{ql_{S,PD}}(s, x, t)$	(D39)	21

Symbol	Description and Definition	def. n.	p.
$\mathrm{ql}_{S,PD}(t, x)$	*Spatial Quale of Perdurants* $\mathrm{ql}_{S,PD}(s, x, t) =_{df} PD(x) \wedge \exists z(\mathrm{mppc}(z, x, t) \wedge \mathrm{ql}_{S,PED}(s, z, t))$	(D38)	21
$\mathrm{ql}_{S,PED}(t, x)$	*Spatial Quale of Physical Endurants* $\mathrm{ql}_{S,PED}(s, x, t) =_{df} PED(x) \wedge \exists z(\mathrm{qt}(SL, z, x) \wedge \mathrm{ql}(s, z, t))$	(D36)	21
$\mathrm{ql}_{S,PQ}(t, x)$	*Spatial Quale of Physical Qualities* $\mathrm{ql}_{S,PQ}(s, x, t) =_{df} PQ(x) \wedge \exists z(\mathrm{qt}(x, z) \wedge \mathrm{ql}_{S,PED}(s, z, t))$	(D37)	21
$\mathrm{ql}_{T}(t, x)$	*Temporal Quale* $\mathrm{ql}_{T}(t, x) =_{df} \mathrm{ql}_{T,ED}(t, x) \vee \mathrm{ql}_{T,PD}(t, x) \vee \mathrm{ql}_{T,Q}(t, x)$	(D35)	20
$\mathrm{ql}_{T,ED}(t, x)$	*Temporal Quale of Endurants* $\mathrm{ql}_{T,ED}(t, x) =_{df} ED(x) \wedge t = \sigma t'(\exists y(\mathrm{PC}(x, y, t))$	(D31)	20
$\mathrm{ql}_{T,PD}(t, x)$	*Temporal Quale of Perdurants* $\mathrm{ql}_{T,PD}(t, x) =_{df} PD(x) \wedge \exists z(\mathrm{qt}(TL, z, x) \wedge \mathrm{ql}(t, z))$	(D30)	20
$\mathrm{ql}_{T,PQ \vee AQ}(t, x)$	*Temporal Quale of Physical or Abstract Qualities* $\mathrm{ql}_{T,PQ \vee AQ}(t, x) =_{df} (PQ(x) \vee AD(x)) \wedge \exists z(\mathrm{qt}(x, z) \wedge \mathrm{ql}_{T,ED}(t, z))$	(D33)	20
$\mathrm{ql}_{T,Q}(t, x)$	*Temporal Quale of Qualities* $\mathrm{ql}_{T,Q}(t, x) =_{df} \mathrm{ql}_{T,TQ}(t, x) \vee \mathrm{ql}_{T,PQ \vee AQ}(t, x)$	(D34)	20
$\mathrm{ql}_{T,TQ}(t, x)$	*Temporal Quale of Temporal Qualities* $\mathrm{ql}_{T,TQ}(t, x) =_{df} TQ(x) \wedge \exists z(\mathrm{qt}(x, z) \wedge \mathrm{ql}_{T,PD}(t, z))$	(D32)	20
$\mathrm{qt}(\phi, x, y)$	*Quality of type* ϕ $\mathrm{qt}(\phi, x, y) =_{df} \mathrm{qt}(x, y) \wedge \phi(x) \wedge \mathrm{SBL}_X(Q, \phi)$	(D29)	20
$\mathrm{RG}(\phi)$	ϕ *is Rigid* $\mathrm{RG}(\phi) =_{df} \Box\forall x(\phi(x) \rightarrow \Box\phi(x))$	(D1)	19
$\mathrm{SB}(\phi, \psi)$	ϕ *Subsumes* ψ $\mathrm{SB}(\phi, \psi) =_{df} \Box\forall x(\psi(x) \rightarrow \phi(x))$	(D4)	19
$\mathrm{SBL}(\phi, \psi)$	ψ *is a Leaf Subsumed by* ϕ $\mathrm{SBL}(\phi, \psi) =_{df} \mathrm{SB}(\phi, \psi) \wedge \mathrm{L}(\psi)$	(D8)	19
$\mathrm{SBL}_X(\phi, \psi)$	ψ *is a Leaf Subsumed by* ϕ *in* Π_X $\mathrm{SBL}_X(\phi, \psi) =_{df} \mathrm{SB}(\phi, \psi) \wedge \mathrm{L}_X(\psi)$	(D11)	20
$\mathrm{SD}(x, y)$	*Specific Constant Dependence between Particulars* $\mathrm{SD}(x, y) =_{df} \Box(\exists t(\mathrm{PR}(x, t)) \wedge \forall t(\mathrm{PR}(x, t) \rightarrow \mathrm{PR}(y, t)))$	(D69)	22
$\mathrm{SD}(\phi, \psi)$	*Specific Constant Dependence* $\mathrm{SD}(\phi, \psi) =_{df} \mathrm{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathrm{SD}(x, y)))$	(D70)	22
$\mathrm{SD}_S(x, y)$	*Specific Spatial Dependence between Particulars* $\mathrm{SD}_S(x, y) =_{df} \Box(\exists t,s(\mathrm{PR}(x, s, t)) \wedge \forall s,t(\mathrm{PR}(x, s, t) \rightarrow \mathrm{PR}(y, s, t)))$	(D78)	23
$\mathrm{SD}_S(\phi, \psi)$	*Specific Spatial Dependence* $\mathrm{SD}_S(\phi, \psi) =_{df} \mathrm{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathrm{SD}_S(x, y)))$	(D81)	23
$\mathrm{SD}_S(x, y, t)$	*Temporary Specific Spatial Dependence* $\mathrm{SD}_S(x, y, t) =_{df} \mathrm{SD}_S(x, y) \wedge \mathrm{PR}(x, t)$	(D88)	23
$\mathrm{SK}(x, y)$	*x is Constantly Specifically Constituted by y* $\mathrm{SK}(x, y) =_{df} \Box(\exists t(\mathrm{PR}(x, t)) \wedge \forall t(\mathrm{PR}(x, t) \rightarrow \mathrm{K}(y, x, t)))$	(D96)	23
$\mathrm{SK}(\phi, \psi)$	ϕ *is Constantly Specific Constituted by* ψ $\mathrm{SK}(\phi, \psi) =_{df} \mathrm{DJ}(\phi, \psi) \wedge \Box\forall x(\phi(x) \rightarrow \exists y(\psi(y) \wedge \mathrm{SK}(x, y)))$	(D97)	23
$\sigma x\phi(x)$	*Sum of* ϕ*'s* $\sigma x\phi(x) =_{df} \iota z\forall y(\mathrm{O}(y, z) \leftrightarrow \exists w(\phi(w) \wedge \mathrm{O}(y, w)))$	(D19)	20
$\sigma' x\phi(x)$	*Asynchronous Sum of* ϕ*'s* $\sigma' x\phi(x) =_{df} \iota z\forall y,t(\mathrm{O}(y, z, t) \leftrightarrow \exists w(\phi(w) \wedge \mathrm{O}(y, w, t)))$	(D27)	20
$x \equiv_t y$	*Coincidence* $x \equiv_t y =_{df} \mathrm{P}(x, y, t) \wedge \mathrm{P}(y, x, t)$	(D24)	20

