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Pierre Grenon

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Kontaktadresse / contact adress:
Institut für Formale Ontologie und Medizinische Informationswissenschaft
Fakultät für Medizin, Universität Leipzig
Härtelstr. 16-18, 04107 Leipzig, Deutschland.
Tel.: (0049) (0)341 97 16170
Fax: (0049) (0)341 97 16179

BFO in a Nutshell:
A Bi-categorial Axiomatization for BFO and Comparison with DOLCE

Pierre Grenon
IFOMIS, University of Leipzig

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This report presents suggestions for a bi-categorial axiomatization of BFO. It prepares the ground for IFOMIS' contribution to the WonderWeb library of ontologies developed at LOA. This material is tentative and the forthcoming contribution will prevail as a specification of BFO. Comments and digressions which may not find a place in a terser specification of BFO might remain useful for future developments.

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1 Introduction and preliminaries

BFO is a bi-ontological theory. It attempts to reconcile so-called three-dimensionalist and four-dimensionalist views. Such a theory can however be stripped down of its meta-ontological flavor. The result is a corresponding bi-categorial ontology, which is in essence a form of non eliminativism three dimensionalism. Continuants are seen as persisting self-identically through time and participating in occurrents of various sorts. The treatment of three dimensional entities is one which finds its roots in (Smith, 1997), a neo-Aristotelian metaphysics of substances.

Why a multi-categorial ontology (rather than a system of ontologies)?

The meta-ontological approach (Grenon, 2003b; Grenon and Smith, 2003) is primarily a tool for analysis. A less convoluted and more traditional approach consists in having a single domain of entities, no ontology to quantify over but moving all the weight from the shoulders of different kinds of ontologies characterizing salient modes of being to those shoulder of a number of corresponding categories. It is not clear to me whether BFO is mature enough for this. Taking such a step now is primarily motivated by the prospective contribution of BFO to the Library of Ontologies in the WonderWeb (LOW) in collaboration with the Laboratory for Applied Ontology in Trento (formerly, LADSEB) – see related online resources in the reference section.

Adaptations of BFO's formal characterization to the library of ontologies

The formal characterization given here is intended to provide as much angle of attachment as possible for the task of feeding BFO to the LOW, and at the same time facilitate the comparison between BFO and DOLCE. Among the benefits, we could expect to clarify both ontologies and their relations, in itself a laudable endeavor. More importantly, we may draw on these results (but this is already true at a superficial level of comparison and philosophical analysis) to come up with a few lines of organization for the LOW itself, in terms of modularity and relations between putative modules. We may identify vague components on the basis of the topics addressed by parts of each theory (mereology, theory of dependence, spatiotemporality, theory of location, theories of qualitative attribution, …). Moreover, we may exemplify the phenomenon of variations and subsumption or incompatibility between variants in those very domains. Thus, we can identify and illustrate a number of alternatives at various levels of generality of the formal ontological analysis, in other words, unveil the complexity of the formal level.

Universals

I will come back later to the differences and similarities between BFO and DOLCE, but a few anticipatory remarks will be needed. The main reason for this is that I regard a couple of discrepancies as potentially serious clashes. No need to entertain suspense, the baroque of BFO's theory of universals and the modal realism of DOLCE are what I have in mind. At the present stage of development of BFO and for the purpose of contributing to the LOW, the best solution is for everybody to pour a bit of water in their wine. I suggest re-using some of the structural vocabulary introduced for the characterization of DOLCE as concerns universals (Masolo *et al.*,

2003), while not fussing about the modal interpretation (what I propose is simply to reuse the syntax). I will present BFO as an ontology of particulars. I will gloss on a number of predicates as corresponding to some of the formal universals recognized by BFO. The BFO's putative native formal approach consists in introducing nominals for so-called genuine formal universals, using the instantiation relation for monadic universals (properties as they are called by most people) and, additionally, some variant of a holding relation for relational universals.

Temporality

BFO has two components. A SNAP ontology of endurants which is reproduced at each moment of time and is used to characterize static views of the world on the side of endurants. This view is motivated by an underlying presentist metaphysics of time (all which exists exists at the present time). No temporal consideration is germane to the SNAP ontology in this very elementary sense. SNAP, then, in order to be used in a manageable way in temporal contexts requires a temporal logic of a certain grade.

There are two devices in BFO in order to handle temporality. The first one – probably not the most manageable one – is to handle temporality in a trans-ontological way. Diachronic relations are relations which hold between entities being constituents of ontologies separated in time. This allows to account for a large number of logical features of temporal entities, but indeed, this is no ontology of temporal entities in itself. Rather, and this is the second device of BFO, the theory contains a temporal fragment or component: the SPAN ontology. This is an ontology of happenings and occurrents and more generally of entities which persist in time by perduring (these are entities which have temporal parts). Trans-ontological SNAP considerations nevertheless provide a useful device for characterizing these SPAN entities which are typically changes in a number of SNAP entities. For instance, a movement is a change in location, a decoloration is a change in the color trope of a material object, and so on… The interdependency and complementarity of the SNAP and SPAN component is BFO's message in a nutshell.

Since in the bi-categorial context, we are doing away with meta-ontological devices (ontologies, the relation of being a constituent of an ontology, …), the theory of diachronic relations is one in which the previously non temporally qualified predicates of BFO are given an additional parameter, namely, the moment or period of time at or during which they obtain. This again brings the formal characterization sketched out here closer to that of DOLCE, which introduces both non temporally qualified and temporally qualified predicates – although not quite for the same reasons (related in DOLCE to its possibilism and its distinction between abstract and concrete entities).

One drawback as far as BFO is concerned might be that certain categorial – or pseudo-categorial as argued in (Grenon, 2003b) – claims will have as well to be temporally qualified. This relates to DOLCE's treatment of universals for which a category includes not only all of its past, present, and future members, but more generally all of its possible members. In BFO, categories have a number of instances

at a time (SNAP case) or they encompass all of their actual (past, present, future) instances (SPAN). In this connection, it is also worth noting that it is unclear which are the rigid categories of BFO (to use DOLCE's linguo). However, it is remarkable that the parametrization of certain statements of categorial membership is primarily not related to time, but to granularity. Somewhat related is a fundamental discrepancy between DOLCE and BFO, since the former makes room for a variety of abstract entities unknown to the naive realism of BFO.

Granularity

Ontologies (rather less than more analogous to worlds in DOLCE) are allegedly sensitive to the level of granularity at which are revealed their constituents. It is in this spirit that, taking account of the granularity paradigm, the categories of substance and aggregate of substances are relative to an ontology (the latter are actually most properly called pseudo-categories for this very reason). I have a number of reservations concerning this paradigm, whichever they are it remains that the characterization provided here is not well suited to do justice to its alleged intuitions. Introducing granularity parameters in the way temporal parameters are introduced would be the simplest solution, maybe, but nevertheless an inadequate one from the realist standpoint of BFO (what are these parameters? in the temporal case they are temporal regions). If the kind of characterization presented here is developed further, I consider it advisable to follow in the main lines the formal treatment of granularity used in Cyc – characterizing granular kinds by pointing at their 'granule' (see online resources). In that connection, a relation of granular parthood as mentioned in (Smith and Grenon, 2003) would seem to go along these lines – it is not presented here.

These preliminaries being made, I will sketch BFO as a theory. I do not ambition much more than paraphrasing a number of axioms provided later on, more convoluted explication and justification may be found in (Grenon, 2003b). I will then draw attention to some of the most salient similarities (with certain qualifications) and dissimilarities between BFO as I understand it and DOLCE as presented in (Masolo *et al.*, 2003). Finally, I provide a tentative formal characterization of BFO in the aforementioned spirit.

2 BFO in a nutshell

The entities considered here are all particulars. Particulars are either endurants (SNAP) or perdurants (SPAN).

2.1 SNAP

SNAP entities are most importantly divided into substantial entities (which are the bearer of properties and change), tropes (which are the latter's qualities, functions, powers, dispositions, and other entities inhering in substantial entities), and spatial regions (which are neither of the former but are simply pure space regions). I will remain mostly silent as concerns the natural/social partition of entities relating to the notion of so-called 'quasi entities'.

The category of substantial entities is the most direct indicator of the kind of neo-Aristotelian metaphysics that BFO is committed to. In the world, there are entities which preserve their identity through time, are subjected to (more or less continuous) change, and are the bearers of a number of qualities and assimilated entities. Among substantial entities, the salient category of substances is that of maximally strongly connected substantial entities with bona fide boundaries.

Qualities and assimilated – SNAP dependent entities (SDE) or tropes – which are particular entities (the instances of property universals) do depend for their existence on substantial entities. They are of various kinds which are best distinguished on modal basis – this will not be available at this stage of the formal characterization. I will limit myself to mentioning some of the relevant sub kinds of the category of SNAP dependent entities (I will continue using the term trope for them), including: states or conditions, functions, powers, dispositions, liabilities. (Observe that at this level BFO does not draw a sharp distinction between the physical and the social.) SNAP dependent entities are those entities which are specifically dependent upon other SNAP entities (more precisely, substantial entities). They divide into monadic ones (dependent upon a single entity) and polyadic or relational ones (dependent upon more than one). The relation between a SDE and its bearer is called inherence (recall, this is a relation between particulars) which is also a form of specific dependence.

