Improving Model Quality through Foundational Ontologies: Two Contrasting Approaches to the Representation of Roles

Sergio de Cesare[1], Brian Henderson-Sellers[2], Chris Partridge[1,3], Mark Lycett[1]

[1] Brunel University London, U.K.
{sergio.decesare, chris.partridge, mark.lycett }@brunel.ac.uk
[2] School of Software, University of Technology Sydney, Australia
brian.henderson-sellers@uts.edu.au
[3] BORO Solution Ltd., London, U.K.
partridgec@borogroup.co.uk

Abstract. Several foundational ontologies have been developed recently. We examine two of these from the point of view of their quality in representing temporal changes, focusing on the example of roles. We discuss how these are modelled in two foundational ontologies: the Unified Foundational Ontology and the BORO foundational ontology. These exhibit two different approaches, endurantist and perdurantist respectively. We illustrate the differences using a running example in the university student domain, wherein one individual is not only a registered student but also, for part of this period, was elected the President of the Student Union. The metaphysical choices made by UFO and BORO lead to different representations of roles. Two key differences which affect the way roles are modelled are exemplified in this paper: (1) different criteria of identity and (2) differences in the way individual objects extend over time and possible worlds. These differences impact upon the quality of the models produced in terms of their respective explanatory power. The UFO model concentrates on the notion of validity in "all possible worlds" and is unable to accurately represent the way particulars are extended in time. The perdurantist approach is best able to describe temporal changes wherein roles are spatio-temporal extents of individuals.

Keywords: 3D and 4D ontologies, metaphysical choices, endurantism, perdurantism, presentism, eternalism, foundational ontology, representation of temporality, roles, BORO, UFO.

1 Introduction

Traditional conceptual and design modelling, especially that using the object-oriented approach, uses class icons to represent classes of things in the real world. These include general types of things, such as roles, which repeatedly appear in models. For example, there will be many models with a class icon for the role Student. However, there is little infrastructure to support these general types of thing. In this paper, we focus on one example, the modelling of roles, which will illustrate the modelling of modality (how individual objects can possibly differ) and temporality (how individuals can change over time).

Foundational ontologies, which provide a complete list of the most general kinds of things, can provide this infrastructure. One way of characterising the foundational structures is metaphysical choices, and two choices that are relevant to modelling roles are the endurantist-perdurantist choice and the closely associated presentist-eternalist choice [1]. We also consider the 'modally extended versus unextended individuals' choice [1]. These choices have an impact on another important choice – what identity criteria there are.

The endurantist-perdurantist choice dictates whether, and how, particulars (individual things) are temporally extended. In endurantism (or 3D) an individual thing (e.g., John Smith) endures through time and is regarded as totally present at any moment in its lifetime. In perdurantism (or 4D) an individual thing perdures through time and is extended in time, and so can be said to be only partially present at any moment in time (e.g., the whole of *John Smith* extends over time from his birth to his death). The 'modally extended versus unextended individuals' choice considers, as the name suggests, whether and how they are extended across many possible worlds. We also look at spatial extension. The presentist-eternalist choice dictates whether and how objects exist in different ways in the past, present and future. The choice of identity criteria determines how one decides whether one is modelling one or more objects (for example, whether '*John as a child*' is the same object as '*John as an adult*'). Many modelling approaches, including UML, take no account of these (and the other) choices – and hence allow models that mix the choices in arbitrary and unstructured ways, with a detrimental effect on quality.

The paper examines two foundational ontologies that have made different clear choices and so mandate a particular way of modelling roles, in particular, and modality and temporality, in general. This provides two contrasting examples on how a foundational approach can raise the quality of role modelling.

UFO-A makes an endurantist choice [2], in which particulars are 'individual concepts' that are regarded as outside space, time and modality. These are then related to snapshots that are temporally and modally unextended – though they are spatially extended. To clarify, the snapshot is world-bound (i.e. in a particular world at a particular point in time). In contrast, a perdurantist approach such as BORO considers all particulars as having a temporal as well as a spatial extent, often referred to as 4D (e.g. [3, 4, 5, 6]).

