A Comparative Illustration of Foundational Ontologies: BORO and UFO

Michael VERDONCK[1], Tiago Prince SALES[2] and Frederik GAILLY[1]
[1]Ghent University, Belgium; [2]University of Trento, Italy

Abstract. This paper investigates the differences that exist between a 3D and a 4D ontology. We examine these differences by comparing both ontologies through the metaphysical choices each ontology makes and explore the composing characteristics that define them. More specifically, the differences between the ontologies were illustrated through several modeling fragments that were derived from a modeling case presented at the 5th OntoCom workshop. Each of these modeling fragments focused on the metaphysical choices that the ontologies make – Essence and Identity, Relationships and Time. These comparisons highlighted the different ontological approaches and structures that exist between the ontologies. Moreover, depending on the ontology, the resulting conceptual model could differ substantially, confirming the impact and importance of the choice of a certain ontology. The observed differences between both ontologies eventually led us to formulate three discussion points that question the applicability of certain metaphysical choices in certain circumstances, and that can serve as a basis for future discussion or future research studies in the domain of ODCM.

Keywords. Foundational ontologies, metaphysical choices, 3D ontology, 4D ontology

1. Introduction

Ontology can be broadly defined as "the set of things whose existence is acknowledged by a particular theory or system of thought" [1]. Research on ontologies has become increasingly widespread in the computer science community, gaining importance in research fields such as Knowledge Engineering, Knowledge Representation and Information Modeling [2]. More specifically in the field of Conceptual Modeling, ontologies provide a foundational theory that articulates and formalizes the conceptual modeling grammars needed to describe the structure and behavior of the modeled domain [3]. As defined by [4], conceptual modeling is the activity of representing aspects of the physical and social world for the purpose of communication, learning and problem solving among human users. The ontological foundation in conceptual modeling manifests itself by means of a formal specification of the semantics of models and describe precisely which modeling constructs represent which phenomena. In this paper we shall refer to all techniques where ontological theories are applied – e.g. evaluation, analysis or theoretical foundation – to improve either the quality of the conceptual modeling process or the quality of the conceptual model, as ontology-driven conceptual modeling (ODCM).

Based upon their level of dependence of a particular task or point of view, different types of ontologies can be distinguished and applied in ODCM [5]. In this article

however, we will focus solely on foundational ontologies. Different kinds of foundational ontologies can be adopted in order to perform ODCM. For instance, based upon the endurantism-perdurantism paradigm, we can differentiate between 3D and 4D ontologies. *3D ontologies* view individual objects as three-dimensional, having only spatial parts, and wholly exist at each moment of their existence. *4D ontologies* on the other hand see individual objects as four-dimensional, having spatial and temporal parts, and existing immutably in space-time [6]. While most research in ODCM has been performed with 3D ontologies [7], 4D ontologies have gained more popularity in recent years [8]–[10]. Several studies [9], [11] have already demonstrated that applying different ontologies can lead to diverse kinds of conceptualizations. Furthermore, the application of a certain ontology can ultimately even influence the model comprehension of the resulting ontology-driven models on its users [12].

In order to further explore and discover the differences between adopting different kinds of foundational ontologies, the 5th International Workshop on Ontologies and Conceptual Modeling (OntoCom) dedicated their full program on this topic at the 36th International Conference on Conceptual Modeling. Leading ontologists and conceptual modelers were invited to discuss and analyze the differences between 3D and 4D foundational ontologies. More specifically, the workshop provided a written modeling case to which participants of the workshop were invited to develop an ontology-driven conceptual model that faithfully represents the case according to the rules and constraints of either the 3D or 4D ontology.

This paper builds further upon this workshop by comparing the differences between the models that were composed during this workshop using both 3D and 4D ontologies. By comparing these models, we aim to highlight the different ontological approaches and structures that exist between their underlying ontologies. Moreover, we will compare these ontologies by emphasizing their ontological commitments and exploring their main characteristics. More specifically, we will focus on the ontological differences that exist between the BORO ontology [13] and the Unified Foundational Ontology (UFO) [14]. By comparing these ontologies, we seek to clarify and determine the differences that arise in the resulting conceptual models when applying a 3D or 4D ontology. We would like to remark that the purpose of this article is not to determine the superiority of a particular ontology over another, but to simply increase awareness and transparency in applying different types of ontologies.

