Design of an empirical study to measure the comprehension of 3D and 4D ontology-driven conceptual models

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Abstract. In this paper, we describe the hypotheses and the design of an empirical study to investigate the impact of adopting a 3D and a 4D foundational ontology on the pragmatic quality of a conceptual model. More specifically, we intend to measure the impact of the metaphysical characteristics of an ontology on the comprehension and understandability of the ontology-driven models by its users. Our research aims to make the following contributions: (1) while much effort in ontology-driven conceptual modeling (ODCM) has been devoted into the syntactic and semantic aspects of models for improving their overall quality, this research focuses on the pragmatic aspect of a model; and (2) since little empirical research has yet been performed in this area, we plan to perform an empirical study in order to investigate the fundamental differences between 3D and 4D ontology-driven models.

1 Introduction

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 [1]. Since a conceptual model is used as a communication, analysis and documentation tool for domain knowledge and system requirements, the quality of the model affects the quality of a developed system or process [2]. Lindland et al. (1994) define model quality in three aspects: syntactic quality, semantic quality and pragmatic quality. While s*yntactic quality* corresponds to the syntactic correctness of a model, the *semantic quality* of a model relates to the validity and completeness of a conceptual model. The last aspect, *pragmatic quality* concerns the comprehension of conceptual models. The better a model is understood, the higher the pragmatic quality of the model, and hence the higher the overall quality of the conceptual model. As a way to improve the quality of conceptual models, ontologies were introduced. An ontology provides a foundational theory, by means of a formal specification of the semantics of models and describe precisely which modeling constructs represent which phenomena [4]. In particular, foundational ontologies are frequently applied since they describe general concepts like space, time and matter, and are independent of a particular problem or domain. In this paper we refer to all techniques where ontologies 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).

Different kind of ontologies can be applied in order to perform ODCM. For example, 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 contrary, see individual objects as four-dimensional, having spatial and temporal parts, and exist immutably in space-time [5]. Although for example the study of [6] has already demonstrated that applying different ontologies can lead to diverse kinds of conceptualizations, there exists little research that profoundly investigates the impact of applying these different kinds of ontologies on the resulting models. Furthermore, while ontologies were introduced to increase the overall quality of conceptual models, past research has mainly emphasized the semantic quality of models, and has spend little effort in examining the pragmatic quality of these models [7].

Therefore, we decided to commence a research project with the goal to investigate these research gaps by (1) assessing the impact of adopting two different ontologies; and (2) measure the corresponding influence of these different ontologies on the pragmatic quality of the models. In a first research effort [8], we theoretically examined the model variations that resulted from constructing different enterprise models with a 3D and a 4D ontology. Since the resulting representations differed quite substantially from one another, we decided to further investigate these differences in an exploratory study [9]. More specifically, the exploratory analysis focused on the comprehension and understandability of ontology-driven models that were developed by either the 3D or 4D ontology. Our results confirmed that the conceptualizations that were realized by the different ontologies have a considerable impact on the understanding and comprehension on its users. Furthermore, the findings suggested that depending on the metaphysical characteristics of an ontology, some ontology-driven models are perceived as more easy or difficult to comprehend.

However, since this was only an exploratory analysis, we aim to perform a more thorough research effort, which rigorously investigates the effects of applying different kinds of ontologies on the interpretation of their resulting models. Further, because of the lack of empirical research that has yet been performed in ODCM [7, 10], we intend to conduct an empirical study. Therefore, as the foundation for the further development of the research project, we formulate our research question as follows: *In which degree is the pragmatic quality of ontology-driven models influenced by the choice of a particular ontology, given a certain understanding of the ontology?* In other words, we are going to investigate the influence of ontology on the understanding of the resulting conceptual models, taking into account the pre-existing knowledge a person has of the respective ontology. In order to formulate a proper answer, this broad research question is translated into a set of hypotheses. The testing hypotheses will be formulated in section 2. Next, we will draft our experimental design that we would apply to test these hypotheses in section 3. Finally, we conclude this paper in section 4.

2 Hypotheses Development

We can distinguish between different kinds of ontologies by regarding their metaphysical characteristics. The metaphysical characteristics of an ontology define its philosophical concepts and structures such as space, time, matter, object, event, action, etc. and how these concepts interrelate with one another [11, 12]. Every ontology has their own metaphysical characteristics and represents real world phenomena in their specific way. For instance, we can make a distinction between 3D and 4D ontologies. More specifically, the main differences between 3D and 4D ontologies can be translated according to the ontological interpretation of the following metaphysical characteristics:

- *The notion of identity and essence defining properties*: this characteristic defines how the ontology assigns a principle of identity to it's entities and how the principle of identity deals with temporary conditions such as roles, states and phases of an element.
- *The formation of relations*: describes how elements form relationships between different entities and how entities can become part of each other or separate from one another.
- *The perception and endurance of time*: defines how entities begin and cease to exist over time, and how they perceive events and changes over time.

