Supporting Ontology Development with ODEd

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Abstract *Ontologies are becoming an important mechanism to build information systems. However, ontology construction is not a simple task. So, it is necessary to provide tools that support ontology development. This paper presents ODEd, an ontology editor that supports the definition of concepts, relations and properties, using graphic representations, besides promoting automatic inclusion of some classes of axioms and derivation of object infrastructures from ontologies. ODEd was built to support ontology development in ODE, a software engineering environment (SEE), so that ODE can be used as a domain-oriented SEE. Thus, ODEd aims to partially support an ontology-based domain engineering process.*

Keywords: *Ontologies, Domain Engineering, Ontology Editors.*

1 Introduction

Any software that does anything useful commits to a model of the relevant world. In other words, software systems implicitly or explicitly make commitments to a domain ontology [1]. As the importance of ontologies in computer science increases, better support for their development is needed.

Building ontologies is not trivial. It involves the specification of concepts and relations that exist in the domain, besides their definitions, properties and constraints, described as axioms [2]. Therefore, tools supporting ontology development are necessary. These tools must support definition of concepts, relations, properties, and constraints, and must enable the inspection, browsing, and codifying of the resulting ontologies [3].

In this paper, we present ODEd, an ontology editor designed to support ontology development in a software engineering environment called ODE (Ontology-based software Development Engineering) [4].

One great difficulty in software development is that, many times, developers are not familiarized with the domain in which the software is being developed. To deal with this problem, several research groups have proposed to improve and to evolve Software Engineering Environments (SEEs) to support software development considering peculiar characteristics of the domain, giving rise to Domain-Oriented SEEs (DOSEEs). DOSEEs are a special class of SEEs that uses domain knowledge to guide software developers across the several phases of the software process. DOSEEs organize the application domain knowledge facilitating problem understanding during system development [5].

In a DOSEE, it is necessary to define a model that turns explicit the basic conceptualization of the domain. Ontologies have been used for this propose and, therefore, ODEd was designed to support domain orientation in ODE [6].

ODEd partially supports the Ontology-based Domain Engineering Process described in [7], that considers ontology development (domain analysis), its mapping to object models (infrastructure specification), and Java objects implementation (infrastructure implementation). To support ontology development, ODEd allows the definition of concepts, relations and properties, using graphic representations, and the definition of some classes of axioms. To support domain design and implementation, ODEd allows the derivation of object infrastructures from ontologies in Java. Finally, to support domain investigation, ODEd offers mechanisms to browse the ontologies defined.

In section 2 we briefly discuss some aspects of the use of ontologies in software development. Section 3 discusses the ontology-based domain engineering process that underlies ODEd functionalities. Section 4 presents an overview of ODEd. Sections 5 and 6 discuss a study case using ODEd. Section 7 presents how ODEd supports domain investigation, allowing ontology browsing. Section 8 presents an infrastructure for ontology instantiation in ODEd. In section 9 we discuss related works. Finally, in section 10 we report our conclusion and future work.

2 Ontologies

People, organizations and software systems must communicate between themselves. However, due to different needs and backgrounds contexts, they can have different conceptualizations regarding the same subject matter. The way to solve this problem is to minimize conceptual and terminological confusion and come to a shared understanding of the domain of interest [8].

However, it is impossible to represent the real world, or even a part of it, with all its details. To represent a phenomenon or part of the world, which we call a domain, it is necessary to focus on a limited number of concepts that are sufficient and relevant to create an abstraction of the phenomenon at hand. Thus, a central aspect of any modeling activity consists of developing a conceptualization [9]. An ontology is an explicit specification of a shared conceptualization [10]. In this context, a conceptualization refers to an abstract model of how people think about things in the world, usually restricted to a particular subject area. An explicit specification means that concepts and relations of this abstract model are given explicit terms and definitions [11].

According to Guarino [12], "an ontology refers to an engineering artifact, constituted by a specific *vocabulary* used to describe a certain reality, plus a set of explicit assumptions regarding the *intended meaning* of the vocabulary words. This set of assumptions has usually the form of a first-order logical theory, where vocabulary words appear as unary or binary predicate names, respectively called concepts and relations. In the simplest case, an ontology describes a hierarchy of concepts related by subsumption relationships; in more sophisticated cases, suitable axioms are added in order to express other relationships between concepts and to constrain their intended interpretation".

Jasper et al. [13] classified applications of ontologies in four main categories, emphasizing that an application may integrate more than one of these categories:

- Neutral Authoring: an ontology is developed in a single language and it is translated into different formats and used in multiple target applications.
- Ontology as Specification: a domain ontology is created and it provides a vocabulary for specifying requirements for one or more target applications. The ontology is used as a basis for software specification and development, allowing knowledge reuse.
- Common Access to Information: an ontology is used to enable multiple target applications (or humans) to have access to heterogeneous sources of information that are expressed using diverse vocabulary.
- Ontology-based Search: an ontology is used for searching an information repository for desired resources, improving precision and reducing the overall amount of time spent in searching.

Analyzing these scenarios, we can notice that working with ontologies has several advantages. One of the main benefits of the use of ontologies in software development is to reuse domain specifications in the requirement specification phase. In traditional Software Engineering, for each new application to be built, a new conceptualization is developed. In an ontology-based approach, requirement elicitation and modeling can be accomplished in two stages. First, the general domain knowledge can be elicited and specified as ontologies. These ontologies are used to guide the second stage of the requirement analysis, when the particularities of a specific application are considered. This way, the same ontology can be used to guide the development of several applications [14]. In other words, ontologies can be used as basis for a domain engineering approach. In this context, ontologies can act as both a domain model and a component in a repository of reusable artifacts. Also, they can be used for structuring this repository.

One of the major drawbacks to a wider use of ontologies in Software Engineering is the lack of approaches to insert ontologies in a more conventional software development process. Since the current leading paradigm in Software Engineering is the object technology, to put ontologies in practice in software development, it is worthwhile to derive object models from ontologies, in order to derive widely reusable assets. Coding ontologies in object infrastructures may lead to reuse in several levels of software development: from analysis to project and implementation [7].

3 An Ontology-based Domain Engineering Process

Falbo et al. [7] proposed an ontological approach to domain engineering that considers ontology development (domain analysis), its mapping to object models (infrastructure specification), and Java components development (infrastructure implementation). The main goal of ODEd is to partially support this ontology-based domain engineering process.

3.1 A Systematic Approach for Building Ontologies

Since ontologies are used as domain models, ontology building must be considered. The ontology development process encompasses the following activities [2]:

- Purpose identification and requirement specification: it concerns to clearly identify the ontology purpose and its intended uses, that is, the competence of the ontology. To do that, competency questions [15] are used.
- Ontology capture: the goal is to capture the domain conceptualization based on the ontology competence. The relevant concepts and relations should be identified and organized. A model using a graphical language, with a dictionary of terms, should be used to facilitate the communication with domain experts.
- Ontology formalization: aims to explicitly represent the conceptualization captured in a formal language.
- Integration of existing ontologies: during the capture and/or formalization steps, it could be necessary to integrate the current ontology with existing ones, in order to seize previously established conceptualizations.
- Ontology evaluation: the ontology must be evaluated to check whether it satisfies the specification requirements. It should also be evaluated in relation to the ontology competence and some design quality criteria, such those proposed by Gruber [10].
- Documentation: all the ontology development must be documented, including purposes, requirements and motivating scenarios, textual descriptions of the conceptualization, the formal ontology and the adopted design criteria.

