3D vs. 4D Ontologies in Enterprise Modeling

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Abstract. This paper presents a comparison between a 3D and a 4D ontology, with the purpose of identifying modeling variations that arise from using these different kinds of ontologies. The modeling variations are illustrated by using two enterprise modeling enigmas to which both ontologies are applied. The goal of our comparison is to demonstrate that the choice of an ontology impacts on the representation of real world phenomena and will eventually result in different enterprise models.

1 Introduction

Enterprise Modeling can be defined as expressing enterprise knowledge, which adds value to the enterprise or needs to be shared. It consists of making models of the structure, behavior and organization of the enterprise [1]. To construct these models, enterprise modeling utilizes conceptual modeling languages. The goal of enterprise modeling is to represent or formalize the structure and behavior of enterprise components and operations in order to understand, engineer or re-engineer, evaluate, optimize, and even control the business organization and operations [2]. Over the years, various methods and modeling techniques have been introduced, which led to a plethora of various enterprise modeling approaches and tools. However, these existing approaches to enterprise modeling lack an adequate specification of the semantics of the terminology of the underlying enterprise meta-model, which leads to inconsistent interpretations and uses of knowledge [3].

In order to provide a foundation for enterprise modeling by means of a formal specification of the semantics of enterprise models and to describe precisely which modeling constructs represent which phenomena, ontologies were introduced [4]. We can define an ontology as a formal specification of a conceptualization [5]. Within the IS domain, similar problems occurred, resulting in the use of ontologies to analyze and improve existing conceptual modeling languages [6]. A great deal of research has been done in analyzing, evaluating and improving the modeling grammars and constructs of conceptual modeling languages with ontologies. This resulted in enriching existing conceptual modeling languages with modeling rules that have their origin in a formalized ontology. We can define this practice as *ontology-driven conceptual modeling* (ODCM). In this paper we have decided to focus on core ontologies in order not to concentrate on a single domain. Core ontologies (also called foundational ontologies) can be defined as ontologies that provide a broad view of the world, suitable for many different target domains [7]. We can distinguish between two kinds of core

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ontologies with respect to their view about the persistence of objects through time, i.e. 3D and 4D ontologies. *3D ontologies* hold that individual objects are three-dimensional, have only spatial parts, and wholly exist at each moment of their existence. *4D ontologies* hold that individual objects are four-dimensional, have spatial and temporal parts, and exist immutably in space-time [8].

Although OCDM leads to theoretically sound models, a recurring problem in this practice is the degree of complexity that results from this formalization. The translation of these ontological axioms results in complex formal modeling rules and consequently ontology-driven conceptual modeling languages that can be hard for a modeler to appropriately apply. As a consequence, an increasingly problematic bottleneck in IS and enterprise modeling has come about, i.e. a growing demand for constant creation of formal models in specific and dynamic operational contexts, combined with a lack of people who are capable and willing to perform the modeling required [9]. It is the author's belief that this bottleneck can be reduced by aiding the modeler in the choice of a suitable ontology, saving time and effort in comparing and evaluating various ontologies. One way to do this is to link an ontology with the 'goal' or purpose and intended use of the conceptual model. An example of such a goal could be to improve the communication by means of using a limited set of concepts and relationships. Other goals could be based upon re-engineering purposes or system analysis. Since every goal has different kinds of purposes and intended uses, they could be linked to different kinds of ontologies. Nowadays it is up to the modeler to choose the ontology he would like to integrate into the conceptual model. A clear motivation of why the chosen ontology is the better fit is difficult to find.

Having this in mind, the goal of this paper is to explore the impact of choosing a certain ontology by understanding and demonstrating that, depending on the aspect of the real world that has to be modeled, the choice of an ontology will impact the modeling of these real world phenomena and will eventually result in different enterprise models. We intended to do this by comparing the modeling variations that arise by using two rather different ontologies on similar enterprise modeling enigmas. In section 2, we will introduce the two foundational ontologies and motivate our choice for picking these two specific ontologies. Section 3 will then demonstrate the modeling variations that arise by applying the ontologies on the same modeling enigmas of real-world phenomena in the enterprise domain. Finally in section 4, we will discuss the result of the overall comparison of both the ontologies and explore the kind of modeling purposes they can be applied to.