Both ontologies make an eternalist choice - adopting what McTaggert [7] calls the Series B view of time. This choice is noted to give context to the frameworks. As the two ontologies make the same choice, there is nothing to compare.

In modelling domains with no infrastructure for change over time, one particular contentious kind of entity is the role or roletype; this is intended to capture where a particular temporarily acquires one or more characteristics and may later shed them.

There are two broad choices, illustrated by the two sample ontologies, of an entity that might be regarded as a rigid basekind in an endurantist ontology. In traditional approaches, like UML, roles are essentially labels attached to a class representation – either as an end of association label (UML), as a class that is a specialization (in the OO sense) of a basekind (using UFO terminology) or as a class linked to a basekind with an association (e.g. [8]). Detailed discussions of various means of doing this are to be found in, for instance, [9, 10, 11, 2].

These choices are intimately related to the identity criteria issue [8]. This can be illustrated by considering the identity of collections. If one regards, for example, being a person as belonging to the collection of persons and being a student as the person belonging to the collection of students then, as in Fig. 1, the collections change over time. So in this approach, the membership of a collection is not fixed and so cannot simply be its identity criteria.

A different approach would be to regard being a person as belonging to the collection of persons and being a student as belonging to the collection of students – where student is a state of a person – a different object from the person. In this approach the collections are more like sets, and the identity criteria of the collection-set can be its members.

The two sample ontologies illustrate these choices. UFO takes the first approach where the person is a student. BORO takes the second approach, where a person has a (different) student state – and hence can adopt an extensional criterion of identity.

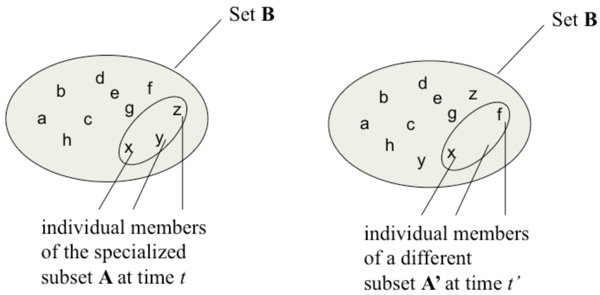

Fig. 1. Temporal changes in set members requires the creation of a new set (after [12])

Both endurantist and perdurantist approaches are arguably successful and acceptable philosophically. Some authors claim to need the adoption of one of these two approaches to the exclusion of the other, whilst other authors show more equanimity by accepting that the choice of approach depends upon the problem to be solved. Here, we discuss and compare two different ontological approaches: one predominantly endurantist (UFO) and one perdurantist (BORO).

In Section 2, we provide a brief overview of these ontological approaches. In Section 3, we describe a problem that is frequently encountered in information systems design and, in Section 4, apply each of the ontological approaches in turn to this problem. Our conclusions are then presented in Section 5.

2 Overview of the Two Foundational Ontologies

2.1 The Unified Foundational Ontology

The Unified Foundational Ontology (UFO) [2] has a number of parts, labelled UFO-A, UFO-B and UFO-C. We focus on UFO-A as it contains a class roles – though UFO has other types of roles. UFO-A is a 3D or endurantist foundational ontology. UFO-B contains perdurantist aspects mostly targeted at agent-oriented modelling; whilst UFO-C takes a first step towards a socially-focussed foundational ontology. UFO-A is depicted in Fig. 2, which shows the Kind and Role classes used to characterise roles.

Each of these classes in UFO represents some ontological aspect and leads to a particular commitment within a modelling approach. In particular, it means that we could have in our domain model classes such as Person:Kind, Student:Role and StudentPresident:Role.