In section 2 we will briefly discuss the UFO and BORO ontology. Section 3 will then compare these ontologies through the metaphysical choices they make and illustrate the differences of these choices with certain modeling fragments from the OntoCom modeling case. In section 4, we will discuss the impact of these metaphysical choices, and also compose several questions that arose from the comparison and which can serve as the basis for future research. Finally, in section 5 we summarize the findings of this paper.

2. The BORO and UFO ontologies

During the OntoCom workshop, two foundational ontologies – i.e. BORO and UFO – were emphasized and applied for the development of the ontology-driven conceptual models based upon the modeling case. Comparing these two ontologies makes sense since they are built upon completely different paradigms – i.e. BORO is a 4D ontology while UFO is a 3D ontology. Since they adopt different interpretations on real-world

phenomena, it makes them quite interesting to compare. Moreover, they were also developed to fulfil entirely different purposes. On the one hand, UFO was developed to provide sound ontological foundations for various domains (domain appropriateness) and conceptual clarity (comprehensibility appropriateness) of modeling languages [15]. BORO on the other hand, was designed to support information systems re-engineering and integration in a transparent and straightforward manner [13].

BORO distinguishes three main categories [16]: Elements, Types, and tuples. Every object belongs to one of these categories. *Elements* are individual objects whose identity is given by the element's spatiotemporal extent i.e. the space and time it occupies. An example of an element would be the person John. *Types* are collections of any type of object (in other words, objects of any of the three categories). The identity of a type is determined by its extension, the collection of its instances or members. For example, the extension of the type Persons is the set of all people. Finally, *Tuples* are relations between objects. The identity of a tuple is defined by the places in the tuple. An example is (Mary, John) in which the elements Mary and John occupy places 1 and 2 in the tuple, respectively. Tuples can be collected into types, called tuple types. An example is parentOf, which is the collection of all relations between parents and their children.

UFO is a much more complex ontology, being composed of three core modules, namely UFO-A, an ontology of endurants (objects) [14]; UFO-B, an ontology of perdurants (events) [17]; and UFO-C and ontology of social entities that specializes the former two [18]. UFO's most fundamental distinction is between individuals and universals. *Universals* are abstract patterns of features that can be realized in a number of different *individuals*. In UFO, the identity of universals is separated from their extensions, allowing, for instance, that the extension of a universal changes through time, as well as that two universals have the same extension at a given moment.

A second fundamental distinction in UFO is that between endurants and perdurants. *Endurants* are individuals that are wholly present whenever they are present (e.g a ball, a person), whilst *perdurants* are individuals extended in time, through which they accumulate temporal parts (e.g. a football match, a party). UFO further categories endurants into substantials and moments. *Substantials* are existentially-independent endurants (e.g., an animal, a table), whilst *moments* are individuals that necessarily inhere in others, their bearers, to which they are existentially-dependent on (e.g., the color of an object, the weight of a person). In UFO, endurants can be characterized by both essential and contingent properties, which means that they can genuinely change while keeping their identity [14]. For instance, being a mammal is an essential property for dogs, whilst being overweight is a contingent one. Thus, no dog can change in such a way that it ceases to be a mammal, whilst any dog can change its weight and remain the same individual. Perdurants, conversely, are exclusively characterized by essential properties, thus they cannot genuinely change) [17].

Perhaps the main differentiation between both ontologies arrives through the different underlying paradigms on which they define and classify concepts and phenomena. While the UFO ontology adopts an endurantist approach (3D), the BORO ontology corresponds with a perdurantist view (4D). In endurantism an individual thing such as for example John Doe endures through time and is regarded as totally present at any moment in its lifetime. In a perdurantist ontology, 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 extends over time from his birth to his death. Thus, while 3D ontologies view objects only from the present and assume that the same object can exist over time and may be fully identified at different points in time, the 4D

ontological view emphasizes the continuity of objects over space-time, where these objects exist immutably. These differences between endurants and perdurants determine whether and how objects exist in different ways in the past, present and future. Or in other words these differences determine how an ontology is formed. In the section below, we will discuss the different metaphysical choices that shape the fundamentals of an ontology through several illustrations that are based upon the case study of the OntoCom workshop. Finally, since we will not cover all the concepts of both ontologies in this paper, we like to refer the reader for a more detailed reading of the BORO ontology to [13], [19] and for the UFO ontology to [14], [15].

