The Temporal Essence of Spatial Objects

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1. Introduction[1]

We aim to characterize some properties of concrete objects that seems to be reflected in language use and that make for different categories of references. A difference is made here between so-called spatial objects, and concrete, or material objects (cars, dogs, pools of mud, accountants or puffs of smoke). When talking about spatial objects, one often means entities having an extension in space (either material or immaterial). Of course, being in space is only one consequence of the existence of such objects, and it is certainly the most salient when are considered for instance so-called "spatial" prepositions or "motion" verbs relating these objects. Having a material extent means more, however: a certain persistence in time (which is clear when considering motion verbs), which in turns raises the question of what "existence" means for material objects. We argue here that categorizing uses in spatial language is actually to be put in a somewhat larger ontological perspective. We will thus study the role of the temporal dimension in characterizing different ways of referencing objects in the perceived world.

We will have to clarify our position with respect to two classical problems while doing this. The first one is as old as ontology and is related to the link between our assumed ontology and language use: what kinds of objects are there independently of our linguistic way of describing them? and are there objects in that sense? The second problem is the link between those objects, if we decide this is meaningful, and language. Are there linguistic criteria to distinguish kinds of objects, are there categories of reference (with clear-cut syntactic or semantic differences) that reflect differences between object categories?

As an illustration, let's consider the much-studied difference between so-called "mass terms" and "count nouns". There is an admitted difference between the use of, e.g., *mud* and *dog*, as can be seen from the following sentences:

(1) *There is mud in my garden.*

(2) *There is a dog in my garden.*

The syntactic difference between the use of the two singular common nouns is sometimes taken as an *a priori* categorial difference between two things they denote: an animal (a dog), and an indeterminate amount of a particular substance (mud). The difference can be further characterized from a more semantic point of view by noticing that any suitable part of *mud* in the same context can also be considered as *mud* (what is sometimes called dissectivity or homogeneity of the reference in Pelletier and Schubert (1989: 328), whereas not any suitable part of a dog can be said to be a dog. Of course we now have to explain what is a suitable part of an object: a molecule of clay is not mud, a dog without its tail might still be a dog.

What is at stake here are the kinds of entities that can be described as dogs or mud or anything else. Whether it is of a purely semantic nature (Wierzbicka, 1996), because language use induces a conceptualization of objects without *a priori* existence, is a heavily debated issue.

Thus a count noun evokes an individuation, as opposed to a mass term. Calling what I'm sitting on a "chair" or a "piece of plastic" would then just be a different way of considering a given entity, not a description of an intrinsic property. In that case, our task will be to model the properties conventionally ascribed to these conceptualizations.

The problem of the link between an ontology and language use can be seen on our example when considering what Pelletier has called the "universal grinder" (Pelletier, 1979; Pelletier & Schubert, 1989) , namely the fact that sentences of the following kind can be built for any common noun:

(3) *There is dog [splattered] all over/in my garden.*

Here the "count" noun dog is used as a mass term. Authors following Pelletier will argue that only noun phrases denote mass terms or count nouns. So if we assume an existing ontology and categories of objects, how we map linguistic reference to these categories might not be as simple as saying that they are uniquely attached to lexical items or certain syntactic constructions; cf. also (Aurnague et al.), this volume, for an investigation of this phenomenon for the object-location distinction.

We will take for granted part-whole relations when necessary to define what is an acceptable "part" of an entity (but see the paper by Vieu & Aurnague in the same volume). Deciding what characterizes an entity as a "whole" (the problem of identity) is beyond our scope. We limit ourselves to temporal properties considered in conjunction with spatial properties.

We will then in the following sections present some accepted categories of

reference (not necessarily exclusive), restricted to concrete terms: mass terms versus countable entities, singular versus plural entities, objects versus events involving them. We will leave aside the problem of entities which are not clearly material or immaterial, such as holes. After a presentation of our ontological logical theory we will explain how it can be used to express some differences between the categories of linguistic reference previously introduced.

2. The ontological problem of the reference to concrete entities

2.1. Words and objects

As discussed in the introduction, there are a few different ways of seeing the problem of the reference to concrete objects from an ontological point of view, and this is the traditional philosophical problem of the relation between the physical world and the mental world, see (Russell, 1959).
We can roughly divide the problem into the following, relevant for our purposes, positions: for the "realist", objects exist independently of us, for the "semanticist", objects and language are inter-dependent (we will ignore here the "idealist", such as Berkeley, for whom objects or matter is essentially mental):

1. the "realist" point of view: there are objects in a real world that we can have access to somehow, and these occupy a region of space, possibly changing through time. These objects are independent of language use. This view, most favored by works on qualitative reasoning about physical objects in knowledge representation (Cohn, 1996), is also assumed in a lot of philosophical studies (Simons, 1987; Casati & Varzi, 1999; Heller, 1990) where language is usually considered as an untrustworthy tool when considering ontology problems (see Varzi's chapter, this volume). These do not say that the correspondence between objects and our perception is easy to establish, but only that it is independent from language, or at least that we can reach some understanding of these, abstracting away from linguistic descriptions.
2. the "semanticist" point of view: objects are language-dependent mental constructions; their relation to a real world depends on the role played by these mental entities; this means different languages will have different ways of describing the same perceptions, some of which are arbitrary, up to a certain point (e.g., the mass/countable distinction). This does not mean there cannot be "conceptual" invariants (see for instance the work

of (Wierzbicka, 1996)), but they are mapped with linguistic expressions in different ways across languages.