The metaphysic of space is of a substantivalist kind in the sense that, like substantial entities, spatial regions, too, are entities in their own right. (Spatial regions nonetheless are distinct from substantial entities.) They may be the location of substantial entities as well as of tropes (in first approximation, a trope of a substance is collocated with its bearer). By principle, spatial regions are (exactly) located at themselves. It is characteristic of substantial entities – and their tropes -- that they may be located at different regions at different times (they can move in space). However, at any time at which they exist they have a single spatial location (this requires fiddling with the temporally qualified version of exact spatial location). It is open whether all spatial regions need to be the location of a substantial entity at each time (BFO supports both variants).

In this formal characterization, I will remain agnostic as concerns cross-categorial sums among SNAP entities. Rather, I will assert the existence of sums of two entities within each of the three mean species of SNAP entities. Characteristically, sums remain in these species (this is called cumulativity) and parts as well (this is called dissectivity).

SNAP entities are said to exist at a time. Indeed they may exist and usually exist at more than one time. Their existence needs be continuous (another statement left out of the present formal characterization). It is open, however, whether there are instantaneous – or very short lived – SNAP entities. As already mentioned, SNAP is in itself not sensitive to time. Inherence, spatial location and other spatial relations are forms of co-existence. The temporal qualification of the elementary forms (non temporally qualified) of SNAP predicates will allow more flexibility in dealing with diachronic states of affairs. A genuinely diachronic relation is that of *genidentity* (weaker than identity – absent from this characterization) it is the such-as-to-have-come-forth-from relation.

2.2 SPAN

SPAN entities are divided mainly into *processual entities* (which are happenings or occurring entities, changes in substantial entities), *temporal regions* (the whole of time and all of its parts), and *spatiotemporal regions* (four dimensional regions of spacetime, i.e., the whole of pure spacetime – as a locational substratum for occurrents – and all of its parts). These sub kinds of SPAN entity are disjoint. Temporal regions (no more than spatial regions) are not parts of spacetime. It is remarkable that there is nothing analogous to tropes (SNAP dependent entities) in SPAN (no qualities of processes as entities).

As it is the case with the category of substantial entities, a species of the category of processual entities is singled out on the basis of its instances topological properties. Processes are the self-connected processuals. The intuition goes further that most of these should have bona fide boundaries, this might however be a strong claim and the question remains somewhat open. Processes and processuals more generally have a temporal and a spatiotemporal extent. The question is open as to whether these are determinate or whether there is also in certain cases an element of vagueness. Because this part of the ontology is committed to eternalism, processes do not change their locations in time or spacetime (in contradistinction to what is the case with substances in space).

Time is thus given entirely in a canonical SPAN ontology, BFO holds the whole of time to be an entity in its own right. Any part of time is a temporal region (this is definitional). There are both extended and instantaneous temporal regions, the latter are simply called temporal instants. Similarly, spacetime is also an entity in BFO and its parts are the spatiotemporal regions, these may be of various dimensions. BFO regards time as a continuum, in the spirit of (Brentano, 1974), and spacetime as a four-dimensional manifold. (However, no axiom goes further than requesting a linear order here, leaving open the more precise structure of time.) Temporal and spatiotemporal regions are substrata of locations for every SPAN entity, and for

SPAN entities only (SNAP entities are considered to exist in time, not to be located in the sense SPAN ones are). Regions are their own locations in the corresponding dimension and every SPAN entity (this generalizes the statement above concerning processuals) has a unique location both in time and spacetime.

The strategy as concerns sums of SPAN entities is similar to that concerning SNAP entities. Thus, the question of cross-categorial sums among SPAN entities remains open. Here too, I will assert the existence of sums of two entities within each of the three main sub kinds of SPAN entities and, here again, sums remains in these sub kinds – as well as parts. In the case of temporal and spatiotemporal regions, this may come as a corollary of definitions. (I won't bother eliminating such redundancies in the present account).

That SPAN entities are perdurants means among other things that they have temporal parts (the sum of their parts located at a given temporal regions). A temporal slice is a temporal part located at an instant of time. Temporal parts are more generally spatiotemporal parts, those which are carved up only in the temporal dimension. They are sometimes called phases. Processual entities are said to occur at a time when they have a temporal slice which is located at this time.

2.3 SNAP-SPAN and SPAN-SNAP

The first instance of a cross snap-span relation is between a snap entity and a moment of time at which it exists. In the meta-ontological framework this is definable, here it is taken as a primitive relation. From there, we may define *existence during* a period of time (this is a very weak notion, it only amounts to the fact that a SNAP entity exists at every moment of time in a period during which it exists). We can then proceed with temporalizing spatial location and inherence by adding a temporal argument, in the simplest case, a time instant.

Additional native primitive terms of BFO are non temporalized predicates for the relation of *participation* and *realization* (they obtain at a given moment of time). In this context, we can introduce participation in relation to an extended processual which has to occur at the time at which exists its participant and during which the more basic synchronic relation obtains. Additional variants, such as the *complete participation* (when an entity participates to the whole of the processual in question) may be introduced. The *life of* a substantial is the sum of the processual entities it is a complete participant of.

It is not clear to me how the life of a trope is to be defined and whether the previous definition captures the right intuition. We can assume so as a working assumption. In many cases, the realization of a trope is but a part of its own life, and I assume it will be also part of the life of its bearer. I am unsure under which condition(s) tropes may be said to participate in other ways than they get realized (intentional relations come to mind). It is difficult then to define the notion of life for them, since in many instances tropes will exist without being realized. It is unclear how much the life of a trope is a part of that of its bearer or conversely how the life of a substantial is also the life of its trope (e.g., spatial deformation seemed to be shared in this sense). It

may be useful to introduce two categories of tropes: those who have realizations as proper parts of their life (e.g., functions) and those whose lives coincide with their realization (if there are any examples, what about a condition or a state?). It is easy to define a number of sub kinds of processual entities such as that of *functionings* (the processes in which a function is realized – assuming that no single function is realized as a disconnected processual entity).

3 Informal BFO-DOLCE comparison

There are a number of similarities between DOLCE and BFO which are better unveiled through a bi-categorial account and axiomatization of BFO. I alluded to some of them in the introductory part when I mentioned choices for setting up the present formal characterization of BFO (so as to take advantage of these similarities).
– non elminativist three-dimensionalism (the ontologies both contain a category of endurants and perdurants)
– eternalism with indexicalism (Both ontologies have an eternalist stance. Despite SNAP's underlying presentism, the temporal indexation of ontologies to a time is here to remind that BFO as a whole makes available all times. DOLCE which is presented as an eternalist theory also has a notion of being present at a time.)
– theory of parthood (with a number of similar related constraints, e.g., participation as non mereological)
– theory of dependence (The formal characterization of BFO presented here contains only relations of dependence among particulars. Similar relations among universals, which seems to form the bulk of DOLCE's characterization of this topic, are also considered by BFO.)

Despite these similarities, there are of course discrepancies. First, in the specific treatments of certain broad issues mentioned above and how somewhat similar notions apply differently to prima facie similar categories. Second and more importantly, each ontology presents some features absent from the other or provides radically different treatments of certain fundamental issues. It is hard to organize such an account, it would be best to proceed with a linear commentary of the DOLCE's literature from the standpoint of BFO. Issues are however too intertwined to make this readable and I will simply highlight the main features arising by such a reading of section 2 of (Masolo *et al.*, 2003).

Cognitive bias and realist ontology

DOLCE's cognitive bias (2.1, page 8) has a number of faces which are all in opposition with BFO's underlying methodological approach:

– DOLCE is methodologically fundamentally conceptualist while BFO is methodologically fundamentally (if not fundamentalistically) realist (Grenon, 2003a; Grenon and Smith, 2003). I think this is not a real issue for the LOW. BFO, whatever we claim, is still a theoretical construct, esp. once axiomatized.

– Scope: DOLCE seems to be oriented toward commonsense, BFO's naïve realism is in the same spirit. However, BFO ambitions to be a formal ontology of reality and this is somewhat in contradistinction to DOLCE in the following sense. This is not anecdotic. DOLCE makes room for distinctions between abstract and concrete entities, it makes room for agents and intentionality. BFO is deliberately not committed to these distinctions. In particular, the physical / non-physical endurants distinction in DOLCE is, as if by default, absent in BFO. All endurants will behave in the main line the way they appear at the general level of BFO. This means that we conceive an ontology of agents and intentionality as a domain ontology which will reproduce the relevant formal features described in BFO. There has been discussion of a putative quasi category which roughly speaking

corresponds to non physical entities (both continuants and perdurants). However, it is some extent not clear whether this should actually trigger additional categories or whether this preferably leads to a specific domain ontology, the ontology of the quasi (social and so on) domain (to be known as QuasO, I imagine), (Grenon, 2003b).

– Certain categories of DOLCE are either motivated by phenomena or treated with tools of a linguistic or psychological nature.

– Qualities are abstract and they are somehow positioned into quality spaces, i.e., conceptual spaces (pages 11-13, 2.2, Qualities and quality regions). For BFO, qualities (called SNAP dependent entities or tropes) are genuine (spatio-temporal) entities (cf. infra.) Similarly with space and time are not conceptual or abstract in BFO, they are (spatio-temporal) entities, while for DOLCE space and time are in the main quality spaces (cf. infra).

– Homeomericity, for instance, is 'intuitively' defined in relation to the expressions which serve to described entities (page 17, 2.4, Kinds of perdurants, §3), BFO is reluctant to speak about categories which are language dependent.

