Chapter 13
Ontological Foundations of DOLCE

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13.1 Introduction

DOLCE, the *Descriptive Ontology for Linguistic and Cognitive Engineering* (Masolo et al., 2003), is a foundational ontology developed embracing a pluralist perspective: there cannot be a unique standard or universal ontology for knowledge representation. Once it is accepted that the so-called "monolithic approach" is unrealistic, it becomes clear that the different foundational ontologies must be mutually transparent by making explicit their ontological stands and formal constraints: this is necessary to make ontology interaction possible and reliable. Roughly, it is expected that an ontology is, on the one hand, philosophically well founded (by adopting a clear ontological perspective) and, on the other hand, that it provides the information for its correct application and use (for instance, by describing explicitly the basic assumptions and the formal constraints on which it relies). A consequence of this view is that, whenever a foundational ontology does not make an *explicit* commitment with respect to an ontological topic, it is assumed that the ontology is consistent with alternative ontological positions in that topic (in some cases, it may even allow coexistence of these via techniques like parametrization). This general view is quite demanding and requires a careful analysis of the ontology content and structure; DOLCE has been one of the first ontologies explicitly built to follow (and exemplify) this approach.

Regarding the content of the ontology, the aim of DOLCE is to capture the intuitive and cognitive bias underlying common-sense while recognizing standard considerations and examples of linguistic nature. DOLCE does not commit to a strong referentialist metaphysics (it does not make claims on the intrinsic nature of the world) and does not take a scientific perspective (it is not an ontology of, say, physics or of social sciences). Rather, it looks at reality from the mesoscopic and

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conceptual level aiming at a formal description of a particular, yet fairly natural, conceptualization of the world.

Technically, DOLCE is the result of a careful selection of constraints (principles, primitives, axioms, definitions, and theorems) expressed in a rich logical language, namely first-order logic, in order to guarantee expressiveness, precision, interoperability, and simplicity of use. These claims are sustained by the accompanying documentation that provides information on the ontological choices and the motivations for both the structure and the formalization of DOLCE.

Due to the introductory nature of this paper (and the limited space available), this work describes and formalizes only the most general categories of the DOLCE ontology. We advise the reader that what is presented here departs in some aspects from the original DOLCE (Masolo et al., 2003): indeed in these pages we actually discuss a new and improved version of the DOLCE kernel that we call DOLCE-CORE (Borgo and Masolo, 2009).

13.2 A Bit of History

DOLCE is part of the *WonderWeb* project[1]. The aim of this project is to develop the infrastructure required for the large-scale deployment of ontologies as the foundation for the Semantic Web. On the one hand, this goal involves the establishment of a Web standard ontology language and related ontological engineering technology, on the other the development of a library of foundational ontologies reflecting different ontological choices. DOLCE, which came out in 2002, is one of the ontologies included in the WonderWeb library and, at the time of writing, it is also the most developed. It has been constructed as an ontology of particulars with a clear cognitive bias: the categories have been explicitly characterized as "cognitive artifacts ultimately depending on human perception, cultural imprints and social conventions" (Masolo et al., 2003, p. 13). So far the ontology has not undergone changes[2] while extensions have been proposed to cover more closely some application domains. Over the years, DOLCE has been tested in several projects ranging over a variety of areas as manufacturing, business transaction, insurance services, biomedicine, multimedia, social interaction, linguistics, and the Semantic Web at large.[3]

The real use of the ontology in application projects is increased by the alignment with WordNet (Gangemi et al., 2003) which provided a basis to study the relationship between ontologies and linguistic resources (Prevot et al., 2005). The ontology is publicly distributed in several formats[4] like first-order logic FOL (including

[1] http://wonderweb.semanticweb.org

[2] The version we present here can be considered as the first proposal to update the ontology and it comes after almost 6 years of experience in applying it.

[3] See http://www.loa-cnr.it/DOLCE.html for a list of institution and projects that are using or have expressed interest in the DOLCE ontology.

[4] The different versions of DOLCE can be downloaded from http://www.loa-cnr.it/DOLCE.html. The main version is in first-order logic. Versions in other languages have been produced approx-

KIF), OWL, DAML+OIL, LOOM, and RDFS. It is also available in the Common Algebraic Specification Language,[5] CASL, via the Hets extension[6] which makes available theorem provers and graphical devices.

13.3 Ontological vs. Conceptual Level

To understand the DOLCE view, we should begin with the distinction between ontological entities and conceptual entities. Entities in the first group exist in the "real" world independently of our mind. The latter group comprises entities that are the result of conceptual processes (typically over ontological entities). Generally speaking, this distinction is important to understand the different modeling choices on which theories rely: for example, *event theories of time* build intervals and instants of time from temporal relationships between events. That is, in these theories intervals and instants (times in general) are taken to be conceptual entities while events are ontological entities.

Technically, a disagreement on the ontological-conceptual classification of some type of entity indicates an inhomogeneity (or, better, heterogeneity) among theories. The usual (strong) reading of Quine's principle "to be is to be the value of a variable" highlights a sharp separation between ontological and conceptual entities with the consequence that, for instance, *times* should be banned from the domain of quantification whenever they are conceptually constructed from events. Clearly, it is not possible to do justice of common-sense language about time with such a position where times are expunged from the formal theory.

In order to make possible the comparison (and perhaps the interaction) of heterogeneous ontological options at the syntactic level within a unified formal framework (namely, within FOL), we adopt a soft reading of the Quinean principle and assume that entities in the domain of quantification can be of ontological or of conceptual nature. That is, a claim of type "$\exists x \varphi$" in the formal ontology is not necessarily addressing the ontological/conceptual status of the entities satisfying φ. In this way one can include, say, both events and times in the domain of quantification without committing to them ontologically. It is then possible to formally relate these kinds of entities within the theory itself. Furthermore, note that this choice allows us to avoid the problems of reductionism which are particularly critical in foundational ontologies. Indeed, as Heil notices:

> How, for instance, could we hope to re-express truths about the global political consequences of a decline in the GNP of Eastern Europe in terms of interactions among

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imating the content of the FOL version by taking into account the different expressive powers of the other languages.