For the pure realist, no two different objects can occupy the same region of space at the same time (or the same region of space-time). Thus a chair and the plastic it's made of must describe the same entity. The semantic point of view is more inclined to accept that different mental objects are ascribed to the same portion of space at a given time. An extreme stand would then be to consider every linguistic description as introducing a different object. A less extreme approach due to Wiggins would be to consider that there are categories of reference, and that objects can be conceptualized with respect to these categories. Thus no two objects of the same category can occupy the same region of space at the same time, but a "quantity of substance" (e.g., *plastic*) can be said to coincide with an "object" (e.g., *a chair*). Such categories are called "substantial sortals" in (Wiggins, 1980).

2.2. Part, wholes, categories

A lot of the considerations made above depends on a proper notion of a "part" of an object. Defining an object or more generally a material entity is defining what makes a "whole", and a whole can be defined in relation to its parts. Parts can be material parts (a portion of the space occupied by something, or of the matter it is made of), or more intrinsic parts, either because they are essential to an entity (losing that part is the end of it), or because they play a specific role within an entity. The dynamics of parts is thus very important in the definition of what is a proper object, as Hobbes' Ship of Theseus paradox shows (Wiggins, 1980; Simons, 1987).

Conversely, the notion of part depends on different categorizations of objects: see (Winston, Chaffin, & Herrmann, 1987; Aurnague & Vieu, 1993) and Vieu & Aurnague's chapter in this volume, for a study of different part-whole relations that can be defined on the basis of a category system for concrete entities.

The basis for many ontological theories is some kind of part-of relation, and we will use a "mereology" (Lesniewski, 1992), to describe parts of objects. For simplicity, we will assume that parts of objects are only spatio-temporal parts. If parts are to be considered something more elaborate (distinguishing functional parts, essential parts, material parts, ...), we will point out where our theory should be amended to account for this more complex notion perhaps with other relations. Part-whole relations are then central in explaining what makes a collective entity different from a singular entity, or a substance different from a countable entity.

2.3. Occurrents vs Continuants ontology

Concrete objects exist in space *and* time and we are going to study their different spatio-temporal properties. This raises the question of the existence of temporal entities. Since Davidson's work (Davidson, 1967), a lot of people admit the existence of such things as "events", evidenced in ordinary language. There is a classical debate in formal ontology about the difference between objects and events, and the question of their relative existence. There is on one side a philosophical tradition claiming that every material object is in fact nothing else than just a process in space-time (Whitehead, 1929; Quine, 1960; Russell, 1959) and that objects are constructed from events. More qualified points of views might consider that both are kinds of spatio-temporal entities and investigate the differences, as we will here (Noonan, 1976; Goodman, 1977; Heller, 1990). This is still the source of some debate, as a lot of authors refuse this ontological assumption. For them, events are essentially different as they *occur* in time (and thus are often called "occurrents") while objects *exist* through time (Hacker, 1982), and thus are sometimes called continuants or endurants. For many authors, continuants are thus not to be considered as having a temporal extension (Simons, 1987; Geach, 1972; Thomson, 1983). A lot of objects only have a limited existence, unfortunately, so there must also be an existence function in an ontology of continuants, and a need for a theory of change of these entities. The seemingly different points of view might thus be explained away by an unclear notion of existence, if one accepts that the problem is not merely verbal, Sider (1997: 55); we will also argue that something is to be gained by recasting some puzzles into a spatio-temporal framework.
In our perspective, events occupy space, and objects have an extension in time. Favored by the few philosophers mentioned above, this ontology is sometimes called "four-dimensional", since objects and events are seen as subsets of a space-time combining the three spatial and the temporal dimensions. We will speak more generally of a spatio-temporal ontology, since dimension does not play any part in our discussion. What is central instead in the interplay of a topological theory (for space-time as a whole) and a temporal one (mostly, an order on entities).

3. Expressing spatial and temporal properties in a unified ontology

To be serious about a different foundation for categories of spatial entities, we need to have a theory that can describe the kind of properties that will explain

the categories, at least from the spatial and temporal point of view. A formal (logical) theory of a space-time mereology has already been proposed, in which some of the ideas of the proponent of a spatio-temporal ontology can be formulated (Muller, 1998). In particular, it is in line with Nelson Goodman's calculus of individuals (Leonard & Goodman, 1940), and the ideas of (Quine, 1960; Heller, 1990). It has also been argued that we need at least a topology to account for a notion of "whole" and to make all the distinctions already mentioned. The only originality here is the formal investigation of the relations between a spatio-temporal topology and an order on spatio-temporal histories. This can be seen as a simplified but more thorough version of what was intended in (Hayes, 1985).

3.1. A spatio-temporal mereology and topology

The particulars of the logical theory will not be precised here. It has been written down in other papers (see (Muller, 2002), for the interested readers) and it is rather a technical problem. What will be relevant here are the relations that can be expressed within such a theory, and some of the properties they entail.

In particular, the following will be useful. Other relations can be defined, and will be introduced when needed.

- referents of objects and events are regions or "histories" of space-time (a topological space actually);
- these regions can be arbitrary regions of space-time, their intersections when they exist (noted $\cdot$), unions (noted $+$), and complements (noted $-$);
- all knowledge is expressed by relations between entities: part of (P), proper-part-of (PP), connection (C, meaning roughly that two entities share something or touch each other), temporal precedence ($<$), temporal connection ($\bowtie$), temporal overlap (σ), temporal inclusion ($\subseteq_t$), temporal equivalence $\equiv_t$.

In this theory, time is intended to be a linear space: any pair of temporally atomic entities (such as punctual events) can be ordered.

In the following, graphical representations will often be used to illustrate some of our points. To represent histories of objects we consider time as an axis as any other in a geometrical representation. Representations will be thus given in two dimensions, where space and time each correspond to one dimension (thus spatial objects in a classical sense will be segments). This will yield clearer illustrations than a cluttered three-dimensional figure, but might seem somewhat unintuitive at first.