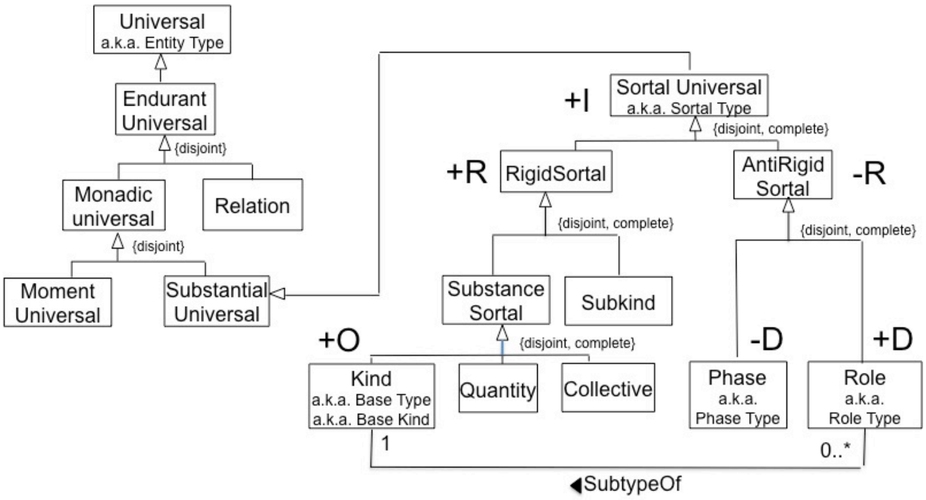

Fig. 2. The UFO-A hierarchy of Universals, focussing on the subtypes of Endurant Universal (adapted from diagrams in [2]) where I, R, D and O refer to the metaproperties (as defined in [13]) of identity condition, rigidity, external dependency and identity provision

In UFO, Kind and Role classes obtain identity criteria in different ways. Instances of Kind supply identity. Role types (instances of RoleType) carry identity and not supply it [2], they obtain their identity from Kinds. In UFO a Student obtains identity, by specializing a base kind such as Person. We take this model as most representative of UFO as practised [2, 11]. This is the representation that will be examined in the case of our exemplar in Section 4.

2.3 BORO

BORO [3] is an extensionalist 4D foundational ontology, which has been used extensively for software applications [14, 15]. The relevant subset (for the example) is visualised in Fig. 3 using UML.

The top object within the BORO foundational ontology is Object (a.k.a. Thing), which has everything that exists as instances. The ontology has three major ontological categories: Element, Type and Tuple. Every object belongs to one and only one of the three categories, which have their own identity criteria. For example, an element is a particular/physical entity whose identity is given by its spatio-temporal extent. A type is a collection (set) of objects (playing a similar role to universals). A type can collect any type of object (in other words, objects of any of the three categories). Tuples relate objects. For the example, the key relationship is *temporalWholePart*; this relates an individual with its temporal parts (states and/or events).

3 Exemplar Problem

An exemplar problem is here defined in order to illustrate how the foundational ontologies described in Section 2 represent roles, and so temporality and modality.

Temporality and modality are intrinsic to the modelling of any real world phenomenon and this study focuses on roles as an exemplar since (1) the temporal and modal dimensions are quite clearly evident and (2) the representations of roles in the chosen foundational ontologies are different due to the metaphysical choices that these ontologies make.

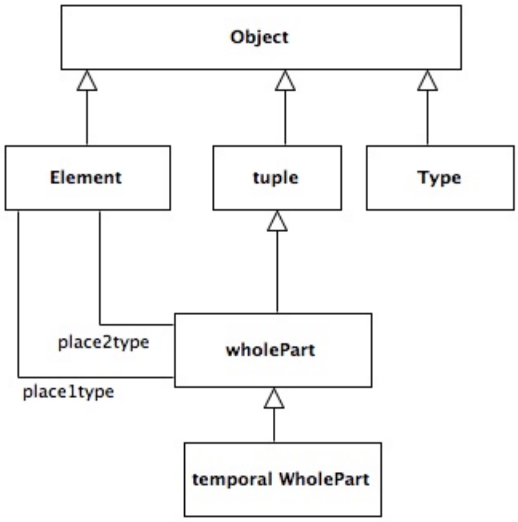

Fig. 3. BORO foundational ontology (partial view).

Role, as defined by the Oxford Advanced Learner Dictionary, is "the function assumed or part played by a person or thing in a particular situation". Examples include president, student, employee, patient, parent, spouse and so on. A role normally initiates with a specific event and terminates with another event. These events can occur on the basis of laws (e.g., election of members of Parliament), agreements (e.g., contract of employment) or natural events (e.g., the birth of a child). Roles can even be played by non-humans, for example a software system responsible for carrying out a specific task in a business process (e.g., a credit scoring system). Moreover, a person or a thing can play several roles at once (e.g., mother, employee and student).

