Foundational Choices in DOLCE

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Summary. Foundational ontologies are ontologies that have a large scope, can be highly reusable in different modeling scenarios, are philosophically and conceptually well founded, and are semantically transparent.

After the analysis and comparison of alternative theories on general notions like 'having a property', 'being in time' and 'change through time', this paper shows how specific elements of these theories can be coherently integrated into a foundational ontology. The ontology is here proposed as an improvement of the core elements of the ontology DOLCE and is thus called DOLCE-CORE.

1 Introduction

Chapter "What is an *Ontology*?" analyses what ontologies are and their peculiarities with respect to other methods and technologies that exist in conceptual modeling and knowledge representation. *Foundational ontologies* are ontologies that: (1) have a large scope, (2) can be highly reusable in different modeling scenarios, (3) are philosophically and conceptually well founded, and (4) are semantically transparent and (therefore) richly axiomatized.

Foundational ontologies focus on very general and basic concepts (like the concepts of object, event, quality, role) and relations (like constitution, participation, dependence, parthood), that are not specific to particular domains but can be suitably refined to match application requirements. These notions have been largely investigated by philosophers and, even though foundational ontologies assume a modeling and engineering perspective (far from the absolutist view of most philosophical theories), one relies on philosophical considerations for the construction, comparison, organization, and assessment of the ontologies themselves.

To achieve semantic transparency, a careful choice of the primitives and a precise characterization of their meaning are needed. This goal requires a formal language with clear semantics and adequate expressive power (in this chapter we will use first-order logic). Unfortunately, application concerns lead to work with languages that are suitable for run-time reasoning and one often has to give up on expressivity and semantic clearness. For these reasons, foundational ontologies are used in applications only in approximated forms via partial translations into different application-oriented languages. Thus, the relevance of foundational ontologies does not rely in their direct impact on applications but in their ability to providing *conceptual handles* with which to carry out a coherent and structured analysis of the domains of interest.

The paper is organized as follows. Section 2 analyzes and compares alternative well founded theories on central notions like 'having a property', 'being in time' and 'change through time'. Then, in Sect. 3, we study how specific elements of these theories can be integrated into a foundational ontology that we call DOLCE-CORE and constitutes a first step in the revision of DOLCE[1] [17]. Other foundational ontologies are not discussed in this paper for lack of space.[2]

2 Foundational Distinctions

The literature on ontological choices is primarily of philosophical character. Several tenable positions for each issue have been individuated and some have been described to a rich level of detail. Unfortunately, there is no homogeneity in the depth of the analysis: some topics, like the theories of parthood and space, have been well studied others, e.g., the theories of dependence and unity still lack a stable landscape [26]. Perhaps more worryingly, there is no comprehensive list of ontological issues relevant to foundational ontologies.

2.1 Theories of Properties

The nature of properties, the explanation of what it means that an individual has a property, and, more specifically, of how different individuals can have the *same* property, have been widely discussed and investigated ([1,15,20] are good surveys). Intuitively, the term *individual* (or, alternatively *particular*) refers to entities that cannot have instances, that is, entities that cannot be predicated of others like Aristotle, the Tour Eiffel, the Mars planet. On the contrary, the term *property* denotes entities that can have instances, that is, entities that qualify other entities, e.g., Red (the color), Person (the kind), Fiat Panda (the car model). Traditionally, the notion of property has been formally represented in two ways. In the first, it is associated with the set-theoretical notion of *class*[3] and, in the latter, with the logical notion of *predicate*.

[1] `http://www.loa-cnr.it/DOLCE.html`

[2] See, for instance, BFO: `http://www.ifomis.org/bfo`; GFO: `http://www.onto-med.de/ontologies/gfo.html`; OPENCYC: `http://www.opencyc.org`; SUMO: `http://www.ontologyportal.org/`

[3] As usual in this area, we use the terms 'class' and 'set' interchangeably.

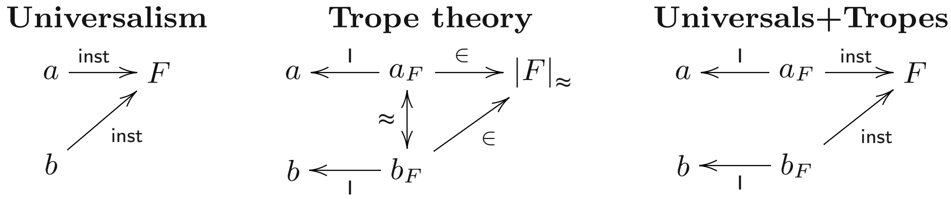

Fig. 1. Philosophical positions on properties

Our goal in this section is to briefly introduce a few alternative positions that are of particular interest in modeling. Consider the expression “the individuals a and b share the property F” (as exemplified by, say, “my car and my pen are both red”).

Figure 1 illustrates three different ways to represent this expression.[4]

Universalism claims that both entities a and b *instantiate* (inst) the *universal* F which, in short, means that F is a repeatable and independent entity (a universal) that is *wholly present in* both a and b. Intuitively, one could rephrase this view by saying “may car and my pen both instantiate redness”. The instance-of relation, inst, is different from the set-theoretical membership relation, $\in$, (exemplified by expression “my car and my pen both belong to the class of red things”) for two reasons: (1) the latter is extensional (two different classes must have at least a different member) while the first might not (nothing prevents different universals to have exactly the same instances); and (2) classes are closed under union and intersection while nothing suggests that the union or intersection of two universals must be a universal itself. Universals are, so to speak, *sparse* and *minimal* since they cannot be generated by syntactic manipulations. They correspond to truly ontological distinctions that are present *in the world*.