Figure 1 is an example of such a diagram. Time is on the vertical axis, so if this is to be interpreted in a more usual way, at the beginning there are two

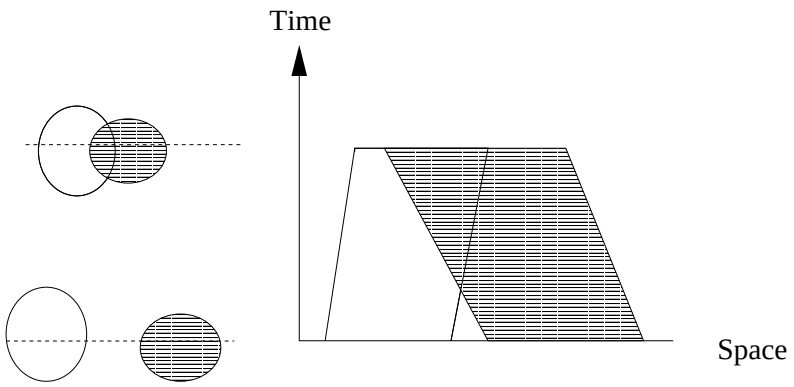

Figure 1: History diagram

separate segments, moving towards each other until they overlap.
On the left are spatial drawings of the initial and final situations corresponding to that diagram, if the objects were two-dimensional.
Such diagrams give a compact means of illustration of motion in space-time and are arguably representative of the expressing power of a global spatio-temporal theory.

3.2. Temporal parts

A crucial notion that is definable in our framework is that of a temporal part. Most ontologies only consider temporal parts of eventualities, or "purely" temporal entities (states, events,...). In an ontology where everything has a temporal extension, everything can have a temporal part. The most intuitive notion of temporal part is that of a "slice". A slice of an object is part of its history, which means this is the maximal part of an entity during a given time extent. The slice referred to can be an essential part of the entity (*the late Wittgenstein*, *Woody Allen's childhood*), or it can be defined externally by another entity (*my neighbor during WWII*). Very often such slices are determined by another contemporaneous entity, but it is generally enough for two objects to temporally overlap to allow for such descriptions. Some authors refer to the same notion with the words "phase" (Simons, 1987) or "stage" (Carlson, 1980).
Formally, it is defined in the following way in our ontology: x is a temporal slice (TS) of y whenever x is a part of y and for each part z of y that is temporally included in x, z is also a part of x (i.e. x is a maximal part of y during the life-span of x). Logical symbols used below are the classical $\forall, \exists, \wedge, \vee, \rightarrow$ for, respectively "for all", "exists", "and", "or", and "implies".

The $\triangleq$ symbol introduces a formal definition.

$$\mathrm{TS}(x, y) \triangleq \mathrm{P}(x, y) \wedge \forall z \, ((\mathrm{P}(z, y) \wedge z \subseteq_t x) \rightarrow \mathrm{P}(z, x))$$

With the same kind of illustration as before, a slice is thus a horizontal slice of an history in space-time (cf. figure 2). Among the properties of this notion,

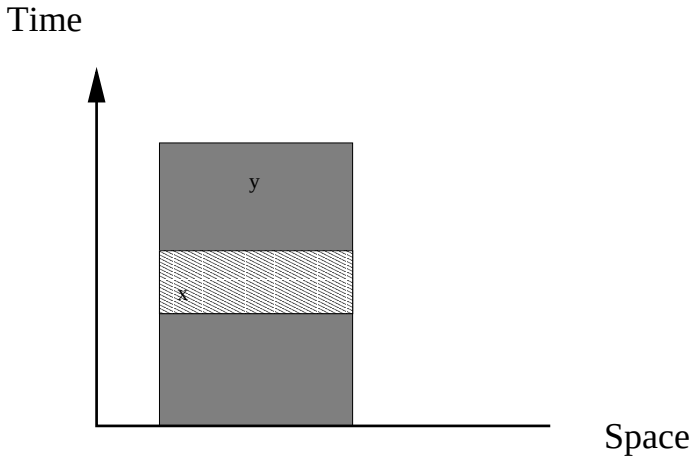

Figure 2: An entity slice

one must note that it is reflexive (anything is a temporal slice of itself), anti-symmetric (if x is a slice of y and conversely, then $x = y$), and transitive (a slice x of y, which is a slice of z, is also a slice of z) (Muller, 2002). Besides , we assume the following property (mentioned above): every time two entities overlap in time, we assume there are contemporaneous slices of each one. We can express this equivalently by saying that

$$y \subseteq_t w \rightarrow \exists u \, (\mathrm{TS}(u, w) \wedge u \equiv_t y)$$

This says that if y (e.g., WWII) "occurs" during w which is (the life of) John Doe, there is such a thing as "John Doe during WWII" (u) which we can predicate upon. In this specific example, the exact spatio-temporal extension of an event such as WWII is not really important, since what is relevant is the temporal relation between y and w.
It is easy to show that this part u is unique, and we will denote it by w/y. Figure 3 illustrates this situation.

4. Reconsidering categories of reference

Now that our ontological framework has been introduced, we need to specify which categories of entities are relevant to the issues mentioned above.