[5] http://www.brics.dk/Projects/CoFI/CASL.html

[6] From http://www.informatik.uni-bremen.de/agbkb/forschung/formal_methods/CoFI/hets/index_e.htm: Hets is a parsing, static analysis and proof management tool combining various tools for different specification languages.

> fundamental particles? Even if such a reduction were possible, however, it would be self-defeating. Important higher-level patterns and relations are invisible to physics. (Heil, 2005, p.31)

13.4 Properties

Once one has established how to consider entities in the domain of the ontology, she has to decide how to *describe* (and thus differentiate) entities, i.e., how to deal with properties. The nature of properties,[7] the explanation of what it means that an entity has a property, and, more specifically, of how different entities can have the *same* property, have been widely discussed and investigated, see Armstrong (1989), Loux (1976), and Mellor and Oliver (1997) for exhaustive surveys. Moreover, *persisting* entities (i.e. entities that exist at different times) can *change* through time by having different properties at different times: a may have property F (say, "being red") at time t_1 and an incompatible property G (say, "being green") at t_2. The nature of time and the way entities persist and change through time are topics central to foundational ontology and highly debated in the literature. An introduction to these debates is out of the scope of this paper, we refer the interested reader to Sider (2001) for an interesting presentation.

Informally, we use the term *individual* to refer to entities that cannot have instances, that is, entities that cannot be predicated of others. For example, Aristotle, the Tour Eiffel and the Mars planet are individuals. On the contrary, the term *property* denotes entities that can have instances, i.e., entities that qualify other entities, e.g. Red (the color), Person (the kind), Fiat Panda (the car type).

DOLCE-CORE provides three different options to represent properties and temporary properties. The first option consists in the introduction of an *extensional predicate* as in the standard technique for the formalization of categories and primitives. In this option, to model temporal change one uses a binary predicate with a temporal parameter as in expression $F(a,t)$; here F is a predicate reserved for the given property, a an individual to which the property applies, t a time and expression $F(a,t)$ states that a has property F at t.[8] To be more precise, since we aim at a wide-ranging view we read formulas of this form as done in Merricks (1994): *a exists* at t and it *has* the property F at t (i.e., when t is/was/will be present). The change from a property to one incompatible with it (as in changing colors) is then neutrally represented by writing $F(a,t_1) \wedge G(a,t_2)$. Less neutral interpretations of formula $F(a,t)$ are possible, we will see this later. Note that with this choice one cannot explicate whether the property is related to contextual or social constructions. The idea is that predicates are reserved to model the basic conceptualization of the world that the user takes for granted. Summing up, this option is to be preferred for static and context-independent properties.

[7] Here we discuss the case of properties only. Relations are treated analogously.

[8] This solution allows to represent dynamics in the properties but it introduces a series of problems when considering roles, see Steimann (2000).

The second option consists in reifying properties, that is, in associating them to entities (here called *concepts*) that are included in the domain of quantification. In order to deal with concepts (and to relate concepts to an entity according to the properties the latter has), a possibly intensional “instance-of” relation, called *classification*, is introduced in the ontology. The idea is to use concepts to represent properties whose intensional, contextual, or dynamic aspects are deemed important: “being a student”, “being a catalyst”, “being money”. As we will see, cf. (A10), concepts in DOLCE-CORE are entities in time, they are created, can be destroyed, etc. We proceed along the lines of Masolo et al. (2004) that introduces concepts to represent *roles*[9] in terms of relationships among different entities. The properties that are best captured in this way are *anti-rigid* (Guarino and Welty, 2004), that is, those that are not essential to any of their instances. Roles provide a clear example: one (a person) may play a role (student) for a limited time, perhaps resume it in different periods, and yet she (the person) is not ontologically altered by having that role or else. Furthermore, different entities can play exactly the same role, perhaps at the same time, and a single entity can play several roles contemporarily.

The third option relies on the notions of *individual quality*, *quality-type* and *quality-space*. Similarly to concepts, with this option one can characterize the intensional, temporal, and contextual dimensions of properties. The novelty is that in this case, as we explain below, one can model also the interconnection among the way different individuals manifest a property: the quality-types isolate properties that can be meaningfully compared (like colors, weights, smells, temperatures, etc.) and quality-spaces (*spaces* for short) provide different ways to evaluate properties.

For each property of an individual, there is a correspondent individual quality (*quality* for short) that existentially depends on the individual itself. The quality *inheres in* the individual and models the specific way in which that individual has that property. The color of my car depends on my car and it is necessarily different from the color of my phone (that depends on my phone) even though both are the same shade of red: indeed the way my car is red is different from the way my phone is red. In this view, we say that my car and my phone have the *same* color because their individual qualities *exactly resemble* each other (individual qualities of different entities are necessarily distinct).