Figure 1 shows the steps in this ontology development process and their interrelationship. The dotted lines indicate that there is a constant interaction, albeit weaker, between the associated steps. The filled lines show the main workflow in the ontology building process. The box involving the capture and formalization steps enhances the strong interaction, and consequently iteration, between them.

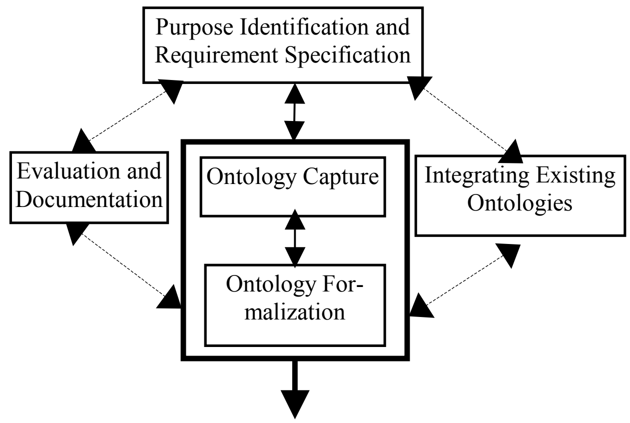


Figure 1: Steps in the ontology development process.

ODEd aims to support this process. It allows competency question definition, supports ontology capture by supporting the definition of concepts, relations and properties using graphical representations, and it lets defining some classes of axioms, among others.

3.2 From Ontologies to Objects

Generally, a domain model is not directly useful to operational reuse. There exists a gap between the kinds and forms of the domain knowledge in a domain model and the content and form of software assets that can be reused in software construction. To bring this gap, we need to build a reuse infrastructure. This infrastructure should support the efficient operation of a reuse system and should also be adapted to its technology [16].

The ontology-based domain engineering approach proposes a set of directives, design patterns and transformation rules for deriving object infrastructures from ontologies. The directives are used to guide the mapping from the epistemological structures of the domain ontology (concepts, relations, properties and roles) to their counterparts in the object-oriented paradigm (classes, associations, attributes and roles, respectively). Design patterns and transformation rules are applied in axiom mapping.

In the reuse infrastructure specification phase, the following activities are proposed:

- Set-based ontology axiomatization: to derive objects from domain ontologies, it is worthwhile to adopt a formalism that lies at an intermediate abstraction level between first-order logics and objects. For this purpose, a hybrid approach based on pure first-order logic, relational theory and, predominantly, set theory was proposed in [14]. So, the first step is to perform the complete axiomatization of the domain ontology using this set-based formalism.
- Class identification: starting from the sets formally defined, a preliminary list of the classes of the object-oriented model can be established;
- Epistemological structure translation: since the classes are defined, relations among concepts and epistemological axioms should be translated to the corresponding object-oriented structures, producing an initial class diagram;
- Other axiom translation: the class diagram derived in the step above should be refined to consider the others axioms that are not related to the structural organization of concepts and relations.

Finally, the reuse infrastructure should be implemented. The mapping directives and transformation rules proposed in [14] consider Java as the target programming language, so that the resulting reuse infrastructure is implemented as Java-objects.

ODEd partially supports this domain design and implementation process, leading to codifying ontologies in Java. In the next sections we present ODEd and how it partially supports this ontology-based domain engineering approach.

4 ODEd: ODE's Ontology Editor

As pointed out in section 1, ODEd was developed to support domain engineering in ODE (Ontology-based software Development Environment), so that ODE could be considered a Domain Oriented Software Engineering Environment (DOSEE). To do this, ODEd's requirements include [6]:

R1. *Competency question definition:* To support ontology purpose identification and requirement specification, ODEd should support competency questions definition.

R2. *Concept, relation and property definition using a graphical language*: During the ontology capture phase, the use of a graphical representation is essential in order to facilitate the communication between domain engineers and experts. Thus, ODEd should support the definition of concepts, relations and properties using a graphical language.

R3. *Axiom definition*: To support constraints capturing, ODEd should support axiom definition.

R4. *Ontology integration*: A domain is, usually, wide and rich in details. A way to build large domain ontologies is to subdivide them in sub-ontologies. So, it is necessary to integrate them. Also, ontology integration is necessary to allow reuse of ontologies previously defined.

R5. *Ontology evaluation*: it is important to guarantee that an ontology describes the domain it intends to model. Therefore, it is necessary to verify if the ontology is able to satisfy its requirements, i.e., its competency questions.

R6. *Documentation of the ontology development process*: like any software process, the ontology development process should be documented.

R7. *Ontology instantiation*: in DOSEEs, ontology instantiation is important because instances of domain concepts can be defined and stored in domain knowledge repositories, so that they can be used to support domain understanding.

R8. *Domain investigation*: in a DOSEE, during the software process, developers will use ontologies to learn about the domain. Therefore, ODEd should offer mechanisms to browse ontologies.

R9. *Generating software assets from ontologies*: To support domain design activities – reuse infrastructure specification and implementation, ODEd should support deriving reuse infrastructures from ontologies. If an ontology editor is capable of generating software assets from the ontology, these assets can be shared and reused by applications developed in the DOSEE. In this way, knowledge reuse is promoted, once the assets are built based on the ontologies and several applications can be developed using those assets.

ODEd implements a three-layered architecture, as shown in Figure 2. Basically, ontologies are developed through the *presentation layer* and they are described according to a model defined in the *domain layer*. The *data management layer* is responsible for the physical storage of the ontologies developed.

Figure 2: ODEd's Architecture.

This architecture uses a three-tier design philosophy that suggests that the central classes, in the domain layer, are not aware of how the ontologies are presented to the user (presentation layer) or stored in the system (data management layer). The portion of the system that handles the graphical representation of the ontologies (presentation layer) is independent from the rest of the architecture and it communicates with the domain layer. The data management layer provides the basic infrastructure for storing and retrieving objects in the system. Its purpose is to isolate the impacts of the technology of data management on the editor's architecture.

Since presentation and domain layers are very important for understanding ODEd's working, following they are discussed in more details.

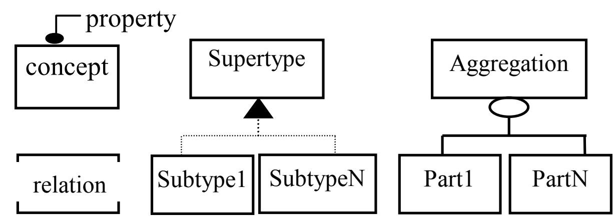
4.1 ODEd's Presentation Layer

The presentation layer supports the ontology capture using graphical representations (R2). In ontology building, a graphical representation is basically a language representing a meta-ontology. So, this language must have basic primitives to represent a domain conceptualization and, in its simplest form, it should have notations to represent concepts, relations and properties [2].