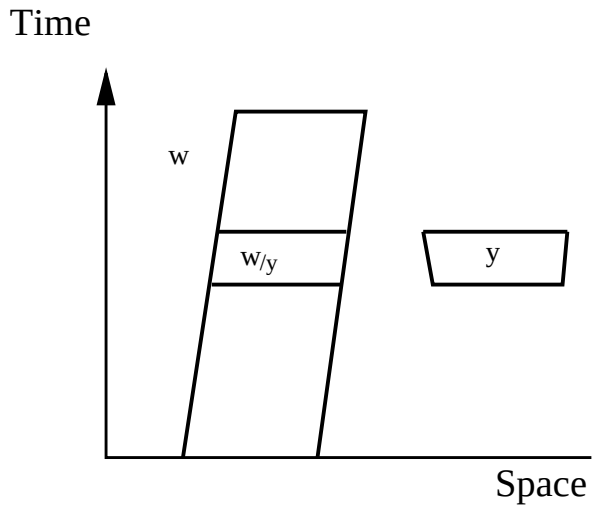

Figure 3: Two histories overlapping in time, defining a common episode

We claim that the following distinctions have specific spatial and temporal properties that can be partly explained in a spatio-temporal framework:

1. mass reference/countable reference;
2. singular reference/ plural reference;
3. object / event.

We will now characterize these with the use of the formal vocabulary introduced in the previous section.

4.1. Object and substance

We already mentioned the distinction between mass terms, which seem to denote non-countable entities (e.g., quantities of substances), and countable entities denoted by noun phrases such as *a dog*. This distinction offers a basis for many examples supporting the apparent existence of different objects occupying the same spatial location. Consider the following example from (Link, 1983):

(4) *The ring is new but the gold making up the ring is old.*

Here one could consider that the entity in question could be described either as *a ring* or *a piece of gold* (and one could anaphorically refer to the other, e.g., *this piece of gold*). This example however shows that the object "the ring" has different properties (it's "newer") than the substance it is made of ("the gold"), thus indicating that they are two different things, while they necessarily occupy the same location in space.

A standard account of this situation is to consider a function assigning a substance to an object (Wiggins, 1980; Link, 1983). Then a ring and its substance

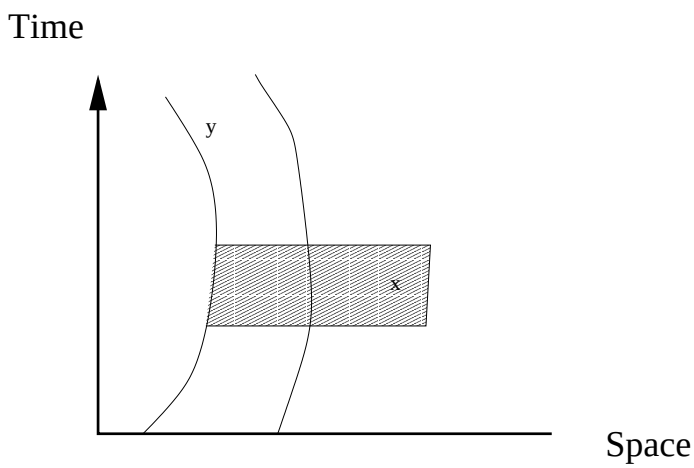

Figure 4: The ring (x) of gold (y)

are distinct, but are functionally related. Formally, the sentence above could be represented as follows:

$$ring(x) \wedge new(x) \wedge old(substance(x)) \wedge gold(substance(x))$$

An obvious problem with this solution is that different kinds of substance could be considered for the same object (the ring is made of gold is made of atoms, which are made of particles and so on), and what determines a proper substance is unclear.
We do not need to distinguish objects and quantities of substances as *a priori* different types and we don't need a function relating an amount of a given substance (or multiple substances) to the object it makes up. We need only consider different histories in space-time, and knowledge expressed about *some* stages of these histories.
The ring is indeed more temporary than the gold it is (partially or entirely) made of and this is why different predications can be applied to the two entities: they *are* different spatio-temporal histories ($x \neq y$). Formally:

$$ring(x) \wedge gold(y) \wedge O(x, y) \wedge new(x) \wedge old(y)$$

The ring (x) can be new, the "older" gold (y) can overlap the ring ($O(x, y)$) which means they have a part in common. That temporary part, which can be the entire ring or not, can be described either as a ring or as a piece of gold, because these descriptions correspond (briefly) to the same portion of space-time. Figure 4 illustrates this situation. Here we consider that when an object and the substance it's made of are created and destroyed at the same time, they are indistinguishable, following among others (Heller, 1990).

Now we are in a position to make more precise the difference between mass terms and count nouns. We have seen that some authors argue convincingly that "mass" or "countable" reference are more specific to certain noun phrases that just common nouns. This debate does not concern us here, since we only want to characterize the semantic side-effect of such references and not their conditions of occurrence. Thus we will consider examples of nouns that are typically more often used in mass terms or countable reference as representative of mass terms or countable reference.

The first obvious difference between the two is "homogeneity" of reference: we can very easily express that any part of a "mud" history is the history of some mud. As for count nouns, in a spatial ontology, it is assumed that a count noun can only refer to a whole, and not to any of its parts. When considered in space-time, this is slightly different: only a slice of the history of a dog can have the property of being a dog. Formally:

$$(\mathsf{mud}(x) \wedge \mathrm{P}(y, x)) \rightarrow \mathsf{mud}(y)$$

$$(\mathsf{dog}(z) \wedge \mathrm{TS}(t, z)) \rightarrow \mathsf{dog}(t)$$

If we want to take into account the fact that at a finer level, mud parts are not mud anymore (but molecules or atoms, or particles), we could say that such substances have at least a set of parts that are still of the same substance and that property would still set them apart from dogs.