Properties can be more or less specific, compare “being scarlet” and “being red”. In the philosophical tradition, often only the more specific properties (aka *basic properties*) are assumed to correspond to truly *ontological* properties. In some approaches (Armstrong, 1997). Johansson (2000) even general properties (universals) are counted as ontological thus including properties like “being colored”, “being shaped” and the like. The idea is that these universals need to exist in order to conceive, e.g., the functional laws of physics (Armstrong, 1997). Johansson (2000)

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[9]Differently from that approach, here we do not rely on logical definitions for concepts, instead the intensional aspect is (partially) characterized by explicitly stating when concepts are different. Reviews of this topic that cover a variety of perspectives are in Steiman, (2000), Masolo et al. (2004) and Loebe (2007).

isolates these properties, which characterize what we call the quality types, in terms of *maximal incompatibility* and *maximal comparability*: *(i)* each entity that has a quality type *F* must have just one basic property that is a specification of *F*, and *(ii)* all the basic properties that are specifications of *F* are qualitatively comparable. Qualities that share a basic property are exactly similar, while qualities that share a non-basic property are only *inexactly* similar in the sense that they resemble each other but only up to a *degree*. In applications, a variety of degrees of resemblance are empirically determined (due to species preferences, culture, available information, adopted measurement instruments or methods etc). From an empirical, applicative, and cognitive perspective, we need to recognize that properties can be arranged in different taxonomies each motivated by particular resemblance relations whose interest is motivated by needs in some domain or application. Furthermore, sometimes properties are structured in complex ways: complex topological or geometrical relations on properties are common like in the case of the color's splinter (Gärdenfors, 2000).

The use of spaces in DOLCE as complex structures of properties is inspired by Gärdenfors (2000). In this view, it is natural to think that quality types partition the individual qualities and that each quality type is associated to one or more spaces (motivated by culture, instruments of investigation, application concerns etc.) Therefore while a quality type collects the qualities that can be compared (one can reserve a quality type for color, one for smell, one for temperature etc.), quality spaces provide a way for classifying individual qualities that are in the same quality type (a variety of color classifications are used in physics, manufacturing, fashion etc., each of these isolates a different quality space).

As clear from the examples, some spaces are motivated by applications. In particular, spaces may rely on *relative* notions of resemblance: instruments present different sensitivities and each distinguishes aspects of entities only up to some *granularity*. This fact allows to order groups of spaces according to a notion of granularity (one can even postulate the existence of a space of finest granularity that recognizes all ontologically possible distinctions). In sum, spaces provide a way to make room for "subjective" (context dependent, qualitative, etc.) points of view on qualities: a quality type for color can provide the whole color spectrum, another a rough distinction in warm-cold colors, a third may discriminate by looking at brightness only etc. Note that spaces can be combined to model complex properties, i.e., properties seen as the result of interaction of other properties (the latter are then considered more basic, in a sense). This choice is often preferred when modeling properties like velocity, density and force but, as we have seen, it can be used also to structure basic properties like color.

Finally, changes in individual qualities are explained by changes in their space locations: the fact that my phone changes color is represented by the fact that over time the individual color-quality of my phone changes location in the color-space. Since the qualities of an entity exist whenever the entity exists, this third modeling option is to be considered only for properties that are necessary to an entity. Typical examples for physical objects, beside color, are mass and shape.

13.5 Basic Categories

DOLCE-CORE takes into account only entities that exist in time called *temporal particulars*. With respect to the original DOLCE neither abstract entities nor abstract qualities are considered. Our subjective perspective on spaces and the consequent idea that spaces may be created, adopted, abandoned, etc. induces us to introduce regions in time. This is different from the original DOLCE where regions are considered to be abstract entities. However, DOLCE abstract regions can be "simulated" in DOLCE-CORE by means of regions that exist at all times, i.e. regions that are neither created nor abandoned. Following Masolo et al. (2004), a similar argument holds for *concepts* (not considered in the original DOLCE) which therefore exist in time as well. Indeed, honestly, it is yet unclear to us which of the abstract or the temporal view is more appropriate for a general (and fairly comprehensive) ontology.

DOLCE-CORE partitions *temporal-particulars* (PT_t) (thereafter simply *particulars*) into *objects* (O), *events* (E), *individual qualities* (Q), *regions* (R), *concepts* (C), and *arbitrary sums* (AS). All these categories are rigid: an entity cannot change from one category to another over time. Note that the categories O (object) and E (event) correspond to the DOLCE's categories ED (endurant) and PD (perdurant), respectively. This change in teminology is motivated by the observations in Section 13.11.

Individual qualities are themselves partioned into *quality types* (Q_i). To each quality type Q_i are associated one or more *spaces* (S_{ij}), to the result that individual qualities in Q_i have locations in (i.e. they are located in regions belonging to) the associated spaces S_{ij}. Since we impose that the spaces are disjoint, regions are themselves partitioned into the spaces S_{ij}. For the sake of simplicity, we here consider a unique space T for (regions of) times. All these statements are enforced in the system by logical axioms although we do not report them here.

13.6 Parthood

Although mereology, the theory of parthood, is nowadays mostly used in modeling the spatial or spatio-temporal domain, the theory is not limited to this; it applies equally well to entities that are only in time (like, for instance, word meanings, beliefs, desires, societies) or that are neither in space nor in time. Indeed, mereology was introduced by Lesniewski (1991) as an alternative to set theory (the latter is based on cognitively unsatisfactory notions like the empty set and the distinction between urelements and sets) while maintaining the same level of generality.

Since the usefulness of a foundational ontology relies on the balance between ontological constraints and freedom, it is advisable to start with an ontologically weak theory and add (carefully and systematically) all the needed constraints. This approach suggests that the weak ontological commitment of mereology (at least when compared to set-theory) together with its cognitive acceptability is providing an acceptable basis for DOLCE-CORE.