– The multiplicativism of DOLCE (page 9, 2.1) and its theory of constitution (page 15, 2.3, Constitution) denote the same kind of power attributed to language and concepts (cf. infra).

– Related is DOLCE's particularist orientation (as an ontology of particular). The reasons for which DOLCE makes this choice are not entirely explicit. At any rate, the precise stance about universals (e.g., rather linguistic or conceptualist, but seemingly not realist) is actually not clear to me.

– Finally, entities are cheap in DOLCE which is an overtly possibilistic ontology, i.e., including possible entities. To my understanding, there are no such fictions in BFO. More generally, there are no fictional or conceptual entities are in BFO.

Specific discrepancies

The foregoing considerations as such are not crucial to the LOW and to the DOLCE-BFO comparison. But they indicate more significant discrepancies between the two ontologies, the main ones being related to:

– universals and particulars

– qualities

– constitution

– spatio-temporality

Treatment of universals

As already mentioned, DOLCE is intended as an ontology of particulars. BFO is intended to be an ontology of both universals and particulars. More precisely, BFO's categories are conceived both as taxonomies of universals and partitions of particulars. For BFO considers that universals exist in their instance (they are instantiated) and predicates are not merely general terms standing for concepts. Things are actually muddier than that but it remains that the preferred metaphysics

and ‘natural’ formal treatments might differ from an ontology to the other. For instance, DOLCE employs predicates, BFO would more naturally employ nominals (universals would be in the domain of quantification of a first order theory). This is however something that has been presented as a putative extension. I have also mentioned that for the purpose of a formal characterization, we are happy with using predicate letters provided that the point as concerns their interpretation is made. It seems to me that BFO will need to be more mature before we can make real fuss about this.

Treatment of qualities

In DOLCE, qualities are abstract entities which may not be found in space or time. Moreover, the origin (and nature) of qualities seems to be essentially cognitive or perceptual (page 11, Qualities and quality regions, §1, line 1). Space and time as well are given a ‘quality region’ treatment. (cf. infra)

There are higher order qualities in DOLCE (page 11, 2.2, Qualities and quality regions, §1, lines 4-5; page 13, 2.2, Direct and indirect qualities, §2), as so-called ‘complex qualities’ have qualities inhering in them which indirectly inhere in objects (in DOLCE’s terminology). BFO has an altogether different attitude. Tropes instantiate quality universals (Grenon, 2003b; Grenon and Smith, 2003). These universals are in the determinate-determinable relation (Johansson, 2000). The color of Rose-1 instantiates a determinate of the determinable red (the property universal), the latter is a determinate of the determinable color. The color of Rose-1 instantiates it as well. It instantiates all universals which are in a determinate-determinable relation equally directly. Indirect inherence refers to another relation in BFO – at least putatively as suggested by (Grenon, 2003b). (cf. infra)

In that respect, note 1 on page 12 is misled. It seems to assume a ‘multiplicative approach’ to tropes. It is not necessarily so, at any rate, it is not so in BFO. There may be cases of changes in things which are creations, destructions, or substitutions of tropes. But many cases of qualitative changes – such as in color or temperature -- are cases in which the very same trope inhering in a thing instantiates different determinates of a given determinable at different times.

In DOLCE, qualities do not have parts (page 13, 2.2, Parts of qualities). For BFO, the proxies of DOLCE’s qualities (tropes) may have parts in space (it is not actually clear that this is the case for all of them). Notice that in DOLCE this is a direct argument for making qualities neither endurants nor perdurants (idem).

In contradistinction, for BFO, the category of qualities and assimilated entities (tropes) is one of the main subcategory of that of endurants. They are located in space and exist at a time in the very same way that the entities in which they inhere (i.e., that they are the qualities of). The latter are called substantial entities. So not all entities have tropes inhering in them in BFO, in contradistinction to DOLCE (page 11, 2.2, Qualities and quality regions, §1, lines 4-5). If for BFO there is any sort of indirect inherence this is in the sense in which a trope which inhere in a part of a substance may be said to inhere indirectly in the substance itself (Grenon, 2003b).

Despite this important ontological distinction, there is a strong logical analogy to be drawn between DOLCE's and BFO's treatment of inherence (more precisely between direct quality – dqt – and inherence – InheresIn). The constraints seem to be very similar in each case (page 11, 2.2, Qualities and quality regions, §1, lines 9-11). In addition, then, DOLCE takes a stance according to which a quality inheres in an entity and that quality is of a certain *quale* (from line 11 to the end of the same paragraph). In parallel, BFO takes the stance that a quality inheres in a substantial and instantiates a qualitative universal. The quality regions of DOLCE are in close correspondence with the determinate-determinable hierarchies of quality universals in BFO.

Constitution

In immediate relation to the foregoing is a major distinction between both ontologies. DOLCE takes a so-called 'multiplicative approach' (page 9, 2.1, § 4). Nothing of that nature is intended in BFO. Substances are what they are, they have qualities, functions, roles, and so on – period. So the whole apparatus for constituency in DOLCE is not to be found in BFO (this will be qualified shortly).

The vase and the clay are not to be genuinely distinguished in BFO (but putatively at different levels of granularity, see the somewhat conciliatory paragraph below). The clay happens to have a particular shape (a trope), that's all there is to it. En passant, I see no problem saying that a piece of clay has a handle (page 9, 2.1, § 4). This is a very general statement and it may not be helpful, but it seems to me that multiplicativism in DOLCE fundamentally rests on a number of inexplicit (to my knowledge) but arguable assumptions about the way names designate, and this has nothing to do with ontology. And, en passant again, I think BFO if it agrees with me is closer to common sense than DOLCE. The issue is well illustrated again with the putative distinction between GOLIATH (or Goliath, a statue) and LUMPL (or Lumpl, a lump of clay which 'constitutes' GOLIATH during some time) – (page 15, 2.3, Constitution). Goliath is nothing over and above Lumpl. 'GOLIATH' is just a name for Lumpl when it has a particular shape. If you remove a part of Goliath Lumpl or replace it, Goliath Lumpl has changed (mereological change, maybe even morphological). The same is true with patients undergoing transplantation of organs (it is arguably different in the case of a prosthesis). Of course the problem of temporary parthood is intricate – DOLCE's solution seems to be some sort of mereological essentialism (it seems that to understand endurance its theory of constitution fits well, fair enough). However, DOLCE's reasons for distinguishing between Goliath and Lumpl do not seem tenable in the context of BFO (the less tenable is the third).

Amount of matter, Objects, and features

Again, there is no constitution in BFO. For instance, what DOLCE sees as amounts of matter (page 16-17, Physical and non-physical endurants) are, I think, just substantials entities for BFO, maybe even substances for some of them. Fiat parts are not considered features in DOLCE. If they were, I think there would be a close correspondence between the categories of substances and objects on the one hand and on the other hand between that of substantial entities and the union of the categories of features and objects – throw in arbitrary sums. (It seems that features

cover a number of kinds of substantial entities recognized by BFO, in particular sites. Boundaries which are in many cases considered parts in BFO are also features for DOLCE. The view that features are 'specifically dependent on physical objects' may be a source of dissonance and needs closer examination from BFO's standpoint.) I do not assume prima facie singling out a putative category of amounts of matter. Not because it wouldn't make sense at all, but because to my understanding, in BFO, this is a matter of granularity. Assuming that the unity of amounts of matter – it is not completely clear whether this is the case – is connection (their arbitrary sums are not themselves amounts of matter), this category is just a specialization of substance in BFO. In other words, maybe the suggestion is that the categories of amounts of matter, on the one hand, and those of features and objects, on the other hand, should not be placed on the same level in DOLCE's hierarchy. There might be an additional route for arranging a more spacious room for mutual understanding as constitution applied to material objects tentatively appears to me as a form of granular parthood.

Treatment of spatio-temporality

The comparison of the treatment of spatio-temporality in DOLCE is multifaceted. The first noticeable difference is the one noted earlier, namely that generally speaking, DOLCE has a conceptualist approach and handles space and time as it handles qualities, while in BFO space and time are entities of a more concrete type, so to speak (the abstract-concrete terminology is a bit misleading given its technical signification in DOLCE, maybe conceptual-real is a more apt distinction).

– Space: In BFO, space is an endurant (spatial regions are all of its parts). Space and spatial regions share with substantial entities (roughly, the endurants of DOLCE) their independent nature. However, space has no quality (here 'quality' means trope) – of course, it doesn't mean that space has no property (in a sense neighboring that which is given to the term in DOLCE), e.g., connectedness and so on.

– Time (and spacetime): The way BFO treats time is analogous to the way it treats space in the sense that time is an perdurant on a par with the occurrents which are located in it. In addition, BFO recognizes spacetime as yet another entity (a perduring one as well) – this is distinction is absent from DOLCE.

Despite this, DOLCE and BFO are more or less in line concerning the distinction between space and time as some sort of substrata for location and the entities which are located in them. This is modulo the different treatment of spacetime, of course. Spatial and temporal regions are defined as parts of space and time, respectively, in BFO. Thus, as DOLCE allows reasoning on parts of quality regions, there seems to be further family resemblance.

In addition, BFO and DOLCE are in agreement in claiming that occurrents are only indirectly located in space, namely through their participants. (page 12-13, 2.2, Direct and indirect qualities, §1). However, DOLCE claims that endurants are analogously mediately located in time via the occurrents they are participating in. (same paragraph). Strictly speaking, it seems to me that this claim has to be rejected by BFO, which considers that occurrents are specifically dependents on their participants.