The second difference has to do with cumulative reference: any two "mud" histories can be combined and still be considered as some mud history Quine (1960: 91). So there is a sum (+) of the two and it is still mud.

$$(\mathsf{mud}(x) \wedge \mathsf{mud}(y)) \rightarrow (\mathsf{mud}(x + y))$$

This is not true for a dog, since two histories of a dog can be two different dogs (perhaps at the same time). The only other case is when two histories are stages of the same dog history. We can express otherwise this property as: a count noun cannot describe two histories, one being part of the other, unless the part is a slice of the other history.

$$(\mathsf{dog}(z) \wedge \mathsf{dog}(t) \wedge \mathrm{P}(t, z)) \rightarrow \mathrm{TS}(t, z)$$

The problem of deciding when two dogs are the same is then a problem of identity. Figure 5 illustrates what parts of each kind of reference are of the same type.

4.2. Substantial vs non-substantial count nouns

By specifying certain meta-properties at the spatio-temporal level, we can go even further and specify some of the differences between two other kinds

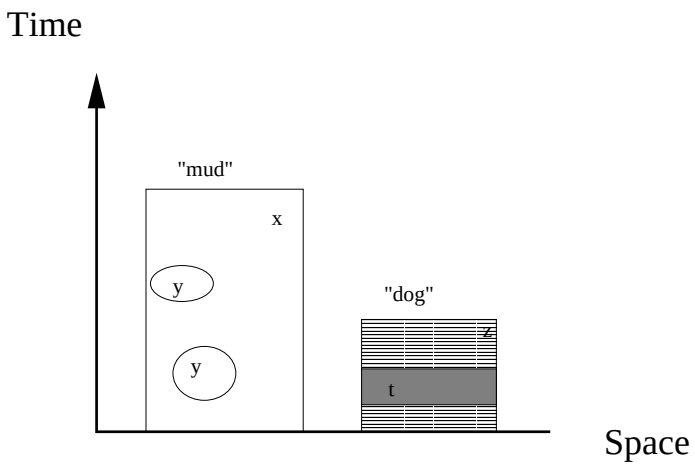

Figure 5: Comparing mass histories and countable histories

of countable predications, what some authors call the substantial and non-substantial count nouns. This is an important difference, emphasized in Nicola Guarino's work (Guarino, Carrara, & Giaretta, 1994) on meta-categories, and that is the basis of the stage-level/individual level distinction for predicates in the work of (Carlson, 1980).

A stage-level predicate is one that does not necessarily applies to the whole lifespan of an entity, whereas an individual-level predicate must be true at any time during an entity's lifespan. In a similar way, a substantial predicate is defined as a predicate that denotes an essential property of an entity ("apple"), whereas a non-substantial denotes a non-essential property of something (e.g., "student" might be true of someone at a certain time only). A substantial predicate is intrinsically related to the notion of identity of an entity.

It is important to represent the difference from a spatio-temporal point of view, in order to explain for instance the following example, where the subject of the main predicate is described with a property ("lawyer") that was not true at the time of the state described by the verb:

(5) *Most lawyers had unhappy childhood.*

The easiest way to express this in a spatio-temporal ontology is to say that for a non-substantial description (such as "student" or "lawyer") of an entity there is another slice of the same entity that does not fit the description. So besides being countable (hence homogeneous, cf the previous section), non-substantial predicates verify the following property:

$$\mathsf{student}(x) \rightarrow \exists y\ \mathrm{TS}(x,y) \wedge \neg\mathsf{student}(y)$$

This could be an exaggeration as this is only a typical property: some entity might keep a non-essential property, by accident so to speak. A weaker version would then be to say that at least one entity must obey this definition:

$$\exists x \exists y\ \mathsf{student}(x) \wedge \mathrm{TS}(x,y) \wedge \neg\mathsf{student}(y)$$

The distinction between substantial and non-substantial predicates involves much more than just spatio-temporal aspects (since it is based on the notion of essential characteristics and identity properties), which in this case might only be a by-product or a more general concept of identity.
Equivalently, for substantial predicates, such as "dog", we could express that if something that has the property "dog" is a slice of something else, then that something else is a dog:

$$[\mathsf{dog}(z) \wedge \mathrm{TS}(z, y)] \rightarrow \mathsf{dog}(y)$$

This could be a problem if our ontology accepts arbitrary entities built up from more basic ones, for instance with the sum operation. Indeed, two non contemporaneous entities of different sorts would then share their substantial properties: let's say x is an apple and z is a dog (at a later time, so that $x < z$), then we have $\mathrm{TS}(z, x + z)$ so by the previous principle, $x + z$ is a dog too, and so is any temporal slice of it, hence x is a dog. The difficulty here is in the definition of a whole of a given kind. We could either prohibit sums of different sorts, but that seems somewhat arbitrary, or we could rely on an external definition of what counts as a part of another entity, by taking into account more than just spatial or temporal properties. We would then reach the limits of our program, and leave room for further work on what is a relevant "part". Again, this calls for a definition of the identity of something, if "the identity of a thing at different moments is the identity of a totality embracing different elements", Goodman (1977: 94).
Nevertheless, our previous principle could then be written:

$$[\mathsf{dog}(z) \wedge \mathrm{TS}(z, y) \wedge \mathrm{part}(z, y)] \rightarrow \mathsf{dog}(y)$$

This can be said also of our characterization of non-substantial predicates: if any history can be said to be a slice of something larger, then the property is always true. We could then add a property opposing substantials and non-substantials: a non-substantial verifies the previous property, but it is a slice of a larger substantial (let's call it R; since there is only a finite number of substantial predicates, this amounts to a more complex but still first-order formula, that is abbreviated here as a pseudo-second order one):

$$\mathsf{student}(x) \rightarrow \exists R, y \; substantial(R) \wedge R(y) \wedge \mathrm{TS}(x, y) \wedge \neg\mathsf{student}(y)$$

If a non-substantial predicate is subsumed by a substantial one (student implies human, for instance), we would have more simply:

$$\mathsf{student}(x) \rightarrow \exists y \; \mathsf{human}(y) \wedge \mathrm{TS}(x, y) \wedge \neg\mathsf{student}(y)$$

This way we have made the two definitions inter-dependent.