Some authors tend to identify mereology with spatio-temporal inclusion. If it is true that spatio-temporally extended entities that are one part of the other are also spatio-temporally coincident, the vice versa does not hold in general: it is possible to maintain in mereology that the clay constituting a statue and the statue itself are not one part of the other although they are spatio-temporally coincident entities (see Rea (1996) for a discussion of this topic). In particular, DOLCE-CORE carefully distinguishes spatio-temporal inclusion from formal parthood. Indeed, DOLCE-CORE adopts the axioms of extensional mereology, namely (A1)–(A4), and apply them to all entities in the domain. Note also that the existence of the sum of two entities is not generally enforced: this choice depends on the entities one has in the domain (which, in turn, depends on the use one wants to do of the ontology). In short, the user of the ontology is free to impose existence of sum as a further constraint, to accept it only restricted to some categories or even to reject it in general.

In DOLCE-CORE, parthood (P) is defined on the whole domain, $\mathsf{P}(x,y)$ stands for "x is part of y".

D1 $\mathsf{O}(x,y) \triangleq \exists z(\mathsf{P}(z,x) \wedge \mathsf{P}(z,y))$ (*x and y overlap*)

D2 $\mathsf{SUM}(z,x,y) \triangleq \forall w(\mathsf{O}(w,z) \leftrightarrow (\mathsf{O}(w,x) \vee \mathsf{O}(w,y)))$ (*z is the mereological sum of x and y*)

A1 $\mathsf{P}(x,x)$ (*reflexivity*)

A2 $\mathsf{P}(x,y) \wedge \mathsf{P}(y,z) \rightarrow \mathsf{P}(x,z)$ (*transitivity*)

A3 $\mathsf{P}(x,y) \wedge \mathsf{P}(y,x) \rightarrow x = y$ (*antisymmetry*)

A4 $\neg\mathsf{P}(x,y) \rightarrow \exists z(\mathsf{P}(z,x) \wedge \neg\mathsf{O}(z,y))$ (*extensionality*)

A5 If ϕ is $\mathrm{O}, \mathrm{E}, \mathrm{Q}_i, \mathrm{S}_{jk}$, or C,: $\phi(y) \wedge \mathsf{P}(x,y) \rightarrow \phi(x)$ (*dissectivity*)

A6 If ϕ is $\mathrm{O}, \mathrm{E}, \mathrm{Q}_i, \mathrm{S}_{jk}$, or C: $\phi(x) \wedge \phi(y) \wedge \mathsf{SUM}(z,x,y) \rightarrow \phi(z)$ (*additivity*)

Axiom (A4) states that if x is not part of y, then there is at least a part of x that does not overlap y. Axiom (A5) states that elements of a category have only parts that belong to the same category (closure under parthood) while axiom (A6) states that summing elements of a category one obtains an element in the same category (closure under sum).

13.7 Time

An ontology that aims at wide applicability has to model time. Furthermore, among the entities in the domain of quantification, it has to distinguish those that exist *in time* and, for these, *when* they exist. The expression $\mathsf{PRE}(x,t)$ in DOLCE-CORE stands for "x is present at t" where the second argument t is a time. Times form the special class T in the ontology but this is done with commitment to neither a specific kind of times (points vs. intervals) nor a specific structure of time (dense vs. discrete, linear vs. branching, etc.). Also, because of our weak reading of the existential quantifier, times in DOLCE-CORE may be considered full-fledged ontological entities or simply conceptual entities. The latter case is illustrated, for instance, by the construction of times from events (Kamp, 1979), a construction that can be adopted in this ontology.

The structure of DOLCE-CORE makes times and PRE compatible with both a *substantialist* position (the Newtonian view that time is absolute, a container-like manifold) and a *relativist* position (the Leibnizianian view that time is conceptually constructed from events). This lack of commitment is important since there are alternative ways to model times depending on the application interests and the temporal information one wants to represent. E.g., being present at a time can be reduced to being simultaneous with (being before, being after) some other entity (Simons, 1991), or to being located at one specific region in a temporal quality space (Masolo et al., 2004). In addition, note that we are not distinguishing different ways of being in time like "existing in time" vs. "occurring in time" (related to the distinction objects vs. events discussed in Section 13.11) or "being wholly present" vs. "being partially present" (see the distinction endurants vs. perdurants in Section 13.8).

In short, $\mathsf{PRE}(x,t)$ is a minimal representation device that is needed just to identify the entities that are in time and that is neutral with respect to the different ontological commitments on time, existence of events, temporal relations, theories of properties, etc. Due to the limited space, we do not enter into further details on time (for instance, on the additional constraints one can add to commit to one or the other position). A few axioms of general interest are[10]: x is present at t only if t is a time (A7) and being present is dissective and additive over t (A8) and (A9). Note that (A8) characterizes $\mathsf{PRE}(x,t)$ as "x is present at the whole t", i.e. it is not possible to find a sub-time of t at which x is not present.

A7 $\mathsf{PRE}(x,t) \rightarrow \mathrm{T}(t)$

A8 $\mathsf{PRE}(x,t) \wedge \mathsf{P}(t',t) \rightarrow \mathsf{PRE}(x,t')$

A9 $\mathsf{PRE}(x,t') \wedge \mathsf{PRE}(x,t'') \wedge \mathsf{SUM}(t,t',t'') \rightarrow \mathsf{PRE}(x,t)$

Since, as stated in Section 13.5, in this paper we limit our discussion to the DOLCE-CORE fragment, it happens that all the entities here considered exist in time, that is

A10 $\mathrm{PT}_t(x) \rightarrow \exists t(\mathsf{PRE}(x,t))$

(*all entities of the* DOLCE-CORE *fragment exist in time*)

Of course, not all the entities in the general DOLCE ontology exist in time. In this case, it is enough to consider a new "top" category that includes both temporal and abstract particulars.

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[10]Given the assumption of having just one time-space T, the constraint $\mathrm{T}(t) \rightarrow \mathsf{PRE}(t,t)$ can be added without any additional restriction (see also axiom (A45)).