The second diagram in Fig. 1 depicts the *trope theory* (see [5] for a good survey). This theory is based on the notion of *individual property* or *trope*. A trope *inheres in* (I) one single individual and it represents the distinct way an individual has a property (“my car is red” means that there is a specific individual property, a trope, of my car and this trope is classified red). If a and b are different individuals, then the way a is F (has property F) is necessarily different from the way b is F because a and b rely on different tropes. In Fig. 1, a_F is the F-trope of a and b_F the F-trope of b. This means that (1) the inherence relation between a trope and its bearer satisfies the *non migration principle*, i.e., tropes inhere in a unique bearer (a1), and that (2) tropes are existentially dependent on their bearers, i.e., tropes cannot exist without a bearer (a2). If we read $\mathsf{I}(x, y)$ as “x inheres in y” and $\textsc{trope}(t)$ as “t is a trope”, then

a1 $\mathsf{I}(t, x) \wedge \mathsf{I}(t, y) \rightarrow x = y$
a2 $\textsc{trope}(t) \rightarrow \exists x(\mathsf{I}(t, x))$

[4] There are other positions like, e.g., the *bundle theory* [23].

Then, if John and Paul have the same weight, this does not mean that they have the same trope but that their distinct tropes (relative to weight) are somehow similar. Trope sameness is an a equivalent relation called *indistinguishability* or *resemblance* ($\approx$): a and b share the property F if and only if $a_F \approx b_F$. In short, trope theory reduces properties to equivalence classes of resembling tropes.

Note that trope theory and universalism are not antithetical. One can rely on tropes and the inherence relation while substituting the classes of resembling tropes by universals and membership (between tropes and classes) by instantiation (between tropes and universals). That is, the universalist view can be adopted to classify the tropes instead of the entities as in the third diagram in Fig. 1.

Basic Properties, Quality Kinds, and Spaces

People compare entities along a variety of aspects such as color, weight, smell, etc. For each aspect, similarities are established depending on the tools people dispose of, or on the specific analysis they are interested in. This knowledge disparity is often dismissed by philosophers as an epistemological or empirical issue: the entities, they say, have a completely determined shade of color even though in practice it is not accessible to the observer. This attitude somehow prevents the assessment of a philosophical analysis of this issue, of course, but the available philosophical notions still provide a good starting point for building a philosophically based and yet application oriented framework.

In [10, 11] an important *determinate-determinable* relation (dD) between properties has been suggested by combining subsumption and partitioning: $\mathsf{dD}(F, G)$ means that entities that have the property F also have the (more general) property G and entities that have the property G have at least one of the (more specific) properties that are the *determinates* of G, among which there is F. For example, "being crimson" and "being scarlet" are both determinates of "being red" and the latter is a determinate of "being colored". The dD relation induces a partial-order over properties. According to this ordering, properties about the same aspect of objects are organized in a tree the leaves of which are formed by the most specific properties, hereafter called *basic properties*. Then, any entity that has a property is claimed to have also a basic property in the corresponding tree. It is this basic property that makes the entity ontologically indistinguishable (with respect to the given aspect) from the other entities with the same basic property: two entities enjoying property "being $1m$ long" cannot be differentiated on the basis of their lengths. Vice versa, entities that have different basic properties are surely different. Sharing *non* basic properties indicates some form of similarity but has no direct import on the distinguishable/indistinguishable status of the entities.

In trope theory, sharing a basic property corresponds to having two *exactly resembling* tropes: two '$1m$ long' entities have *exactly similar* (yet distinct) length-tropes. If they resemble each other inexactly, it is said that their length-tropes resemble each other only *up to a degree*. One can add structure in the class of tropes by saying that $1m$ and $2m$ length-tropes have a higher degree of resemblance than the $1m$ and $30m$ length-tropes or analogously, that a scarlet-trope and a crimson-trope resemble each other better than a scarlet-trope and a turquoise-trope. In this view, non basic properties are built as classes of *inexactly* resembling tropes. Exploiting the degrees of resemblance, all the tropes can be collected in few large classes. However, if we put together a $1m$-trope and a 'red'-trope or a $1kg$-trope, we contradict the initial intuition that the comparison between entities has to be done for 'homogeneous' properties, i.e., properties on the same aspect of entities: the comparison between the length of an object with the color of another object is not really plausible.

General properties that identify specific aspects of entities (like "being colored", "being shaped", etc.) cannot be discharged: without these we cannot even conceive the functional laws of physics [2]. Ingvar Johansson [10] characterizes these general properties, hereafter called *quality kinds*, in terms of *maximal incompatibility and maximal comparability* of their determinates: (1) each entity that has a quality kind F must have just one basic property that is a determinate of F, and (2) all the basic properties that are determinate of F are qualitatively comparable. Summing up, each *quality kind* is a (non basic) property that corresponds to one aspect/dimension of comparison for entities, the property is partitioned into more specific properties that give different levels of distinctions for that aspect, the lowest level is that of the basic properties.

Properties in the same quality kind can be organized in taxonomies or in more sophisticated ways: from ordering (weight, length) to complex topological or geometrical relations (color splinter). Following [6] we call *spaces* these complex structures of properties. Sometimes properties can be combined together to model multi-dimensional or multi-aspectual properties like density, speed or force. The color property can also be seen as a multi-dimensional property since one can distinguish hue, saturation, and brightness as different quality kinds. These cases indicate that property spaces can combine to very specialized structures.

Often spaces are motivated by applications or epistemological considerations, it is quite natural to associate each quality kind to several spaces, each organizing properties (and thus objects) according to different principles, instruments of investigation, applications concerns, etc. These spaces rely on relative notions of resemblance that are discussed, adopted, and abandoned by (communities of) intentional agents. This view of spaces as generated (and eventually destroyed) structures leads to model spaces as temporal entities. Alternative spaces can differ on several aspects: their structure, the level of detail the adopted measuring tool can reach, or the point of view that motivate them. This variety of spaces can be partially ordered according to the level of detail they are capable of distinguishing, a notion often called *granularity*.