Another important ontological distinction we want to study is between collective entities and singular entities. A team is a collective entity, as it is composed of *distinct* members. Collective entities are also commonly described with plural expressions in natural language: *you and I, the neighbours, politicians,...*.

What are the ontological problems associated with concrete collective entities? They are similar to problems encountered with the object/substance distinction: seemingly identical entities seem to be designated either with a singular or a plural noun phrase: the rice/ the grains of rice, the team/the members of the team, so the question remains of the actual number of things that should be counted. This is crucial as a plural may introduce different modes of predication. Consider the following example (Lønning, 1997):

(6) *Bunsen and Kirchoff laid the foundations of the spectral theory.*

This shows there is something called "plural reference" which is more than just ascribing a property to a set of individuals. Here we have a "collective" reading, as Bunsen or Kirchoff cannot be said to have laid the foundations alone. It is the collective that has a property, as opposed to a distributive reading where each member has a given property as in *Politicians I know like to appear on TV*. Thus an ontology must be able to distinguish between a collective entity and what seems to make it up.

Again, to address this, (Link, 1983) proposed to add some structure to the set of referents of a semantic theory by imposing an algebraic structure (a lattice) on the set of referents E. This lattice is made of atomic referents of a given set (singulars, individual entities) and referents built up from atoms with a sum operator (a function from $E \times E$ to E). Thus if b denotes Bunsen and k denotes Kirchoff, $b + k$ would be the sum of Bunsen and Kirchoff, and could be an argument of a predicate (see also (Fox, 2000; Lønning, 1997)). This has the advantage of being easily related to a mereological theory dealing with part-whole relations, provided a sum operator is properly defined (Leonard & Goodman, 1940).

Another solution is to treat plurals as denoting sets in the manner of (Kamp & Reyle, 1993). For instance:

(7) *A thousand boats passed under the bridge.*

A set-based representation of this sentence could be:

$$(7) \quad BOAT^*(U) \wedge |U| = 1000 \wedge \forall x \in U \; \exists e(pass\_under\_the\_bridge(e, x))$$

Where U is the set of all the boats, of cardinal 1000, and BOAT* is a predicate which applies to sets of boats. This means representations become second-order, all the more as collective readings imply sets as arguments of predicates, and that might be considered uncomfortable by some. Moreover this leaves open what is an acceptable argument for a plural predicate.

Another problem raised is the question of the exact material extent of the plural entity considered, and that is not always clear with example (7). This logical representation indeed ignores the reading where a boat can be counted many times for each different passing under the bridge.
The following example adds another difficulty:

(8) *The last ten US presidents lived in the White House.*

In this extreme case the plural can *only* be read as time-dependent as there is only one president living in the White House at a given time. This means that at any time at which the truth value of the sentence could be evaluated there is only one existing president. This could be paraphrased with a temporal quantification (*At any time, the acting president lives in the White House.*), because here the reading is distributive, but the plural notion is lost, and this doesn't extend to collective readings, as in *US presidents made the USA what it is today*.
It is probably apparent by now that handling plural entities is not a problem in a spatio-temporal theory, whether the plural entity includes contemporaneous entities or not. We can keep the same kind of structure as in a lattice-based theory of entities, *à la* Link. We will use the spatio-temporal sum "+", and we can express what makes a proper plural entity.
For illustrating what our aim is, figures (6) and (7) show two kinds of admissible plural entities. On the left side, the shaded region x could be the referent for *the last three UN presidents*, and on the right side, the shaded region x could be the referent for *three bald men*, for instance during a particular event y.

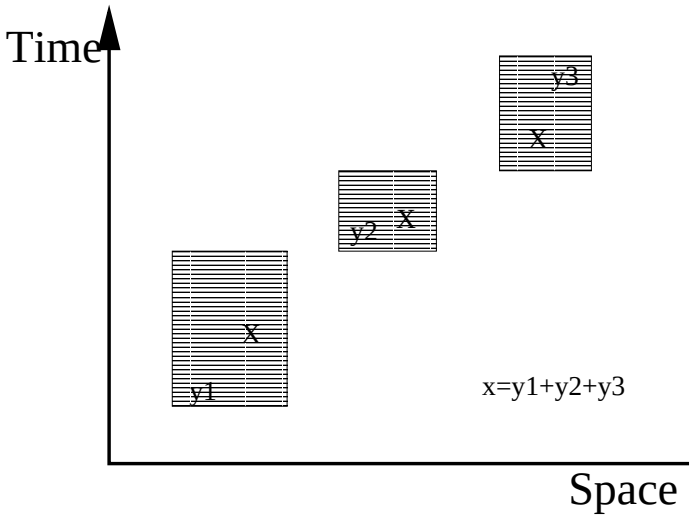

Figure 6: A temporally plural entity

We can express more formally how references to plural entities are allowed. Let's say we have something that can be described by a singular predicate such