13.8 Temporary Parthood

DOLCE-CORE adopts a temporary extensional mereology, also denoted by P, which is based on axioms (A12)-(A15), i.e., those of extensional mereology (Section 13.6) enriched with an extra temporal argument. Further mereological aspects are also enforced (see below the constraints for time regular relations). Expression $\mathsf{P}(x,y,t)$ stands for "x is part of y at time t."

D3 $\mathsf{O}(x,y,t) \triangleq \exists z(\mathsf{P}(z,x,t) \land \mathsf{P}(z,y,t))$ (*x and y overlapat time t*)

A11 $\mathsf{P}(x,y,t) \to \mathsf{PRE}(x,t) \land \mathsf{PRE}(y,t)$ (*parthood implies being present*)

A12 $\mathsf{PRE}(x,t) \to \mathsf{P}(x,x,t)$ (*temporary reflexivity*)

A13 $\mathsf{P}(x,y,t) \land \mathsf{P}(y,z,t) \to \mathsf{P}(x,z,t)$ (*temporary transitivity*)

A14 $\mathsf{PRE}(x,t) \land \mathsf{PRE}(y,t) \land$ (*temporary extensionality*)
$\neg\mathsf{P}(x,y,t) \to \exists z(\mathsf{P}(z,x,t) \land \neg\mathsf{O}(z,y,t))$

A15 If ϕ is $\mathrm{O}, \mathrm{E}, \mathrm{Q}_i, \mathrm{S}_{jk}$ or C: $\phi(y) \land \mathsf{P}(x,y,t) \to \phi(x)$ (*temporary dissectivity*)

For standard parthood we stated axiom (A3) so that entities indistinguishable with respect to parthood are identical. This claim does not hold when temporary parthood is involved. Temporal coincidence (D4) provides a suitable form of identification: two entities x and y that are temporary coincident at time t, formally $\mathsf{CC}(x,y,t)$, are indistinguishable relatively to time t but can still be different in general.[11] If $\mathsf{CC}(x,y,t)$, then all the properties of x at t are also properties of y at t and vice versa.

For properties that are formalized via concepts or qualities, the constraint is explicitly introduced by the *substitutivity* axioms. In the case of the primitive relations of *classification* and *location* (that we will introduce later) an axiom of the form (SB) (given below) is enough, while in the case of the *inherence* relation, axioms (A25) and (A26) do the work. Note however that from these axioms no constraint follows on properties of x and y at a time different from t nor on properties represented by means of additional predicates introduced by the user.

Axiom (A16) states that, for entities in time, parthood simpliciter can be defined on the basis of temporary parthood. The opposite is true only if one commits to the existence of temporal parts (at every time of existence), an option compatible with both DOLCE and DOLCE-CORE but that is not enforced. This means that the axioms for temporary parthood are compatible with both the endurantist and perdurantist views of persistence through time. Assuming that x and y persist through time, endurantists read the formula $\mathsf{P}(x,y,t)$ as "x and y are both *wholly* present at t and x is part of y", while perdurantists read that formula as "the temporal part of x at t is part of the temporal part of y at t". Therefore, perdurantists need to assume the existence of x and y as well as that of the temporal parts of x and y.

[11] From a perdurantist perspective (see Section 13.11) where entities are considered as four-dimensional "worms", this simply means that two possibly different four-dimensional worms (x and y) have the same temporal slice at t.

D4 $\mathsf{CC}(x,y,t) \triangleq \mathsf{P}(x,y,t) \wedge \mathsf{P}(y,x,t)$ *(x, y coincide at t)*
D5 $\mathsf{CP}(x,y) \triangleq \exists t(\mathsf{PRE}(x,t)) \wedge \forall t(\mathsf{PRE}(x,t) \rightarrow \mathsf{P}(x,y,t))$ *(x is a constant part of y)*
A16 $\exists t(\mathsf{PRE}(x,t)) \rightarrow (\mathsf{CP}(x,y) \leftrightarrow \mathsf{P}(x,y))$
(for entities in time, "constant part" and "parthood" are equivalent)

Temporary parthood presents three main novelties with respect to the corresponding relationship of DOLCE: *(i)* it is defined on all the particulars that are in time; *(ii)* the existence of sums is not guaranteed; *(iii)* (A16) is new (in DOLCE it was considered as a possible extension).

Let us say that a relation R is *time regular* whenever it satisfies the following:

(DS) $R(x,y,t) \wedge \mathsf{P}(t',t) \rightarrow R(x,y,t')$ *(dissectivity)*
(AD) $R(x,y,t') \wedge R(x,y,t'') \wedge \mathsf{SUM}(t,t',t'') \rightarrow R(x,y,t)$ *(additivity)*
(SB) $R(x,y,t) \wedge \mathsf{CC}(x',x,t) \wedge \mathsf{CC}(y',y,t) \rightarrow R(x',y',t)$ *(substitutivity)*

We can rephrase these properties as follows: if the relation holds at a time, it holds at any sub-time; if the relation holds at two times, then it holds also at the time spanning the two; if a relation holds at t for two entities, then it holds for any two entities temporally coincident at t with them. These properties are collected here since they characterize several relations in DOLCE-CORE. In particular, we conclude our partial presentation of temporary parthood by stating that this relation is time regular, that is, it satisfies all the above constraints.