Miscellaneous related remarks

– DOLCE is not committed to any feature (property in the sense of DOLCE) of its time and space spaces. (page 12, Space and time locations as qualities) BFO is slightly more committed and requests at least linear order for time.

– The notion of temporary parthood (page 14, Parthood and temporary parthood, §1) from the BFO standpoint is in essence no more than syntactic sugar. This is because time is just but a parameter in the indexation of parthood.

– The notion of mereological invariance (page 14, Parthood and temporary parthood, §2) seems to be meaningless in BFO.

4 Formal characterization of BFO

The language used here is a first-order one with equality. It contains the usual logical symbols (infix notation): ~ for negation, ∧ for conjunction, ∨ for disjunction, → for material implication, ↔ for logical equivalence, = for equality, ∀ (respectively ∃) for the universal (respectively existential) quantifier. I use the following conventions:

– variables (individuals): x, y, z, v, w, …

– constants (individuals): lower case strings of Latin letters

– predicates: concatenations of capitalized strings of Latin letters (prefix notation)

– In a couple of occurrences I will use schematic letters.

– I use the symbols 'PT', 'SB', and 'DJ' from (Masolo *et al.*, 2003) for partition, subsumption, and disjointness among categories (with the expected interpretations given the earlier discussions on universals).

I do not offer a full logic, in particular there will be no consideration on a deductive system. I simply assume all the tautologies of classical predicate calculus and standard rules of inference, the alleged corollaries or theorems are so in natural deduction. All formulas are given a number by order of appearance. The number should not be given any specific signification (although, of course, new formulas are asserted in contexts which generally assume previously asserted formulas or introduction of the relevant primitives). Furthermore, 'A' next to a number indicates that the formula is an axiom, 'D' that it is a definition, 'C' that it is a putative corollary.

There is a disclaimer on the axiomatization provided here. The sources – when there is any – are somewhat heterogeneous, even in a single section (mereotopology in particular). Starting with section 4.5, I also had to draw on programmatic and sometimes merely suggested material or make new suggestions. Obviously, there must be flows and this material should be regarded as a transitory result of a work in progress.

4.1 Mereology

Material in this section is based on or adapted from (Simons, 1987; Smith, 1997; Smith and Varzi, 2000)

Primitive term

Part(x,y) means that x is a part of y. Part is the only primitive mereological relation.

Defined terms

ProperPart(x,y) means that x is a proper part of y, i.e., x and y are distinct but x is a part of y (or a is part of y but b is not part of x).

Overlaps(x,y) means that x overlaps with y, i.e., x and y have a part in common.

Underlaps(x,y) means that x and y are both parts of a third entity.

Fusion(y,[Φx]) means that y is the fusion of the Φers, where Φ is a formula of the language with at least one free variable. I do not use an operator for definite descriptions. Rather, I systematically use relations. The definition and further uses are probably best read as axiom schemas. Uniqueness of the fusion is demanded in the definition. Existential axioms need be supplied contextually.

Sum(x,y,z) means that x is the sum of y and z, i.e., x is the fusion of all entities overlapping y or x.

Difference(x,y,z) means that x is the difference between y and z, i.e., the fusion of all parts of y which do not overlap z.

Product(x,y,z) means that x is the product of z, i.e., the fusion of all common parts of y and z.

Complement(x,y) holds when x is the complement of y, i.e., the sum of all entities which do not overlap with y. In practice this will be useless unless relative to a given category. An amended concept could be introduced by requiring the fused entities to instantiate a given universal, for instance, a cumulative one instantiated by y.

Cumulative universals (predicates) are such that the sum of their instances falls under them as well.

Dissective ones are such the parts of their instances is one of their instances as well.

Axioms for Part

$\text{Part}(x, x)$ (A 1)

$(\text{Part}(x, y) \wedge \text{Part}(y, z) \rightarrow \text{Part}(x, z)$ (A 2)

$(\text{Part}(x, y) \wedge \text{Part}(y, x)) \rightarrow x = y$ (A 3)

Definitions

$\text{ProperPart}(x, y) \equiv_{def} \text{Part}(x, y) \wedge \sim(x = y))$ (D 4)

$\text{Overlaps}(x, y) \equiv_{def} \exists z\ (\text{Part}(z, y) \wedge \text{Part}(z, y))$ (D 5)

$\text{Underlaps}(x,y) \equiv_{def} \exists z\ (\text{Part}(x,z) \wedge \text{Part}(y,z))$ (D 6)

$\text{Fusion}(y,x[\Phi x]) \equiv_{def} \forall z\ ((o(z, y) \leftrightarrow \exists x\ (\Phi x \wedge o(z, w)))$

$\wedge\ \forall z'\ (o(z, y) \leftrightarrow \exists x\ (\Phi x \wedge o(z, w))) \rightarrow z = z'))$ (D 7)

$\text{Sum}(x, y, z) \equiv_{def} \text{Fusion}(x,w)\ [\text{Part}(w,y) \vee \text{Part}(w,z)]$ (D 8)

$\text{Difference}(x,y,z) \equiv_{def} \text{Fusion}(x,z[P(z,x) \wedge \sim\text{Overlaps}(z,y)])$ (D 9)

$\text{Product}(x, y, z) \equiv_{def} \text{Fusion}(x,w[\text{Part}(w,y) \wedge \text{Part}(w,z)])$ (D 10)

$\text{Complement}(x, y) \equiv_{def} \text{Fusion}(x,z[\sim\text{Overlaps}(z,y)])$ (D 11)

Two axiom schemas

Using the schematic letter '**P**' for a given predicate symbol, here are a couple of definitions adapted from (Simons, 1987):

(D 12) **P** is dissective:

$$\forall x \forall y ((\mathbf{P}(x) \wedge \text{Part}(y,x)) \rightarrow \mathbf{P}(y)) \quad \text{(D 12)}$$

(D 13) **P** is cumulative:

$$\forall x \forall y \forall z ((\text{Sum}(x,y,z) \wedge \mathbf{P}(x) \wedge \mathbf{P}(y)) \rightarrow \mathbf{P}(z)) \quad \text{(D 13)}$$

4.2 Mereotopology

Material in this section is based on or adapted from (Smith, 1998; Smith and Varzi, 2000)

Primitive terms

BoundaryFor(x,y) means that x is a bona fide boundary for y; x is not necessarily the whole boundary of y, but any part of it. (Contrast with BoundaryOf to be defined.)

FiatBoundaryFor(x,y) means that x is a fiat boundary for y. FiatBoundaryFor is the fiat counterpart of BoundaryFor. These are parts of the entities they are fiat boundaries for.

Defined terms

BoundaryOf(x,y) means that x is the complete (bona fide) boundary of y. The boundary of an entity is the fusion of all entities which are (bona fide) boundaries for this entity. The boundary of an entity is therefore a boundary for that entity.

Closure(x,y) means that x is the closure of y. The closure of an entity is the sum of this entity with its boundary.

Interior(x,y) means that x is the interior of y. The interior of an entity is the difference between this entity and its closure.

WeaklyConnected(x) means that x is weakly connected, i.e., x is such that any two entities it is the sum of are such that their closure overlap. This is (Smith and Varzi, 2000)'s Connected.

MildlyConnected(x) means that x is mildly connected, i.e., x is such that any two entities it is the sum of are such that one overlaps with the closure of the other or vice versa. This is (Smith and Varzi, 2000)'s Connected*.

StronglyConnected(x) means that x is strongly connected, i.e., its interior is mildly connected.

ConnectsWith(x,y) means that x is connected to y, i.e., x and y overlap or x overlaps with the closure of y or y overlaps with the closure of x.

ExternallyConnectsWith(x,y) means that x is connected to y but they do not overlap.

Closed(x) means that x is closed, i.e., it is its own closure. A bona fide boundary – in particular, the boundary of this entity – for closed entity is a part of this entity.

InternalPart(x,y) (resp. FiatInternalPart(x,y)) means that x is a part of y and no boundary for (resp. fiat boundary for) x overlaps with y.

Boundary(x) means that x is a boundary of an entity (at least one).

FiatInternalPart(x,y) means that x is a fiat part of y.

FiatBoundary(x) means that x is a fiat boundary of some entity.

FiatConnected(x) means that x is a fiat entity which is self-connected.

