Permanent Generic Relatedness and Silent Change

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Abstract. Given the assertion of a relation between two types, like: "*Epidermis* **has_part** `some` *Keratinocyte*", we define *silent* change as any kind of change of the instance-relata of the relation in question that does not change the truth-value of the respective type-level assertion. Such assertions are notoriously difficult to model in OWL 2. To address this problem, we distinguish different modes of type-level relatedness giving rise to this problem and describe a conservative extension to the BFO top-level ontology that allows expressing these modes.

Keywords. Description Logics, OWL 2, Basic Formal Ontology, Ontology Design Patterns, Processes, Change

1. Introduction

Like many assertions about biological reality, *Human skin tissue contains keratinocytes* appears to be static if stated at the type level. Once translated to the instance level, however, it becomes clear that such assertions may be true in spite of constant change in the relata: skin tissue is made up of different cells at different times. The type-level assertions are *silent* about the changes at the instance level. Such assertions are notoriously difficult to model in OWL 2. *Prima facie*, the following expression seems to convey the intended fact:

SkinTissue `SubclassOf` **has_part** `some` *Keratinocyte* (1)

But given the first-order semantics of OWL 2, **has_part** is just a set of tuples $\langle x, y \rangle$. This means that two individuals, skin s_1 and cell c_1, are all that is required to make this assertion true, where nothing needs to be said about the respective lifetimes of s_1 and c_1. Thus c_1 might have been a part of s_1 for the whole life of s_1 or just for one brief interval.

To counter this problem, the Graz release of the BFO [1] top-level ontology introduced the object property **has_continuant_part_at_some_time** and its subrelation **has_continuant_part_at_all_times**. Unfortunately, neither of these object properties can be used to represent silent change. The at-some-time version is too weak to convey the intended meaning because it only asserts that a cell is *temporarily* part of the skin (i.e. there could be a time where the skin has no cells), and the at-all-times version is too

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strong since it implies that there is a *specific* cell that is permanently part of the skin over its entire lifetime. In contrast we require cells of a certain type to be part of skin tissue *generically* – which means that different individual cells can perform this service provided only that some cell of the appropriate type is present at all times. Hence our talk of "silent change".

The objective of this paper is the presentation and discussion of a new OWL design pattern that allows expression of this missing case of dynamicity that allows silent change to be expressed in a OWL 2 compliant, BFO 2-based ontology, but could have much wider application.

2. Background

2.1. Basic Formal Ontology (BFO)

The uppermost partition in the BFO hierarchy reflects two distinct modes of existence in time: *Continuants* are entities that (1) exist in full at any time that they exists at all, and (2) continue to exist self-identically for as long as they exist; *occurrents* are entities that unfold over a period of time and thus have temporal parts. For example, a cell is a continuant, while the process of cell division is an occurrent. Continuants may change while preserving their identity.

BFO thus accepts both the 3D and a 4D view of the world as valid ontological perspectives. A crucial binding link between these two viewpoints is the **history_of** relation, which establishes a one-to-one relationship between a material entity and a special process called its *history*, defined as "a process that is the sum of the totality of processes taking place in the spatiotemporal region occupied by a material entity or site, including processes on the surface of the entity or within the cavities to which it serves as host"[2].

So while a cell, as a continuant, is a three-dimensional entity that cannot have temporal parts, its corresponding history can be broken up into distinct temporal parts such as prophase, metaphase, anaphase, and so on.

2.2. Representing temporal information in OWL

One conventional strategy for representing time-sensitive relations is to use explicit time-indexes to specify the time interval over which a relational assertion is valid, and then quantify over the time interval. In first order logic, this could be expressed as:

$$\forall x,t \ \left(\left(\mathit{SkinTissue}(x) \land \textbf{exists\_at}(x,t) \right) \rightarrow \exists y \ \left(\mathit{Keratinocyte}(y) \land \textbf{has\_part\_at}(x,y,t) \right) \right) \tag{2}$$

This approach is not available in OWL 2 due to the restriction to binary predicates, so to achieve something similar one needs to resort to *reification*, i.e. representing relational assertions as explicit individuals in the domain [3]. Examples of such approaches include the strictly four-dimensionalist approach of Welty and Fikes [4] or that of Zamborlini and Guizzardi [5], who essentially duplicate representing the very same entities both in a 3D- and a 4D-view. Neither of these approaches is compatible with the stance taken by BFO.

3. Methods

3.1. Phases and Temporally Qualified Continuants (TQCs)

To be able to model the cases of permanent generic relatedness and thus to allow for the phenomenon of silent change, we want to build on the BFO concept of histories. It is easy and useful to talk about specific temporal parts of a continuant's history, for example, "Socrates' youth", or "the mosquito stage of this *Plasmodium*'s life-cycle". These parts still share many traits of the history, because they are also comprised of a sum of processes. That process sum corresponds to the totality of all processes taking place in a specific spatiotemporal region and also pertains to a single entity.