13.9 Concepts

The formalization of properties as extensional predicates (the first option of Section 13.4) is straightforward and requires no new formal element. Instead, the second option we considered involves two notions which are not in the original version of DOLCE: the category of concepts C and the relation of classification CF. $\mathsf{CF}(x,y,t)$ stands for "x classifies y at time t" and is characterized in DOLCE-CORE as a time regular relation that satisfies

A17 $\mathsf{CF}(x,y,t) \rightarrow \mathrm{C}(x)$
A18 $\mathsf{CF}(x,y,t) \rightarrow \mathsf{PRE}(y,t)$

In addition we require that concepts are mereologically constant, i.e., with respect to parthood they do not change over time:

A19 $\mathrm{C}(x) \wedge \mathsf{PRE}(x,t) \wedge \mathsf{PRE}(x,t') \rightarrow \forall y(\mathsf{P}(y,x,t) \leftrightarrow \mathsf{P}(y,x,t'))$

13.10 Qualities and Locations

The third option to formally represent properties is via individual qualities.

Each individual quality, say "the color of my car" or "the weight of John", and its host are in a special relationship called *inheritance*. Formally, it is expressed by expressions of form $\mathsf{I}(x, y)$, whose intended reading is "the individual quality x inheres in the entity y".[12] This relationship binds a specific bearer as shown by (A21) while (A22) says that each quality existentially depends on the entity that bears it; in the previous examples the bearers are my car and John, respectively. Furthermore, from axiom (A23) qualities exist during the whole life of their bearers.[13]

We anticipated that individual qualities are grouped into quality types, say Q_i is the color-quality type, Q_j the weight-quality type etc. These constraints are simple and we do not report them explicitly except for axiom (A24) according to which an entity can have at most one individual quality for each specific quality type. Axioms (A25) and (A26) say that if two particulars coincide at t then they need to have qualities of the same type and these qualities also coincide at t. In other terms, entities coincident at t must have qualities that are indistinguishable at t. Axiom (A27) says that the sum of qualities of the same type that inhere in two objects inheres in the sum of the objects (provided these sums exist).

A20 $\mathsf{I}(x, y) \rightarrow \mathrm{Q}(x)$
A21 $\mathsf{I}(x, y) \wedge \mathsf{I}(x, y') \rightarrow y = y'$
A22 $\mathrm{Q}(x) \rightarrow \exists y(\mathsf{I}(x, y))$
A23 $\mathsf{I}(x, y) \rightarrow \forall t(\mathsf{PRE}(x, t) \leftrightarrow \mathsf{PRE}(y, t))$
A24 $\mathsf{I}(x, y) \wedge \mathsf{I}(x', y) \wedge \mathrm{Q}_i(x) \wedge \mathrm{Q}_i(x') \rightarrow x = x'$
A25 $\mathsf{CC}(x, y, t) \rightarrow (\exists z(\mathsf{I}(z, x) \wedge \mathrm{Q}_i(z)) \leftrightarrow \exists z'(\mathsf{I}(z', y) \wedge \mathrm{Q}_i(z')))$
A26 $\mathsf{CC}(x, y, t) \wedge \mathsf{I}(z, x) \wedge \mathsf{I}(z', y) \wedge \mathrm{Q}_i(z) \wedge \mathrm{Q}_i(z') \rightarrow \mathsf{CC}(z, z', t)$
A27 $\mathsf{I}(x, y) \wedge \mathsf{I}(v, w) \wedge \mathrm{Q}_i(x) \wedge \mathrm{Q}_i(v) \wedge \mathsf{SUM}(z, x, v) \wedge \mathsf{SUM}(s, y, w) \rightarrow \mathsf{I}(z, s)$

Note that we do not force a schema of form

<u>Rejected</u> $\mathsf{I}(x, y) \wedge \mathrm{Q}_i(x) \wedge \mathsf{P}(y', y) \rightarrow \exists x'(\mathsf{I}(x', y') \wedge \mathrm{Q}_i(x') \wedge \mathsf{P}(x', x))$

because this would prevent properties that inhere in complex objects only, e.g., emergent properties like functionalities of assembled artifacts (when not reducible to functionalities of the components).

The *location* relation, L, provides the link between qualities and spaces. First, we require regions (and in particular spaces) not to change during the time they exist (A28). Then, we write $\mathsf{L}(x, y, t)$ to mean "at time t, region x is the location of the individual quality y" as enforced (in part) by axioms (A30) and (A31).[14] Each individual quality of type Q_i must be located at least in one of the available spaces S_{ij} associated to it (axioms (A34) and (A35)). The location in a single space is unique

[12] In the original version of DOLCE this relation is called *quality* and written qt.

[13] For those familiar with trope theory (Campbell, 1990), qualities can be seen as sums of tropes. Indeed, one can interpret a trope substitution as a change of quality location. The position adopted in DOLCE-CORE is compatible with trope theory without committing to the view that change corresponds to trope substitution.

[14] In the original version of DOLCE this relation is called *quale* and written ql. In DOLCE there was also a distinction between the *immediate* quale (a non temporary relation) and the *temporary* quale. Here we use one temporary relation only and assume that the temporal qualities of an event e at t correspond to the temporal qualities of the maximal part of e spanning t.

(A36) and a quality that has a location in a space needs to have some location in that space during its whole life (A37). (A38) says that two qualities coincident at t are also indistinguishable with respect to their locations. Together with (A25) and (A26), this axiom formalizes the substitutivity of temporary properties represented by qualities: two entities that coincide at t are (at t) indistinguishable with respect to their qualities.

Axioms (A32) and (A33) characterize the fact that the location of an individual quality at t is the mereological sum of all the locations the quality has *during* t, i.e. at all the sub-times of t. Note that if a is the region corresponding to a property value of $1kg$ and b corresponds to a property value of $2kg$, then the sum of a and b is the region including just the two mentioned and is distinguished from the region corresponding to the property value of $3kg$. The sum of locations must not be confused with the sum of property values since, in general, the latter strictly depends on the space structure while the first does not. Therefore, for instance, if t is the sum of t_1 and t_2, and $\mathsf{L}(1kg, x, t_1)$ and $\mathsf{L}(1kg, x, t_2)$, then at t, x is still located a $1kg$ and not at $2kg$.