Axioms for FiatBoundaryFor

$\forall x \forall y ((Part(x,y) \wedge BoundaryFor(y,z)) \rightarrow BoundaryFor(x,z))$ (A 14)

$\forall x \forall y (FiatBoundaryFor(x,y) \rightarrow Part(x,y))$ (A 15)

$\forall x \forall y ((Part(x,y) \wedge FiatBoundaryFor(y,z)) \rightarrow FiatBoundaryFor(x,z))$ (A 16)

Definitions

$BoundaryOf(x,y) \equiv_{def} Fusion(x,z)\ [BoundaryFor(z, y)]$ (D 17)

$Closure(x,y) \equiv_{def} \forall z (BoundaryOf(z,x) \rightarrow Sum(x,y,z))$ (D 18)

$Interior(x,y) \equiv_{def} \forall z (Closure(z,y) \rightarrow Difference(x,y,z))$ (D 19)

$WeaklyConnected(x) \equiv_{def} \forall y \forall z \forall v \forall w ((Sum(x,y,z) \wedge Closure(v,y) \wedge Closure(w,z)) \rightarrow Overlaps(v,w))$ (D 20)

$MildlyConnected(x) \equiv_{def} \forall y \forall z \forall v \forall w ((Sum(x,y,z) \wedge Closure(v,y) \wedge Closure(w,z)) \rightarrow (Overlaps(v,z) \vee Overlaps(w,y))$ (D 21)

$StronglyConnected(x) \equiv_{def} \forall y (interior(y,x) \rightarrow MildyConnected(y))$ (D 22)

$ConnectedWith(x,y) \equiv_{def} \forall v \forall w ((Closure(v,x) \wedge Closure(w,y)) \rightarrow (Overlaps(x,y) \vee Overlaps(v, y) \vee Overlaps(x, w))$ (D 23)

$ExternallyConnectsWith(x,y) \equiv_{def} ConnectsWith(x,y) \wedge \sim Overlaps(x, y)$ (D 24)

$Closed(x) \equiv_{def} Closure(x,x)$ (D 25)

$InternalPart(x,y) \equiv_{def} Part(x,y) \wedge \forall z (BoundaryFor(z,y) \rightarrow \sim Overlaps(x,z))$ (D 26)

$Boundary(x) \equiv_{def} \exists y\ BoundaryFor(x,y)$ (D 27)

$FiatInternalPart(x,y) \equiv_{def} Part(x,y) \wedge \forall z (FiatBoundaryOf(z,y) \rightarrow \sim Overlaps(x,y))$ (D 28)

$FiatBoundary(x) \equiv_{def} \exists y\ FiatBoundaryFor(x,y)$ (D 29)

Additional Axioms

$\forall x \forall y (Closure(x,y) \rightarrow Part(y,x))$ (A 30)

$\forall x \forall y ((Closure(x,y) \wedge Closure(z,x)) \rightarrow Part(z,x))$ (A 31)

$\forall x \forall y \forall z \forall u \forall v \forall w \forall z'$ (Sum(x, y, z) $\wedge$ Closure(u,x)
$\wedge$ Closure(v,y) $\wedge$ Closure(w,z) $\wedge$ Sum(z',v,w)) $\rightarrow$ z = z') (A 32)

$\forall x \forall y$ (BoundaryOf(x,y) $\rightarrow$ BoundaryFor(x,y)) (C 33)

$\forall x \forall y$ ((Closed(x) $\wedge$ BoundaryFor(x,y)) $\rightarrow$ Part(x,y)) (C 34)

$\forall x \forall y$ (Sum(x,y,z) $\rightarrow$ FiatConnectedWith(y,z)) (A 35)

$\forall x$ ((Boundary(x) $\wedge$ FiatConnected(x))
$\rightarrow \exists y \exists z$ (FiatConnected(y) $\wedge$ BoundaryFor(x,y) $\wedge$ InternalPart(z,y))) (A 36)

$\forall x$ ((Boundary(x) $\wedge$ FiatConnected(x)) $\rightarrow \exists y \exists z$
(FiatConnected(y) $\wedge$ FiatBoundaryFor(x,y) $\wedge$ FiatInternalPart(z,y))) (A 37)

The following are held to be theorem by (Smith and Varzi, 2000)

$\forall x \forall y \forall z$ ((BoundaryFor(x,y) $\wedge$ BoundaryFor(y,z))
$\rightarrow$ BoundaryFor(x,z)) (C 38)

$\forall x \forall y \forall z$ ((BoundaryFor(x,y) $\wedge$ Complement(z,y))
$\rightarrow$ BoundaryFor(x,z)) (C 39)

$\forall x \forall y$ ~(ExternallyConnectsWith(x,y) $\wedge$ Closed(x) $\wedge$ Closed(y)) (C 40)

$\forall x \forall y \forall z$ ((FiatBoundaryFor(x,y) $\wedge$ FiatBoundaryFor(y,z))
$\rightarrow$ FiatBoundaryFor(x,z)) (C 41)

4.3 Dependence

Material in this section is based on or adapted from (Smith, 1997; Smith, 1998)

Primitive term

SD(x,y) means that x is specifically dependent on y. Specific dependence is defined by (Smith, 1997) modally and SD(x,y) means that x and y do not overlap and x is such that it necessitates the existence of y in order to exist. Notice in particular that specific dependence is then not a form of parthood. Here, without a modal language, I am taking dependence as primitive.

Defined terms

MSD(x,y) means that x is specifically dependent on y and are distinct entity and y is specifically dependent on x.

OSD(x,y) means that x is specifically dependent on y but y is not dependent on a.

$\forall x \forall y$ (SD(x,y) $\rightarrow$ ~Overlaps(x,y)) (A 42)

MSD(x,y) $\equiv_{def}$ SD(x,y) $\wedge$ SD(y,x) (D 43)

OSD(x,y) $\equiv_{def}$ SD(z,y) $\wedge$ ~SD(y,x) (D 44)

Note : These are all relations among particulars.

4.4 Location

Actually, I will give no general theory of location or regions. This is to keep in line with the modular spirit of BFO and following (Grenon, 2003b). Each of SNAP and SPAN have their theories of location and their adequate primitive. Practically, here, I will only use exact location. A general theory of location can be extrapolated from Casati and Varzi's treatment, in particular their (1996) and (1999).
In the case of the static account of SNAP, location will be a binary relation, while in the case of its temporally sensitive treatment, a ternary one (location in space at a time).

4.5 BFO

In keeping with the modular framework of BFO, following (Grenon, 2003b) I take SNAP and SPAN entities as primitive notions. We can always introduce the term 'Entity' as applying to entities of any of the kinds used here. Since this is only a partial rendition of BFO (most importantly not including universals), I will leave it open as whether SpanEntity and SpanEntity form partitions of this putative Entity, i.e., whether there are any other kinds of entities. Here, the instances of SnapEntity and SpanEntity are all particulars.

SnapEntity(x) means that x is a SNAP entity.

SpanEntity(x) means that x is a SPAN entity.

DJ(SnapEntity,SpanEntity) (D 45)

4.6 SNAP

Material in this section is based on or adapted from (Grenon, 2003b; Grenon and Smith, 2003).

Primitive terms

The term space designates an individual, the spatial universe. It is an independent entity in the broad sense of this term.

SpatialLocation(x,y) means that the SNAP entity x is located at the spatial region y. (This is exact location.)

InheresIn(x,y) means that the trope x inheres in the substantial y. It is direct inherence. (Defining inherence brings about too much sophistications at this stage, in addition, some features of tropes of more specific kinds which are not yet clarified may conflict with the prospective definition.)

Defined terms

SpatialRegion(x) means that x is a spatial region, i.e., a part of space.

SpatialSubsumption(x,y) means that x spatially subsumes y, i.e., the spatial location of x is a part of the spatial location of y.

Substantial(x) means that x is a substantial entity, i.e., an independent SPAN entities which does not overlap with space (substantial entities are located in space).

Substance(x) means that x is a substance, i.e., it is a maximally strongly connected substantial entity. It has a bona fide boundary.

Occupies(x,y) means that x occupies y, i.e., i) x and y (which are both substantial entities) do not overlap and neither do their respective locations, but ii) the location of x is an internal part of the location of the sum of the x and y.

Site(x) means that y is a site, i.e., it is a substantial entity *occupied by* a substance.

Trope(x) means that x is a trope, i.e., it is a SNAP entity which specifically depends on at least one substantial entity, in addition, it does not overlaps with any spatial region (but it is located in space). A number of species of the category of tropes are mentioned, though not more formally characterized than taxonomically. Their theories are still work in progress – so I don't know what these are -- and prospectively requires a modal apparatus (unknown too).

MTrope(x) means that x is a monadic trop, i.e., it is specifically dependent on at most on one substantial entity.

RTrope(x) means that x is a relational trope, i.e., it is specifically dependent on at least two substantial entities.

Main subcategories of SNAP entities

$\text{SpatialRegion}(x) \equiv_{\text{def}} \text{Part}(x, \text{space})$ (D 46)

$\text{Substantial}(x) \equiv_{\text{def}} (\text{SnapEntity}(x) \wedge \sim\exists z\, \text{SD}(x,y) \wedge \sim\text{SpatialRegion}(x))$ (D 47)

$\text{Substance}(x) \equiv_{\text{def}} \text{Substantial}(x) \wedge \text{StronglyConnected}(x)$
$\wedge\, \forall y\, ((\text{Part}(x,y) \wedge \text{StronglyConnected}(y)) \rightarrow x=y)$ (D 48)

$\text{Occupies}(x,y) \equiv_{\text{def}} \sim\text{Overlaps}(x,y) \wedge \forall v \forall w\, (\text{SpatialLocation}(x,v) \wedge$
$\text{SpatialLocation}(y,w) \wedge \text{Sum}(z,v,w))$
$\rightarrow \sim\text{Overlaps}(v,w) \wedge \text{InternalPart}(v,z))$ (D 49)

$\text{Site}(x) \equiv_{\text{def}} \exists y\, (\text{Substance}(x) \wedge \text{Occupies}(x,y))$ (D 50)

$\text{Trope}(x) \equiv_{\text{def}} \text{SnapEntity}(x) \wedge \exists y\, (\text{SnapEntity}(y) \wedge \text{SD}(x,y))$ (D 51)

$\text{MTrope}(x) \equiv_{\text{def}} \forall y \forall z\, (\text{InheresIn}(x,y) \wedge \text{InheresIn}(x,z)) \rightarrow x=z$ (D 52)

$\text{RTrope}(x) \equiv_{\text{def}} \exists y \exists z\, (\text{InheresIn}(x,y) \wedge \text{InheresIn}(x,z) \wedge \sim(y=z))$ (D 53)

The following two blocks of axioms will demand temporal qualifications. They merely indicate the elements of modular (static) SNAP.