We can call these restricted parts of histories *phases* of the corresponding history. Phases of histories are not themselves histories, since a history is defined in such a way that each history is the history of some single continuant. If, then, h is the history of the continuant c, and p is an occurrent part of h, it follows that p cannot also be a history since there is no continuant available to serve as that which it would be the history of, because continuants cannot have temporal parts. Given p, however, as a phase of history h, we can postulate what we call a *temporally qualified continuant* (TQC) of c [6], onto which p projects in the same way as the history h projects onto the continuant c. Two readings of the talk of TQCs are then available: on the one side we can talk of TQCs merely as a *façon de parler* – a way of talking about (a practically useful model of) other things with no ontological commitment; on the other side we can treat TQCs as full-fledged entities. In this paper we remain neutral as between these options.

In analogy to the **history_of** relation between histories and material objects, we introduce another relation, **phase_of**, where **history_of** becomes a subrelation of **phase_of**. This means that for each TQC there is a one-to-one relation to a unique phase.

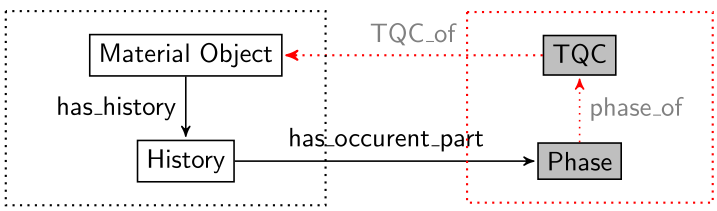

Figure 1. The TQ Entity Square

The relationship between phases and TQCs thus matches that of histories and material objects. Additionally, all histories are phases (of maximal extent) and all continuants are (or can be modelled as) TQCs of maximal extent.

3.2. TQC Modelling Patterns

Our modelling pattern can be applied to relations that have material objects as their domain. The general strategy is to always use the at-all-times version of the relation in question, adding the mechanism of phases and TQCs where necessary. One case of *permanent specific relatedness* would be that the brain is always part of the same individual:

Brain SubclassOf **continuant_part_of_at_all_times** some *Human* (3)

Temporary relatedness will be achieved by asserting that the first continuant relatum, has a sub-phase which maps onto a TQC that is at all times related to the second relatum. For example, teeth may temporarily be part of some animal:

Tooth SubclassOf **has_phase** some **has_occurrent_part** some **phase_of**
some **continuant_part_of_at_all_times** some *Animal* (4)

Permanent generic relatedness is our target case of type-level silent change, and it requires more complex modelling. Here the TQC for every occurrent part of the history of the continuant can either be related to a single entity using an "at all times" relation, or the phase can exclusively be broken down further into sub-phases which fulfil this property. Since this requires a recursive definition that refers to itself, we need to define a helper class (*HasKeratinocytePartPhase*) in (5), and use it in the final axiom (6):

HasKeratinocytePartPhase EquivalentTo((**has_proper_occurrent_part** some
HasKeratinocytePartPhase) and (**has_proper_occurrent_part** only
HasKeratinocytePartPhase))
or **phase_of** some (**has_continuant_part_at_all_times** some *Keratinocyte*) (5)

SkinTissue SubclassOf **has_phase** some *HasKeratinocytePartPhase* (6)

These patterns correctly capture the BFO design that continuant-continuant (or continuant-occurrent) relations have 3D entities as their subjects and transfer the distinction of the different temporal strengths to the relation between temporal parts and wholes. Consequentially, the usual challenges and restrictions of implementing mereotopological relations correctly in OWL 2 still apply. For example, due to the restrictions on the axiom closure in OWL 2, **has_ocurrent_part** cannot be defined as reflexive in BFO 2, loosing some expected inferences along the way.

3.3. Usability Optimisation using Tawny OWL

Since the pattern for the permanent generic case is quite complex, it seemed important to look at ways to improve usability. To this end, we used Tawny OWL [7], a library written in Clojure (a Lisp dialect targeting the Java Virtual Machine). It provides an internal domain specific language for describing OWL 2 ontologies. That means that it is possible to use general programming constructs (functions, loops, conditionals) to construct ontology descriptions. This allows the implementation of macros which capture the modeller's intent and automatically generate the required helper classes and TQC-related sub-expressions, reformulating (5) and (6) as:

```
(o/owl-class "Skin" :super (c/perm-gen "HasKeratinocytePartPhase"
    (o/owl-some b/has_continuant_part_at_all_times "Keratinocyte")))
```

4. Results

We implemented 13 test scenarios covering different cases from different categories in order to be able to pose competency questions challenging various aspects of the scheme. The test matrix combined material entities, processes and immaterial entities as the subjects of the assertions with all three temporal strengths.

We found that apart from the phase/TQC classes and relations BFO 2 was only lacking an axiom stating that all material entities have histories. Validation of the test cases was successful with one exception: Since BFO restricts histories to apply to material entities, it was impossible to model, for example, an electronic health record that gets moved between different physical storage media. The competency questions are implemented as Clojure unit tests in the ontology source available from `http://nie.gr/tqc/`.

5. Conclusions

With minimal interference in the set of axioms provided by BFO 2, we were able to provide modelling patterns that account for silent change throughout the lifetime of a continuant without forcing the user to adopt a flat-out four-dimensionalism, which is far removed from the everyday talk of life-scientists. But while these patterns succeed in enabling the required task, they introduce considerable complexity. Using Tawny OWL mitigates this partially through expressive macros and at the same time enables a more agile write→test→refactor→deploy ontology development methodology.

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