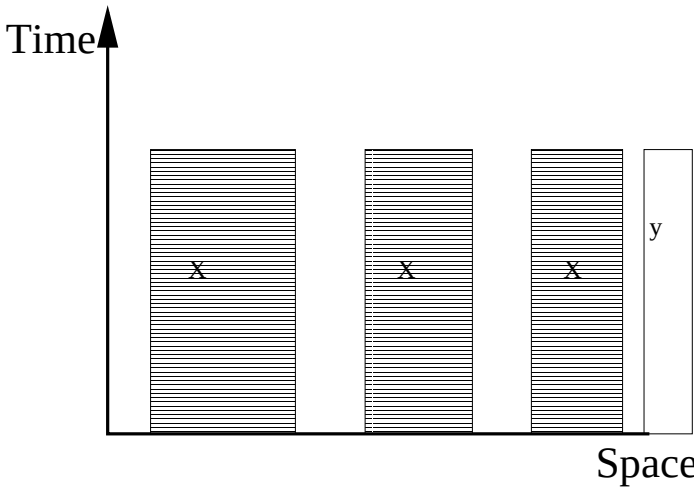

Figure 7: A contemporaneous plural entity

as "president". This must be a countable referent, so it has the properties seen in section 4.1. Now, if the plural "presidents" is applied to a ST history:

1. this history has at least two different (non connected) parts which can be ascribed the singular property;
2. it is a sum of such entities;

Conversely, two disconnected entities that can be said to be president can form a plural entity "presidents", and as "disconnected" means in space-time, they can be either contemporaneous or not. We can still make the difference if it is needed: if all entities in the sum are temporally disconnected from each other, each slice of the plural is a singular denotation.
Formally, we express this situation with the following properties, where we use $\mathsf{president}$ and $\mathsf{president}_*$ as representative of a singular predicate and the corresponding plural property.

$$\mathsf{president}^*(x) \rightarrow (\exists y(\mathsf{president}(y) \wedge \mathrm{PP}(y, x)))$$

This says that a plural has at least a corresponding singular entity has a proper part.

$$(\mathsf{president}(y) \wedge \mathsf{president}(z) \wedge \neg \mathrm{C}(y, z)) \rightarrow \mathsf{president}^*(y + z)$$

This is the property that two disconnected entities can form a plural entity with respect to a countable predicate. We can go even further, and say that a plural reference can only be a collection of disconnected singular references (a disconnected sum of a plural and a singular, or of two singular entities):

$$\begin{aligned}\mathsf{president}^*(x) \leftrightarrow \exists y, z\ (x = y + z \quad & \wedge \neg \mathrm{C}(y, z) \\ & \wedge [(\mathsf{president}^*(y) \wedge \mathsf{president}(y)) \\ & \vee (\mathsf{president}^*(z) \wedge \mathsf{president}(z)) \\ & \vee (\mathsf{president}(z) \wedge \mathsf{president}(y))])\end{aligned}$$

There is one caveat, though: this can apply to *separate* slices of the history of a same object. Thus do we want to consider that the sum of two stages of an entity (say, Woody Allen in the 70s, and Woody Allen in the 80s) are two different entities? Art aside, we want to say there is only one Woody Allen, with two stages. As was noted by Noonan (1976: 38), "every time slice of a man is a man and the same man as every other time-slice of him". So we need a theory of identity if we want to escape a circular reasoning, just as for substantial predicates. What are the criteria for this is beyond the scope of this article but is a heavily discussed matter. A way to explain re-identification of disconnected stages of an entity is to consider some sort of spatio-temporal continuity, as argued in (Hirsch, 1982), something that can be formally expressed in a limited manner in a spatio-temporal mereo-topological theory as in (Muller, 1998).

4.4. Objects and events

Our use of the word "event" has been somewhat loose up to now. We want in fact to include both temporally homogeneous eventualities (more usually called processes) and heterogeneous ones (for which "event" is a widespread denomination).

We have claimed earlier that objects in a classical sense and eventualities are not that different, so that we could consider them on a par in our theory of concrete objects. Our first reason was that there is no a-temporal object: every concrete entity has a life-span and so must be considered in time. Conversely, we should then ask ourselves whether events and processes have a location in space or in space-time. This question has been raised for instance by (Dretske, 1967) (and also in the more recent work of Casati and Varzi (1999: chap. 10). We will assume that events do have an extension in space-time, but their precise extent is a semantic problem, as much as the precise extent of some material objects.

Besides, it has often been noted a similarity between certain kinds of eventualities and objects: it has been said that processes, being homogeneous in time, behave in a similar manner as mass terms, that are considered homogeneous in space. Actually, if things are considered in space-time, the similarity is more obvious between persistent objects and processes, both being homogeneous in time, as noted by Whitehead or Quine.

So the real distinction to be made here is between two kinds of eventualities: events with a culmination point and objects/processes. Consider for instance:

(9) *Youri kept the ball for ten minutes.*

(10) *Youri lost the ball.*

Every temporal part of the eventuality of Youri keeping the ball is a keeping of the ball by Youri, cf. example (9). This is usually called a reference to a process. But the same can be said for instance of "the ball": every temporal part of the history of the ball is an history of the ball. In contrast, no part of losing the ball is a losing of the ball cf. example (10), because this eventuality demands a culmination in time. We will call this a proper event.
Now, if we come back to this example:

(7) *A thousand boats passed under the bridge.*

Its representation seen in the preceding section ignores the reading where a boat can be counted many times for each different passing under the bridge. What has been argued by a few authors (Krifka, 1990; Musan, 1999; Tonhauser, 2002) is that this sentence in fact expresses a quantification on events, or "stages" of objects; they are here stages of boats, i.e. parts of the histories of boats, corresponding to what we called temporal slices above.