Symbol	**Description and Definition**	**def. n.**	**p.**
$x + y$	*Binary Sum* $x + y =_{df} \iota z \forall w(\mathsf{O}(w, z) \leftrightarrow (\mathsf{O}(w, x) \vee \mathsf{O}(w, y)))$	(D18)	20
$x +' y$	*Asynchronous Binary Sum* $x +' y =_{df} \iota z \forall w,t(\mathsf{O}(w, z, t) \leftrightarrow (\mathsf{O}(w, x, t) \vee \mathsf{O}(w, y, t)))$	(D26)	20
$x \subset_{T} y$	*Proper Temporal Inclusion* $x \subset_{T} y =_{df} \exists t,t'(\mathsf{ql}_{T}(t, x) \wedge \mathsf{ql}_{T}(t', y) \wedge \mathsf{PP}(t, t'))$	(D43)	21
$x \subseteq_{T} y$	*Temporal Inclusion* $x \subseteq_{T} y =_{df} \exists t,t'(\mathsf{ql}_{T}(t, x) \wedge \mathsf{ql}_{T}(t', y) \wedge \mathsf{P}(t, t'))$	(D42)	21
$x \subset_{S,t} y$	*Temporary Proper Spatial Inclusion* $x \subset_{S,t} y =_{df} \exists s,s'(\mathsf{ql}_{S}(s, x, t) \wedge \mathsf{ql}_{S}(s', y, t) \wedge \mathsf{PP}(s, s'))$	(D45)	21
$x \subseteq_{S,t} y$	*Temporary Spatial Inclusion* $x \subseteq_{S,t} y =_{df} \exists s,s'(\mathsf{ql}_{S}(s, x, t) \wedge \mathsf{ql}_{S}(s', y, t) \wedge \mathsf{P}(s, s'))$	(D44)	21
$x \subseteq_{ST} y$	*Spatio-temporal Inclusion* $x \subseteq_{ST} y =_{df} \exists t(\mathsf{PR}(x, t)) \wedge \forall t(\mathsf{PR}(x, t) \rightarrow x \subseteq_{S,t} y)$	(D46)	21
$x \subseteq_{ST,t} y$	*Spatio-temp. Incl. during t* $x \subseteq_{ST} y =_{df} \mathsf{PR}(x, t) \wedge \forall t'(\mathsf{AtP}(t', t) \rightarrow x \subseteq_{S,t'} y)$	(D47)	21
$x \approx_{T} y$	*Temporal Coincidence* $x \approx_{T} y =_{df} (x \subseteq_{T} y \wedge y \subseteq_{T} x)$	(D48)	21
$x \approx_{S,t} y$	*Temporary Spatial Coincidence* $x \approx_{S,t} y =_{df} (x \subseteq_{S,t} y \wedge y \subseteq_{S,t} x)$	(D49)	21
$x \approx_{ST} y$	*Spatio-temporal Coincidence* $x \approx_{ST} y =_{df} (x \subseteq_{ST} y \wedge y \subseteq_{ST} x)$	(D50)	21
$x \approx_{ST,t} y$	*Spatio-temp. Coincidence dur. t* $x \approx_{ST,t} y =_{df} \mathsf{PR}(x, t) \wedge \forall t'(\mathsf{AtP}(t', t) \rightarrow x \approx_{S,t'} y)$	(D51)	21
$x \mathsf{O}_{T} y$	*Temporal Overlap* $x \mathsf{O}_{T} y =_{df} \exists t,t'(\mathsf{ql}_{T}(t, x) \wedge \mathsf{ql}_{T}(t', y) \wedge \mathsf{O}(t, t'))$	(D52)	21
$x \mathsf{O}_{S,t} y$	*Temporary Spatial Overlap* $x \mathsf{O}_{S,t} y =_{df} \exists s,s'(\mathsf{ql}_{S}(s, x, t) \wedge \mathsf{ql}_{S}(s', y, t) \wedge \mathsf{O}(s, s'))$	(D53)	21

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