3. Metaphysical Choices

In this section, we will focus on the different metaphysical choices the BORO and UFO ontology make, and illustrate these differences based upon modeling fragments of the modeling case that was given at the OntoCom 2017 workshop. We would like to emphasize that these models were based upon the same case. The case itself describes the University domain. This domain was chosen deliberately in order to exclude any advantages concerning specific domain knowledge. Since most of the participants at the workshop were professors themselves, the University domain and its structure were rather well known.

3.1. Essence and Identity

The notion of identity and essence-defining characteristics – better known as essential properties in 3D ontologies – regards how the ontology assigns a principle of identity to its concepts and dictates whether a certain phenomenon is represented through one or multiple objects. For instance, in the perdurantist view, where all individual objects are four-dimensional and have spatial and temporal parts, objects do not (explicitly) have properties such as weight, height etc. Instead, their features and characteristics are derived from the spatial and temporal parts that are formed with other objects. Another example of how the notion of identity is represented by 3D and 4D ontologies can be demonstrated through the representation of temporary conditions such as roles, states and phases of an element. In a 4D ontology, John as a child and John as an adult are separate elements (i.e. states), that become – temporarily – part of John as a whole. Conversely, in a 3D ontology, John as a child is the same as John as an adult since the essential properties of John do not change. In a 4D ontology, John is wholly present from his birth to his death. John as a child and John as an adult represent temporal parts of John as a whole.

To demonstrate how these ontological distinctions impact conceptual models that follow them, we use a simple scenario in which a person, named John, is a student at a given moment in time, and a professor at another. The corresponding UFO-based and BORO-based models are depicted in Figure 1 and Figure 2, respectively. In Figure 1, we can observe that the concept of PERSON is represented as a Kind and specialized into two subclasses, namely the STUDENT and a PROFESSOR Roles. Note that, at the instance level of this model fragment, an individual can simultaneously instantiate PERSON, STUDENT and/or PROFESSOR. In the figure, we represent that JOHN, an instance of PERSON, instantiates the STUDENT Role at time t_1 and the PROFESSOR Role at time t_2.

In UFO, a Kind is a rigid category that provides an identity principle to its instances. By rigid category, we mean that all individuals that instantiate a given Kind must do so in all possible worlds in which they exist. Thus, by modeling PERSON as a Kind and asserting that JOHN is an instantiation, it follows that JOHN cannot cease to be a PERSON while he exists. Conversely, UFO Roles are anti-rigid and relationally dependent categories. This means that individuals instantiate them "accidentally" and in virtue of a relational change. Thus, in our scenario, a STUDENT is a role that a PERSON plays (instantiates) when related to an EDUCATIONAL INSTITUTION by means of a student ENROLLMENT (omitted from the figure). PROFESSOR is another role which is also relationally depends on an EDUCATIONAL INSTITUTION, but by means of an EMPLOYMENT CONTRACT (also omitted from the figure).

The BORO representation in Figure 2 follows a rather different approach. In the BORO ontology, STUDENT and PROFESSOR are specializations of PERSONSTATES, which is an Element. PERSONS and PERSONSTATES form a relation through the tuple PERSONTEMPORALWHOLEPART (i.e. PERSONTP). TEMPORALWHOLEPARTS is a tupleType that represents relations between objects that temporarily form a WHOLEPART relation with one another. It is important to realize that PERSONSTATES is a different object from PERSONS itself and is not existentially nor relationally dependent upon it. As such, in this approach, collections are more like sets, and the identity criteria of the collection-set can be its members. In the figure, JOHN, PROFESSOR JOHN, and STUDENT JOHN are instances. The element '(JOHN, STUDENT JOHN)' also represents an instance, more specifically that of a TupleType.