Concepts and Roles

The framework just introduced addresses two concerns: (1) representing intensional properties that are created (and eventually destroyed) by agents and (2) classifying qualities according to different points of view and granularities.

The first point is important independently of the need to organize properties in spaces. Take properties like 'being a student', 'being money', 'being a catalyst', etc. that we will call *concepts*. These have a clear conceptual and intensional nature – they are defined in terms of relationships with external entities, e.g., 'a person enrolled in a university', and do not depend on their instances – but do not present any special internal structure. The rich framework given by quality kinds and spaces is largely pointless for these concepts. A mechanism more tailored to these properties is needed.

Roles are a subclass of concepts. The nature and the representation of roles have been long discussed in a variety of fields: knowledge representation, conceptual modeling, multi-agent systems, linguistics, sociology, philosophy, and cognitive semantics (see [14,18,29]). These properties are intensional and *anti-rigid* (see Chapter "An Overview of OntoClean") in the sense that an entity may play a role for a limited time (and perhaps resume it in different periods) without changing its identity. Often in conceptual modeling roles are seen as classes but this approach has severe problems [29].

2.2 Being in Time

The entities that are mostly studied in applied ontology are entities that exist in time. Temporal existence is often modeled via a predicate like $\mathsf{PRE}(x, t)$, whose informal reading is 'x is present at time t'.

Since PRE is defined on *times*, these must be in the domain of quantification. However, this does not necessarily lead to strong ontological commitments on times: times could be constructed from events [12], 'being present at a time' can be reduced to 'being simultaneous with' other entities [27]. Of course, one can take the Newtonian view in which time is an independent container. In this case, PRE is a sort of localization relation in that container. In both cases, one can take times to be punctual or extended and even adopt different structures on them (discrete vs. continuous, linear vs. branching, etc.). Furthermore, there are different ways of being in time: existing in time vs. occurring in time (a distinction related to the contraposition between objects and events, see Sect. 2.4) or being wholly present vs. being partially present (relying on the contraposition between endurants and perdurants, see below).

We give for granted that some entities are present at different times, i.e., they are persisting through time. The explanation of this apparently obvious fact may be quite intricate. *Stage theory* [8] claims that all existing entities, called stages, are temporally instantaneous. In this perspective, 'persisting entity' is meaningless since no entity can exists at different times. Commonsense persistence is modeled by stage theory only at the *conceptual* level:

persisting entities are reconstructed as collections of stages and special rules, called *unity criteria* (see Chapter "An Overview of OntoClean"), are isolated to flag meaningful collections.

Two main philosophical positions accept the ontological existence of persisting entities: *endurantism* and *perdurantism*. Endurantists claim that one and the same entity is *wholly present* at different times (enduring) and read the formula $\mathsf{PRE}(a,t_1) \wedge \mathsf{PRE}(a,t_2)$ as "a is wholly present at both the times t_1 and t_2". 'Being *wholly* present' is often contrasted with 'being *partially* present', i.e., the rationale of perdurantism. Perdurantists claim that the persistence through time is analogous to the extension in space: an entity has different parts at different times (perduring). The previous formula is then read by perdurantists as claiming "a has a part at t_1 and a (different) part at t_2". Therefore, in addition to a, perdurantists commit to the existence of the parts of a that exist only at t_1 and at t_2, respectively.

Despite the disagreement between perdurantism and stage theory on the nature of persisting entities, both the theories associate each persisting entity with a sequel of other entities. Indeed, the following property holds in these systems (it may fail for endurantists):

a3 $$\mathsf{PRE}(a,t_1) \wedge \mathsf{PRE}(a,t_2) \wedge t_1 \neq t_2 \rightarrow \exists b_1, b_2(\mathsf{PRE}(b_1,t_1) \wedge \forall t(\mathsf{PRE}(b_1,t) \rightarrow t = t_1) \wedge \mathsf{PRE}(b_2,t_2) \wedge \forall t(\mathsf{PRE}(b_2,t) \rightarrow t = t_2))$$

Provided one does not give up on expressive power, it is formally an advantage to have a core theory compatible with different philosophical positions since one can use the very same framework and specialize it, when needed, with the additional constraints of one or the other theory. In this perspective, without (a3) the formula $\mathsf{PRE}(a,t_1) \wedge \mathsf{PRE}(a,t_2)$ can be interpreted freely by endurantism, perdurantism, and stage theory.

2.3 Property Change

Persisting objects change through time by changing their properties: a may be red at time t_1 and green at t_2.[5] It should be clear by now that there are alternative views on properties and on persistence through time. However interesting these topics are, none is as debated as the issue of property change itself. Aiming at a wide-ranging presentation, we formally model properties in first order logic (FOL) via formulas of form $F(a,t)$ without committing to any ontological constraint beside those (fairly weak) of FOL itself. According to [21], $F(a,t)$ can be read in a very general way: "a exists at t and it has the property F when t is (was, will be) present". We will see alternative readings

[5] We limit this presentation to properties. The arguments, *mutatis mutandis*, hold for relations as well.

of $F(a,t)$ in terms of more committed theories. For the time being, let us begin with a minimal condition: since a at t has property F, a needs to exist at t.[6]

a4 $F(x,t) \rightarrow \mathsf{PRE}(x,t)$

Formula $F(a,t_1) \wedge G(a,t_2)$ formalizes the change of a property.