Falbo et al. [2] proposed LINGO as a graphical language for capturing ontologies. LINGO has basic primitives to represent concepts, relations and properties. In addition to these basic notations, LINGO has other notations to capture some types of relations (such as whole-part and subsumption, among others) that have a strong semantics and, indeed, hide a set of well-defined constraints. This is a striking feature of LINGO and what makes it different from other graphical representations: any notation beyond the basic ones aims to incorporate a set of well-defined constraints [2]. This way, using these notations, axioms are automatically incorporated to the ontology. These axioms concern simply the structure of the concepts and are called epistemological axioms (EA).

Figure 3 shows the main notations of LINGO and some of the epistemological axioms imposed by the whole-part relation. These axioms form the core of the mereological theory as presented in [17].

ODEd uses LINGO as a graphic language to describe ontologies, allowing the automatic inclusion of LINGO's notation built-in axioms. Using these notations during ontology capture, an ontology engineer is also defining the axioms that they represent.



(EA1) $\forall x \; \neg partOf(x,x)$

(EA2) $\forall x,y \; partOf(y,x) \leftrightarrow wholeOf(x,y)$

(EA3) $\forall x,y \; partOf(y,x) \rightarrow \neg \, partOf(x,y)$

(EA4) $\forall x,y,z \; partOf(z,y) \wedge partOf(y,x) \rightarrow partOf(z,x)$

(EA5) $\forall x,y \; disjoint(x,y \rightarrow \neg\exists z \; partOf(z,x) \wedge partOf(z,y)$

(EA6) $\forall x \; atomic(x) \rightarrow \neg\exists y \; partOf(y,x)$

Figure 3: LINGO's main notations and some axioms.

ODEd allows ontology capturing in UML too. UML has also been used as an ontology modeling language [18]. However, it is necessary to emphasize that there are some problems in using UML as an ontology modeling language. First, an important criterion to evaluate ontology design quality is minimum ontological commitments [10]. Based on this principle, an ontology modeling language must embody only notations that are necessary to express ontologies. This is not the case of UML and majority graphical languages available. Second, since ontologies intend to be formal models, it is important that the language used to describe them has formal semantics. Again, this is not the case of the majority graphical languages available, including UML [19]. However, we cannot ignore that UML is a standard and its use is widely diffused. Moreover, there are efforts to define UML semantics, such as pUML [20]. Based on that, ODEd uses a subset of UML's elements that plays the same role of LINGO's notation, i.e., these UML's elements are applied using the same semantics imposed by the corresponding elements in LINGO. For instance, the epistemological axioms imposed by the whole-part relation presented in Figure 3 are also automatically incorporated to the ontology by ODEd when the aggregation notation of UML is used. In fact, ODEd has its internal meta-ontology model, described in the domain layer, that could be presented using LINGO or UML.

Figure 4 shows the subset of UML's elements used in ODEd. Stereotyped classes (<<*Concept*>>) represent concepts. Relations are defined as labeled associations, and properties are represented as attributes. Relations that contain properties or relation of arity bigger than two are represented as stereotyped associative classes (<<*Relation*>>). Super-type and whole-part relations among concepts are represented as generalization/specialization and aggregation relationships, respectively.

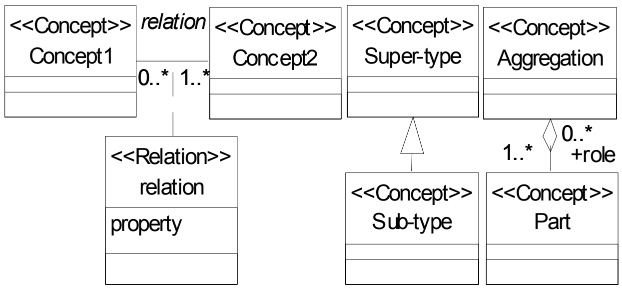


Figure 4: Subset of UML to represent ontologies.

ODEd allows the ontology engineer to choose the graphical representation to be used. The ontology can be captured in LINGO or UML, but this is only its graphical representation. The elements that capture the ontology in the domain layer are created independently of the graphical representation used. I.e., in spite of different presentation representations, the ontology domain model is the same. The presentation layer only provides an interface for capturing ontologies and improves modularity by encapsulating the way their contents are represented.

4.2 ODEd's Domain Layer

Figure 5 shows the domain layer's model, that describes how ontologies are internally represented in ODEd.