Additionally, we would like to remark that we have assigned colors to the different objects in these diagrams in order to emphasize the nature of these entities. More specifically, red represents endurants, green represents relationships or tuples while yellow corresponds to perdurants. This differentiation in colors immediately draws our attention for example to the fact that how an exact same case is completely represented by only Endurants in UFO, while in BORO the diagram is composed out of entities that are either Perdurants or Tuples. Moreover, note that instances are represented with slightly darker shades of the color assigned to the types they instantiate – relations which are represented in the figures through dotted lines with the 'iof' label.

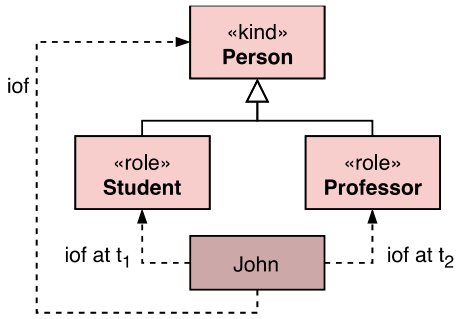

Figure 1: Roles in UFO

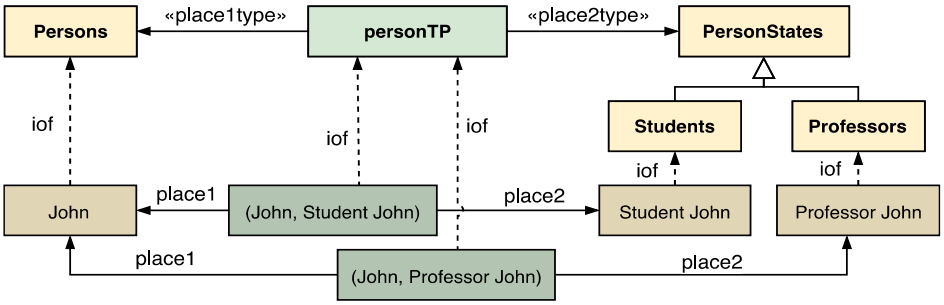

Figure 2: States in BORO, based upon [16].

3.2. Relationships

Similarly to the notion of identity, the metaphysical choice of both ontologies concerning the formation of *relationships* defines the way entities can become part of each other or separate from one another. In UFO, relationships can be distinguished based upon a certain meaning that is derived from the kinds of entities they link together. One concept in the UFO ontology – the Relator – forms an important element in relating entities. Relators are moment universals that represent the objectification of a relational property, which are existentially dependent on a multitude of individuals, as such, mediating them. Relators are the truth makers of the so-called material relations [20]. In BORO, relationships are defined as tuples that aggregate any kinds of entities. The identity of a tuple is defined by the places in the tuple. A tuple (or tupleType) defines the types that the places of its instances must instantiate. Different kinds of tuples exist. For instance, the wholeParts tuple represents a relation between two elements in which the 4D extent of one element is completely contained within that of another element for the entire existence of both. The example of John and his brain would fit this kind of tuple. TemporalWholeParts tuples are a subtype of the tuple type WholeParts, and represent relationships of two elements in which the 4D extent of one element is completely contained within that of another element, but only for a particular period of time.

To illustrate the conceptual differences that rise between both ontologies, we represent the modeling fragment of John being enrolled at the UGent (University Ghent) by the UFO ontology in Figure 3 and by the BORO ontology in Figure 4. Similar to the example above, STUDENT is represented as a Role, which is derived from the Kind PERSON. This Role is then connected with a UNIVERSITY through a Relator which represents the ENROLLMENT relationship. A Relator idiosyncratically binds two elements with one material relation and two mediation relation. While the material relation is directly derived from the relator, the mediation relation is a formal relation – a specific type of existential dependence that takes place between a Relator and the element it mediates. Finally, JOHN, UGENT and JOHN'S ENROLLMENT AT UGENT represent the instances from the Kind, Role and Relator.

