Conceptual Modeling of Formal and Material Relations Applied to Ontologies

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Abstract. *Ontologies represent a shared conceptualization of a knowledge community. They are built from the description of the meaning of concepts, expressed through their attributes and their relationships. Relationships are used to describe how the concepts are structured in the world. This work reviews the literature on formal and material relations, especially on mereological and partonomic relations, and proposes an alternative for the conceptual modeling of such relations in a domain ontology. This alternative has been made available in the ontology building tool of the Obaitá Project.*

1. Introduction

This work falls in the area of Conceptual Modeling and Knowledge Engineering, focusing on the ontological foundations and conceptual modeling of relations applied to ontologies.

Ontology represents a shared conceptualization that includes concepts, its attributes and the relationships between the concepts. In addition to the subsumption relationships that build the taxonomies of concepts, other formal and material relations assist in structuring the domain and the conceptual definition. The main existing modeling tools, such as Protégé, WebODE and others, however, are still deficient in differentiating the various types of formal and material relationships in order to assign the possibilities of automated reasoning.

Obaitá Project is a tool for collaborative construction of visual domain ontologies based on foundational ontology. Continuing the development of the Obaitá ontology building tool, this work provides support to the ontological foundations of the relations, enforcing ontological consistency and providing visual component support into the ontology relations.

The main goals of this research project include providing:

- foundation ontological constructs to support the ontological choices of the kinds of relations through the semantic expressiveness of a foundational ontology, especially the formal (mereological and partonomic) and material relations;

- support to the inference of the ontological meta-type of the relations based on the meta-types of the respective related concepts;

- visual ontological constructs to represent the visual knowledge about relations among the ontology concepts, supporting imagistic domains;

- intuitive interface which, through the use of natural language, does not require users to have any prior knowledge of ontological representation formal languages.

Following, in Section 2, we present an overview of ontology and relations; in Section 3, we present an analysis on some of the main ontology building tools; in Section 4, we present our implemented solution; in Section 5, we present an example of use of the system; and finally, in Section 6, we present our conclusions about this work.

2. Ontology and Relations

In recent years, there has been a growing interest in the use of foundational ontologies for evaluating conceptual modeling languages, developing guidelines for their use and providing real-world semantics for their modeling constructs (Guizzardi and Wagner, 2010). One of the main foundational ontologies is UFO (Unified Foundational Ontology), which is divided into three incrementally layered compliance sets: UFO-A defines the core of UFO, as a comprehensive ontology of endurants; UFO-B defines, as an increment to UFO-A, terms related to perdurants; UFO-C defines, as an increment to UFO-A and UFO-B, terms related to the spheres of intentional and social entities (Guizzardi et al., 2007).

The importance of conceptual relationships is highlighted by (Bala and Aghila, 2011) when they state that relationships are fundamental to express semantics in ontology in order to associate concepts and associate instances. Relationships are defined according to their properties, like reflexivity, symmetry, transitivity. As argued in (Guarino, 2009) and (Grenon, 2003), relations can be divided into two broad categories, namely *formal* and *material* relations. Formal relations hold between two or more entities (*relata*) directly, without any further intervening individual. Figure 1 exemplifies a formal relation between alcohol and wine, where alcohol is part of wine.

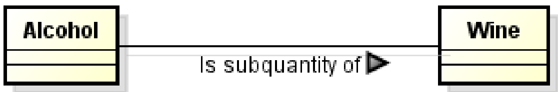

Figure 1. An example of formal relation.

Four sorts of conceptual formal part-whole relations are defined in (Guizzardi, 2005) with different semantics, based on the type of the related entities: component-of relates individuals that are functional complexes, subquantity-of relates individuals that are quantities, subcollection-of relates individuals that are collectives, and member-of relates individuals that are functional complexes or collectives (as part) and a collective (as a whole).

Parthood relationships are especially important for modeling visual knowledge, since the object recognition by cognitive systems that support vision is strongly based on composition and decomposition operations.

Unlike formal relations, material relations have material structure of their own and include examples such as working at; for a material relation of being treated in between Paul and a medical unit to exist, another entity must exist which mediates Paul and the medical unit. These entities are named *relators* (Guizzardi and Wagner, 2010). Figure 2 depicts an example of material relation between employee and company (*relata*), where, if an employee works for a company, another entity (*relator*), such as employment, must exist in order to mediate them.