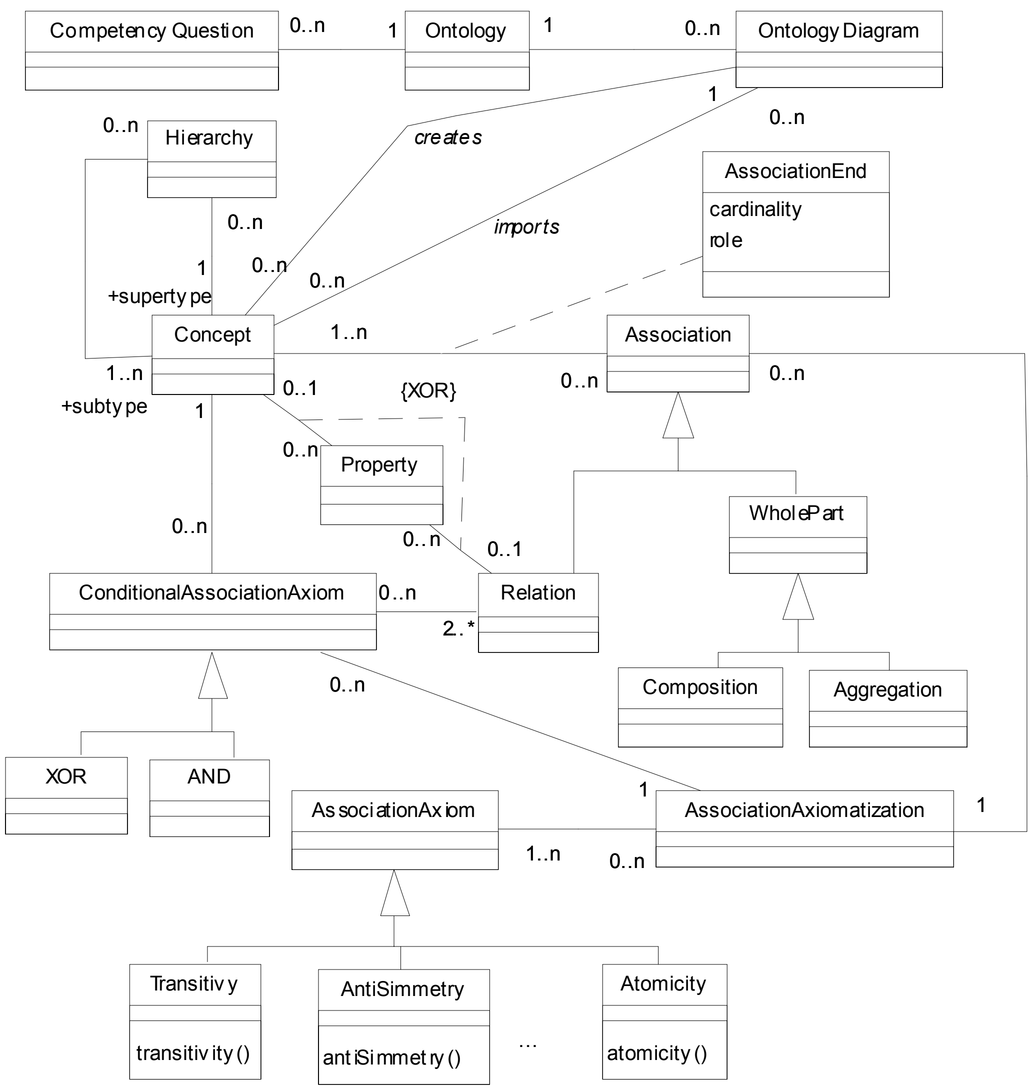


Figure 5: ODEd's Layer Domain Model.

The ontology purpose and its intended uses are identified through *competency questions*. An *ontology* is represented by a set of *ontology diagrams,* which contains *concepts created* in or *imported* to the ontology. Concepts are related through *associations* and *hierarchies*. Hierarchies denote subsumption relationships. Associations can be *relations* or *whole-part* relationships, which in turn are classified into *aggregation* and *composition*. Concepts and relations may have *properties* and in an *association*, concepts have *roles* and *cardinalities*.

Associations may have a set of constraints, expressed as *association axioms*, that defines the *association axiomatization*. Association axioms are classified into: *reflexivity, irrreflexivity, symmetry, anti-symmetry, atomicity, disjointed, exclusivity,* and *transitivity*. This categorization is based on the axiom categories proposed by Staab and Maedche [21]. Each association axiom is dealt by a subclass of `AssociationAxiom` (some of these classes are presented in Figure 5). These classes are responsible for checking if the constraints imposed by the corresponding axiom type holds. For instance, the `anti_symmetry()` method of the `AntiSymmetry` class is responsible for checking if a relation is anti-symmetric. It executes a method `relation()` (representing a relation among concepts) of an object `obj` (representing an instance of a concept). If `obj` is not returned by `relation`, then the anti-symmetry property is truth and the relation is anti-symmetric.

Sometimes, two or more relations have some conditional constraints related to a concept. This is the case of the associations involving `Property` in Figure 5. A property belongs either to a concept or to a relation. To deal with these situations, *conditional association axioms* (XOR and AND) were defined.

As discussed in the previous subsection, LINGO's notations have built-in axioms, called epistemological axioms (EA), and ODEd is able to automatically capture those axioms. For example, Whole-Part axiomatization includes the following association axioms: irrreflexivity, anti-symmetry and transitivity.

But besides the epistemological axioms, other axioms can be used to represent knowledge. These axioms can be of two types [2]: consolidation axioms (CA) and ontological axioms (OA). The former aims to impose constraints that must be satisfied for a relation to be consistently established. The latter intends to represent declarative knowledge that is able to derive knowledge from the factual knowledge represented in the ontology.

To deal with these kinds of axioms, ODEd allows the ontology engineer to define his/hers own axiomatizations and to apply them to relations in the ontology, in an approach similar to that presented in [21]. The core idea is to use the axiom categorization to provide a compact, intuitively and accessible representation to certain widespread axiom types.

To support association axiomatization in ODEd, the Pre-Condition Pattern defined in [14] was applied. This pattern establishes that: $\forall x{:}X,\ y{:}Y\ relation(x,y) \rightarrow (preCondition1) \wedge (preCondition\ 2) \wedge \ldots \wedge (preConditionN)$. In other words, it guarantees the evaluation of each one of the preconditions before a relation can be established. This pattern uses the *Template Method pattern* [22], where the *template method* is the method `setRelation()` and the *hook methods* are those responsible for evaluating the fulfillment of the preconditions.

In ODEd, the hook methods are the methods of the classes representing the association axioms. They are responsible for evaluating the fulfillment of the preconditions of the corresponding association axioms. Thus, the PreCondition Pattern applied in ODEd has the following format: $\forall x{:}X,\ y{:}Y\ relation(x,y) \rightarrow (associationAxiom1) \wedge (associationAxiom2) \wedge \ldots \wedge (associationAxiomN)$.

5 Developing an Ontology of Software Quality Using ODEd

To show how ODEd supports ontology development, we use as an example the *Software Quality Ontology* developed in [19]. Due to limitations of space, we present only part of this ontology.

Following the ontology development process described in section 3.1, the first step of the ontology development is the purpose identification and requirement specification. To support this activity (R1), ODEd allows the user to define competency questions, as shown in Figure 6. It should be pointed out that, in the current version of ODEd, competency questions are written in natural language (informal competency questions) and are used only for documentation purposes.

Once the competency questions are defined, ontology capture can begin. To support this activity, ODEd supports a graphical representation of the ontologies using LINGO and UML (R2), as discussed in section 4.1. Figure 7 shows part of the Software Quality Ontology [19], written in LINGO.

As stated by this ontology, a software *quality characteristic* can be classified according to two criteria. The first one indicates if a quality characteristic can be directly measured or not. A *non-measurable quality characteristic* must be decomposed into sub-characteristics (represented by the roles *super* and *sub characteristic*), and its value is computed by the aggregation of their sub-characteristic measures. A *measurable quality characteristic* can be directly *quantified* applying some *metric*. The second classification enforces that *product quality characteristics* should only be used to evaluate software artifacts and *process quality characteristics* are used to evaluate software processes. *Artifact* is a concept imported from the *Software Process Ontology* [2], which were integrated with the software quality ontology been presented.

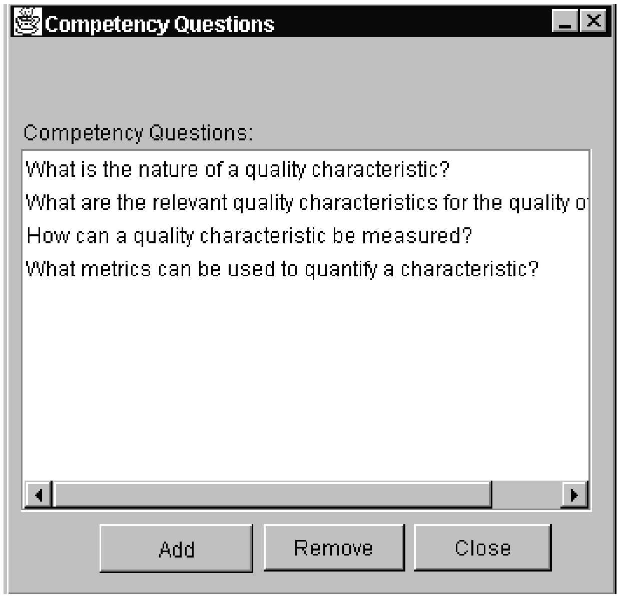


Figure 6: Competency questions of the Quality Ontology.

