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Mapping BFO and DOLCE

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Abstract

Upper level ontologies are key technology for integrating heterogeneous information coming from different sources. DOLCE and BFO, are the favorite candidates which propose rigorous foundational principles to model any domain. The objective of the AKENATON project is to improve alert management and to support patient-centered medical decision in telecardiology. This requires to integrate information transmitted by implantable cardiac devices with clinical data extracted from patient health records. To achieve this goal, we have designed an ontology of telecardiology based on DOLCE. In order to integrate ontologies based on BFO such as FMA, we have developed a framework for mapping BFO and DOLCE categories in terms of equivalence and subsumption between categories.

***Keywords*:**

Upper level ontologies, BFO, DOLCE, Ontology, Mapping, Telecardiology

Introduction

Upper level ontologies (ULO), also called top ontologies or foundational ontologies describe very general concepts (e.g. *substance*, *physical object, event, quality*) and relations (e.g. *parthood, participation*) that are common to all domains. They are key technology for integrating heterogeneous knowledge coming from different sources [1]. DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) [2] and BFO (Basic Formal Ontology) [3], are the favorite candidates which propose rigorous foundational principles to model any domain. These ontologies were elaborated in the context of the WonderWeb project [2], whose ultimate aim was to build a library of foundational ontologies, and to establish the foundations enabling the "negotiation of meaning" between agents. In the biomedical domain, several projects rely on BFO as a foundational ontology, e.g. [4, 5] while others use DOLCE, e.g. [6,7, 8].

In the AKENATON[1] project, we have designed an ontology of telecardiology in order to enrich and classify automatically alerts coming from Implantable Cardiac Device (ICD). The goal is to integrate clinical information from the patient health record (e.g. *diseases, prescriptions, procedures*) together with information provided by the ICD. The objective is to help physicians to assess their relevance and emergency level and to support patient-centered medical decision in telecardiology. The AKENATON ontology is based on DOLCE as it appears that DOLCE offers a better support for representing temporal qualities (e.g. *heart rate, atrial fibrillation duration*) and cognitive entities (e.g. *prescriptions, diagnosis, therapy plan*). However, our choice of DOLCE as framework should not hinder the future reuse of ontologies aligned to BFO (e.g. FMA, Foundational model of anatomy [9]). Conversely, it should not be an obstacle to ensure interoperability between the AKENATON ontology and ontologies based on BFO. Therefore, we investigated the compatibility between BFO and DOLCE. In this paper, we propose a mapping between BFO and DOLCE categories, in terms of equivalence and subsumption relationships between their respective categories.

[1] http://resmed.univ-rennes1.fr/akenaton/

Material and method

Several authors have proposed methods for mapping or merging ontologies, including lexical methods, structural methods, logical and semantic approaches based on models such as propositional satisfiability (SAT) and modal SAT techniques or description logic based techniques [1]. Contrary to domain ontologies and application ontologies, top ontologies would not benefit from these mapping techniques. ULOs adopt different philosophical perspectives that guide their defining of formal categories. Consequently, we generated the mappings between BFO and DOLCE categories, by analyzing and comparing their respective formal, textual definitions, with a focus on constraints and characteristics as well as examples of each category provided by authors. We focused on *equivalence* and *subsumption* relations. For each category of BFO (respectively DOLCE) we determined relations of equivalence or of subsumption considering the constraints of their DOLCE (respectively BFO) counterpart, and their philosophical approach.

BFO

BFO adopts a *realistic* approach. According to the modes of existence in time of the entities populating the world, BFO subdivides the reality into two orthogonal ontologies: SNAP and SPAN.

SNAP: SNAP ontology (Figure 1) is an ontology of *Continuants* (also called *Endurants*), which are entities that have continuous existence and fully exist in any instant of

time at which they exist. SNAP entities are separated into three main categories:

1. `bfo:Substantial entities` subsumes the categories of substances, their fiat parts, their aggregates, their boundaries and sites.
   - `bfo:Substances` are maximal connected substantials which they have the following main features: *i)* not depend entities, *ii)* bearers of qualities, *iii)* preserves their identity *iv)* located in space *v)* they are self-connected wholes with bona fide boundaries. Examples are organism and organ such as *human* and *heart*.
   - `bfo:Fiat parts` are part of `bfo:Substances`, on which they depend. `bfo:Fiat parts` cannot have their own complete bona fide exterior boundary, e.g. some body part such as *leg* and *nose*.
   - `bfo:Aggregates of substances` are mereological sums comprehending separate substances as parts. They may be scattered and thus have non-connected boundaries. Examples include *groups of human beings*.
   - `bfo:Boundaries` are lower-dimensional parts of spatial entities. Examples are *surface of skin* and *external surface of heart*.
   - `bfo:Sites` are holes, cavities and similar entities. They are generally filled by a medium such as air or water. Examples are *atrial cavity*.
2. `bfo:SNAP dependent entities` are continuant entities that depend for their existence on the `bfo:Substances` which are their bearers. However, if endurance and dependence are necessary conditions for `bfo:SNAP dependent entities`, they are not sufficient conditions. The distinguishing feature of these entities is that they *inhere in* `bfo:Substances`. They include particularized `bfo:Qualities` (e.g. *blood pressure, blood glucose level*), `bfo:Functions` (e.g. *function of heart to pump blood*), `bfo:Roles` (as *patient*, as *physician*).