Regarding the BORO fragment in Figure 4, the enrollment between a PERSON and a UNIVERSITY is represented through the tuple ENROLLEDAT. A tuple can consist of two or more 'places' that define the identity of the tuple. In this case, the tuple can be filled with two states, on the instance level being UGENT STUDENT JOHN and UGENT HOSTING JOHN. We would like to remark that the order of the places in the tuple carry meaning: JOHN (place 1) is enrolled at the UGENT (place 2). The opposite would have an entirely different meaning and would make no sense in this example.

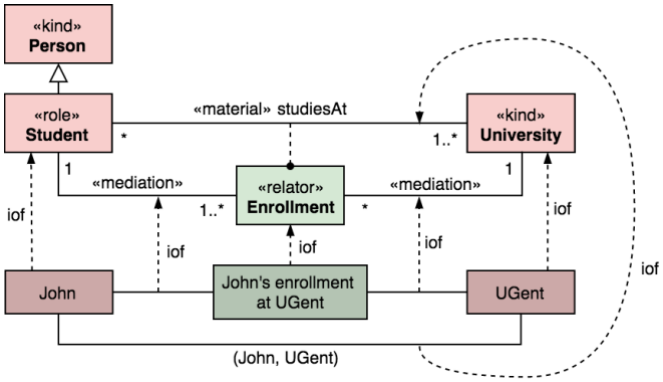

Figure 3: Student enrollment as represented by the UFO ontology

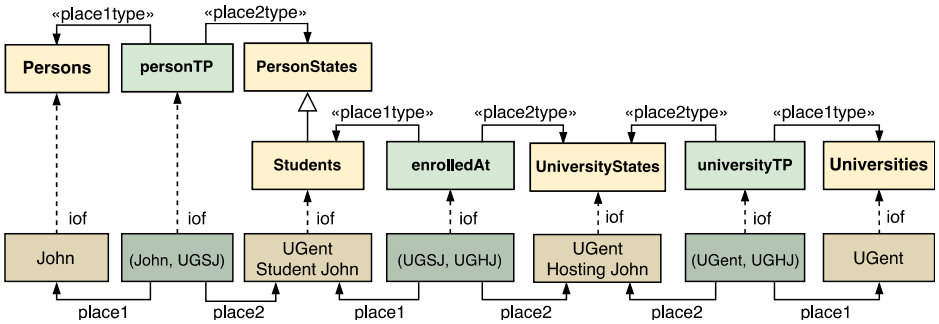

Figure 4: Student enrollment as represented by the BORO ontology

3.3. Time

The metaphysical choice of an ontology concerning time determines how entities begin and cease to exist over *time*, and how they define events and changes. In a 4D ontology, objects and relationships are represented immutably in space-time while 3D ontologies represent these objects and relationships in the present, with their current traits and characteristics. In the UFO ontology, time-related elements are represented through Events, which are individuals composed of temporal parts. They happen in time in the sense that they extend in time accumulating temporal parts. The interactions between events and their relationships are derived from the base relations in Allen's interval algebra for temporal reasoning [21]. Events can be atomic or complex, depending on their mereological structure. Whilst atomic events have no proper parts, complex events are aggregations of at least two disjoint events. This composition implies that whenever an event is present, it is not necessarily the case that all its temporal parts are present. For instance, childhood and adulthood can be considered as Complex Events that are composed of a series of disjoint Atomic Events. As stated above, an element in BORO is defined by its spatiotemporal extent – i.e. the space and time it occupies – where the element extends through time and is not fully present at any instant in time (excluding elements with a zero temporal extent). Moreover, different segments of space-time are elements themselves. Consequently, a temporal slice (e.g. a second, a day or a century) can therefore be seen as 4D extensions. In order to represent occurrences or time intervals, BORO applies upper-level patterns such as 'happensIn' in order to represent the

occurrence of an element in a specific time period or instant. In fact, these happensIn patterns are simple wholePart tuples. Similarly, in order to represent temporal sequencing, BORO provides the 'before-after' pattern to represent such changes, which is essentially just a tuple.