Finally, the *valuation* relation indicates that a non-measurable quality characteristic can be valued through other measurable or non-measurable quality characteristics.

Cardinalities are used to show how many instances of a concept can participate in a relation. In Figure 7, cardinality (1,n) in the relation `quantification` implies that a measurable characteristic must be valued by, at least, one metric: *(∀qc) (mensqc(qc) → (∃m) (quantification(qc,m))*. Cardinality (1,1) still adds that a metric evaluates only one measurable characteristic: *(∀m, qc1, qc2) (quantification(m,qc1) ∧ quantification(m,qc2) → qc1 = qc2)*. Since cardinality (0,n) does not impose any constraint, it is not represented.

Figure 8 shows the Software Quality ontology captured using UML. The same objects modeled in Figure 7 are presented here, but using a different graphical notation. A stereotyped class `QualityCharacteristic`, for example, represents the *QualityCharacteristic* concept. The relation *relevance* is presented as an association.

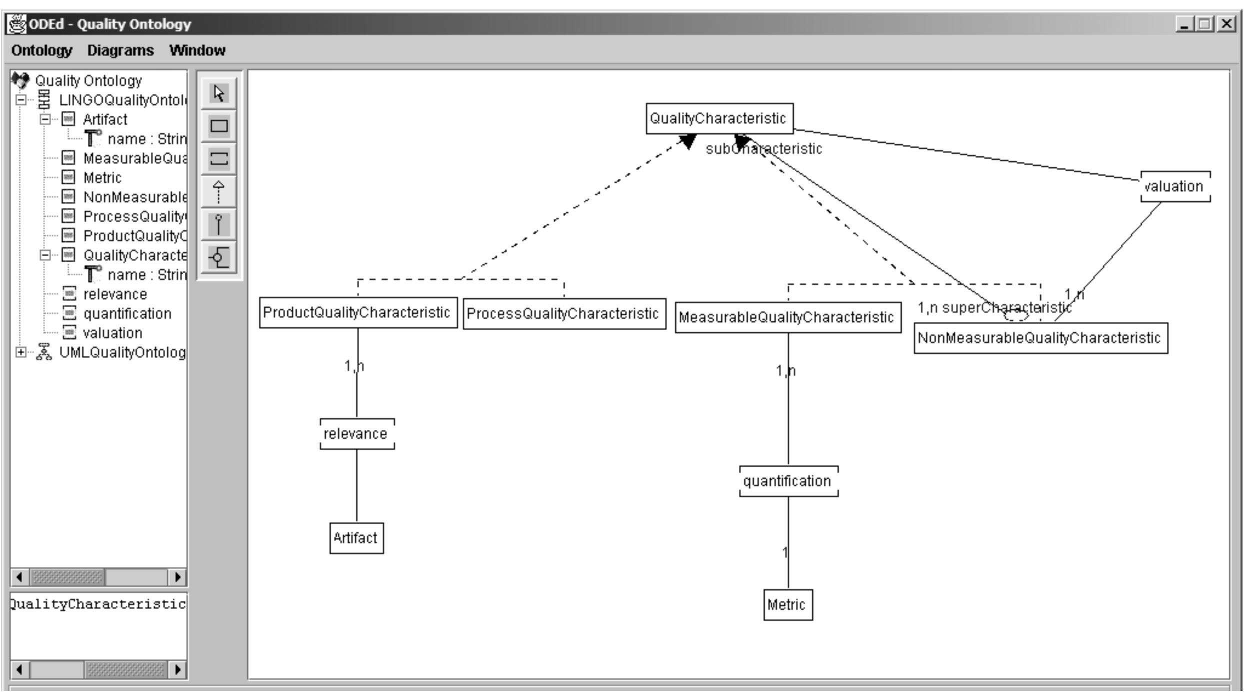


Figure 7: LINGO's Diagram of Software Quality Ontology.

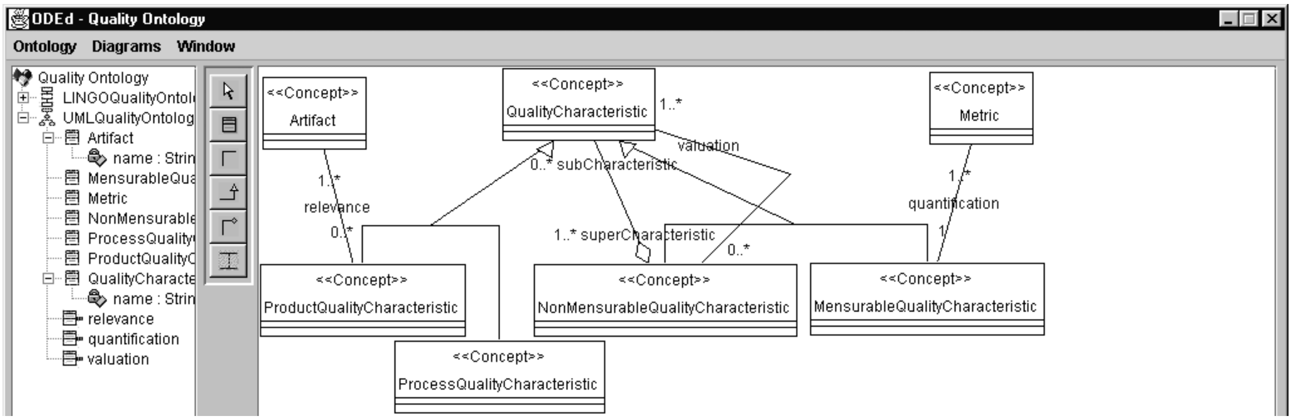


Figure 8: Representing the Software Quality Ontology using UML.

Table 1 presents some axioms of the quality ontology, indicating their type: epistemological axioms (EA), ontological axioms (OA) or consolidation axioms (CA).

ID	Axiom
EA1	(∀ qc) (nmensqc(qc) → qchar(qc))
EA2	(∀ qc) (mensqc(qc) → qchar(qc))
EA3	(∀ qc) (prodqc(qc) → qchar(qc))
EA4	(∀ qc) (procqc(qc) → qchar(qc))
EA5	(∀ qc1, qc2) (subqc(qc1, qc2) → ¬ subqc(qc2 , qc1))
EA6	(∀ qc) (mensqc (qc) ↔ ¬ (∃ qc1) (subqc(qc1, qc)))
EA7	(∀ qc1, qc2, qc3) (subqc(qc1, qc2) ∧ subqc(qc2, qc3) → subqc(qc1 , qc3))
EA8	(∀ qc1, qc2) (disjointed(qc1, qc2) ↔ ¬ (∃ qc3) (subqc(qc3, qc1) ∧ subcarq(qc3, qc2)))
OA1	(∀ qc, qc1) (valuation(qc, qc1) → ¬ valuation(qc1, qc))

Table 1: Some axioms of the Software Quality Ontology.