Depending on these characteristics, an ontology can emphasize certain elements or structures such as time or identity, which can then influence the final representation of a conceptualization. For example, in the theoretical research of Al Debei (2012), the 3D object-role modeling (ORM) paradigm was analytically compared to the 4D object paradigm (OP). The conducted comparison reveals that the OP paradigm can provide semantically richer representations of phenomena than the ORM paradigm. Also [6] and our initial research effort [8], theoretically examined the way in which a 3D ontology and a 4D ontology represent temporal changes, concluding that each of the ontologies can lead to different representations and interpretations. As such, based upon the related research and our own previous research efforts [8, 9] we formulate **three hypotheses**:

- *H_1: The notion of identity and essence defining properties is more difficult to comprehend with 3D ontology-driven models than with 4D ontology-driven models, given a certain understanding of the respective ontology*. As also pointed out by Krieger et al. (2008) and Pease & Niles (2002), 3D ontologies have more difficulty with the identification of essential properties that hold over some period of time than 4D ontologies.
- *H_2: The formation of relations between entities is more difficult to comprehend with 4D ontology-driven models than with 3D ontology-driven models, given a certain understanding of the respective ontology.* In our exploratory analysis [9], feedback of subjects reported that the representation of relationships in the 4D ontology-driven models were difficult to comprehend and felt unnatural to several of our subjects. Similar remarks about the counterintuitive feeling of the space-time continuity were also mentioned in Pease & Niles (2002).
- *H_3: The perception of time is more difficult to comprehend with 3D ontology-driven models than with 4D ontology-driven models, given a certain understanding of the respective ontology.* As mentioned by Hales & Johnson (2003), 4D ontologies emphasize the continuity of objects over space-time and should thus be more suitable to represent time-related concepts. Also de Cesare et al. (2015) illustrated in their research how a 4D ontology is more appropriate to represent temporality and modality in the form of roles.

3 Experimental Design

In this section we will outline our experimental design in order to test the hypotheses above. The experimental design is based upon the work of Wohlin et al. (2012). We first define our variables that will be tested. Next, we specify the selection of our subjects. Finally, we explain the choice of our experimental design type, which is composed of an experiment and a protocol analysis.

3.1 Variable development

Independent Variables: In our study, the independent or affecting variables constitute of the ontologies that were chosen to construct the ontology-driven models. In other words, in our experimental setting, we can control if we either assign our test subjects with 3D ontology-driven models or 4D ontology-driven models. More specifically, we decided to work with UFO (i.e. a 3D ontology) [17] and BORO (i.e. a 4D ontology) [18] in our experiment. Both ontologies are used in the context of ODCM and are both foundational ontologies. Foundational ontologies are independent of a particular problem or domain. On the contrary, domain ontologies describe a hierarchical structure of concepts within a specific domain, like medicine or automobiles. By comparing foundational ontologies, a subject has no additional advantage of expertise in a certain domain.

Dependent variables: Model comprehension can be measured with several different approaches. A first approach is a direct measurement of the model comprehension. For example, akin to our purpose, the research studies of [19, 20] also compared the comprehension and understandability of different kinds of models that were constructed with different development techniques. In order to measure the comprehension and understandability of these models, they distinguish between different kinds of questions: comprehension and problem-solving questions. While the *comprehension questions* assess a basic level of model comprehension, the *problem-solving questions* are more challenging and target a deeper level of model comprehension from the subjects. Similarly, we will also measure the model comprehension of our ontology-driven models by differentiating between comprehension and problem-solving questions. A second, more indirect approach to measure model comprehension is by assessing the *amount of time* needed to understand the models. Measuring the time required for subjects to comprehend the different models allows us to estimate which models were perceived as more difficult or more easy to comprehend with respect to other models. Finally, we intend to measure the model comprehension by assessing the perceived ease of use, expressed as the *ease of interpretation* (EOI). The EOI aims to assess the amount of effort a subject had to spend in order to interpret the model or its related tasks. The reliability and validity of this variable has already been proven in several research efforts [21, 22]. In our experiment, we will link the EOI questions to the comprehension and problem-solving question in order to discover which comprehension tasks were the most difficult to answer.