`bfo:Spatial regions` are continuants, such that other SNAP entities can be located at or in them.

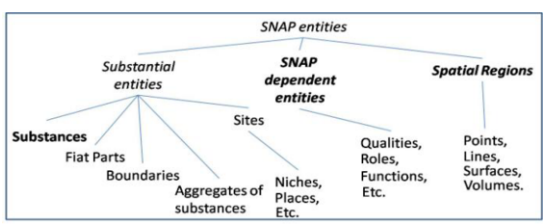

Figure 1-Top SNAP entities from BFO

SPAN: SPAN ontology (Figure 2) is an ontology of *Occurrents* (also called *Perdurants*), which are entities that occur in time and they unfold themselves through a period of time. The SPAN entities are divided into three separate categories:

1. `bfo:Processual entities` are entities that happen in time**,** they involve participants of a kind of `bfo:Substantial entities`. They are dependent on their participants, and occupy spatiotemporal regions. Conversely to `bfo:Substantial entities`, `bfo:Processual entities` do not have qualities [10]. Five main categories are subsumed by `bfo:Processual entities`:
   - `bfo:Processes` are those extended `bfo:Processual entities` which are self-connected wholes, they have beginnings and endings corresponding to real discontinuities, which are their bona fide boundaries. Examples are *blood circulation*, *course of disease*, *life*.
   - `bfo:Fiat parts of process`. All the proper parts of a process share the same level of granularity (e.g. *first phase of blood circulation*, and *metastasis phase of cancer*).
   - `bfo:Events` are instantaneous boundaries of processes and instantaneous transitions within processes. Examples are *birth, death, stroke, cardiac arrest*.
   - `bfo:Aggregates of Processes`. Examples include the aggregate of *all episodes of atrial fibrillation* in a given year; and the aggregate of *all surgical procedure* in a given period.
2. `bfo:Temporal region`, *Time*, the maximal temporal region, is an occurrent, and thus a SPAN entity. A `bfo:temporal region` is a part of *Time*.
3. `bfo:Spatiotemporal region` the totality of spatiotemporal regions reflects the totality of possible fiat demarcations of that maximal region, called *spacetime*.

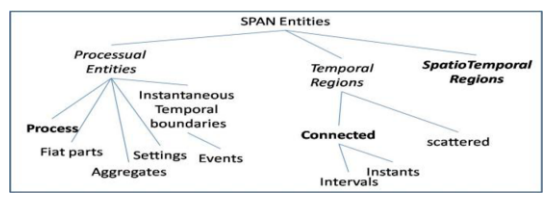

Figure 2-Top SPAN entities from BFO

DOLCE is a foundational ontology of *Particulars* which adopts a *Descriptive/Multiplicative*[2] approach and has a clear *cognitive bias*. Entities are classified into four separate categories, depending on their modes of existence (Figure 3):

1. `dol:Endurants` are entities that "are wholly present in time". Among `dol:Endurants`, and according to whether the entity has direct spatial qualities, `dol: Physical Endurants` (e.g. *heart, lung*) are distinguished from `dol:Non-Physical Endurants` (e.g. *prescriptions*, *diagnosis*), which cover social and cognitive entities. Furthermore, based on the unity criterion discussed in [11], `dol:Physical endurants` are divided into:
   - `dol:Amount of Matter` are `dol:Endurants` with no unity (according to [11], none of them is an essential whole). Examples are *some blood, some gas, and some water*.
   - `dol:Physical Objects` are `dol:Endurants` with unity. `dol:Physical Objects` change some of their

[2] A multiplicative ontology allows for different entities to be *co-localized* in the same space-time. This case is often presented through the problem of the vase and the clay it is made of [2].

parts while keeping their identity. Examples are *humans*, and *pacemakers*.

- `dol:Features` whose typical examples are "parasitic entities" such as *holes*, *boundaries*, *surfaces*, or *stains*, which are generically constantly dependent on `dol:Physical objects` (their hosts). Examples are *lesions*, *interior surface of coronary artery*, and *edema*.