Spatial location

$\forall x \forall y$ (SpatialLocation(x,y) $\rightarrow$ (SnapEntity(x) $\wedge$ SpatialRegion(y))) (A 54)

$\forall x \forall y$ ((SpatialLocation(x,y) $\wedge$ SpatialLocation(x,z)) $\rightarrow$ x = z) (A 55)

$\forall x$ (SnapEntity(x) $\rightarrow \exists y$ SpatialLocation(x,y)) (A 56)

Inherence

$\forall x \forall y$ (InheresIn(x, y) $\rightarrow$ (Trope(x) $\wedge$ Substantial(y) $\wedge$ SD(x,y))) (A 57)

$\forall x \forall y$ ((InheresIn(x, y) $\wedge$ SpatialLocation(x,v)
$\wedge$ SpatialLocation(y,w))$\rightarrow$ v = w) (A 58)

$\forall x$ (Trope(x) $\rightarrow \exists y$ InheresIn(x,y)) (A 59)

$\forall x$ (Substance(x) $\rightarrow \exists y$ InheresIn(y,x)) (A 60)

$\forall x \forall y$ ((Substantial(x) $\wedge$ Part(y,x)) $\rightarrow \exists z$ InheresIn(z,y))) (A 61)

Subcategories of that of tropes (some examples)

PT(Trope,MTrope,RTrope) (A 62)

SB(Trope,Function) (A 63)

SB(Trope,Quality) (A 64)

SB(Trope,Role) (A 65)

DJ(Quality,Function) (A 66)

DJ(Role,Function) (A 67)

DJ(Role,Quality) (A 68)

possible axiom

SB(RTrope,Role) (A 69)

Mereological and existential axioms and corollaries

Substantial entities

$\forall x \forall y$ ((Substantial(x) $\wedge$ Substantial(y)) $\rightarrow \exists z$ sum(z,x,y)) (A 70)

$\forall x \forall y \forall z$ ((Sum(x,y,z) $\wedge$ Substantial(y) $\wedge$ Substantial(z))
$\rightarrow$ Substantial(x)) (A 71)

$\forall x \forall y$ (Substantial(x) $\wedge$ Part(y,x) $\rightarrow$ Substantial(y)) (A 72)

Possible corollaries

$\forall x \forall y$ ((Substance(x) $\wedge$ Substance(y) $\wedge$ Part(x, y)) $\rightarrow$ x = y) (C 73)

$\forall x$ (Substantial(x) $\leftrightarrow \exists y$ (Substance(y) $\wedge$ Overlaps(x,y))) (C 74)

possible axiom

$\forall x \forall y$ (Substantial(x) $\wedge$ Part(x,y) $\rightarrow$ Substantial(y)) (A 75)

$\forall x \forall y$ (Substantial(x) $\wedge$ Substantial(x) $\wedge$ SpatialSubsumption(x,y) $\rightarrow$ Part (y,x)) (A 76)

Tropes

$\forall x \forall y$ ((Trope(x) $\wedge$ Trope(y)) $\rightarrow \exists z$ sum(z,x,y)) (A 77)

$\forall x \forall y \forall z$ ((Sum(x,y,z) $\wedge$ Trope(y) $\wedge$ Trope(z)) $\rightarrow$ Trope(x)) (A 78)

$\forall x \forall y$ (Trope(x) $\wedge$ Part(y,x) $\rightarrow$ Trope(y)) (A 79)

possible axiom

$\forall x \forall y$ (Trope(x) $\wedge$ Part(x,y) $\rightarrow$ Trope(y)) (A 80)

Spatial regions

SnapEntity(space) (A 81)

$\forall x$ (SpatialRegion(x) $\rightarrow \sim \exists z$ SD(x,y)) (A 82)

-Substantial(space) (C 83)

$\forall x \forall y$ ((SpatialRegion(x) $\wedge$ SpatialRegion(y)) $\rightarrow \exists z$ sum(z,x,y)) (A 84)

$\forall x \forall y \forall z$ ((Sum(x,y,z) $\wedge$ SpatialRegion(y) $\wedge$ SpatialRegion(z)) $\rightarrow$ SpatialRegion(x)) (A 85)

$\forall x \forall y$ ((SpatialRegion(x) $\wedge$ Part(y,x)) $\rightarrow$ SpatialRegion(y)) (A 86)

possible axiom

$\forall x \forall y$ ((SpatialRegion(x) $\wedge$ Part(x,y)) $\rightarrow$ SpatialRegion(y)) (A 87)

Snap entities

$\forall x \forall y \forall z$ ((Sum(x,y,z) $\wedge$ SnapEntity(y) $\wedge$ SnapEntity(z)) $\rightarrow$ SnapEntity(x)) (A 88)

$\forall x \forall y$ (SnapEntity(x) $\wedge$ Part(x,y) $\rightarrow$ SnapEntity(y)) (A 89)

PT(SNAPEntity,Substantial,Trope,SpatialRegion) (A 90)

4.7 SPAN

Material in this section is based on or adapted from (Grenon, 2003b; Grenon and Smith, 2003).

Primitive terms

The term time designates an individual: the whole of time.

TemporalLocation(x,y) means that x is the temporal region at which y is (uniquely) located. (It is exact temporal location.)

The term spacetime designates an individual: the whole of spacetime.

SpatiotemporalLocation(x,y) means that x is the temporal region at which y is (uniquely) located. (It is exact spatiotemporal location.)

Before(x,y) means that the temporal instant x is earlier than the temporal instant y. (This is the minimum we need in this presentation, BFO ought to be given an interval calculus a la Allen on extended regions. In addition, generalized temporal order on non regions will be definable straightforwardly from order relations on regions and locational relations.)

Defined terms

TemporalRegion(x) means that x is a region of time, i.e., a part of time which may be extended or instantaneous (a time instant), connected to various degrees or scattered.

Time Instant(x) means that x is an instant of time, i.e., a maximally strongly connected boundary of a temporal region.

AtTime(x,y) means that x is temporally located at y and that y is an instant of time.

TemporalCollocation(x,y) means that x and y are located at the same region of time.

TemporalSubsumption(x,y) means that x temporally subsumes y, i.e., the temporal location of x is a part of the temporal location of y.

TemporalPart(x,y) means that x is a temporal part of y, i.e., x is a part of y such that all parts of y temporally collocated with x are parts of x. (It is trivial to introduce a ternary relation indicating the time of location of x)

TemporalSlice(x,y) means that x is a temporal slice of y, i.e., x is an instantaneous temporal part of y.

SpatiotemporalRegion(x) means that x is a region of spacetime, i.e., a part of spacetime.

SpatiotemporalCollocation(x,y) means that x and y are located at the same region of spacetime.

SpatiotemporalSubsumption(x,y) means that x temporally subsumes y, i.e., the spatiotemporal location of x is a part of the spatiotemporal location of y.

SpatiotemporalPart(x,y) means that x is a spatiotemporal part of y, i.e., x is a part of y such that all parts of y spatiotemporally collocated with x are parts of x.

Processual(x) means that x is a processual, i.e., an happening, an occurrent (not a temporal or spatiotemporal region).

Process(x) means that x is a process, i.e., a maximally strongly connected occurrent (processual).

Event(x) means that x is an event, i.e., a temporal slice of a processual.

BonaFideEvent(x) manes that x is a bona fide event, i.e., a maximally strongly connected boundary of an occurrent.

Temporal and spatiotemporal regions

SpanEntity(time) (A 91)

SpanEntity(spacetime) (A 92)

~ Overlaps(spacetime,time) (A 93)

TemporalRegion(x) $\equiv_{def}$ Part(x, time) (D 94)

TemporalInstant(x) $\equiv_{def} \exists$y (TemporalRegion(y)
$\wedge$ BoundaryOf(x,y) $\wedge$ StronglyConnected(x)
$\wedge \forall$z ((BoundaryOf(z,y) $\wedge$ StronglyConnected(z)) $\rightarrow$ x=z)) (D 95)

SpatiotemporalRegion(x) $\equiv_{def}$ Part(x,spacetime) (D 96)

Temporal location

$\forall$x$\forall$y (TemporalLocation(x,y)
$\rightarrow$ (SpanEntity(x)) $\wedge$ TemporalRegion(y))) (A 97)

$\forall$x$\forall$y ((TemporalLocation(x,y) $\wedge$ TemporalLocation(x,z)) $\rightarrow$ y=z) (A 98)

$\forall$x (SpanEntity(x) $\rightarrow \exists$y TemporalLocation(y,x)) (A 99)

$\forall$x (TemporalRegion(x) $\rightarrow$ TemporalLocation(x,x)) (A 100)

Further defintions

AtTime(x,y) $\equiv_{def}$ (TemporalLocation(x, t) $\wedge$ TimeInstant(y)) (D 101)

TemporalColocation(x,y) $\equiv_{def} \exists$z (TemporalLocation(z,x)
$\wedge$ TemporalLocation(z,y)) (D 102)