The exemplar problem has been defined to focus on the key characteristics of roles and is described as follows:

"*John enrols as a university student in Chemistry and graduates three years later. He is elected President of the Students Union (PSU) during his degree serving for one year*."

The following section will present models of this exemplar problem with the chosen foundational ontologies, identifying their strengths and weaknesses.

4 Problem Analysis

4.1 Representation of the Student Role

4.1.1 UFO

Utilizing the UFO, as an underpinning foundational ontology to model the problem statement of Section 3, results in the model described in Fig. 4. In UFO, roles are modelled as subtypes of an instance of Kind. In this problem, both Student and the PSU (President of the Student Union) are role types. These roles obtain their identity from Person – the base kind in this model. Initially we focus on Student, which is represented in Fig. 4.

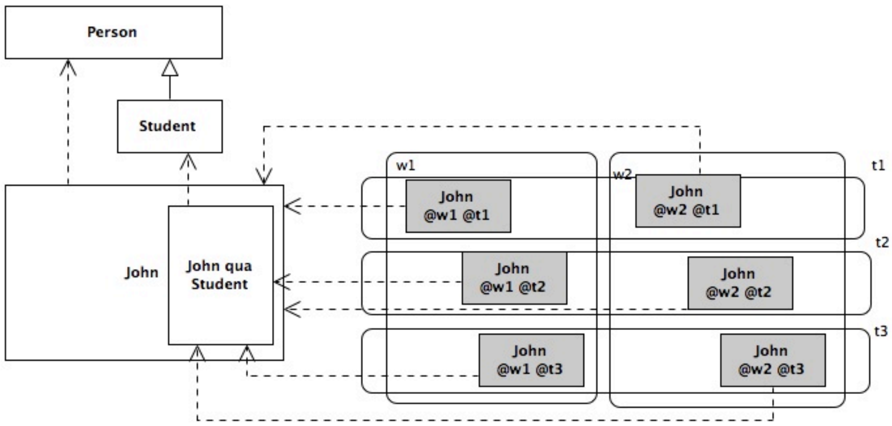

Fig. 4. . Representation of the problem statement according to UFO (Legend: @w_1 means 'at possible world 1'; @t_1 means 'at time t_1'

In the fragment of the example shown in Fig. 4, John is an individual that obtains its identity by virtue of being an instance of the base kind Person. He also is an instance of the role Student – note that as discussed in Section 1, the same thing is both a person and a student. The way in which these differ is that John is always an instance of Person, but only an instance of Student at some times in some worlds – because it is possible that John was never a student, and even in worlds where he was a student, there will be some times where he was not a student. For any world and time, one can ask and so determine whether John is a student [2] (p.276) – another way of expressing this is that there are some world-bound time-slices of John that are snapshot instances of John qua Student, and others that are not. We have tried to illustrate this in Fig. 6 above by having a 'John qua Student' box inside the 'John' box. This is not intended to imply that there are two entities – John and John qua Student – but to have an owner for the snapshot instantiations of John qua Student.

To illustrate how this works, consider how one would determine the duration of the John's studentship. One would first have to fix a world (as the duration could be completely different in different possible worlds – in one world he could be student early in life in another late in life). Then, within that world, one would determine the times when John was a student, and the lower and upper bounds of the times would give the duration.

As UFO makes an eternalist choice, there is no distinction made between the past, present and future 'versions' of John and John qua Student. As it makes an endurantist choice, John is not temporally extended. In this approach, it makes no sense to ask about the temporal extent of John, nor about the modal and spatial extents. The question makes more sense for the world-bound snapshot timeslices. These have a spatial extent, but no temporal or modal extent. One result of this is that there is only one entity John; there is no separate John qua Student entity. Hence, John can inherit identity criteria from Person; and John qua Student, as the same entity, has the same identity criteria.

4.1.3 BORO

In BORO elements are spatio-temporal extents; roles are (types of) temporal parts of elements – often called states.