Axioms (EA1) to (EA4) refer to the super-type relation among quality characteristics. The whole-part relation between quality characteristics imposes the constraints defined by axioms (EA5) to (EA8). The ontology engineer does not need to write down these axioms, since ODEd automatically captures them from the graphical notation used.

The axiom (OA1) refers to the *valuation* relation. It indicates that, if a quality characteristic *qc1* is valuated by a quality characteristic *qc2*, then *qc2* cannot be valuated by *qc1*. In other words, it means that the *valuation* relation is anti-symmetric. So, the anti-symmetry association axiom should be incorporated to its corresponding association axiomatization. Figure 9 shows how association axioms can be manually incorporated to an association axiomatization in ODEd. This form allows the ontology engineer to associate axioms to a relation. In the example shown, anti-symmetry is the only axiom that composes the `valuation`'s axiomatization.

This is the way ODEd currently supports axiom definition (R3). Thus, other axioms that do not fit in the axiom categorization defined cannot be captured. This issue is now being studied, and preliminary results are described in [23].

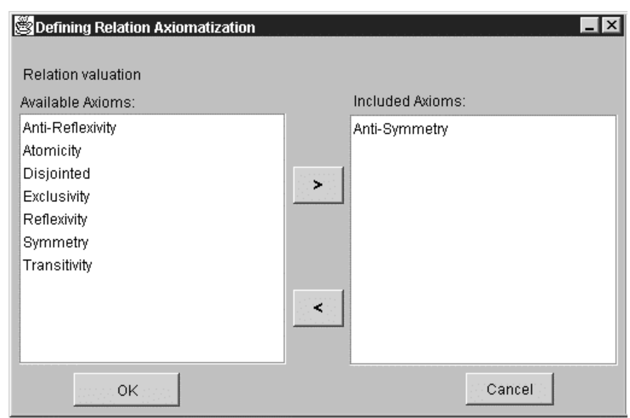


Figure 9: Defining Relation Axiomatization in ODEd.

ODEd also incorporates software agents that help the ontology engineer during ontology development. These agents were added to ODEd to alert the user about eventual structural modeling mistakes and to offer advices on how to solve them according to the user's actions. For example, if the ontology engineer also includes the symmetry axiom in the *valuation*'s axiomatization (presented in Figure 9), the agent points that Symmetry and Anti-Symmetry are opposite axioms and offers a suggestion to solve the problem: remove one of them, as shown in Figure 10.

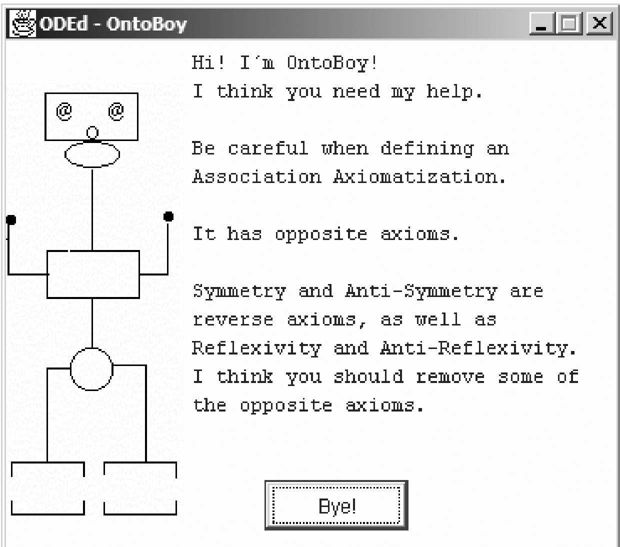


Figure 10: The OntoBoy agent.

The main purposes of the software quality ontology are: (i) to promote software quality knowledge integration in ODE, a software engineering environment, and (ii) to support the development of quality management tools for it [19]. Therefore, this ontology must be integrated to the software process ontology [2] used to support ODE's software process definition and project tracking.

ODEd supports ontology integration (R4) in a very limited way: concepts from existing ontologies can be imported to the current one. Also, if more than one concept is imported and there are relations between them, these relations are also imported to the ontology.

For example, in Figure 7, the *Artifact* concept was imported from the software process ontology and a relation between *Artifact* and *ProductQualityCharacteristic* was created (*relevance*).

If an imported concept or relation is removed from the original ontology, it is automatically removed from the ontology it was imported and no kind of notification is sent to the ontology engineer. It means that if *Artifact* is removed form the software process ontology, it will be removed from the quality ontology, as well as the *relevance* relation. In fact, in the current version, ODEd does not treat ontology evolution nor check consistency among imported concepts and existing concepts.

Finally, in its current version, ODEd does not support ontology documentation (R6). Also ODEd's support to ontology evaluation (R5) is very weak, based on ontology instantiation (R7), as discussed in section 8.

6 From Domain Ontologies to Objects

As pointed in section 3.2, for deriving object infrastrucures from ontologies, Guizzardi et al. [14] defined a set of mapping directives, design patterns and transformation rules. To deal with the requirement of generating software assets from ontologies (R9), in its current version, ODEd considers the mapping directives and some design patterns. But, since ODEd does not yet completely support axiom definition, except those described through association axiomatization, the transformation rules are not being treated. Following, we present how ODEd generates a Java infrastructure from the software quality ontology.

6.1 Mapping Directives

Figure 11 shows the object model derived from the software quality ontology. Classes, like `QualityCharacteristic` and `NonMeasurableCharacteristic`, were derived from the corresponding concepts. Also, associations, like `quantification`, `relevance`, and `valuation`, were derived from the corresponding relations. Properties of the concepts were mapped as attributes of the corresponding classes, as it is the case of the property *name* of the concept *QualityCharacteristic*, which was mapped as the attribute `name` in the class `QualityCharacteristic`. For each derived attribute, methods to get and set values are created.

Still considering the mapping of relations, there are other issues that must be discussed. First, since in an ontology relations are bi-directional, the corresponding associations must be navigable in both directions. Thus, the associations are implemented as attributes, and there are methods in both classes to return them. The returned type of these methods depends directly on the cardinality associated to the relation [14]. For instance, since in the scope of the *quantification* relation a measurable characteristic may be evaluated by several metrics, the method `quantification()` in the class `MeasurableCharacteristic` returns a `Set` of `Metrics`. In the class `Metric`, the return type of the `quantification()` method is a `MeasurableCharacteristic`, since a metric is associated with just one characteristic.

Unary relations are also mapped as associations, and methods are also generated for each association end. However, the name of these methods is, instead of the relation's name, the name of the roles played by the corresponding concepts.