4.4.1. Spatio-temporal properties of events

We are going to mention here where we put a limit between objects and events, as discussed above. We have previously defined quantities of substance as spatio-temporally homogeneous entities and countable persistent entities as temporally homogeneous.
We have also discussed the property of cumulativity of reference and shown what this means for mass terms (they are cumulative in space-time); for collective entities, we have seen that the sum of non identical, disconnected, entities define a plural. We could add that the property of cumulativity itself defines identity in a circular manner: if the sum of two stages of two entities can be described as having a singular countable property (e.g., "dog"), then there is really only one entity (it's the same dog).
Events, if we mean eventualities with a culmination point in time, are not cumulative in that sense, but they are different from processes and persistent objects as they are not homogeneous in time either. We can express this in space-time with the following property, for instance for events of the type "losing a ball" (or "winning a race", etc)

$$\text{losing\_a\_ball}(e) \rightarrow \neg\exists x(\text{PP}(x, e) \wedge \text{losing\_a\_ball}(x))$$

This expresses that no spatio-temporal part (and hence no temporal part either) of the event are of the same type.
We will now return to the question of the interpretation of certain collective entities that could be seen as plural events (see section 4.4).

4.4.2. Plural events

Let's go back to example (7), this time with less boats, so that it's easier to illustrate:

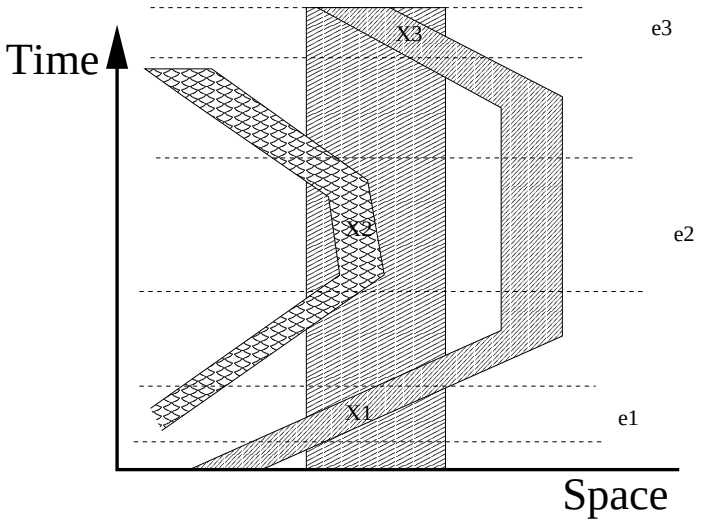

Figure 8: Three events of a boat passing under a bridge

(11) *Three boats passed under the bridge.*

Most of the discussion about this example is on the underspecification of the actual number of different boats passing under the bridge. According to a lot of authors (Musan, 1999; Barker, 1999; Krifka, 1990), this example is ambiguous between two kinds of readings; under one reading, the number of different boats is irrelevant and what is quantified on is the number of events described by the verb phrase. Under another one, the boats are all different and passed under the bridge at the same time. Actually, the first reading can be considered as an underspecified version of all the readings: there are three events of a boat passing in the past of the utterance time. As the plural can only be read distributively in this case, there is no need to wonder whether the boats did something together, at the same time. We can see here that we can easily represent this as quantifying over events involving slices of objects rather than objects *per se*:

$$\neg \mathrm{C}(e1, e2) \wedge \neg \mathrm{C}(e2, e3) \wedge \neg \mathrm{C}(e1, e3)$$
$$\wedge \mathrm{passing\_under}(e_1, x_1) \wedge \mathrm{passing\_under}(e_2, x_2) \wedge \mathrm{passing\_under}(e_3, x_3)$$
$$\wedge \mathrm{boat}(x_1) \wedge \mathrm{boat}(x_2) \wedge \mathrm{boat}(x_3)$$

Here we have left undetermined the relation between e_i and x_i (i =1,2 or 3), but our proposal is compatible either with the hypothesis (1) that each event extent is only the slice of a boat, in which case we should say that each $x_i = e_i$ or (2) that the event may involve something else "spatially", in which case we only have $P(x_i, e_i)$. In all cases, the treatment is very similar to the treatment of plurals we have presented above, since objects and events have similar properties from a spatio-temporal point of view.

Figure 8 is an illustration of this form of quantification on events. Here is a boat going twice through whatever can be considered as the "under a bridge"

region of space-time, and another boat going through it at another time. This is perfectly consistent with the representation given above.

5. Conclusion and open questions

We have studied how considering concrete objects in their temporal dimension as well as their spatial one can bring a somewhat new light into a few classical problems for categorizing language reference to such objects. We have looked at the amount of substance/object distinction, the singular/collective distinction, and to some extent the difference between objects and eventualities.

While doing this, a few problems have been left open. We tried to stay neutral with respect to some of these issues, whereas others have an influence on the choices we have made, and should be further studied. Other issues have not be mentioned yet but are still central to the ontology of spatial entities, which we prefer to call spatio-temporal entities. While we remain rather agnostic on these, they are worth mentioning as further tests of ontological theories. Some of these open problems are:

- how many entities can there be in one space-time region?
- what is the precise extension of an event? (spatially for instance)
- how can we account for temporal vagueness:

  (12) *I saw the statue when it was just a piece of clay.*

  This amounts to determining where does a thing ends and when something "else" begins, that is made of some of the parts of the previous entity. Does temporal vagueness raise the same kinds of problem as spatial vagueness of objects?
- when can we say that something is the same entity or not? This is the problem of re-identification of stages of a same entity. This is also related to the possibility of testing the existence of categories, if one accepts that two objects of the same category cannot occupy the same portion of space (or space-time, from our point of view). For instance, is the following example a relevant test?

  (13) *A student went to the library when it was an empty building/? a city hall.*

Finally we hope to have shown that the ontological issue of categorizing material entities cannot avoid the question of the temporal dimension of existence and identity.

Notes

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