Control Variable: Since we will be testing users' comprehension of 3D and 4D ontology-driven models, we need to be certain that all subjects have an equal understanding of the 3D or 4D models they are dealing with. Therefore, we need to assure that the interpretation of a certain model can be linked to the ontology that was applied to construct the model, and not to a limitation of the subject's knowledge of the ontology-driven models. As such, we apply a control variable to test every subject's knowledge and understanding of the ontology-driven models, before the start of the experiment. This control variable will be incorporated into the analysis of our results, and will be applied to measure the effect of a subjects' knowledge of the ontology (and respectively the associated paradigm) and the comprehension of the derived models.

3.2 Subject Selection

The subjects in our study all had prior experience and education in the domain of conceptual modeling, and were either completing their Masters or PhD at the University of Ghent. We decided to select students as our test subjects since they have no prior knowledge of ontologies, and can thus be seen as a 'tabula rasa'. Consequently, we can train them with an ontology and a new paradigm without the interference of any pre-used paradigm of another ontology. This allows us to measure the full impact of the comprehension of the ontology-driven models. Furthermore, all subjects were around the same age (i.e. mid twenties) and the majority of our subjects have a business-oriented background. This specific selection thus leads to a controlled sample of subjects with the same level of experience in conceptual modeling and with no prior knowledge about any of the ontologies that were applied in the empirical study.

3.3 Experimental Design Type

Similar to the research of [23, 24], two empirical studies were designed to test our formulated hypotheses. Our design can be divided into two phases: in the first phase we will conduct an experiment with the purpose to generate a significant amount of data to test our hypotheses. The second phase will perform a protocol analysis, as an in-depth analysis in order to provide additional insights into the nature of our results. While the experiment will be performed on a larger scale with more subjects, the protocol analysis will be performed with a smaller set of subjects, since the goal of the protocol analysis is not to produce data but to acquire knowledge about how subjects perceive the experiment.

Experiment

An experiment consists of a series of tests of different treatments. To get the desired results to answer our research question, the series of tests must be carefully planned and designed. The design of our experiment is based upon the testing hypotheses we developed earlier. From these hypotheses, we can derive two treatments: a BORO treatment and a UFO treatment. The series of test in each treatment constitute of the different models that each emphasize a specific metaphysical characteristic. Our subjects are thus divided into two different treatments, where each treatment submits the subjects to similar tests where the comprehension of the models is measured. We have assigned the subjects to these treatments according to the *balancing design principle* [16]. By balancing the treatments, we assign an equal number of subjects to each separate treatment, to arrive at a balanced design. Balancing is desirable since it both simplifies and strengthens the statistical analysis of the data.

The design type of our experiment is a *two factors with two treatments* design, meaning that we compare the two treatments against each other with one independent variable (i.e. model comprehension), taken into account the control variable (understanding of the ontology). Our design will also be completely randomized, meaning that subjects will be allocated randomly to either one of the treatments. Each subject also takes part in only one treatment. Most commonly, the means of the dependent variable for each treatment are compared. We will thus assign scores to the different measures of the dependent variable, i.e. the comprehension questions, the problem-solving questions, the amount of time required to solve the task and the ease of interpretation questions, in order to compare our two different treatments objectively.

Protocol Analysis

A protocol analysis is a research method that elicits verbal reports from research participants. The data obtained from a protocol analysis method reveals the mental processes taking place as individuals work on the interpretation of the models. Subjects are required to verbalize their thought processes and strategies, as well to verbalize their answers to the comprehension, problem solving and EOI questions. These verbal reports and the progress of the subjects are closely monitored by the researcher guiding the treatment. A protocol analysis thus allows us to closely monitor the interpretation of the models by the subjects, and carefully register the model comprehension of each individual subject.

Therefore, after the experiment has been conducted, we will perform the protocol analysis on a new set of subjects, in the exact way as our experiment but with the purpose to better understand the outcome of our results. By performing the experiment in the form of a protocol analysis, we can observe in which phases of the experiment subjects experience any breakdowns or difficulties. As such, this allows us to better understand the nature of our results, and give a more detailed explanation to the results of our hypotheses. The protocol analysis will be performed on new subjects, since performing the protocol analysis with the same subjects would alter the results since they have already performed the experiment before.

4 Conclusion and future research

This paper carefully structures and describes the hypotheses and design of an empirical study that would investigate the impact of adopting a 3D and a 4D foundational ontology on the pragmatic quality of a conceptual model. More specifically, this study intends to measure the impact of the metaphysical characteristics of an ontology on the comprehension and understandability of the ontology-driven models by its users. As the next phase in this research project, we are preparing and identifying subjects to participate in our empirical study. Furthermore, in order to enhance the external validity of the empirical study, we intend to participate with foreign universities in order to achieve a more diverse subject group.

5 Bibliography

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