Ontology Composition using a Role Modeling Approach

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Abstract: There is an increasing use of ontologies to represent domain knowledge, however, no notion of ontology components has so far been established. This lack hampers partial reuse of ontologies and makes a reuse-oriented engineering approach difficult. We propose to enable component-based ontology engineering by bringing together ontologies and role modeling, a well-known modeling paradigm from the object-oriented software community. Ontological role models provide an intuitive reuse unit, ontology components, and allow for a clearer and more natural way of modeling.

1 Introduction

An ontology is a model used to capture and represent knowledge by describing the concepts of a domain and relations between them. Ontologies are employed in artificial intelligence, software engineering, and biomedical informatics, as well as in the semantic web [BLHL01] to enhance web content with semantics. The distinguishing feature of an ontology compared to other knowledge representation mechanisms is its underlying formalism. Most ontology languages are based on Description Logics [BCM$^+$03] that allow, for instance, to derive new knowledge from existing one and check the consistency of a given knowledge base.

A major question discussed in the research community is how to enable (partial) reuse of ontologies in order to built new ontologies from existing parts. One of today's most important ontology languages is the Web Ontology Language OWL, standardized and recommended by W3C [DS04]. Unfortunately, it provides very limited reuse mechanisms, namely *linking* and the *owl:imports* construct, that seem to be inflexible in the kind of reuse they provide, in particular regarding the granularity of components.

Our proposed solution makes use of *role modeling*, a well-known concept from object-oriented software engineering [Ree96, Ste00, Rie00]. The main idea is that objects can be abstracted in two ways. One abstraction regards their inherent properties and classifies them accordingly. This yields *natural types*, or classes, the major modeling concept in object-oriented software development as well as in ontologies. The other abstraction analyzes how objects collaborate in order to achieve a specific goal and leads to *role types* [Sow84]. *Person* for example is a natural type, while *Parent*, *Child*, or *Teacher* are role types. Related role types can be joined to a *role model*, a self-containing component describing one particular collaboration between objects.

This work tries to solve the problem of limited reuse in ontologies with the help of role modeling. We present *ontological roles* and *ontological role models* [PHA07], an extension of ontologies able to improve modeling and provide means for reuse. Our main contributions are:

- The conceptual idea of ontological roles illustrated by examples.
- Definition of ontological roles and role models on a conceptual and formal level.
- A methodology for role-based ontology engineering (omitted here).
- A syntactical extension of the Web Ontology Language OWL and translational semantics accompanied by a usable implementation.

2 Using Roles in Ontologies

The exclusive use of classes in ontological modeling to abstract from similar individuals has a number of deficiencies. First, classes are relatively coarse-grained units of abstraction. This not only leads to complex classes, but also to advanced complexity of their relations. Second, ontology classes often merge properties from different contexts, that is, multiple concerns are mixed into one conceptual unit. Finally, high complexity of class relations and missing separation of concerns hamper ontology reuse and composition. We argue that these problems can be overcome by introducing roles into ontologies as an additional modeling concept.

In object-oriented software development, a role describes the *behavior* of an object in a certain context. In ontologies, though, there is no dynamism or behavior. Therefore, an ontological role describes context-dependent *properties*.

> **Definition: Ontological roles and role types**
> An ontological role describes the properties of an individual in a certain context. A set of roles with similar properties is abstracted by an ontological role type.

Based on this, we define what we consider a role model in an ontological setting.

> **Definition: Ontological role models**
> An ontological role model describes a set of related ontological role types and as such encapsulates common relationships between ontological roles.

The ontology in Figure 1 includes three classes *Wine*, *Winery*, and *Food* representing natural types (rectangles with gray background), as well as five roles types (rectangles with rounded corners and white background). The roles types can be grouped into the two role models *Product* and *Meal*. An individual of class *Wine* may appear in different contexts, for instance being a product produced by a winery, or being a drink that accompanies a

meal. Depending on the context, individuals play completely unrelated roles, and thus, we express them as role types *Product* and *Drink*. This separation of concerns leads to a clearer and more natural way of modeling. Furthermore, reuse is facilitated: E.g. *Product* appears in a self-containing role model with two more role types (*Consumer* and *Producer*) providing an ontological component that may be applied in other ontologies as well.

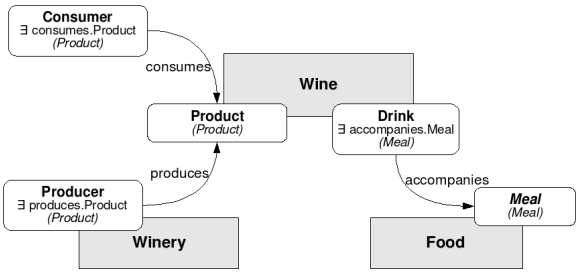

Figure 1: Different concerns of the *Wine* class are separated by the role types *Product* and *Drink*.

3 Semantics of Role-Based Ontologies

Description Logics (DLs) are the underlying formalism of most ontology languages. We therefore propose an extension of the $\mathcal{ALC}$ DL. In order to be able to use existing tools such as reasoners, we provide a translation from our extended DL syntax into standard DL.

We introduce two axioms into the $\mathcal{ALC}$ DL: The *role binding* axiom $R \rhd C$, where R is a role type bound to the class C, and the *role assertion* axiom $R(a)$ expressing that a specific individual a plays a role R.

The extended syntax may be translated to standard $\mathcal{ALC}$ (and thus, into a standard ontology language) by the following algorithm:

1. Make all imported role type definitions available as classes in the ontology.
2. For each role type R used in the ontology:
   (a) Let $\{C_1, \ldots, C_n\}$ be the set of classes to which R is bound ($R \rhd C_i$). Then add axiom $R \sqsubseteq C_1 \sqcup \cdots \sqcup C_n \sqcup \bot$ to the ontology.
   (b) For each role assertion $R(a)$, make the same assertion available in the resulting ontology, now referring to the class-representative for the role type R.
3. Remove all role binding axioms.

Also, we propose an extension of OWL using the Manchester OWL syntax [HDG+06] and provide its translational semantics [PHA07]. This translation has been implemented based on the Reuseware composition framework, that allows for extending arbitrary languages for invasive composition [HAJZ07].

4 Conclusion

Our work shows how roles can be used in ontologies. Ontological roles expose context-dependent properties of ontology classes, leading to models which are more explicit and less complex. Even more important, ontological role models constitute intuitive ontology units that can be reused. This paves the way toward component-based ontology engineering where ontology components are developed independently, shared, and reassembled.

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