2 The BORO and eUFO Ontology

The ontologies that will be compared are eUFO (essential Unified Foundational Ontology) [10] and BORO (Business Object Reference Ontology) [11]. Our choice for these two specific ontologies is driven by various reasons. A first argument for comparing these ontologies is that they are both used in the domain of conceptual modeling and that they are both reference ontologies. Reference ontologies can be defined as rich, axiomatic theories, whose focus is to clarify the intended meanings of terms used in specific conceptual modeling domains [12]. Even though we could say their roots are the same, their branches stretch out in different ways, which brings us to our second argument of comparison: the purpose of their existence and their intended use. eUFO was developed for analyzing modeling languages and to improve them. More specifically, the aim of eUFO is to improve the truthfulness to reality (domain appropriateness) and conceptual clarity (comprehensibility appropriateness) of a modeling language [10]. Or in other words, the stronger the match between reality and its representing model, the easier it is to communicate and reason with that model [13]. The second ontology, BORO, was developed for re-engineering purposes and to integrate systems in a transparent and straightforward manner [11]. By using business objects, its purpose is to make systems simpler and functionally richer so that in practice, they would be cheaper to build and maintain. A last but nonetheless important argument for comparing these ontologies is that eUFO was originally developed based on UFO, a 3D ontology, having a focus on endurants. BORO was developed from the very beginning as an ontology of perdurants, making it a 4D ontology. Below, we will first give a brief description of both ontologies and how they came to exist. Then we will give a quick overview of the concepts they cover.

2.1 eUFO

Since eUFO is derived from UFO, we will first give a small introduction of this ontology. UFO is a reference ontology of endurants, which is based on a number of different theories such as philosophy of language, formal ontology, linguistics, cognitive psychology and philosophical logics [14]. Since UFO is a 3D ontology, it focuses less on processes and events. In order to deal with time and changes, additions to UFO have been made whereas UFO can be grouped into three compliance sets, namely, UFO-A: an ontology of endurants; UFO-B: an ontology of perdurants, and UFO-C, which is built upon UFO-A and B to compose an Ontology of Social Concepts [13]. With the purpose of simplifying the philosophical terminology of UFO and harmonizing it with the informatics terminology, a simplified version was created based upon UFO-A and UFO-B, called the essential Unified Foundational Ontology (eUFO) [10]. Our motivation to evaluate eUFO in this paper and not UFO comes from the fact that eUFO is a simplified version and therefore is less complicated. It is also based upon an ontological view of endurants and also contains perdurants. This makes eUFO more practical for comparing it to another ontology than UFO.

2.2 BORO

BORO is a reference ontology that uses object semantics with the goal of developing models that are functionally rich and structurally simple [11]. Object semantics can be explained as objects where time is treated as another dimension, making it easier to capture change patterns. In other words, object semantics defines objects as four-dimensional extensions in space and time. The origin of BORO lies in the re-engineering of existing information systems into conceptual models with the goal to integrate and align these systems. The re-engineering of these existing systems can be described in two stages: reverse engineering and forward engineering. In the first stage, the existing system's business entities are translated into business objects. The second stage involves the process of modeling with these newly developed business objects. During the second stage or forward engineering, the inaccuracies and constraints of the existing systems are identified and corrected. The power of BORO can be found in the principle of re-use, i.e. it provides a framework that both enables and encourages high levels of reuse. These intended higher levels of re-use would lead to reducing the effort needed to re-develop a system. Another strength from BORO for re-engineering purposes can be found in the extra fourth dimension it offers. The main advantage of perdurantist approaches is simplicity as everything (e.g., individual objects including processes) is treated in a similar way [15].

2.3 Introducing eUFO and BORO

In this section we give a brief overview of the concepts in BORO and eUFO in order to provide a better understanding of the enterprise modeling enigmas in the following section. However, for a complete understanding of these concepts, we refer to [10], [11] and [14].