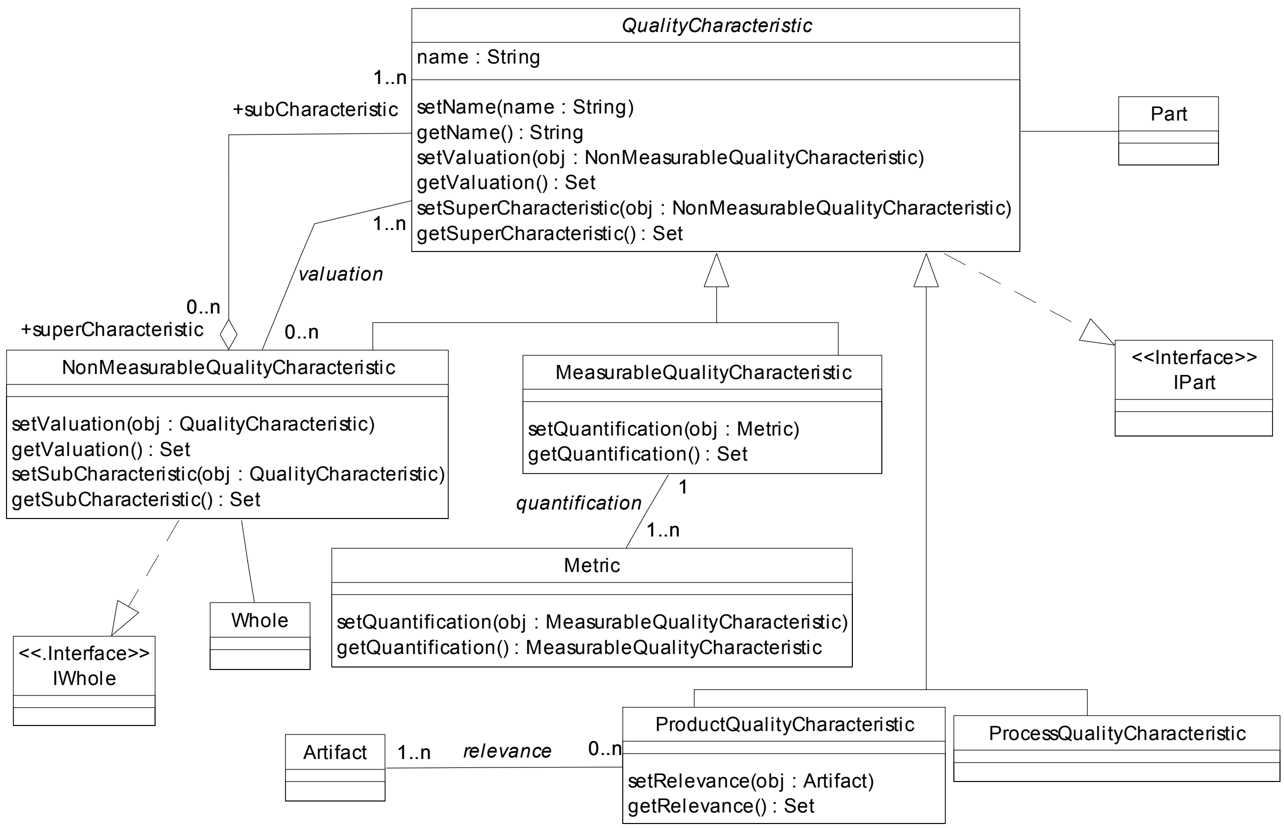


Figure 11: Part of the Object Infrastructure for Software Quality generated by ODEd.

Subtype-of relationships among concepts can be directly mapped to inheritance among classes. So, axioms (EA1) to (EA4) do not require any special treatment. In our example, the subtype hierarchy of quality characteristic gives rise to the following sub-classes: `ProcessQualityCharacteristic`, `ProductQualityCharacteristic`, `NonMeasurableCharacteristic` and `MeasurableCharacteristic`. The class that represents the super-type (`QualityCharacteristic`) is mapped to an abstract class.

6.2 Mapping Axioms

When considering axiom mapping to the corresponding object infrastructure, we should discuss epistemological axioms separately from the others.

As pointed above, subsumption relationships can be directly mapped to class inheritance, and its axioms do not require any special treatment.

This is not the case of whole-part relations. The underlying axioms implied by the proposed notation are not well mapped to aggregation in an object model, i.e., UML notation for aggregation does not guarantee the fulfillment of the imposed constraints of whole-part relations. To deal with this problem, Guizzardi et al. [14] proposed the *Whole-Part Pattern*, shown in Figure 12. In this pattern, the `Whole` class is responsible for assuring to an associated concrete class (class A in Figure 12) the verification of the whole-part set of constraints before a whole-part relation is established. The interfaces `IWhole` and `IPart` must be implemented by the corresponding concrete classes.

In the software quality domain infrastructure (Figure 11), the classes `NonMeasurableCharacteristic` and `QualityCharacteristic` implement interfaces `IWhole` and `IPart`, respectively. Likewise, they are related to the handlers `Aggregation` and `Part`, respectively. As shown in the code fragment below, subcharacteristics of a non-measurable characteristic is accessed through `Aggregation`. The inclusion of a new sub-characteristic is made by including a new part in the aggregation. Axioms (EA5) to (EA8) are checked when the method `setPart()` is evoked.