TemporalSubsumption(x,y) $\equiv_{def} \forall$v$\forall$w ((TemporalLocation(v,x) $\wedge$
TemporalLocation(w,z)) $\rightarrow$ Part(v,w)) (D 103)

Spatiotemporal location

$\forall$x$\forall$y (SpatiotemporalLocation(x,y)
$\rightarrow$ (SpanEntity(x) $\wedge$ SpatiotemporalRegion(y))) (A 104)

$\forall$x$\forall$y$\forall$z ((SpatiotemporalLocation(x,y)
$\wedge$ SpatiotemporalLocation(x,z)) $\rightarrow$ y=z) (A 105)

$\forall$x (SpanEntity(x) $\rightarrow \exists$y SpatiotemporalLocation(x,y)) (A 106)

$\forall$x (SpatiotemporalRegion(x) $\rightarrow$ SpatiotemporalLocation(x,x)) (A 107)

Spatiotemporal and temporal mereology

TemporalPart(x,y) $\equiv_{def}$ Part(x,y) $\wedge$ SpanEntity(x)
$\wedge$ SpanEntity(y) $\wedge \forall$z ((Part(z,y) $\wedge$ TemporallyColocated(x,z))
$\rightarrow$ Part(z,x)) (D 108)

$\forall$x$\forall$y$\forall$v$\forall$w ((TemporalPart(x,y) $\wedge$ TemporalLocation(x,v) $\wedge$
TemporalLocation(y,w)) $\rightarrow$ Part(v,w)) (C 109)

$\text{TemporalSlice}(x,y) \equiv_{\text{def}} \text{TemporalPart}(x,y) \wedge \exists z\ \text{AtTime}(x,z)$ (D 110)

$\text{SpatiotemporalPart}(x,y) \equiv_{\text{def}} \text{Part}(x,y) \wedge \text{SpanEntity}(x) \wedge \text{SpanEntity}(y)$
$\wedge\ \forall z\ ((\text{Part}(z,y) \wedge \text{SpatiotemporallyColocated}(x,z)) \rightarrow \text{Part}(z,x))$ (D 111)

Occurrence and processuals

$\text{OccursAt}(x,y) \equiv_{\text{def}} (\text{SpanEntity}(x) \wedge \sim\text{TemporalRegion}(x)$
$\wedge\sim\text{SpatiotemporalRegion}(x) \wedge\exists z\ (\text{TemporalSlice}(z,x) \wedge \text{AtTime}(z,y))$ (D 112)

$\text{Processual}(x) \equiv_{\text{def}} \exists y\ \text{OccursAt}(x,y)$ (D 113)

$\text{Process}(x) \equiv_{\text{def}} \text{Processual}(x) \wedge \text{StronglyConnected}(x)$
$\wedge\ \forall y\ ((\text{Part}(x,y) \wedge \text{StronglyConnected}(y)) \rightarrow x=y)$ (D 114)

$\text{Event}(x) \equiv_{\text{def}} \exists y\ (\text{Processual}(y) \wedge \text{TemporalSlice}(x, y))$ (D 115)

$\text{Event-BF}(x) \equiv_{\text{def}} \exists y\ (\text{Processual}(y) \wedge \text{TemporalSlice}(x, y)$
$\wedge\ \text{BoundaryFor}(x, y))$ (D 116)

Temporal order (on instants)

$\forall x \forall y\ (\text{Before}(x,y) \rightarrow (\text{TemporalInstant}(x) \wedge \text{TemporalInstant}(y)))$ (A 117)

$\forall x\ \sim\text{Before}(x,x)$ (A 118)

$\forall x \forall y\ (\text{Before}(x,y) \rightarrow \sim\text{Before}(y,x))$ (A 119)

$\forall x \forall y \forall z\ ((\text{Before}(x,y) \wedge \text{Before}(y,z)) \rightarrow \text{Before}(x,z))$ (A 120)

$\forall x \forall y\ ((\text{TemporalInstant}(x) \wedge \text{TemporalInstant}(y))$
$\rightarrow (\text{Before}(x,y) \vee (x = y) \vee \text{Before}(y,x)))$ (A 121)

$\forall x \forall y \forall z\ ((\text{Before}(y,x) \wedge \text{Before}(z,x))$
$\rightarrow (\text{Before}(y,z) \vee \text{Before}(z,y)))$ (A 122)

Mereological and existential axiom

Temporal region

$\forall x \forall y\ ((\text{TemporalRegion}(x) \wedge \text{TemporalRegion}(y))$
$\rightarrow \exists z\ \text{sum}(x,y,z))$ (A 123)

$\forall x \forall y \forall z\ ((\text{Sum}(x,y,z) \wedge \text{TemporalRegion}(y) \wedge \text{TemporalRegion}(z))$
$\rightarrow \text{TemporalRegion}(x))$ (A 124)

$\forall x \forall y\ (\text{TemporalRegion}(x) \wedge \text{Part}(y,x)) \rightarrow \text{TemporalRegion}(y))$ (A 125)

possible axiom

$\forall x \forall y\ (\text{TemporalRegion}(x) \wedge \text{Part}(x,y) \rightarrow \text{TemporalRegion}(y))$ (A 126)

Spatiotemporal region

$\forall x \forall y\ ((\text{SpatiotemporalRegion}(x)$

$\wedge$ SpatiotemporalRegion(y)) $\rightarrow \exists$z Sum(x,y,z)) (A 127)

$\forall$x$\forall$y ((Sum(x,y,z) $\wedge$ SpatiotemporallRegion(y)
$\wedge$ SpatiotemporallRegion(z)) $\rightarrow$ SpatiotemporallRegion(x)) (A 128)

$\forall$x$\forall$y (SpatiotemporalRegion(x) $\wedge$ Part(y,x)
$\rightarrow$ SpatiotemporalRegion(y)) (A 129)

$\forall$x$\forall$y ((SpatiotemporalRegion(x) $\wedge$ Part(x,y))
$\rightarrow$ SpatiotemporalRegion(y)) (A 130)

Processual entities

$\forall$x$\forall$y ((Processual(x) $\wedge$ Part(y,x)) $\rightarrow$ Processual(y)) (A 131)

$\forall$x$\forall$y ((Processual(x) $\wedge$ Processual(y)) $\rightarrow \exists$z Sum(x,y,z)) (A 132)

$\forall$x$\forall$y (Sum(x,y,z) $\wedge$ Processual(y) $\wedge$ Processual(z))
$\rightarrow$ Processual(x)) (A 133)

$\forall$x$\forall$y (Process(x) $\wedge$ Process(y) $\wedge$ p(x, y)) $\rightarrow$ x = y) (A 134)

possible axiom

$\forall$x$\forall$y ((Processual(x) $\wedge$ Part(x,y)) $\rightarrow$ Processual(y)) (A 135)

Span entity

PT(SpanEntity,Processual,TemporalRegion,SpatiotemporalRegion) (A 136)

$\forall$x$\forall$y ((SpanEntity(x) $\wedge$ Part(y,x)) $\rightarrow$ SpanEntity(y)) (A 137)

$\forall$x$\forall$y ((SpanEntity(x) $\wedge$ Part(x,y) $\rightarrow$ SpanEntity(y)) (A 138)

$\forall$x$\forall$y$\forall$z ((Sum(x,y,z) $\wedge$ SpanEntity(y) $\wedge$ SpanEntity(z))
$\rightarrow$ SpanEntity(x)) (A 139)

$\forall$x (SpanEntity(x) $\rightarrow \exists$y TemporalPart(y,x)) (A 140)

$\forall$x (SpanEntity(x) $\rightarrow \exists$y SpatiotemporalPart(y,x)) (A 141)

$\forall$x$\forall$y ((TemporalRegion(x) $\wedge$ SpatiotemporalPart(y,x)) $\rightarrow$ x=y) (A 142)

4.8 Temporalizing BFO

Material in this section is adapted from (Grenon, 2003b; Grenon and Smith, 2003), temporalization relies on section 4.1, 4.2, 4.3, and 4.6.

Existence and explicitly temporalized SNAP vocabulary

ExistsAt(x,y) means that the SNAP entity x exists at the time instant y.

ExistsDuring(x,y) means that the SNAP entity x exists during the whole temporal region y. (It is a very weak claim.)

SpatialLocationAt(x,y,z) means that at the instant of time y, x is spatially located at z.

InheresInAt(x,y,z) means that at the instant of time z, x inheres in y.

Existence

$\forall x \forall y$ (ExistsAt(x,y) $\rightarrow$ (SnapEntity(x) $\wedge$ TemporalInstant (y))) (A 143)

ExistsDuring(x,y) $\equiv_{def}$ TemporalRegion(y)
$\wedge \forall z$ ((TemporalInstant(z) $\wedge$ Part(z,y)) $\rightarrow$ ExistsDuring(x,z)) (D 144)

ExistsDuring(space,time) (A 145)

possible axiom

$\forall x \forall y$ (ExistsDuring(x,y) $\rightarrow$ StronglyConnected(y)) (A 146)

Temporalized spatial location.