Following Sect. 2.1, universalists have three ways to model property change: (1) adding a temporal parameter to inst making it a ternary relation on entities, universals, and times as in (a5); (2) applying temporal modal operators to the binary inst, see (a6); (3) committing to temporal slices $x@t$ (the maximal part of x during t) as seen in perdurantism, see (a7). (Here we use the same letter for both the relational property and its nominalization: cfr. the occurrence of F on the left and on the right of $\leftrightarrow$, resp.ly, in (a5).)

a5 $F(x,t_1) \wedge G(x,t_2) \leftrightarrow \mathsf{inst}(x,F,t_1) \wedge \mathsf{inst}(x,G,t_2)$
a6 $F(x,t_1) \wedge G(x,t_2) \leftrightarrow \Box_{t_1} \mathsf{inst}(x,F) \wedge \Box_{t_2} \mathsf{inst}(x,G)$
a7 $F(x,t_1) \wedge G(x,t_2) \leftrightarrow \mathsf{inst}(x@t_1,F) \wedge \mathsf{inst}(x@t_2,G)$

A trope theorist explains change as trope substitution, (a8).[7] If one accepts both universals and tropes, trope substitution can be formulated as in (a9).

a8 $F(x,t_1) \wedge G(x,t_2) \leftrightarrow \exists f,g(\mathsf{I}(f,x) \wedge \mathsf{I}(g,x) \wedge f \in F \wedge g \in G \wedge \mathsf{PRE}(f,t_1) \wedge \mathsf{PRE}(g,t_2))$
a9 $F(x,t_1) \wedge G(x,t_2) \leftrightarrow \exists f,g(\mathsf{I}(f,x) \wedge \mathsf{I}(g,x) \wedge \mathsf{inst}(f,F) \wedge \mathsf{inst}(g,G) \wedge \mathsf{PRE}(f,t_1) \wedge \mathsf{PRE}(g,t_2))$

If both tropes and universals are considered, a notion of "tropes changing over time" becomes available, we call these *individual qualities*. An individual quality, like a trope, inheres in a unique bearer but, differently from tropes, it can change over time. In this case we can explain change according to the following schemata that are similar to (a5) and (a7), respectively[8]:

a10 $F(x,t_1) \wedge G(x,t_2) \leftrightarrow \exists q(\mathsf{I}(q,x) \wedge \mathsf{inst}(q,F,t_1) \wedge \mathsf{inst}(q,G,t_2))$
a11 $F(x,t_1) \wedge G(x,t_2) \leftrightarrow \exists q(\mathsf{I}(q,x) \wedge \mathsf{inst}(q@t_1,F) \wedge \mathsf{inst}(q@t_2,G))$

In these approaches the color, weight, shape, etc. of an object are each modeled by a different individual quality, and the changing through time of these qualities explain changes in the bearers: intuitively, it is the individual color of an object a that changes from, say, fuchsia to green and the individual weight (a different individual quality of a) that changes from some weight to

[6] Recall the notion of property given in Sect. 2.1. One should refrain from considering boolean combinations of predicates, like 'not being present', as possible values for F.
[7] We use the set-theoretical $\in$ predicate to indicate that here F stands for the class of tropes that satisfy F.
[8] We could do as in (a6) as well but we do not investigate this option here.

another. While (a10) is compatible with both an endurantist and a perdurantist reading about persistence of individual qualities, we see that (a11) is ontologically more demanding since it refers to temporal slices of individual qualities. On the other hand, (a11) has the advantage of being compatible with (a9) if we accept mereological sums of tropes. At the same time, (a9) is to be preferred to (a8) because in (a9) inst can be taken to be intensional.

Of course, one should have some advantage for introducing yet another type of entities like individual qualities. After all, why aren't (a5) and (a7) enough? The usefulness of individual qualities relies on the fact that they are associated to one quality kind only and the latter usually has different spaces associated. A change in the same individual quality is described differently by the different points of views encoded by the spaces. For example, a change in color can be described according to both a RGB and a CYMK color-space. Having a unique individual color-quality related to all the relevant spaces allows for expressing that it is the same aspect of the object (the color) that changes. In [16] alternative positions that avoid individual qualities are analyzed and it is shown that, if expressivity is to be maintained, these systems are technically and conceptually more complicated. These aspects may seem minor to a neophyte and yet they are crucial in setting a foundational ontology as we will see in Sect. 3.

Mereological Change: Endurantism vs. Perdurantism

The difference between the endurantist and perdurantist theories of persistence (Sect. 2.2) can be addressed in terms of the parthood relation. Classical endurantists think that "statements about what parts the object has must be made relative to some time or other" ([8], p. 26), which makes *temporary* parthood a primitive relation to endurantists. On the contrary, perdurantists can derive temporary parthood from the relations of parthood *simpliciter* and 'being present at a time' via schema (a7) (which is applicable since perdurantists accept temporal slices). In [24, 25] Sider provides a direct comparison of these two positions by starting from a temporary parthood relation shaped to be acceptable to both endurantists and perdurantists (even though they would interpret it differently). Sider's formulation of perdurantism is given by the usual axioms for temporary parthood (see Sect. 3.2) plus the existence of temporal slices to characterize the notion of 'being partially present'. On the other hand, the notion of 'being wholly present' (that plays a central role in endurantism) remains somehow obscure and difficult to characterize notwithstanding some attempts have been made [4, 9, 19]. Both endurantists and perdurantists accept the usual axioms for temporary parthood, yet endurantists cannot accept that each entity has a temporal slice at each time at which the entity exists.[9] As noted in [25], either we assume that endurantism

[9] Endurantists do not refuse the existence of temporal parts and temporal slices in general. They do not accept that all the persistent entities necessarily have temporal slices at each time of their existence.

needs nothing more than the general axioms discussed before (therefore it is a theory less constrained than perdurantism), or we need to accept that the endurantist view still lacks a clear and formal characterization. After all, the intuitive notion of 'being wholly present at each instant' is trivially satisfied by temporary parthood even in the perdurantist axiomatization since all the parts of x at t are present at t.

From these observations, perdurantists may indifferently adopt temporary parthood or parthood simpliciter as the primitive relation, while endurantists must rely on temporary parthood. In the perspective of foundational ontology, this is an important result, exploited in Sect. 3.2, since it shows that one can construct a fairly general ontology that is compatible with both endurantism and perdurantism.