2. `dol:Perdurants` are entities that "occur in time" in which `dol:Endurants` *participate* (e.g. *disease cours*). Among `dol:Perdurants`, `dol:Statives` are distinguished from `dol:Events` according to whether the `dol:Perdurants` are *cumulative*[3] or not. `dol:Events` are divided into `dol:Achievements` (e.g. *death*, *cardiac arrest*) and `dol:Accomplishments` (e.g. *scan session*, *clinical studing*) according to whether they are *atomic* or not. `dol:Statives` are divided into `dol:States` (e.g. *setting*) and `dol:Processes` (e.g. *pumping blood*, *coagulation*) according to whether they are *homeomerous*[4] or not.

3. `dol:Qualities` are neither `dol:Endurants`, nor `dol:Perdurants`. They are dependent entities which are *inherent in* either `dol:Endurants`, `dol:Perdurants` or `dol:Qualities`. `dol:Qualities` are entities that we perceive and/or measure. Examples are *blood pressure*, *blood glucose level*, and *duration of atrial fibrillation*.

4. `dol:Qualities` take "values", called `dol:Quales` (e.g. *120/80 mmhg*, *1.12 g/l*, *10 min*) within associated `dol:Region`.

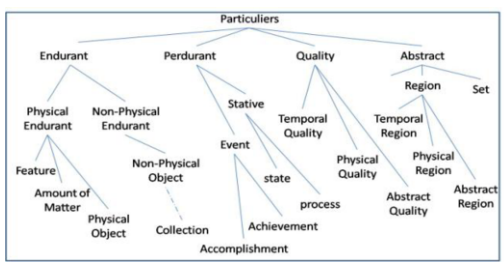

Figure 3-An excerpt from DOLCE's top-level taxonomy.

Mapping result

The result obtained when mapping an ontology O_1 to O_2 is a set of triples $C_1 R C_2$ where `C1`(resp. `C2`) is a concept of O_1 (resp. O_2) and `R` is a relation which is either *equivalence* or *subsumption*.

100% of BFO categories were successfully mapped to DOLCE resulting in 6 equivalence relations and 13 subsumption relations (Figure 4). However, 81% of DOLCE categories were successfully mapped to BFO, and we obtained 6 equivalence relations and 13 subsumption relations. 3 categories in DOLCE did not have any correspondence in BFO, such as the `dol:Temporal qualities`, and `dol:Abstract qualities`, because of BFO *realistic* approach.

Mapping snap entities (see Figure 4):

- `bfo:Substantials entities` is a general category. We map its five sub categories:
  - `bfo:Sites` are defined by examples such as *holes*, *cavities* or *places* depend on physical hosts. These same examples are given by DOLCE for the `dol:Feature` category, whose entities also depend on physical hosts. The `dol:Feature` category also subsumes other categories which are not `bfo:Sites`. Therefore `dol:Feature` *subsumes* `bfo:Sites`.
  - `bfo:Boundaries` are defined as lower-dimensional part of spatial entities, depend on entities they bound, as part depend on wholes. DOLCE gives boundaries as typical examples of `dol:Feature` entities (e.g. *surface of skin*) which also depend and are part of their hosts. Then, as `bfo:Sites`, `bfo:Boundaries` is also *subsumed by* `dol:Feature`.
  - `bfo:Fiat parts` are defined as parts of `bfo:Substances`, on which they depend. BFO distinguishes them according to their boundaries, and considers that each entity with no complete boundaries is a kind of `bfo:Fiat parts` (e.g. *noses*, *hands*). DOLCE is based on identity and unity criteria to determine the kind of entities which are parts of physical entities. Thus, for DOLCE, the body parts such as *legs* and *hands* are kind of `dol:Physical objects` because they keep their identity, even if they are detached from the body. Then, if this position is considered to hold in DOLCE, `bfo:Fiat parts` *are subsumed by* `dol:Physical objects`. If it is rejected, `bfo:Fiat parts` *are subsumed by* `dol:Features`. In our case, we chose the second proposition.
  - `bfo:Aggregates of substances` are defined as mereological sums comprehending separate substances as parts. In DOLCE, a new category called `dol:Collection` was introduced to represent the notion of aggregation [12]. `dol:Collection` is a category defined to manage entities such as *groups*, in which `dol:Endurants` are members. Thus, the *aggregate of humans* of BFO is a *group of humans* in DOLCE where the *humans* are the members. Then `bfo:Aggregates of substances` *are subsumed by* `dol:Collections`.
  - `bfo:Substances` category corresponds to the union of `dol:Physical objects and dol:Amount of matter`, which are based on unity and identity criteria. Unlike BFO, DOLCE distinguishes entities such as *some blood*, *some water* (entities with no unity (**~U**), which change their identity when they change their parts) from objects (entities with unity (±U) which can change some of their parts while keeping their identity). Thus, according to

