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Multi-level ontology-based conceptual modeling

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ABSTRACT

Since the late 1980s, there has been a growing interest in the use of foundational ontologies to provide a sound theoretical basis for the discipline of conceptual modeling. This has led to the development of ontology-based conceptual modeling techniques whose modeling primitives reflect the conceptual categories defined in a foundational ontology. The ontology-based conceptual modeling language OntoUML, for example, incorporates the distinctions underlying the taxonomy of types in the Unified Foundational Ontology (UFO) (e.g., kinds, phases, roles, mixins, etc.). This approach has focused so far on the support to types whose *instances are individuals* in the subject domain, with no provision for *types of types* (or categories of categories). In this paper we address this limitation by extending the Unified Foundational Ontology with the MLT multi-level theory. The UFO-MLT combination serves as a foundation for conceptual models that can benefit from the ontological distinctions of UFO as well as MLT's basic concepts and patterns for multi-level modeling. We discuss the impact of the extended foundation to multi-level conceptual modeling.

1. Introduction

Conceptual modeling is the activity of formally describing some aspects of the physical and social world around us for the purposes of understanding and communication [1]. It is generally considered a fundamental activity in information systems engineering [2], in which a given subject domain is described independently of specific implementation choices [3]. The main artifact of this activity is a conceptual model, i.e., a specification aiming at representing a conceptualization of the subject domain of interest.

Since the late 1980s, there has been a growing interest in the use of foundational ontologies to provide a sound theoretical basis for the discipline of conceptual modeling [4–6]. The initial hypothesis, which was later confirmed by different empirical evidence can be explained by the following arguments: (i) conceptual models are artifacts produced with the aim of representing a certain portion of reality according to a specific conceptualization; (ii) foundational ontologies describe the categories that are used for the development of these conceptualizations. Therefore, an appropriate conceptual modeling language should provide modeling primitives that reflect the conceptual categories defined in a foundational ontology. This

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observation has led to the development of approaches for conceptual modeling based on foundational ontologies. An example of such an approach is OntoUML, which is based on the Unified Foundational Ontology (UFO) [3].

In OntoUML, the taxonomy of types of the Unified Foundational Ontology (UFO) has been reflected in the language such that the distinctions of the foundational ontology can be used to provide useful constraints and modeling guidelines, ultimately leading to ontologically well-founded conceptual models. The resulting conceptual models consist of a collection of *types (classes) of individuals in the subject domain* (e.g., the "Person" kind, the "Child" phase, the "Student" role). Each of these domain types instantiate types in the foundational ontology (e.g., kind, subkind, role, phase, etc.).

The approach is so far unable to describe subject domains in which the categorization scheme itself is part of the subject matter. In these subject domains, experts make use of categories of categories in their accounts. For instance, considering the domain of human resource management, organizations are often staffed according to *employee types* (e.g. "Engineer", "Pilot", "Secretary"). They may need to classify those *employee types* giving rise to *types of employee types*. In this case, "Engineer" and "Pilot" could be considered as examples of "Technical Employee Type", as opposed to "Secretary" which is an example of "Administrative Employee Type". Finally, they need to track the allocation of personnel to specific departments (e.g., to capture the fact that John is an Engineer in the Maintenance Department). Thus, to describe the conceptualization underlying this domain, one needs to represent entities of different (but nonetheless related) classification levels, such as *individual persons* ("John"), *employee types* ("Engineer", "Pilot", "Secretary"), and *types of employee types* ("Technical Employee Type", "Administrative Employee Type").

The need to support the representation of subject domains that deal with multiple classification levels has given rise to what has been referred to as multi-level modeling [9,10]. In order to address the challenge of multi-level modeling, we have proposed in [11] a theory called MLT. MLT formally characterizes the nature of classification levels, and precisely defines the relations that may occur between elements of different classification levels, encompassing different notions of power type [12,13]. Here, we apply MLT to UFO, in order to extend its applicability to domains that require multiple levels of classification. Conceptual models built with the UFO-MLT combination benefit from the ontological distinctions of UFO as well as the basic concepts and patterns for multi-level modeling of MLT.

This paper is an extension of a paper presented at the 2015 edition of the International Conference on Conceptual Modeling (ER 2015) [14]. It deals with a larger fragment of UFO, and provides a fuller treatment of modeling rules and patterns that arise from the combination of UFO and MLT. It is further structured as follows: Section 2 presents a fragment of UFO and its implication to ontology-based conceptual modeling; Section 3 presents the MLT multi-level modeling theory; Section 4 discusses the combination of MLT and UFO to provide foundations for ontology-based multi-level modeling; Section 5 identifies guidelines for multi-level conceptual modeling that arise from the foundational ontology; Section 6 positions the combined foundations with respect to the existing work on multi-level conceptual modeling and finally Section 7 presents concluding remarks and topics for further investigation.

2. Ontological foundations for conceptual models

The Unified Foundational Ontology (UFO) is a domain independent system of categories aggregating results from disciplines such as Analytical Philosophy, Cognitive Science, Philosophical Logics and Linguistics. Over the years, UFO has been successfully employed to analyze all the classical conceptual modeling constructs including Object Types and Taxonomic Structures, Part-Whole Relations, Intrinsic and Relational Properties, Weak Entities, Attributes and Datatypes, etc. [3,7]. Here we present a fragment of UFO that is relevant for this article. An in-depth discussion, formal characterization and discussion regarding empirical support for UFO's categories see [3].

2.1. Key concepts

UFO begins with a distinction between *universals* and *individuals*. Universals are patterns of features that can be realized in a number of individuals. For example, "John" and "Mary" are individuals that instantiate the universals "Man" and "Woman" respectively. UFO includes a taxonomy of individuals and a taxonomy of universals.

The topmost distinction in the taxonomy of individuals is that between endurants and events. Endurants (as opposed to events) are the individuals said to be wholly present whenever they are present, i.e., they can endure in time, suffering a number of qualitatively changes while maintaining their identity (e.g., a house, a person). Since in this paper we are especially interested in a portion of UFO that accounts for structural (as opposed to dynamic) aspects of conceptual modeling, we focus solely on endurants. Endurants are further classified into *Substantials* and *Moments*. *Substantials* are existentially independent endurants (e.g. a person, a forest). A moment, in contrast, is an endurant that *inheres in*, and, therefore, is existentially dependent of, another endurant(s). Moments that are dependent of one single individual are *Intrinsic Moments* (e.g. a person's age) whereas moments that depend on a plurality of individuals are instances of *Relator* (e.g. a marriage, an employment, an enrollment).

Intrinsic moments in UFO are further classified into: (i) those that are measurable and directly related to some quality structure are termed *Qualities* (e.g. a car's weight has a measurable value in a one-dimensional structure of positive numbers). In contrast, intrinsic moments not directly related to measure structures are termed *Modes* (e.g., a person's skills, intentions, beliefs or symptoms).