Parthood and Spatio-Temporal Inclusion

Perdurantists often see parthood as spatio-temporal inclusion and thus rely on extensional mereology (axioms (A1)-(A4) and definition (D2) of Sect. 3.2). This view pushes them to reject the existence of spatio-temporally coincident entities: if x and y have the same spatio-temporal extension then both $\mathsf{P}(x, y)$ and $\mathsf{P}(y, x)$ hold and consequently, due to antisymmetry of parthood, they are identical. This position is, however, more restrictive than the original proposal of Lesniewski [13]. Lesniewski proposed mereology as an alternative to set theory that avoids the cognitively obscure distinction between *urelements* and *sets* (not to mention the puzzling notion of empty set). The goal was to ensure that the entity $a+b$, obtained combining a and b, is nothing more than a *and* b (and not an abstract element like the set with members a and b). Indeed, in mereology the sum and the addenda have the same ontological status.

In its general perspective, extensional mereology is a purely formal theory and it applies to all kinds of entities (the spatio-temporal entities are just one case).[10] Parthood, when applied to spatio-temporal entities, is strictly related to spatio-temporal inclusion. Nonetheless, these relations must not be confused: philosophers and engineers like to apply parthood and mereological change even to entities like, e.g., mathematical theories, word meanings, beliefs and societies, i.e., entities that are said to be in time but not in space. On the other hand, it is unquestioned that two spatio-temporally extended entities, that are one part of the other, are also spatio-temporally included. The vice versa does not necessarily hold: some authors accept that some crete constituted a given statue and yet reject that crete is part of the statue [22].

2.4 Events and Objects

We can all distinguish *what changes* from the *changing* event itself. A lively and long discussion on the ontological status of events and on what distinguishes

[10] Analogously for temporary parthood even though, of course, this relation requires a notion of 'existence in time'.

them from objects has taken place especially in the philosophy of language [3]. Recently, philosophers have been discussing proposals to reduce events to other basic notions, while researchers from the cognitive, the common-sense, and the modeling perspectives are engaged in exploiting the strength and relevance of the category of events and its relationship with that of objects. There are formal and applicative advantages if events are part of the domain (quantifying over actions, predicating on causality, overcoming reductionist views.)

Several authors collapse the object vs. event distinction to the endurant vs. perdurant one by identifying objects with endurants and events with perdurants. The unification is endorsed by the observations that 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) and ‘John’ is *wholly* present whenever it exists (the existence of temporal parts is not required). However, if this match were correct, classical perdurantism would not be able to embrace the object vs. event distinction. The reason is easily stated: as shown in Sect. 2.3, all the entities in a perdurantist view have temporal parts when they exist but 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 must identity them. Furthermore, it is not really an option to insist that ‘John’ is part of the ‘life of John’ or viceversa. These observations pushed some philosophers to reject as naive the previous identification and to look for a separate (and perhaps more general) foundation of the distinction between objects and events.

Hacker [7] puts emphasis on the fact that events are *primarily* in (directly related to) time while (material) objects are *primarily* in (directly related to) space. This division is based on a series of observations among which:

- 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, etc. and are related by 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 to other events.
- Space plays a role in the identification of material objects and in their unity criteria, 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 [30].

Of course, even though events are primarily in time and objects primarily in other dimensions, there are strong interrelationships between them. Several authors [7, 27] claim that events are not possible without objects and vice versa. Since technically there seems to be no real advantage in committing to a reductionist view (either choosing that events are the truly basic entities or, alternatively, attributing to objects this role), the most general option is to consider both events and objects as forming two primary and related categories: 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 [28], 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.

3 DOLCE-CORE: The New Basis for DOLCE

DOLCE [17] is a foundational ontology developed with the vision that a unique universal ontology for knowledge representation cannot exist. The idea behind DOLCE is that an ontology should be philosophically consistent and transparent (i.e., embrace a clear ontological perspective) and promote its correct application (e.g., by describing explicitly the basic assumptions on which it relies). Furthermore, DOLCE puts much emphasis on interoperability, in particular with other ontological systems, and exploits the "no hidden choice" principle: if a philosophical or applicative position is compatible with the *explicit* commitments of an ontology, then this ontology can indeed be extended to formalize that position. DOLCE goes even further in this view by allowing coexistence of alternative ontological views via parametrization and other formal techniques.

The aim of DOLCE is to capture the intuitive and cognitive bias underlying common-sense while recognizing standard considerations and examples of linguistic nature. These claims are sustained by the accompanying documentation that carefully describes the foundational choices and motivates both the structure and the formalization of DOLCE. Generally speaking, DOLCE does not commit to a strong referentialist metaphysics (it does not make claims on the intrinsic nature of the world) nor to a scientific enterprise. Rather, it looks at reality from the mesoscopic and conceptual level aiming at a formal description of a specific conceptualization of the world. Technically, DOLCE is the result of a careful selection of constraints so to guarantee expressiveness, precision, and simplicity of use.

In the following, we resume our discussion in the previous sections to present the ontological choices made by DOLCE. The discussion is limited to a fragment of the whole ontology (the core formed by the most general categories) and, in some cases, it departs from the published version [17]. For this reason, we dub the ontology in these pages the 'core of DOLCE' or DOLCE-CORE, which forms the basis for the next version of the ontology. Due to lack of space, we will explain only major consequences of these changes.

3.1 Basic Categories

DOLCE-CORE is an ontology limited to entities that exist in time, called *temporal particulars*. While in DOLCE regions and spaces are abstract entities (i.e., entities that are outside time and space), DOLCE-CORE adopts a contextual perspective by introducing them as temporal entities that are created, adopted, abandoned, etc. Following [18], *concepts* (not considered in the original DOLCE) are treated similarly. These assumptions are somehow debatable but have the advantage of providing a general and comprehensive perspective on ontology which is well suited for applications. Abstract regions (and abstract entities in general) can of course exist in the full ontology. They are simply not discussed in the DOLCE-CORE fragment.