Both BORO and eUFO make a distinction between so called entities and entity types. In BORO these are called elements (or individuals or bodies) and classes (or types), in eUFO they are called individuals and universals. From then on, many differences arise between the two ontologies. While eUFO clearly distinguishes different kinds of individuals and has many sub-categories within these individuals, BORO does not. In BORO, all elements have a spatio-temporal extension and so are all, by definition, physical. Classes are any collections of objects; hence they may have similar features but do not necessarily have to. For example, the class person classifies all elements that are persons. An important feature of elements is that they are space-time based and thus four-dimensional. BORO is a timeless ontology in the sense that the real world is modeled with a view from nowhere; hence the model is not relative to the view of a specific person or situation. In BORO a fundamental relation between elements is whole-parts. Whole-part patterns also explain how different four-dimensional objects overlap. This overlap can be both spatial and/or temporal. For example, if a car was red last week and is green this week, we can see this as a red temporal part followed by a green temporal part, where the temporal parts are time-slices of the whole car. Classes in BORO are defined as sets and therefore are immutable, similarly to sets in mathematical set theory.

In eUFO, individuals are 'things' that have a unique identity. They exist in time and space in "the real world". Universals are feature-based classifiers that classify, at any moment in time, a set of individuals with similar features. Universals are equivalent to classes in BORO. Looking closer at individuals, there is a distinction between substance individuals, trope individuals and events. The latter can be defined as a perdurants while the former two can be seen as endurants. Substance individuals are fully present whenever they are present, i.e., they are in time. Examples are a person or an amount of seawater. *Events* are individuals composed of temporal parts. They happen in time in the sense that they extend in time accumulating temporal parts [16]. An example is today's rise of the sun. Whenever an event is present, it is not the case that all its temporal parts are present. *Trope individuals* are defined through their relations with other individuals, i.e., they are existentially dependent on other individuals. Examples are the red color of the sunrise or a certain skill of a person.

To capture relations between objects, BORO makes use of *tuples*. The extension of a tuple is given by the places that the objects occupy in the relation therefore the use of the mathematical definition to define the identity of a tuple. For example, in the tuple <*John*, *John's childhood*>, *John* occupies place 1 of the tuple and *John's childhood* place 2. Therefore in BORO the identity of an element is defined by its 4D spatiotemporal extension, the identity of a class by its instances (or members) and the identity of a tuple by the places in the tuple. Elements, classes and tuples are the three types of objects that exist in BORO; all objects must be an instance of one of those three types.

In eUFO, relations are expressed using relators. Relators are trope individuals with the power of connecting entities. The relationships can be either formal or material. Formal relationships are direct relationships between two or more entities. They can be based on existential dependency or on part/whole relations. Material relations however have a material structure of themselves; they have a relator, or mediating individual, with the purpose of connecting individuals. Material relationships include examples such as 'enrolled at', 'working at' or 'being connected to'. In order to represent changes, BORO introduces change objects called states and events. States and events are types of physical bodies and represent temporal parts. States are bounded by events. Change can be defined as a succession of temporal parts. States are seen as 'change objects' and thus also have a four-dimensional extension. Events are change objects, similar to states, but of a different kind. While events and states are both temporal parts, events unlike states do not persist through time. They only occupy an instant in time; they have a zero thickness along the time dimension. In eUFO, time and changes are being expressed by events, roles and phases. The creation, change and destruction of substance individuals are being executed by object participation events. Since trope individuals are existentially dependent upon substance individuals, object participation events indirectly also impact trope individuals. Phases are universals that can be used to express different time-changes in a substance individual.

3 Enterprise Modeling Enigmas

Our enterprise modeling enigmas are chosen as such so they would address rather different aspects of the ontologies, making this comparison more interesting. Also, we will not be using a modeling language with the purpose to remain 'neutral' on this aspect; we will instead use a generic and abstract form of representing some of the enigmas.

3.1 The Troy Enigma

Let us start with our first enterprise enigma, which will focus on how both ontologies view the persistence of objects through time. The enigma involves the fusion of two departments in a company Troy, specialized in IT security. The first department was responsible for the IT support of the back office while the second department was responsible for the IT support of the front office. Since both the responsibilities of front and back office have grown closer to each other and started using the same information systems, the higher management of Troy decided that both the IT support departments fulfill similar tasks and can therefore be fused into one. This new department would simply manage all IT support for both front and back office. Let us now describe this situation with both ontologies:

In eUFO, both departments and the company are substance individuals. The company and the departments are linked with each other through formal relationships since the departments are parts of the company. The departments each also assume a role, that of support for respectively the front and back office. The number of personnel of the departments, their efficiency, the total cost and other characteristics can be defined as qualities of the department. The decision taken by the higher management can be seen as an event. This event results in different object participation events. The first being two object destruction events that eliminate the two existing IT departments and further one object creation event, which creates a new IT department as a new substance individual. The destruction of the two existing departments also invokes the destruction of the roles they assumed, the qualities they embedded and the relations that were formed with these departments. For a more detailed explanation on how this 'destruction' is actually performed, we refer to [17]. The creation of the new IT department also indirectly creates a new role, new relationships and new qualities that are a combination of the roles, relationships and qualities from the two departments that ceased to exist. Figure 1 gives a graphical representation through time.