To exemplify the concepts of both ontologies, we display a fragment that outlines the situation where a THESIS DEFENSE precedes GRADUATION for UFO in Figure 5 and for BORO in Figure 6. As can be seen in the UFO diagram, both DEFENSE and GRADUATION are depicted as Events. These Events can be either atomic or complex, depending on the interpretation of the modeler. The before-after relation represents the order of the Events in which they should take place. In the BORO fragment, DEFENSE and GRADUATION are separate Elements. To represent the temporal sequencing of both Elements, the before-after pattern is applied, which relates both instances JOHN'S DEFENSE and JOHN'S GRADUATION. Again, the order of the places in the tuple are important since they determine which Element precedes the other (before-after).

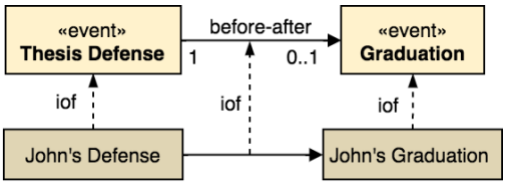

Figure 5: Temporal concepts and sequencing in UFO

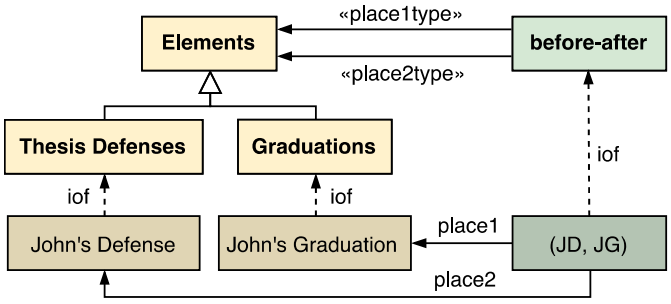

Figure 6: Temporal concepts and sequencing in BORO

4. Discussion

Based upon the metaphysical choices discussed above, and the different conceptual representations that were created from the same case study, we will discuss both ontologies and list several questions that can serve as a basis for future discussion or future research studies.

A first distinction we can make between both models is that their overall structure differs rather substantially. UFO distinguishes several principal identity-bearing concepts – e.g. Person and University – where other concepts can borrow their principle of identify from (e.g. STUDENT or PROFESSOR). Between these concepts relationships are formed that are either represented through Relators, specialization relationships or simple association relationships. In BORO, we can observe an overall rather different

structure. In the modeling fragments, all concepts are independent elements (i.e. PERSONS, PERSONSTATES, UNIVERSITIES) that interact with one another through WHOLEPART and TEMPORALPART relationships, which are represented through tuples. While UFO also allows the modeling of temporal parts of event [22], the frequent use of WHOLEPART and TEMPORALPART relationships in BORO emphasizes the perception and enduring of time concerning the concepts. Additionally, the common use of STATES (e.g. PERSONSTATES, UNIVERSITYSTATES) also accentuates the perduring and changing nature of several concepts. This observation is in line with the literature involving 4D ontologies, where Hales & Johnson (2003) affirm that since 4D ontologies emphasize the continuity of objects over space-time, they are more suitable to express time-related concepts. Therefore, the first question we can formulate based upon the modeling fragments and assumptions of existing literature is the following:

- *Does the BORO application of states, wholePart and temporalPart relationships allow of a more systematic representation of temporal aspects of concepts compared to the UFO ontology?*

Next, adopting the BORO and UFO ontology leads to quite different outcomes concerning the identity of certain entities. For instance, UFO assumes that STUDENT (a Role) is a specialization of PERSON (a Kind). Thus, an instance of STUDENT is also an instance of PERSON. In BORO however, these are different elements with their own identity – or spatio-temporal extents – a PERSON, and STUDENT as a personState. The main difference here is that these objects are not related through a specialization relationship, but through a temporalWholePart relationship. In other words, UFO builds upon the intuition that a Professor is a way of being while BORO sees them as different things. Moreover, according to the study of [9] this differentiation in identity criteria would even lead to a more difficult characterization of sub-roles with the UFO ontology compared to the BORO ontology. On the other hand, as mentioned by [23], this paradigm of viewing every entity as a separate element can lead to the disadvantage that the ontology feels rather counterintuitive, since objects and processes are not distinguished and thus things that are typically regarded as objects have temporal parts. As such, our second question can be defined as following:

- *In which cases is the adoption of the BORO or UFO ontology concerning the ontological differentiation in identity preferred to form a representation?*