DOLCE-CORE partitions *temporal-particulars* (PT) (hereafter *particulars*) into six basic categories: *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. Following the observations in Sect. 2.4, the DOLCE's categories ED (endurant) and PD (perdurant) are, respectively, renamed O (object) and E (event). Individual qualities are themselves partitioned into *quality kinds* (Q_i). Each quality kind Q_i is associated to one or more *spaces* (S_{ij}): each individual quality in Q_i has location in (i.e., is associated to a region in each of) 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) time.[11]

3.2 Parthood and Temporary Parthood

DOLCE-CORE carefully distinguishes spatio-temporal inclusion and parthood by adopting the axioms (A1)-(A4) of extensional mereology, see below. These axioms apply to all entities in the domain. The basic categories, with the exception of AS, are homogeneous: the parts and the sums of entities belonging to one category are still in the same category (see (A5) and (A6)). AS collects those *mixed* entities that are obtained as sum of elements in different basic categories. However, note that the ontology does not enforce any mereological sum of entities to exist. In particular, AS may very well be an empty category. It is left to the user to enforce this constraint (perhaps limited to specific kinds of entities) when needed.

In the following $\mathsf{P}(x,y)$ stands for 'x is part of y', $\mathsf{O}(x,y)$ for 'x overlaps with y', and $\mathsf{SUM}(z,x,y)$ for 'z is the mereological sum of x and y'.

D1 $\mathsf{O}(x,y) \triangleq \exists z(\mathsf{P}(z,x) \wedge \mathsf{P}(z,y))$ (*Overlap*)
D2 $\mathsf{SUM}(z,x,y) \triangleq \forall w(\mathsf{O}(w,z) \leftrightarrow (\mathsf{O}(w,x) \vee \mathsf{O}(w,y)))$ (*Binary Sum*)

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

[11] All these statements are easily stated in logic. Here we omit their formal characterization.

As anticipated in Sect. 2.2 we introduce the primitive predicate ‘being present at’ (PRE) to identify at which times entities exist. No commitment to a specific notion of time is taken in DOLCE-CORE. Nonetheless, in Sect. 3.4 we will analyze different readings of this predicate depending on the category of entities it applies to. PRE is defined on times (A7) and it is dissective and additive over time ((A8) and (A9)).

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

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

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

As stated in Sect. 3.1, all the entities considered in DOLCE-CORE exist in time:

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

To include entities not in time, one should add to DOLCE-CORE a more general category that includes both temporal and abstract particulars. In this general ontology, DOLCE-CORE provides the formalization of the subclass of temporal particulars.

DOLCE-CORE adopts a temporary extensional mereology, also denoted by P, which is based on axioms (A12)-(A15), i.e., those of extensional mereology adapted to the extra temporal parameter. Further mereological aspects are enforced via the notion of *time regular relation* (see below). Expression $\mathsf{P}(x,y,t)$ stands for ‘x is part of y at time t’, analogously for $\mathsf{O}(x,y,t)$.

D3 $\mathsf{O}(x,y,t) \triangleq \exists z(\mathsf{P}(z,x,t) \wedge \mathsf{P}(z,y,t))$ (*Temporary Overlap*)

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

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

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

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

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

Axiom (A3) implies that entities indistinguishable with respect to parthood are identical. Temporary coincidence (D4) provides a weaker 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 (they can still differ in general).[12] If $\mathsf{CC}(x,y,t)$ then all the properties of x at t are also properties of y at t and vice versa.[13] Yet, no constraint follows on properties of x and y at a time different from t.

[12] Perdurantists read $\mathsf{CC}(x,y,t)$ as the identity of the temporal slices $x@t$ and $y@t$.

[13] This claim has to be taken with a *grain of salt* since one should not consider properties that constrain x before or after t itself, e.g., ‘being red an year after t’ (provided this actually counts as a property).

Axiom (A16) states that in DOLCE-CORE parthood simpliciter can be defined on the basis of temporary parthood, i.e., temporary parthood is more informative. The opposite is true only committing to the existence of temporal parts that is not enforced here. This means that the axioms for temporary parthood are compatible with both the endurantist and perdurantist views of persistence through time. Note that axioms (A10) and (A16) make possible to define parthood simpliciter in terms of temporary parthood. Yet, we use two distinct primitives to avoid hidden commitments: in an extension of DOLCE-CORE that includes abstract entities, both the primitives are necessary (and the two axioms maintain their validity).

D4 $\mathsf{CC}(x,y,t) \triangleq \mathsf{P}(x,y,t) \wedge \mathsf{P}(y,x,t)$ (*Temp. Coincidence*)
D5 $\mathsf{CP}(x,y) \triangleq \exists t(\mathsf{PRE}(x,t)) \wedge \forall t(\mathsf{PRE}(x,t) \rightarrow \mathsf{P}(x,y,t))$ (*Const. Part*)

A16 $\exists t(\mathsf{PRE}(x,t)) \rightarrow (\mathsf{CP}(x,y) \leftrightarrow \mathsf{P}(x,y))$

Temporary parthood presents three main novelties with respect to the corresponding relationship of DOLCE: (1) it is defined on all the particulars that are in time; (2) the existence of sums is not guaranteed; (3) (A16) is new (in DOLCE it was given as a possible extension).

DOLCE-CORE makes use of a few relations that satisfy the following structural axioms:

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

We can rephrase these constraints 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 (provided it exists); if the relation holds for two entities at t, then it holds for entities temporally coincident with them at t.