[3] An occurrence is cumulative if its corresponds to the mereological sum of two of its instances

[4] An occurrences is homeomerous if each part of the instance stay belong the same occurrence. eg: each part of an instance of *setting* is a *setting*

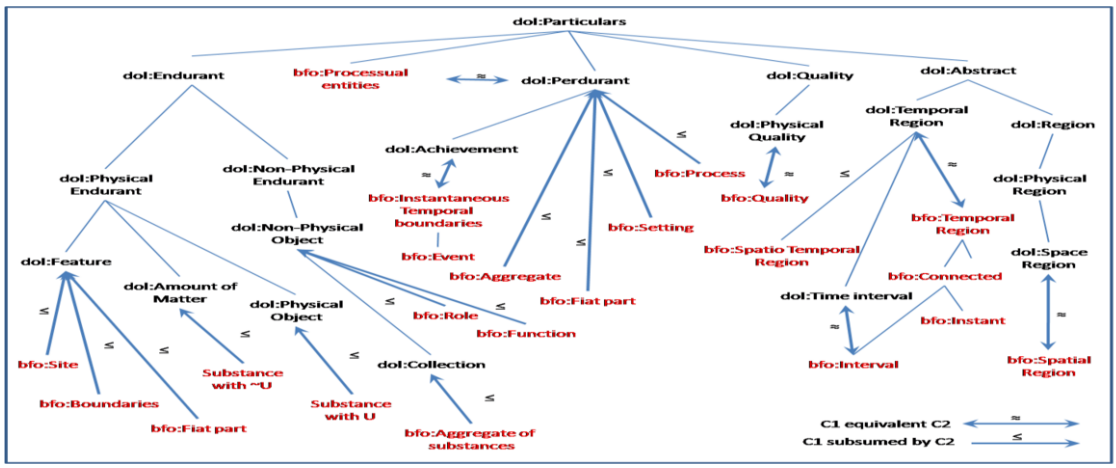

Figure 4- Mapping BFO to DOLCE

DOLCE distinctions, we subdivided `bfo: Substances` into two categories: `Substances with ±U` *subsumed by* `dol:Physical objects` and `Substances with ~U` *subsumed by* `dol:Amount of matter`.

- Except `bfo:Qualities` all categories subsumed by `bfo:Dependent entities` such as `bfo:Functions`, `bfo:Plans` and `bfo:Roles` are in DOLCE *subsumed by* `dol:Non-physical objects`, which are defined also as dependent entities with no spatial location. Concerning `bfo:Qualities`, because BFO considers only qualities for substantial entities, `bfo:Qualities` *are equivalent to* `dol:Physical qualities`.
- `bfo:Spatial Region` *is equivalent to* `dol:Space region`.

Mapping span entities (see Figure 4):

`bfo:Processual entities` are equivalent to `dol:Perdurants` in DOLCE. Moreover, DOLCE distinguishes `dol:Perdurants` according to three criteria: *cummulativity*, *homeomerousity,* and *atomicity.* However, often designers find these criteria elusive and not very intuitive. Therefore, we suggest that categories subsumed by `bfo:Processual entities` are directly *subsumed by* `dol:Perdurants`.

Actually, we cannot map directly in DOLCE the category `bfo:Processes` which are defined as `bfo:Processual entities` with unity criterion and with a beginning and an ending. Indeed, an entity, which is a kind of `bfo:Processes` may be either a kind of `dol:Process` (e.g. *cardiac rhythm*), or `dol:State` (e.g. *waiting*) or `dol:Accomplishment` (e.g. *scan session*). All of these examples have an unity criterion and have a beginning and an ending, but according to DOLCE *cardiac rhythm* is a `dol:Process` because it is *cumulative* and non *homeomerous*; *waiting* is a `dol:State` because it is *cumulative* and *homeomerous;* and *scan session* is an `dol:Accomplishment` because it is non *cumulative* and non *atomic*. Furthermore, at the same level of granularity, `bfo:Fiat part` of a `dol:Process` is a `dol:Process`, and `bfo:Fiat part` of a `dol:State` is a `dol:State`. However, `bfo:Events` defined in BFO as instantaneous temporal boundaries *are equivalent to* `dol:Achievements`. Because they are instantaneous, they satisfy the atomicity criterion. Otherwise, if designers want to adopt the DOLCE distinctions criteria of `dol:Perdurants`, they must examine the DOLCE criteria for each new subcategories of `dol:Perdurants` which may require to split one category into several categories. `bfo:Temporal region` as a part of *time is equivalent to* `dol:Temporal region` of DOLCE. However, the notion of `bfo:Spatiotemporal region` is not represented in DOLCE but can be easily added as a new specialization of `dol:Region`.