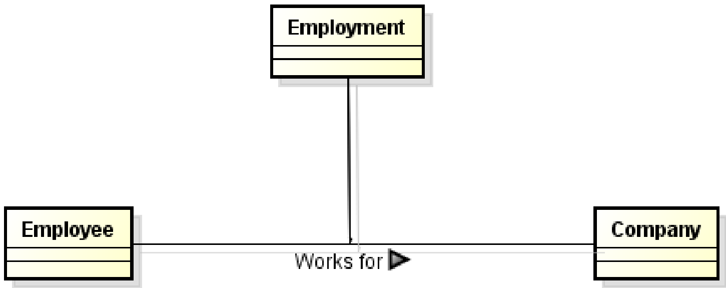

Figure 2. An example of material relation.

3. Relations in Ontology Building Tools

The main ontology building tools, such as Protégé and WebODE, among others, provide different support for specifying the ontology relations.

3.1. Protégé

Protégé 4 (Horridge et al., 2007) can compute subsumption relationships between classes, and detect inconsistent classes. It can be computed automatically by a reasoner. Binary relations, linking two individuals together, are represented by slots.

Properties describe binary relationships. There are two main types of properties: datatype properties and object properties. Datatype properties describe relationships between individuals and data values, and object properties describe relationships between individuals. Object properties may define some characteristics, such as functional, inverse functional, transitive, symmetric, asymmetric, reflexive, irreflexive.

Properties may present some restrictions, which fall into three main categories: quantifier, cardinality and hasValue restrictions. The quantifier restrictions effectively put constraints on the relations that the individual participates in. It does this by either specifying that at least one kind of relationship must exist (existential restrictions), or by specifying the only kinds of relationships that can exist (universal restrictions). The cardinality restrictions are the number of relationships that an individual may participate in for a given property. Cardinality restrictions may specify the minimum and the maximum cardinality restrictions. The hasValue restrictions describe the class of individuals that have at least one relationship to another specific individual.

3.2. WebODE

WebODE (Arpírez et al., 2001) allows the post-processing of the ontology, using the OntoClean methodology for identifying incorrect taxonomic (is-a) relations. WebODE works with both built-in relations and ad-hoc relations.

Built-in relations are predefined relations related to the representation of taxonomies of concepts and mereology relationships between concepts. They are divided into three groups: taxonomical relations between concepts, taxonomical relations between groups and concepts, and mereological relations between concepts. The taxonomical relations between concepts have two predefined relations: subclass-of and not-subclass-of. Single and multiple inheritance are allowed. The taxonomical relations between groups and concepts have two predefined relations: disjoint-subclass-partition and exhaustive-subclass-partition. The mereological relations between concepts have two predefined relations: transitive-part-of and intransitive-part-of.

Ad-hoc relations are characterized by their name, the source and target concepts name, and its cardinality. WebODE allows just binary ad-hoc relations to be created between concepts. The creation of relations of higher arity must be made by reification.

3.3. Remarks about the tools

Analyzing the available tools, we noticed that most of them have both implementation and user interface oriented to formal languages of representation, like OWL, making it harder for users who do not have this expertise to use them properly. We also noticed that these tools do not include ontological foundations or visual domains.

The analyzed tools do not provide adequate support to the ontological choice problem: how to choose the best primitives to represent the needed relations. These issues may produce different specifications for the same conceptual model, or result in different interpretations of the same model by different users. Likewise, the construction of the relations in the user mind is strongly based in visual knowledge, but this topic is still incipient for the main ontology building tools. In the next section we describe the solution that has been implemented in order to achieve the goals of this research project.

4. Implemented Solution

This work supports the relation ontological foundations (according to UFO-A), enforces ontological consistency, provides inference, and provides visual component support.