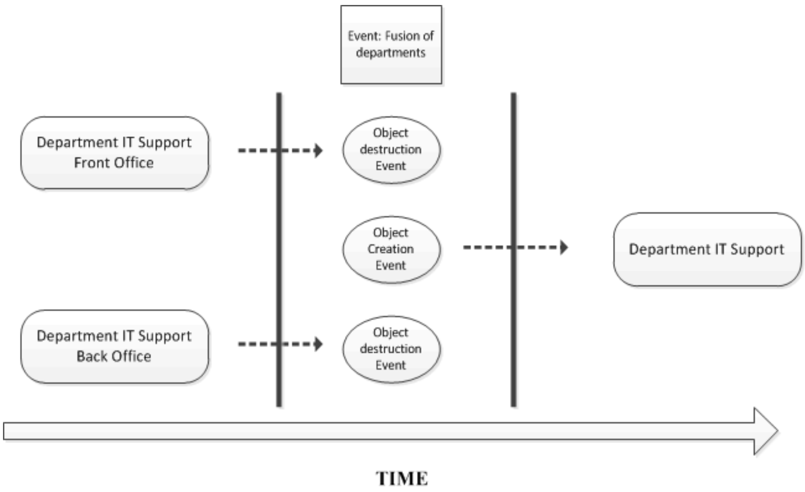

Fig. 1. eUFO and the Troy enigma

In the ontology of BORO, the fusion of the departments is viewed in a different way than that of eUFO. Both the IT support departments for respectively front and back office are individual objects. Each of them share a spatio-temporal part with respectively the role of IT support front office and the role of IT support back office. Also all the characteristics of the departments (efficiency, cost factors, etc.) involve spatial and/or temporal parts of the departments. We can also identify many tuples around these departments such as <Front office IT support department; Front office> based upon their support function towards the front office.

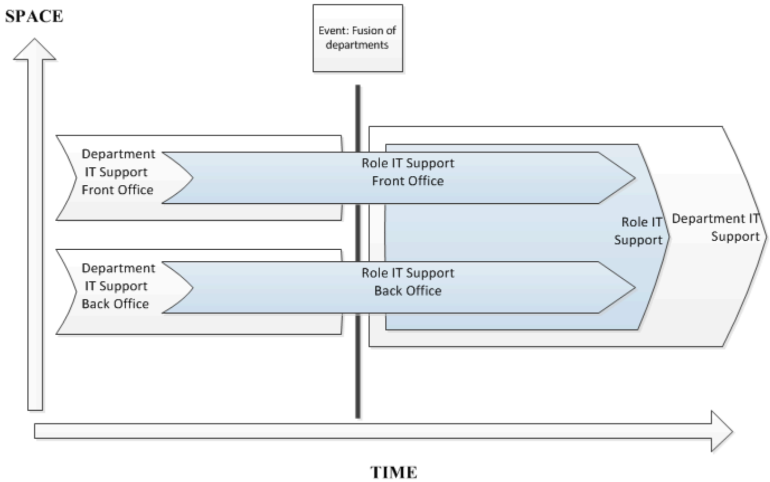

Fig. 2. BORO and the Troy enigma

The roles of IT support front office and of IT support back office are now also part of a new role: IT support. The two original departments no longer share a spatial part with the object company. After the fusion event, the spatio-temporal extensions of both the front and back office stop. Instead, the spatio-temporal extension of a new object, the IT Support department starts. Figure 2 gives a graphical representation on a space-time map.