$\forall x \forall y \forall z$ (SpatialLocationAt(x,y,z) $\rightarrow$ (SnapEntity(x)
$\wedge$ SpatialRegion(y) $\wedge$ TemporalRegion(z))) (A 147)

$\forall x \forall y \forall z$ (SpatialLocationAt(x,y,z) $\rightarrow$ (ExistsDuring(x,z)
$\wedge$ ExistsDuring(y,z))) (A 148)

$\forall x \forall y \forall z$ ((SpatialLocationAt(x,y,z) $\wedge$ SpatialLocationAt(w,y,z))
$\rightarrow$ x = w) (A 149)

Note: In A 144, the second conjunct of the consequent is actually redundant.

Temporalized Inherence.

$\forall x \forall y \forall z$ (InheresIn(x,y,z)
$\rightarrow$ (Trope(y) $\wedge$ Substantial(y) $\wedge$ TemporalRegion(z))) (A 150)

$\forall x \forall y \forall z$ (InheresIn(x,y,z) $\rightarrow$ (ExistsDuring(x,z)
$\wedge$ ExistsDuring(y,z))) (A 151)

$\forall x \forall y$ (InheresIn(x,y,z) $\rightarrow$ SD(x,y) (A 152)

$\forall x \forall y \forall z$ ((InheresIn(x,y,z) $\wedge$ SpatialLocationAt(x,v,z)
$\wedge$ SpatialLocationAt(y,w,z))$\rightarrow$ v = w) (A 153)

$\forall x \forall y$ ((Trope(x) $\wedge$ ExistsAt(x,y)) $\rightarrow \exists z$ InheresIn(x,z,y)) (A 154)

$\forall x \forall y$ ((Substance(x) $\wedge$ ExistsAt(x,y)) $\rightarrow \exists z$ InheresIn(z,x,y)) (A 155)

Mtrope(x) $\equiv_{def} \forall y \forall v \forall w$
((InheresIn(x,v,y) $\wedge$ InheresIn(x,w,y))$\rightarrow$ v = w) (D 156)

Rtrope(x) $\equiv_{def} \exists y \exists z \exists w$
(InheresIn(x,y,w) $\wedge$ InheresIn(x,z,w) $\wedge$ ~(y = z)) (D 157)

Temporalizing the remaining vocabulary

Primitive terms

Part(x,y,z) means that x is a part of y at z. Part is the only primitive mereological relation. In the case of perdurants, z will be the time of location of x (so, it is definable in this context).

BoundaryFor(x,y) means that a is a bona fide boundary for b. a is not necessarily the whole boundary, but any part of it. (Contrast with BoundaryOf to be defined.)

FiatBoundaryFor(x,y) means that a is a fiat boundary for b. FiatBoundaryFor is the fiat counterpart of BoundaryFor. These are parts of the entities they are fiat boundaries for.

SD(x,y,z) means that x is specifically dependent on y at z.

Defined terms

As in the mereological case, the temporalized SPAN vocabulary is definable in terms of temporal or spatial location and the non temporalized primitive. All definitions based on the non temporalized primitive are given more or less straightforwardly in the expected way.

4.9 SNAP and SPAN

Material in this section is partially based on or adapted from (Grenon, 2003c; Grenon, 2003b; Grenon and Smith, 2003).

Primitive terms

The native primitive terms of BFO are non temporalized predicates for the relation of participation and realization which obtains at a given moment of time. ParticipatesIn(x,y) means that x participates in y (x exists at the time of obtainment of the relation and y is located at that time). The most fundamental form of participation is thus between a SNAP entity and a temporal slice of a process (an event) – (Grenon, 2003c). It is this variant but with the mention of the time of location of the event in question which I will take as primitive. The other native primitive is Realization(x,y) where x is a trope – with analogous qualifications.

ParticipatesAt(x,y,z) means that x is a substantial or a trope which participates in event y at z.

RealizedAt(x,y,z) means that x is in a process of realization in the event y at z.

Defined terms

STParticipantAt(x,y,z) means that there is an instantaneous spatiotemporal part of y at z in which x participates.

TParticipantAt(x,y,z) means that there is a temporal slice of y at z in which x participates.

CParticipantIn(x,y) means that x is a complete participant in y, i.e., x participates in each temporal slice of y at the time at which it occurs.

Life(x,y) means that x is the life of y. The life of a substantial is the fusion of all processuals it is a complete participant of.

SpatialLocalizationAt(x,y,z) means that the event x is spatially localized at the spatial region y at the instant of time z; y is the spatial location of the fusion of the location of the participants in x at z.

Functioning(x) means that x is a functioning process, i.e., the realization of a function.

Axioms for ParticipatesAt

$\forall x \forall y \forall z$ (ParticipatesAt(x,y,z) $\rightarrow$ (ExistsAt(x,z) $\wedge$ AtTime(y,z))) (A 158)

$\forall x \forall y \forall z$ (ParticipatesAt(x,y,z) $\rightarrow$
(Substantial(x) $\wedge$ Event(y) $\wedge$ TemporalInstant(y))) (C 159)

$\forall x \forall y \forall z$ (ParticipatesAt(x,y,z) $\rightarrow$ SD(y,x)) (A 160)

possible axioms

$\forall x$ (Processual(x) $\rightarrow \exists y \exists z$ ParticipatesAt(y,x,z)) (A 161)

$\forall x$ (Substantial(x) $\rightarrow \exists y \exists z$ ParticipatesAt(x,y,z)) (A 162)

Definitions

STParticipantAt(x,y,z) $\equiv_{def} \exists w$ (SpatiotemporalPart(w,y)
$\wedge$ ParticipatesAt(x,w,z)) (A 163)

TParticipantAt(x,y,z) $\equiv_{def} \exists w$ (TemporalPart(w,y)
$\wedge$ ParticipatesAt(x,w,z)) (A 164)

CParticipantIn(x,y) $\equiv_{def} \forall v$ (OccursAt(y,t) $\rightarrow$
$\exists w$ (TemporalPart(w,y) $\wedge$ AtTime(w,t) $\wedge$ ParticipatesAt(x,w,t)) (A 165)

Life(x,y) $\equiv_{def}$ Fusion(x,w[CParticipantIn(y,w)]) (A 166)

SpatialLocalizationAt(x,y,z)
$\equiv_{def}$ Fusion(y,w[ParticipatesAt(v,x,z) $\wedge$ SpatialLocationAt(v,w,z)]) (A 167)

possible corollaries

$\forall x$ (Substantial(x) $\rightarrow \exists y$ Life(y,x)) (A 168)

$\forall x \forall y$ (Life(x,y) $\rightarrow$ SD(x,y)) (A 169)

possible axioms (can this at any rate characterize a kind of substantials entities?)

$\forall x \forall y \forall z \forall w$ (ParticipatesAt(x,y,z) $\wedge$ (Part(w,x))
$\rightarrow$ ParticipatesAt(w,y,z)) (A 170)

Axioms for RealizedAt

$\forall x \forall y \forall z$ (RealizedAt(x,y,z)
$\rightarrow \exists w$ (InheresIn(x,w,z) $\wedge$ ParticipatesAt(w,y,z)) (A 171)

$\forall x \forall y \forall z$ ((InheresIn(x,y,z) $\wedge$ RealizedAt(x,w,z))
$\rightarrow$ ParticipatesAt(y,w,z))) (A 172)

$\forall x \forall y \forall z \forall v \forall w$ (RealizedAt(x,y,z) $\wedge$ (InheresIn(x,v,z) $\wedge$ Life(w,z))
$\rightarrow$ Part(x,w,z)) (C 173)

Functioning(x) $\equiv_{def} \exists y \exists z$ (RealizedAt(x,y,z) $\wedge$ Function(y)) (A 174)

5 Concluding Remarks

This report is intended as a preliminary stab at laying out the institutional stance on BFO's stable fundaments – both its definite underlying metaphysics and a putative formal characterization – and comparing it with other ontologies, DOLCE in the first place.

The axiomatization presented is intended primarily as indicative of a prospective more exhaustive characterization of BFO. Again, it does not either pretend to be free of flows. (Of course, definitions can change, corollaries may be identified, axioms added or replaced, ...) For the most part, with few exceptions, I tried to avoid introducing terms and notions which were either straightforwardly following from the primitives and major defined terms or serve no purpose in the present characterization. One task might be to explicit these definitional extensions to the language and see when and where additional terms would useful (e.g., things similar to SpatialSubsumption and so on).

It is much more important to provide robust formal characterization of the notions alluded to in BFO's informal discussions (e.g., the various kinds of tropes) and identify the formal framework needed. In that connection, it will eventually be time to use more powerful tools than FOL, namely, a modal logic of some sort (which? where and when?) This is yet a remote objective, it seems to me, the next step is still to decide as concerns the stable parts of BFO whether a number of possible axioms are desirable and where are the missing ones, while polishing the currently tentative axiom system.

As for the elements of comparison with DOLCE given here, these need to be evaluated or backed up at IFOMIS and with feedback from the LOA. This should provide enough grounds for closer and more focused interaction. In that connection, IFOMIS should also more actively endorse some, if not all, of LOAs objectives as stated in (Masolo *et al.*, 2003, 4, p. 29).

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OpenCyc http://opencyc.org

IFOMIS http://www.ifomis.uni-leipzig.de

LOA http://www.loa-cnr.it/

WonderWeb http://wonderweb.semanticweb.org/index.shtml

WonderWeb Deliverable 17
http://wonderweb.semanticweb.org/deliverables/D17.shtml

Ontology Library http://wonderweb.semanticweb.org/deliverables/D17.shtml

Smith's BFO page http://ontology.buffalo.edu/bfo/BFO.htm