Relations are specialized in formal or material relations, as seen in Figure 3. Material relations contain a *relator* and two *relata*. Formal relations contain two *relata*. The *relata* are existing concepts from the domain ontology, and the *relator* is a relational moment. Formal relations may be further specialized as part-whole relations (component-of, member-of, subcollection-of or subquantity-of), enforcing the following constraints: component-of, both *relata* are functional complexes (kind), they have to be irreflexive, asymmetric and nontransitive, and they have weak supplementation; member-of, the whole individual is a collective, while the part can be either a collective or a functional complex (kind), they have to be irreflexive, asymmetric and intransitive, and they have weak supplementation; subcollection-of, both *relata* are collectives, they have to be irreflexive, asymmetric and transitive, and they have weak supplementation; and subquantity-of, both *relata* are quantities, they have to be irreflexive, asymmetric and transitive, they have strong supplementation, and they have to be nonshareable.

When editing a concept relation, it is possible to choose its name, its type (classification by UFO-A), the target concept, the source and target cardinalities, the *relator* (for material relations) and its icon (visual component). The source concept is automatically selected as the concept that is being viewed in detail in the system.

In order to help users to define the relation type, the system guides them by asking questions, without requiring users to have any knowledge of ontological representation. For example, if he/she answers the question telling the system that the relation needs the existence of a mediating entity, then the relation type is “material”.

The system also has the ability to infer the relation type based on the meta-types of the respective related concepts. For example, if the meta-type of both related concepts is “quantity”, then the relation type is “subquantity-of”. Next, we present an example of use through a real domain ontology, from the Sedimentary Stratigraphy area, in order to evaluate our research project proposed approach.

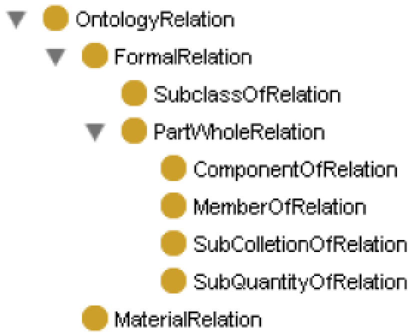

Figure 3. The meta-ontology relation structure.

5. Example of Use

In order to validate the system in a real environment, we brought an example of use in the Sedimentary Stratigraphy domain, an area of Geology responsible for studying the formation processes of sedimentary rocks. In (Lorenzatti et al., 2010), a domain ontology was built with the help of experts, serving as the basis for initiating the system. This domain has been chosen because it presents some important aspects for our focus: it is strongly based on visual knowledge; its structure is complex; and it has scientific and economic relevance, studying the generation and depositional conditions of important mineral deposits, such as coal and oil.

From this example of use, we intend to evaluate the approach proposed by our research project, considering the following parameters:

- Total of existing relations: "before" and "after" the activities performed by the geologists, classified by relation type (only "after" the activities performed by the geologists; the previous ontology relations were not based on ontological foundation).

- Total of changes performed on the relations: added relations, updated relations and removed relations, classified by relation type.

After these evaluations, then it will be possible to identify the contributions and resulting benefits from this research project approach regarding the ontological consistency of the created ontology concept relations. In the next section, we present our conclusions and some open possibilities for future improvement of this work.

6. Conclusions

The main contributions of this work include the definition of the ontological relations based on a set of metadata, providing specialized ontological constructs for creating the domain ontology relations and supporting the inference of the relation ontological meta-types. The ontology building environment is independent of the representation formal languages, providing intuitive interface so that users do not need any previous ontological representation knowledge in order to interact with the ontology. Some constructs allow the association of icons in order to obtain a higher domain understanding. This work takes in consideration the importance of the relation ontological foundations and the visual knowledge as supporting instruments.

As a result of our researches, our ontology building tool is constantly under improvement; we keep adding important features on its implementation, which many of them we do not find on most of the other tools. Thus, this specific research project has fundamental importance, continuing the evolution of an innovative tool for both academic and commercial purposes. An extensive evaluation on the modeling of the ontology relationships still has to be performed, as described in the previous section. Its benefits have already become explicit through the conceptual and intuitive approach added to the tool. The capabilities of the proposed metadata model will be assessed through a practical application by the construction of an ontology for the Sedimentary Stratigraphy domain from Geology.

This work can be considered as a step for future work in order to complement the ontological foundation of relations into the Obaitá ontology building tool, such as taking in consideration the taxonomic relations and the temporal relations.

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