These constraints are important in setting the DOLCE-CORE framework and relations satisfying them are dubbed *time regular*. In particular, we enforce the temporal parthood of DOLCE-CORE to be *time regular*.

3.3 Properties

DOLCE-CORE offers three different options to represent properties and temporary properties. The first option is standard and consists in the introduction of an *extensional predicate*. With this choice one cannot represent whether the property is related to contextual or social constructions nor its intensional aspects. In addition, to model change through time one needs to add a temporal parameter as in expression $F(a,t)$, i.e., 'a has the property F at t'. This last solution allows to represent dynamics in the properties but, as anticipated, is not suited for roles [29]. For these reasons, predicates are adequate to model the *basic elements* of the user's conceptualization of the world as well as the categories and the primitive relations of DOLCE-CORE. The formalization of properties as extensional predicates is straightforward and requires no special formalism.

The second option consists in reifying properties, that is, in associating them to entities in the category of concepts, C. 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* (CF), is introduced in the ontology. $\mathsf{CF}(x, y, t)$ stands for 'x classifies y as it is at time t' and is characterized in DOLCE-CORE as a *time regular* relation that satisfies also

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

The idea is to use concepts to represent properties for which the intensional, contextual, or dynamic aspects are important (as in the case of roles [18]): 'being a student', 'being a catalyst', 'being money'.[14] Since concepts are temporal entities, they can be created, destroyed, etc. Note, however, that they are mereologically constant i.e. they do not change through time with respect to parthood:

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

The third option relies on the notions of *individual quality*, *quality kind* and (quality-)*space* introduced in Sect. 2.1. Each individual quality, say "the color of my car" or "the weight of John", and its host are in a special relationship called *inherence* (I). Formally, expression $\mathsf{I}(x, y)$, stands for "the individual quality x inheres in the entity y".[15] This relationship binds a specific bearer (A21) and each quality existentially depends on the entity that bears it (A22); in the previous examples the bearers are my car and John, respectively. Finally, axiom (A23) states that qualities exist during the whole life of their bearers.[16]

We anticipated that individual qualities are grouped into quality kinds, say $\textsc{q}_i$ is the color-quality kind, $\textsc{q}_j$ the weight-quality kind, 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 kind. Axioms (A25) and (A26) say that if two particulars coincide at t then they need to have qualities of the same kind and

[14] Differently from [18], here we do not rely on logical definitions for concepts. The intensional aspect is (partially) characterized by explicitly stating when concepts are different.

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

[16] For those familiar with trope theory [5], qualities can be seen as sums of tropes. Indeed, one can interpret 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.

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 kind 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 $\mathsf{I}(x,y) \wedge \mathsf{I}(v,w) \wedge \mathrm{Q}_i(x) \wedge \mathrm{Q}_i(v) \wedge \mathsf{Sum}(z,x,v) \wedge \mathsf{Sum}(s,y,w) \rightarrow \mathsf{I}(z,s)$

The *location* relation (L) provides the link between qualities and spaces. First, we require regions (and in particular spaces) not to change over the time they exist (A28). Expression $\mathsf{L}(x,y,t)$ is used to state "at time t, region x is the location of the individual quality y" as enforced (at least in part) by axioms (A30) and (A31).[17] Each individual quality in Q_i must be located at least in one of the associated spaces S_{ij} (axioms (A34) and (A35)). The location in a single space is unique (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 indistinguishable at t 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.

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

[17] In DOLCE this relation is called *quale* and written ql. In DOLCE there is also a distinction between the *immediate* quale (a non temporary relation) and the *temporary* quale. DOLCE-CORE uses one temporary relation only since the temporal qualities of an event e at t correspond to the temporal qualities of the maximal part of e that spans t.

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

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

A34 $\mathsf{L}(x,y,t) \wedge \textsc{q}_i(y) \rightarrow \bigvee_j \textsc{s}_{ij}(x)$

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

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

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

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*)

3.4 Objects and Events

DOLCE-CORE characterizes the distinction between objects and events following the discussion in Sect. 2.4. In this approach events are primarily in time while objects are primarily in space (in the case of physical objects) or in other dimensions. Since by (A10) qualities, concepts, and regions are in time as well, their participation to events (like their creation or destruction) is plausible. One can investigate this position further and note that Q, C and R can be considered as specializations (subcategories) of O. However, to ensure generality, we made the assumption that qualities, concepts, and regions form categories disjoint from the category of objects.

The DOLCE-CORE unified framework relies on the *participation* relation (PC) to relate the temporal qualities of events and the atemporal qualities of objects. Participation is taken to be a *time regular* relation defined between objects and events: $\mathsf{PC}(x,y,t)$ stands for "the object 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 relies on unity criteria neither for objects nor for events [26]. 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 (its parts participate to it as well) and an event does not individuate its participants by the virtue of some special unity property (any larger event has those participants also). 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. Axiom (A44) makes explicit that a quality kind directly related to events cannot be also directly related to objects and vice versa. Note that the exact list of quality kinds that apply to objects and events are not fixed, they depend on the modeling interests of the user.

A39 $\mathsf{PC}(x,y,t) \rightarrow \textsc{o}(x) \wedge \textsc{e}(y)$

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

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

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

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

A44 $\mathsf{I}(x,y) \wedge \textsc{q}_i(x) \wedge \textsc{e}(y) \wedge \mathsf{I}(z,v) \wedge \textsc{q}_j(z) \wedge \textsc{o}(v) \rightarrow \neg\textsc{q}_j(x) \wedge \neg\textsc{q}_i(z)$

Regarding the property of 'being primarily in time', we introduce the quality kind 'being time-located'.[18] Let us use TQ for the quality kind for time and recall that T, introduced in Sect. 3.1, is the unique space associated to TQ. 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, events have a direct temporal location, while objects are located in time just because they participate to events [28]. Analogously, physical 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) guarantees that the events have a time-quality. These axioms, together with (A10) and the axioms on inheritance and location guarantee that, for events, 'being in time' reduces to having a time-quality located in T. In addition, together with (A41) and (A44) they show that objects are in time because of their participation in events.