Finally, our last question involves a more philosophical distinction, namely the modeling of modality – both temporal modality as well as alethic modality (i.e. modality that connotes the estimation of the logical necessity, possibility or impossibility) – or how individual objects can possibly differ and how they are extended across many possible worlds. This is an important feature since modeling possible or future scenarios occurs often, for instance in the case of not knowing the time when two parties will agree to their contractual obligations. In UFO, individual objects are world-indexed, meaning that they are part of a snapshot that is world-bound (i.e. in a particular world at a particular time). These objects however are not 'locked' inside a particular world. In UFO, an instance of a Kind can exist in different possible worlds as long as they keep being instances of that Kind. The only way that they can be re-identified as the very same entity in different worlds is because of the principle of identity provided by that Kind. BORO on the opposite adopts Lewis' (1986) theory of possible worlds and counterparts. In

BORO, all objects are separate elements, and they each have counterparts in other possible worlds to represent such scenarios. This different paradigm in modality between both ontologies has already given rise to several arguments favoring the modality of a particular ontology. For instance, one can question if the modality in BORO is not of a more fragile nature. In UFO endurants are the natural bearers of modal properties, there exists a cross-world identity between them. Endurants can change due to the distinction between essential and accidental properties [22]. In BORO however, objects are immutable, meaning that they cannot change and as such cannot be different in any way. Consequently, there is no cross-world identity between objects in BORO. Moreover, when one would ask the question 'What kind of changes can something undergo and still be the same?', the answer for the BORO ontology would be none due the immutability of objects. In UFO, this change would depend on the type of entity and its composing properties. These arguments give raise to the doubt if BORO can properly represent modality, and as such we formulate our last question as follows:

- *Does the UFO ontology allow for a more appropriate representation of modality compared to the BORO ontology?*

5. Conclusion

In this paper, we compared the differences that exist between a 3D and a 4D ontology according to the metaphysical choices that they make and that defines the structure and composition of these ontologies. More specifically, we compared the BORO and the UFO ontology, and investigated the differences between them through several modeling fragments that were derived from a modeling case presented at the 5th OntoCom workshop. Each of these modeling fragments focused on the metaphysical choices that the ontologies make, i.e. Essence and Identity, Relationships and Time. By comparing these models, we could highlight the different ontological approaches and structures that exist between these ontologies. For instance, the modeling fragments illustrated the intensive use of the BORO ontology of wholePart and temporalWholeParts relationships between entities. Moreover, practically all entities in BORO are seen as separate elements, while UFO distinguishes several principal identity-bearing entities (Kinds) where other concepts can borrow their principle of identify from (Roles or Phases). The observed differences between both ontologies eventually led us to formulate three questions that challenge the applicability of certain metaphysical choices in certain circumstances, and that can serve as a basis for future discussion or future research studies in the domain of ODCM. Moreover, future research efforts could also focus on comparing different kinds of ontologies (e.g. not only 3D and 4D ontologies; or other specific ontologies rather than the BORO and UFO ontology) or could examine different metaphysical choices (for instance how ontologies deal with parthood, dependency and unity). Finally, we would like to emphasize that the purpose of this paper was to clarify and determine the differences of applying different kinds of ontologies and their influence on the resulting conceptual models. It was not our intention to advocate the superiority of a certain ontology, but rather to simply increase awareness and transparency in applying different types of ontologies.

References

[1] T. Honderich, *The Oxford Companion to Philosophy*. Oxford University Press, 2006.

[2] R. Ashenhurst, "Ontological aspects of information modeling," *Minds Mach.*, vol. 6, no. 3, pp. 287–394, 1996.

[3] Wand and R. Weber, "On the ontological expressiveness of information systems analysis and design grammars," *Inf. Syst. J.*, vol. 3, no. 4, pp. 217–237, 1993.

[4] J. Mylopoulos, "Conceptual modeling and telos," in *Conceptual Modelling, Databases and CASE: An Integrated View of Information Systems Development.*, P. Loucopoulos and R. Zicari, Eds. Wiley, 1992.

[5] N. Guarino, "Formal ontology and information systems," in *FOIS conference*, 1998, no. June, pp. 3–15.