A28 $\mathrm{R}(x) \wedge \mathsf{PRE}(x,t) \wedge \mathsf{PRE}(x,t') \rightarrow \forall y(\mathsf{P}(y,x,t) \leftrightarrow \mathsf{P}(y,x,t'))$

A29 $\mathrm{S}_{ij}(x) \wedge \mathrm{S}_{ij}(y) \wedge \mathsf{PRE}(x,t) \rightarrow \mathsf{PRE}(y,t)$

A30 $\mathsf{L}(x,y,t) \rightarrow \mathrm{R}(x) \wedge \mathrm{Q}(y)$

A31 $\mathsf{L}(x,y,t) \rightarrow \mathsf{PRE}(y,t)$

A32 $\mathsf{L}(x,y,t) \wedge \mathsf{P}(t',t) \wedge \mathsf{L}(x',y,t') \wedge \mathrm{S}_{ij}(x) \wedge \mathrm{S}_{ij}(x') \rightarrow \forall t''(\mathsf{PRE}(x,t'') \rightarrow \mathsf{P}(x',x,t''))$

A33 $\mathsf{L}(x',y,t') \wedge \mathsf{L}(x'',y,t'') \wedge \mathsf{SUM}(t,t',t'') \wedge \mathsf{SUM}(x,x',x'') \wedge \mathrm{S}_{ij}(x') \wedge \mathrm{S}_{ij}(x'') \rightarrow \mathsf{L}(x,y,t)$

A34 $\mathsf{L}(x,y,t) \wedge \mathrm{Q}_i(y) \rightarrow \bigvee_j \mathrm{S}_{ij}(x)$

A35 $\mathrm{Q}(y) \wedge \mathsf{PRE}(y,t) \rightarrow \exists x(\mathsf{L}(x,y,t))$

A36 $\mathsf{L}(x,y,t) \wedge \mathsf{L}(x',y,t) \wedge \mathrm{S}_{jk}(x) \wedge \mathrm{S}_{jk}(x') \rightarrow x = x'$

A37 $\mathsf{L}(x,y,t) \wedge \mathsf{PRE}(y,t') \wedge \mathrm{S}_{jk}(x) \rightarrow \exists x'(\mathsf{L}(x',y,t') \wedge \mathrm{S}_{jk}(x'))$

A38 $\mathsf{L}(x,y,t) \wedge \mathsf{CC}(x',x,t) \wedge \mathsf{CC}(y',y,t) \rightarrow \mathsf{L}(x',y',t)$ (L-*substitutivity*)

The next formula is not an axiom since not all properties are dissective (see the previous example using weights)

<u>Rejected</u> $\mathsf{L}(x,y,t) \wedge \mathsf{P}(t',t) \rightarrow \mathsf{L}(x,y,t')$

Additivity is also non-valid for L: it does not hold for properties like mass.

<u>Rejected</u> $\mathsf{L}(x,y',t) \wedge \mathsf{L}(x,y'',t) \wedge \mathsf{SUM}(y,y',y'') \rightarrow \mathsf{L}(x,y,t)$

13.11 Objects and Events

We all experience a tendency to distinguish *what changes* from the *changing* itself. A lively and long discussion on the ontological status of events and on what distinguishes them from objects has taken place especially in the philosophy of language

(Casati and Varzi, 1996). There are formal and applicative advantages in accepting events, e.g., one can (*i*) quantify over actions, (*ii*) predicate on causality, and (*iii*) avoid reductionist views.

The orginal DOLCE formulated the object vs. event distinction in terms of the endurant vs. perdurant partition by identifying objects with endurants and events with perdurants. This choice reflects the position of several philosophers and is based on the observation that, say, the "life of John" is only *partially* present at each time at which it exists (it has distinct temporal parts at each time at which it exists) while "John" is *wholly* present whenever it exists (it does not depend on the existence of temporal parts). However, with this position classical perdurantism would not be able to embrace the object vs. event distinction for the simple reason that perdurantists accept only perdurant entities. In addition, in a strict reading of perdurantism, all particulars must be spatio-temporally extended and two distinct entities cannot have exactly the same spatio-temporal location. Thus, since "John" and "the life of John" have exactly the same spatio-temporal location, perdurantists would be forced to identify them. This shows that the previous identification, although motivated by some aspects of the theories, is perhaps too naïve and a different (and more general) foundation of the distinction between objects and events should be sought.

Hacker (1982) proposes to characterize the distinction on the fact that events are *primarily* in (directly related to) time while material, and more generally physical, objects are *primarily* in (directly related to) space. Indeed,

- the properties (and qualities) that apply to material objects are different from those that apply to events. Typically, material objects have weight, size, shape, texture, color etc. and they are related by specific spatial relationships like congruence. Events, on the other hand, can be sudden, brief or prolonged, fast or slow, etc. and can occur before, after, simultaneously with other events. Moreover, relations like causation seem to be strictly linked to events and not to objects.
- Space plays a role in the identification of material objects, time in that of events. Material objects that are simultaneously located at different places are different and events that have different temporal locations are different (Zemach, 1970).
- The unity criteria of objects is primarily spatial, while the one of event is primarily temporal (Hacker, 1982).

This division extends to non-material objects as well since these are also characterized by non-temporal properties and specific individuation and unity criteria (space is the realm of these criteria for material objects, other objects rely on other dimensions, all distinct from time). In short, what differentiates events from (material or immaterial) objects is the special connection to time and temporal relations.