A45 $\mathsf{L}(x, y, t) \wedge \text{TQ}(y) \rightarrow x = t$
A46 $\text{E}(x) \rightarrow \exists y(\text{TQ}(y) \wedge \mathsf{I}(y, x))$

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 and temporary parthood ensures that these two entities, although spatio-temporally coincident, are not identified.

4 Conclusions

In writing this introductory paper, we had three major goals: (1) to distinguish foundational studies from the rest of the ontology research, (2) to introduce topics and methodology typical of foundational ontology and (3) to show a concrete example of how these theoretical arguments can be used to build a foundational ontology. Unfortunately, in literature there is no good reference that presents this research area at length and any attempt to introduce these topics in the limited space of a paper are deemed to be unsatisfactory on several aspects. At least, we hope that the paper gives the average reader the opportunity to appreciate the goals of this area of research as well as the subtle interactions between philosophy, logic and representational issues. Finally, we are glad of the opportunity to present the DOLCE-CORE system of Sect. 3 which is the first step, after the release of the DOLCE ontology in 2002, toward a new version of this ontological system.

[18] Analogously, the ontology comprises the quality kind 'being space-located' which is not presented here.

References

1. D. M. Armstrong. *Universals: An Opinionated Introduction*. Westview Press, 1989.
2. D. M. Armstrong. *A World of States of Affairs*. Cambridge Studies in Philosophy. Cambridge University Press, Cambridge, 1997.
3. R. Casati and A. C. Varzi, editors. *Events*. Dartmund, Aldershot, 1996.
4. Thomas M. Crisp and Donald P. Smith. Wholly present defined. *Philosophy and Phenomenological Research*, 71:318–344, 2005.
5. Chris Daly. Tropes. In D.H. Mellor and A. Oliver, editors, *Properties*, pages 140–159. Oxford University Press, Oxford, 1997.
6. Peter Gärdenfors. *Conceptual Spaces: the Geometry of Thought*. MIT Press, Cambridge, Massachussetts, 2000.
7. P. M. S. Hacker. Events and objects in space and time. *Mind*, 91:1–19, 1982.
8. K. Hawley. *How Thing Persist*. Clarendon Press, Oxford, UK, 2001.
9. Christopher Hughes. More fuss about formulation: Sider (and me) on three- and four-dimensionalism. *Dialectica*, 59(4):463–480, 2005.
10. Ingvar Johansson. Determinables as universals. *The Monist*, 83(1):101–121, 2000.
11. W. E. Johnson. *Logic*, volume 1. Cambridge University Press, Cambridge, 1921.
12. H. Kamp. Events, istants and temporal reference. In R. Baüerle, U. Egli, and A von Stechow, editors, *Semantics from Different Points of View*, pages 376–417. Springer, Berlin, 1979.
13. S. Lesniewski. *Collected Works*. Kluwer, Dordrecht, 1991.
14. F. Loebe. Abstract vs. social roles - towards a general theoretical account of roles. *Applied Ontology*, 2(2):127–258, 2007.
15. Michael J. Loux, editor. *Universals and Particulars: Readings in Ontology*. University of Notre Dame Press, London, 1976.
16. C. Masolo and S. Borgo. Qualities in formal ontology. In P. Hitzler, C. Lutz, and G. Stumme, editors, *Foundational Aspects of Ontologies (FOnt 2005) Workshop at KI 2005*, pages 2–16, Koblenz, Germany, 2005.
17. Claudio Masolo, Stefano Borgo, Aldo Gangemi, Nicola Guarino, and Alessandro Oltramari. Wonderweb deliverable d18. Technical report, CNR, 2003.
18. Claudio Masolo, Laure Vieu, Emanuele Bottazzi, Carola Catenacci, Roberta Ferrario, Aldo Gangemi, and Nicola Guarino. Social roles and their descriptions. In D. Dubois, C. Welty, and M.-A. Williams, editors, *Ninth International Conference on the Principles of Knowledge Representation and Reasoning*, Whistler Canada, 2004.
19. Neil McKinnon. The endurance/perdurance distinction. *Australasian Journal of Philosophy*, 80(3):288–306, 2002.
20. D. H. Mellor and A. Oliver, editors. *Properties*. Oxford University Press, 1997.
21. Trenton Merricks. Endurance and indiscernibility. *Journal of Philosophy*, 91(4):165–184, 1994.
22. M. Rea, editor. *Material Constitution*. Rowman and Littlefield Publishers, 1996.
23. B. Russel. *Human Knowledge. Its Scope and Limits*. Allen and Unwin, London, 1948. parte IV, cap. 8; trad. it., La conoscenza umana, Longanesi, Milano 1963, parte IV, cap. 8, pp. 298-313.
24. T. Sider. Four-dimensionalism. *The Philosophical Review*, 106:197–231, 1997.
25. T. Sider. *Four-Dimensionalism. An Ontology of Persistence and Time*. Clarendon Press, Oxford, 2001.

26. P. Simons. *Parts: a Study in Ontology*. Clarendon Press, Oxford, 1987.
27. P. Simons. On being spread out in time: temporal parts and the problem of change. In Wolfang Spohn et al., editor, *Existence and Explanation*, pages 131–147. Kluwer Academic Publishers, 1991.
28. Peter Simons. How to exist at a time when you have no temporal parts. *The Monist*, 83(3):419–436, 2000.
29. Friedrich Steimann. On the representation of roles in object-oriented and conceptual modelling. *Data and Knowledge Engineering*, 35:83–106, 2000.
30. Eddy M. Zemach. Four ontologies. *Journal of Philosophy*, 67(8):231–247, 1970.