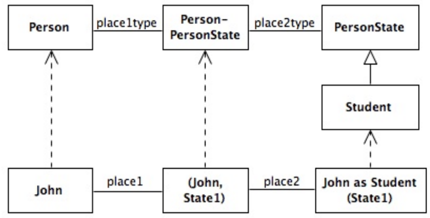

Fig. 5a. Representation of the problem statement using BORO

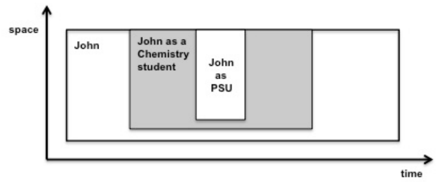

Fig. 5b. Example space-time map showing the role student and additional PSU subrole

Fig. 5a exemplifies this for John. Here Student is a subtype of PersonState and Person is related to PersonState. John is an instance of Person and there is a state (temporal stage) of John that is an instance of Student.

Since BORO elements are extended in space and time, they can be visualised in a space-time map, where each element's spatial extent is depicted on the x-axis and temporal extent on the y-axis. Fig. 5b provides an example based on our scenario. As the space-time map makes clear, the duration of John's studentship is determined by the temporal boundaries of John's Student state.

As BORO (like UFO) makes an eternalist choice, there is no distinction made between the past, present and future 'versions' of John or of the Student state. As it makes a perdurantist choice, John is temporally extended, as well as spatially extended. John is not modally extended, but world-bound to a particular possible world. In BORO modality is handled through a counterpart relation.

Note that as discussed in Section 1, in BORO, there are two entities, John and John's Student state. This enables the use of spatio-temporal extents as identity criteria.

4.2 Subroles versus Subtypes

The metaphysical choices described above also lead to less obvious differences in the ways which roles are modelled. This can be illustrated with the second part of the example, in which John is President of the Student Union (or PSU Occupation). In this example, only a person who is a student can be elected as PSU. It is a case of a role of roles. The following subsections compare UFO and BORO. The former considers PSU Occupation as a subtype of the Student role, whereas the latter represents it as a subrole (with temporal whole-parts). In both examples, PSU Occupation is compared to the role of being a Chemistry Student, where Chemistry Student is a sub-type (rather than sub-role) of Student. What is at issue here, is that (as far as the example is concerned), if one is a Chemistry Student, then one is always a Chemistry Student when one is a student. However, while one is a Student one can sometime be a PSU and sometimes not.

4.2.1 UFO

Fig. 6a is the UFO representation of PSU Occupation and Chemistry Student. Both roles are subtypes of Student and, like Student, they are anti-rigid sortals whose principle of identity is inherited from the base kind Person. The subtyping of a rigid sortal by an anti-rigid sortal is permitted in UFO but not when adhering to the OCL constraints specified in the UML. Furthermore, as seen in Fig. 6.a, the introduction of a (true) subtype of Student, say ChemistryStudent, utilizes the same subsumption notation – but (presumably) with different semantics to that of the PSU-Student relationship.

Architecturally, this is because the qua mechanism is between rigid and anti-rigid classes, and so an anti-rigid class cannot be, so to speak, anti-anti-rigid (or a quaQuaIndividual. A different mechanism is needed.