Mapping DOLCE categories to BFO (see Figure 5).

As we did with BFO categories, we now map the DOLCE categories to BFO with respect of BFO philosophical approach. Some categories are mapped without difficulties: such as: *i)* `dol:Feature` (union of `bfo:Sites`, `bfo:Boundaries`, and `bfo:Fiat parts`) *is subsumed by* `bfo:Substantial entities`, *ii)* `dol:Physical objects` and `dol:Amount of matter` *are subsumed by* `bfo:Substances`. *iii)* `dol:Physical qualities` *are equivalent to* `bfo:Qualities`. Although BFO does not accept the notion of `dol:Non-physical objects`, we find that categories such as `bfo:plans`, `bfo:functions`, `bfo:roles` subsumed by `bfo:Snap dependent entities`, *are subsumed by* `dol:Non-physical objects` in DOLCE. Hence, `dol:Non-physical objects` *are subsumed by* `bfo:Snap dependent entities`.

Furthermore, we have to be careful that all subcategories satisfy the constraints. For example, `dol:Collections` can be either collection of `dol:Physical objects` or `dol:Non Physical objects` in DOLCE. Since in BFO, `bfo:`

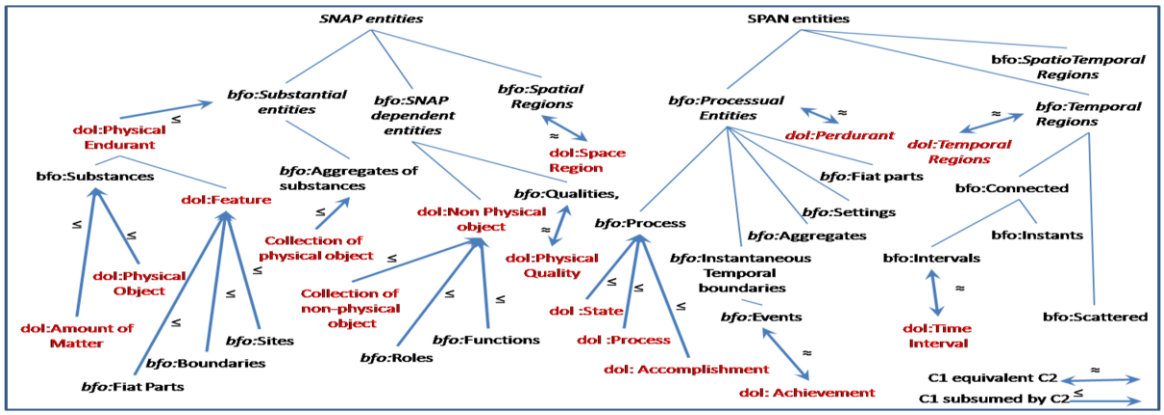

Figure 5-Mapping DOLCE to BFO

`Aggregates of substances` are kind of substantial, we divide collections into `Collections of physical objects` *subsumed by* `bfo:Aggregates of substances`, and `Collection of non physical objects` *subsumed by* `bfo:Snap dependent entities`.

Discussion

Grenon compared informally the main DOLCE and BFO categories. He presented similarities and differences between them, and gave some indications to do the mapping [10]. To our knowledge, no effective mapping between these foundational ontologies has been made available. However, this mapping is a crucial preliminary step to address interoperability issues. In this work, the goal is not to approve a particular model or to discuss philosophical choices, but rather, to give an opportunity to those who chose to use DOLCE (respectively BFO) as a framework, to reuse ontologies designed under BFO (respectively DOLCE). We have developed this mapping with respect to the philosophical approach inherent of foundational ontologies. There are aspects in DOLCE, e.g. qualities for perdurants, that are no recognized in BFO, because of the *realistic* approach of BFO. In fact, it is not yet clear how one can represent notions such as, *duration*, and *heart rate* in BFO. It is then difficult to give a satisfactory mapping for this kind of entities. This work proposed a mapping between the DOLCE and BFO upper-level ontologies, where their respective *realistic* and *cognitive* could be reconciled. We have developed and evaluated the mappings in the AKENATON project. The expected outcome is to support future mappings between a domain ontology based on DOLCE and another one based on BFO in other biomedical projects.

Acknowledgments

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