3.2 The Helena Enigma

Our second enterprise enigma emphasizes existential dependencies within the ontologies. The enigma involves the sale of a graphical design product called Helena being owned by another IT security company called Archea and sold to the company Troy. Since the product exists out of many complex algorithms, there is a specific team of engineers working at Archea for the continuous maintenance and further development of these algorithms. Since the team's know-how is essential for the proper functioning of Helena, the team is also being transferred to Troy. Although there is an event 'Sale of Helena', we will not focus on this event since time dependency was discussed during the previous enigma.

According to eUFO, both the company Archea, Troy and the product Helena are substance individuals. Before the sale, Archea owned Helena and therefore they formed a material relationship linked through the relator ownership. The team that was linked to Helena is a part of Archea and therefore, a formal relationship exists. The engineers working in the team however do not have a formal relationship with Troy. Instead, we have a material relationship between the engineers and the company Troy connected through the relator ‘employment’. Also, a material relationship exists between Helena and the team through the relator ‘Maintenance and development’. Let us take a look at the details of both the team and Helena. The team has a unique know-how of Helena. In eUFO, this know-how can be defined as a ‘mode’, which is a trope individual and existentially dependent on the team. The algorithms that are a part of Helena are also trope individuals but instead of modes, they are qualities. Qualities are also existentially dependent upon the substance individual so in the case that the product Helena would cease to exist, also the qualities (and modes) of Helena would no longer exist. After the sales event, eUFO stays rather consistent. The relationships and existential dependencies remain with the sole difference that they are no longer formed with the substance individual Archea but instead with the substance individual Troy.

In BORO all relationships between objects are formed through tuples, no matter what the existential dependency or connector is. Thus the relationships between the objects Helena, Troy, and Engineer, based upon ownership or employment would all be formed into tuples such as these: <Helena, Troy>, based upon ownership and <Engineer, Troy>, based upon employment. However, states also have an impact on the construction of tuples. Since tuples should not change according to object semantics, we form tuples with states of an object to guarantee the continuous nature of tuples. The reason for this is that we cannot construct two tuples where both Troy and Archea own the product Helena. Instead, the product Helena has two separate states: Helena owned by Archea and Helena owned by Troy. This allows us to create the following two tuples: <Helena owned by Archea, Archea> and <Helena owned by Troy, Troy>. These tuples thus represent the relationship between the object Helena and the objects Archea and Troy, based on ownership without contradicting one another.

4 Discussion

At a first glance, the modeler can become rather overwhelmed by the many different concepts that eUFO introduces, resulting in many relationships and dependencies between these concepts. Important aspects are existential dependency and rigidity, which are used as a way to classify and distinguish the concepts from one another. As a consequence, eUFO can seem rather complex, requiring more time to fully understand all of its concepts and dependencies. Since everything in the BORO ontology can be defined as a timeless object, it has no need for ways to classify or distinguish these objects, resulting in fewer concepts and dependencies and therefore strikes as less complex than eUFO does. However, BORO’s way of viewing real-world phenomena in four-dimensional extensions feels rather unnatural in human thinking. A similar ascertainment is found in [18], where object-oriented analysis and design are rather difficult to learn and practice, even though they are practiced intensively in industry and academics. So in a way, both ontologies have a more complicated aspect than the other, depending on the perspective.

If we return to the different goals of enterprise models [2] and according to the intended purpose of the ontologies, eUFO would for example be better fit to formalize, understand and explain structures and behaviors of the enterprise. BORO according to its origin would be better fit to engineer or re-engineer enterprise structures. However, the modeling enigmas above demonstrate that both ontologies expand their original purposes. eUFO's advantage of having a high semantic preciseness and richness of concepts could prove very practical in re-engineering or optimizing the business organization and its operations. BORO's integrated approach and the simplicity towards objects and processes can be used to deliver a general overview of the whole organization and all of its components. With these first observations we intend to conduct further research on this topic, by identifying different kind of purposes and uses of enterprise models, and associating them with ontologies.

5 Conclusion

The enterprise modeling enigmas above demonstrate that there are some great differences between the ontologies eUFO and BORO. Since each has a different foundational view of the real world, the resulting enterprise model will also be different. We argue that a modeler will benefit from a better understanding and comprehension in ontologies and the modeling variations they bring about. This should also lead to a more motivated choice of an ontology. These modeling variations were demonstrated when applying both BORO and eUFO to the enterprise modeling enigmas above, resulting in rather different representations of the real world.

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