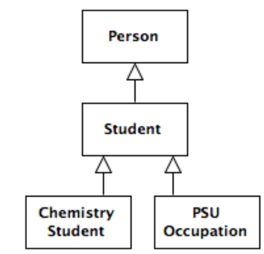

Fig. 6a. Modelling PSU and ChemistryStudent in UFO

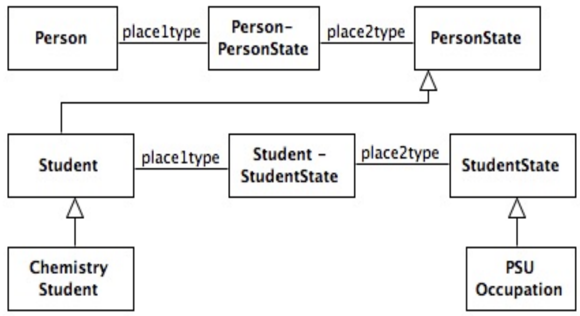

Fig. 6b. Modelling PSU and ChemistryStudent in in BORO

4.2.2 BORO

Fig. 6.b is the BORO representation of PSU Occupation and Chemistry Student. These two roles are not modelled in the same way. Since individual objects (elements) are spatio-temporally extended in BORO, we must consider the extension of the elements that instantiate the type. In fact, as Fig. 5b illustrates, John-as-PSU is spatio-temporally contained within John as a Chemistry Student (see also Fig. 5b). John as a Student and John as a Chemistry Student are the same extent since John is a Chemistry student during his whole studentship. Hence, while the type ChemistryStudent is a subtype of Student, since all instances of the former are always instances of the latter, PSUOccupation is a subtype of StudentState and related to Student via a whole-part relation. Therefore PSUOccupation is modelled as a subrole of the role Student. BORO can take advantage of the different types of relation (sub-type and temporal part) to characterise the difference between sub-types and sub-roles of roles.

4.3 Comparative Analysis

BORO’s and UFO's choices lead to quite a different account of what entities exist. If one applies that basic ontological test of counting and comparing entities, one gets very different answers. In UFO there is just John (who is identical to John qua

Student and John qua PSU), in BORO there are three elements with their own identity (spatio-temporal extents) John, John's Student state and John as PSU.

In UFO, the instance of Person and Student is the same object - John – across all possible worlds in which John exists. John, his studentships and his presidencies in this world and across possible worlds and times are characterised through the use of world- and time-bounded snapshots. Given there are an infinite number of worlds and times to play with, there are an infinite number of snapshots.

In BORO John, his studentships and his presidencies are all distinct objects. They have counterparts in other possible worlds. As there are an infinite number of possible worlds (as noted above), there are an infinite number of counterparts.

UFO builds upon the intuition that a student is a way of being rather than a different thing – so John qua Student is John being a Student. BORO builds upon the intuition that the same thing cannot be different at different times, and so John's student stage is not exactly the same as John, but a temporal-part. One can start to see a connection between these two positions if you regard Armstrong's view [16] that parthood is partial identity (and temporal parthood a strong form of partial identity. So the states of John are partially, but not completely identical to John.

However, as illustrated in the second part of the example, UFO's architectural choices make it less easy to characterise sub-roles (roles of roles). Moreover the explanatory power of BORO is enhanced by the temporal whole-part relationships that underpin its mereology. As shown in Section 4.2.2, roles of roles are modelled simply by adopting the whole-part pattern of the foundational ontology. In UFO, since PSUOccupation is merely modelled as a subtype of Student, then the representation lacks in being able to show that being a PSU is the state of a student and not a student.

This analysis is not aimed at establishing the superiority of one approach over the other, but instead the superiority of making explicit the meta-ontological choices made. If this is done, then it is possible for conceptual modellers to create more understandable models and better quality modelling languages because there is an agreed common grounding which modellers can refer to. As a consequence, conceptual models are more self-explanatory, hence higher quality. Where the meta-ontological choices are known, then the model is capable of expressing much more of its own semantics to the reader, without recourse to the authors.

5 Summary and Conclusions

We have examined the way in which two foundational ontologies improve the model quality by providing a general architectural infrastructure for roles. We have characterised the architectures in terms of key metaphysical choices [17]. We used an illustrative example, to show how roles are modelled in quite different ways in the Unified Foundational Ontology (endurantist) and the BORO foundational ontology (perdurantist). Our running example is in the university student domain, wherein one individual is not only a registered student but also, for part of this period, the President of the Student Union. By examining the PSU role, we have shown how quite subtle differences can emerge between the choices by looking at how both ontologies handle the requirement for a role of a role. Given the need for conceptual modelling to improve its quality with more general infrastructure for things such as roles, hopefully this paper has raised awareness of the need to architect this infrastructure using, for example, metaphysical choices and to be aware of the consequences of these choices. As an aside, where there is no architecting, these choices are still being made, but in a heterogeneous and random way, so there is no management of the consequences of the choices and a consequent reduction in quality.

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