Of course, even though events are primarily in time while objects are primarily in other dimensions, there are strong interrelationships between them. Several author (Simons, 1991; Hacker, 1982) claim that events are not possible without objects and vice versa. Since from the representation perspective there seems to be no real advantage in committing to a reductionist view (either choosing that events are the truly basic entities or, on the contrary, attributing to objects this role), the preferred option is to consider both categories of events and of objects as primary categories and to highlight their relationships: events need participants (objects) and objects need lives (events). By means of the relationship between objects and events (aka *participation*), it is possible to say that an object a exists at a certain time t "if and because" its life exists at t (Simons, 2000), i.e. it is the life of a that is the truth-maker for the proposition "a exists at t". On the other hand, events are related to space only indirectly via the material objects participating in them.

DOLCE-CORE characterizes the distinction between objects and events (two basic categories in the ontology structure) following this latter approach. However, by (A10), qualities, concepts, and regions are in time too and, intuitively, their participation to events (like their creation or destruction) seems plausible. In this perspective, qualities, concepts and regions could be considered as subcategories of O (in this view objects are not necessarily extended in space). Here we do not commit to this position and therefore we maintain our initial assumption where qualities, concepts, and regions are disjoint from objects.

Participation is taken to be a *time regular* relation defined between objects and events: $\mathsf{PC}(x,y,t)$ stands for "the entity x participates in the event y at t". Axioms (A40) and (A41) capture the mutual existential dependence between events and objects. Axioms (A42) and (A43) make explicit the fact that participation does not rely on unity criteria for objects or for events (Simons, 1987). This simply means that the participation relation is not bound by these unity criteria: an object does not participate to an event as a whole (since also its parts participates to it) as well as an event does not have participants because of some special unity property (since all the events, of which it is part, have those participants too). Participation, of course, can be used to define more specific relations that take into account unity criteria. Since these criteria often depend on the purposes for which one wants to use the ontology, they are not discussed here.

A39 $\mathsf{PC}(x,y,t) \rightarrow \mathrm{O}(x) \wedge \mathrm{E}(y)$

A40 $\mathrm{E}(x) \wedge \mathsf{PRE}(x,t) \rightarrow \exists y(\mathsf{PC}(y,x,t))$

A41 $\mathrm{O}(x) \wedge \mathsf{PRE}(x,t) \rightarrow \exists y(\mathsf{PC}(x,y,t))$

A42 $\mathsf{PC}(x,y,t) \wedge \mathsf{P}(y,y',t) \wedge \mathrm{E}(y') \rightarrow \mathsf{PC}(x,y',t)$

A43 $\mathsf{PC}(x,y,t) \wedge \mathsf{P}(x',x,t) \rightarrow \mathsf{PC}(x',y,t)$

We now clarify how DOLCE-CORE manages to formalize events and objects as entities with different qualities, and how it represents "being *primarily* in time (space)". Axiom (A44) makes explicit the fact that quality types directly connected to events cannot be directly related to objects and vice versa.

A44 $\mathsf{I}(x,y) \wedge \mathrm{Q}_i(x) \wedge \mathrm{E}(y) \wedge \mathsf{I}(z,v) \wedge \mathrm{Q}_j(z) \wedge \mathrm{O}(v) \rightarrow \neg\mathrm{Q}_j(x) \wedge \neg\mathrm{Q}_i(z)$

The exact quality types that apply to objects and events depend on the modeling interests of the user. Nonetheless, as motivated earlier, qualities that apply to events are strictly connected to time (fast vs. slow, sudden vs. prolonged, etc.).

Regarding the property of "being primarily in time", we introduce the quality type "being time-located".[15] Let us use TQ for this quality type for time and let us make the simplifying assumption that there is just one space for the time individual qualities; as seen in Section 13.5, we call it T. DOLCE-CORE (as well as DOLCE) distinguishes *direct* qualities, i.e., properties that can be predicated of x because it has a corresponding individual quality, from *indirect* qualities, i.e., properties of x that are inherited from the relations x has with other entities. For instance, following Simons (2000), events have a direct temporal location, while objects are located in time just because they participate to events (e.g. their own lives). Analogously, material objects have a direct spatial location, while events are indirectly located in space through the spatial location of their participants.

(A45) makes explicit the temporal nature of the parameter t in the location relation. (A46) says that for events "being in time" reduces to having a time-quality located in time, which, together with (A10) and (A44), guarantees that all and only the events have a time-quality. These axioms together with (A41), show that objects are in time because of their participation in events.

A45 $\mathsf{L}(x,y,t) \wedge \mathrm{TQ}(y) \rightarrow x = t$

A46 $\mathrm{E}(x) \wedge \mathsf{PRE}(x,t) \leftrightarrow \exists y(\mathrm{TQ}(y) \wedge \mathsf{I}(y,x) \wedge \mathsf{L}(t,y,t))$

Note that if we define the spatial location of events via the location of their participants, and the life of an object as the minimal event in which it (maximally) participates, we obtain that an object spatio-temporally coincides with its life. The distinction between participation, temporary parthood, and spatial inclusion ensures that these two entities, although spatio-temporally coincident, are not identified.

As stated before, in DOLCE-CORE qualities cannot participate in events. This holds in particular for the qualities of objects even though in this case qualities are related to time by axiom (A23) through the objects they inhere in (which necessarily exist by axiom (A22)). Time is (at least) an "indirect" quality of qualities of objects. However one could follow the opposite intuition that qualities can participate in events, assuming that only qualities are the "true" participants in events. In this perspective, objects would participate only indirectly *because of* the qualities they have.

Several important questions have been left out of this paper. We hope, nonetheless, that the approach adopted in building first DOLCE and then DOLCE-CORE stands out, that the foundational choices we have made can be appreciated for the careful analysis they rely upon, and that the general methodology we apply here has been fairly illustrated.

[15] Analogously, the ontology comprises the quality type "being space-located" which is not presented here.

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