[6] S. D. S. Hales and T. T. A. Johnson, "Endurantism, perdurantism and special relativity," *Philos. Q.*, vol. 53, no. 213, pp. 524–539, 2003.

[7] Verdonck and F. Gailly, "Insights on the Use and Application of Ontology and Conceptual Modeling Languages in Ontology-Driven Conceptual Modeling," in *Conceptual Modeling - ER 2016, Lecture Notes in Computer Science, vol. 9974*, 2016, vol. 9974 LNCS, pp. 83–97.

[8] M. M. Al Debei, "Conceptual Modelling and the Quality of Ontologies : Endurantism Vs Perdurantism," *Int. J. Database Manag. Syst.*, vol. 4, no. 3, pp. 1–19, Jun. 2012.

[9] S. de Cesare, B. Henderson-Sellers, C. Partridge, and M. Lycett, "Improving Model Quality Through Foundational Ontologies: Two Contrasting Approaches to the Representation of Roles," in *ER 2015*, 2015, vol. 1, pp. 304–314.

[10] S. de Cesare and G. L. Geerts, "Toward a perdurantist ontology of contracts," *Lect. Notes Bus. Inf. Process.*, vol. 112 LNBIP, pp. 85–96, 2012.

[11] I. Hadar and P. Soffer, "Variations in Conceptual Modeling," *J. Assoc. Inf. Syst.*, vol. 7, no. 8, pp. 568–592, 2006.

[12] Verdonck and F. Gailly, "An Exploratory Analysis on the Comprehension of 3D and 4D Ontology-Driven Conceptual Models," in *Conceptual Modeling - ER 2016, Lecture Notes in Computer Science, vol. 9975*, 2016, vol. 9975, no. 2, pp. 163–172.

[13] C. Partridge, *Business Objects: Re-engineering for Reuse*. Butterworth-Heinemann, 2005.

[14] G. Guizzardi, *Ontological Foundations for Structural Conceptual Models*. CTIT, Centre for Telematics and Information Technology, 2005.

[15] G. Guizzardi, G. Wagner, J. P. A. Almeida, and R. S. S. Guizzardi, "Towards ontological foundations for conceptual modeling: The unified foundational ontology (UFO) story," *Appl. Ontol.*, vol. 10, no. 3–4, pp. 259–271, 2015.

[16] S. de Cesare and C. Partridge, "BORO as a Foundation to Enterprise Ontology," *J. Inf. Syst.*, vol. 30, no. 2, pp. 83–112, 2016.

[17] G. Guizzardi, G. Wagner, R. de Almeida Falbo, R. S. Guizzardi, J. Almeida, and R. D. A. Falbo, "Towards Ontological Foundations for the Conceptual Modeling of Events Background : The Unified Foundational Ontology (UFO)," *Concept. Model.*, vol. 8217, pp. 327–341, 2013.

[18] G. Guizzardi, R. de A. Falbo, and R. Guizzardi, "Grounding Software Domain Ontologies in the Unified Foundational Ontology (UFO): The case of the ODE Software Process Ontology.," *CIbSE*, no. i, 2008.

[19] S. de Cesare and C. Partridge, “BORO as a Foundation to Enterprise Ontology,” *J. Inf. Syst.*, vol. 30, no. 2, pp. 83–112, 2016.

[20] N. Guarino and G. Guizzardi, “We need to discuss the relationship: Revisiting relationships as modeling constructs,” *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 9097, pp. 279–294, 2015.

[21] J. F. Allen, “Maintaining knowledge about temporal intervals,” in *Readings in qualitative reasoning about physical systems*, Elsevier, 1990, pp. 361–372.

[22] G. Guizzardi, N. Guarino, and J. P. A. Almeida, “Ontological considerations about the representation of events and endurants in business models,” *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 9850 LNCS, pp. 20–36, 2016.

[23] A. Pease and I. Niles, “IEEE standard upper ontology : a progress report,” *Knowl. Eng. Rev.*, vol. 17, pp. 65–70, 2002.

[24] D. Lewis, “On the plurality of worlds,” *London*, vol. 5, pp. 221–236, 1986.