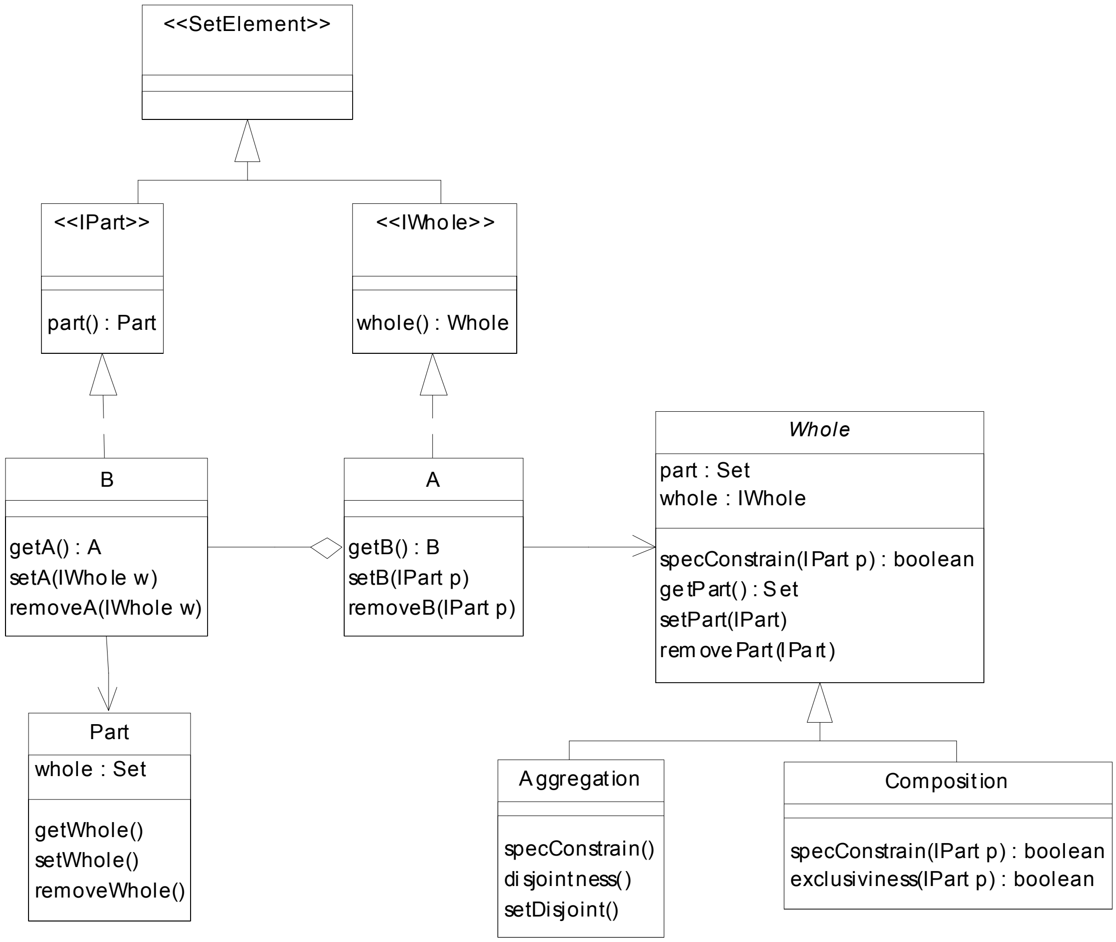


Figure 12: The Whole-Part pattern [14].

```
public class
NonMeasurableCharacteristic implements
                                IWhole
{
  Aggregation a = new Aggregation();

  public boolean setSubCharacteristic
             (QualityCharacteristic c)
  {
     return a.setPart(c);
  }

  public Set getSubCharacteristic ()
  {
      return a.part();
  }
}
```

As discussed in section 4, to support association axiomatization in ODEd, the Pre-Condition Pattern [14] was applied. So this pattern is used jointly with the Whole-Part Pattern, and it required changes in the last one. Instead of implementing the axioms of the whole-part axiomatization, the `Whole` class is now related to the corresponding association axioms that compose the whole-part axiomatization, as shown in the code fragment below. In this way, the `setPart()` method in the `Whole` class evokes the association axiom classes (`AntiSymmetry`, `Atomicity`, `Transitivity`, and `AntiReflexivity`) to check if the whole-part constraints hold.

```
public abstract class Whole
{
  IWhole whole;
  Set part = new Set();
  AntiSymmetry s = new AntiSymmetry();
  Atomicity a = new Atomicity();
  Transitivity t = new Transitivity();
  AntiReflexivity r = new
                 AntiReflexivity();
  public boolean setPart(IPart c)
```

```
   {
     boolean result = false;
     if (specConstrain(c)) &&
       transitivity(this,c,"getPart")&&
     anti_symmetry(this,c,"getPart")&&
  anti_reflexivity(this,c,"getPart")&&
         atomicity (this,c,"getPart"))
     {
        result = true;
        part.add(c);
        (c.part()).setWhole(whole);
      }
     return result;
   }
}
```

To deal with the axioms that are incorporated to association axiomatizations (like is the case of the *valuation* relation shown in Figure 9), a similar approach to the whole-part relation is used. Each class involved in a relation is associated with the association axiom classes that compose the relation axiomatization. When an instance of this relation is to be created, the axioms are checked. The code fragment below shows this approach applied to the *valuation* relation.

```
public abstract class
QualityCharacteristic implements
                                  IWhole  {
  Set valuation = new Set();
  AntiSymmetry s = new AntiSymmetry();

  public Set getValuation()
  { return valuation; }

  public boolean setValuation
       (NonMeasurableCharacteristic c)
  {
    boolean result = false;
    if s.anti_symmetry(this,
                      c,"valuation")
    {
      result = true;
      valuation.add(c);
      c.setValuation (this);
    }
    return result;
  }
}
```

Since `QualityCharacteristic` partakes of the `valuation` relation (that is anti-symmetric), it is related to the `AntiSymmetry` class through the attribute `s`. Before setting a non-measurable characteristic as capable of valuating the current quality characteristic (`this`), the `valuation` axiomatization should be checked. To verify axiom (OA1), the method `s.anti_symmetry(this, c, "valuation")` of the `Anti-Symmetry` class is executed. This method evokes the `getValuation()` method from the non-measurable characteristic `c`. If the current characteristic (`this`) is not in the valuation list of `c`, then it does not value `c`. Therefore, the axioms (OA1) holds and `c` can be added to the `valuation` list of the current quality characteristic.

7 Browsing Ontologies

To support domain investigation (R8), ODEd provides automatic generation of hypertexts based on the ontologies designed. Using these hypertexts, developers can browse and search the domain concepts, relations, properties and constraints.

The language chosen to build these documents was XML [24], because it allows defining the syntax of structured documents. Besides, XML schema and ontologies have a common goal: to provide vocabulary and structure for describing information to be exchanged (although XML does not provide semantics for a domain conceptualization, as ontologies do).

To generate the XML documents, a set of tags was defined to represent the ODEd's ontology description model (concepts, properties, relations, and so on, as shown in Figure 5). Ontologies were mapped to XML files, marked with these tags. The code fragment below presents the definition of the *QualityCharacteristic* concept (<CONCEPT>) in a XML file. It is possible to see its description (<DESCRIPTION>) and its properties (<PROPERTY>). The tags <ISSUPERTYPEON/> and <ISSUBTYPEON/> indicate, respectively, in which hierarchies this concept is a super and a sub-type.

```
<CONCEPT oid="1859:8">
  <NAME>QualityCharacteristic</NAME>
  <DESCRIPTION>attributes of an artifact or
  of a software process used to evaluate the
  quality of a software product or process.
  </DESCRIPTION>
  <PROPERTY oid="1860:1">
     <NAME>name</NAME>
     <TYPE>String</TYPE>
  </PROPERTY>
  <ISSUPERTYPEON oid="1859:24"/>
  <ISSUBTYPEON oid="1859:25"/>
</CONCEPT>
```

All the elements that compose the document are identified by the property **oid** (object identifier) in the tags. This identifier allows to associate elements inside the XML document. The code below, for example, presents the hierarchy (<HIERARCHY>) of the *QualityCharacteristic* concept. The tags *istic* concept. The tags <SUPERTYPE/> and <SUBTYPE/> indicate, through the identifier **oid**, which concepts are the super-type and the subtypes of the hierarchy, respectively. In the example, the super-type of the hierarchy is the concept which oid is equal to "**1859:8**" (*QualityCharacteristic*).

```
<HIERARCHY oid="1859:24">
    <SUPERTYPE oid="1859:8"/>
     <SUBTYPE oid="1859:10"/>
     <SUBTYPE oid="1871:1"/>
</ HIERARCHY >
```

It should be noted, however, that XML only deals with data and does not deal with visual presentation of documents. To define the presentation format of XML documents, style sheets are used. A style sheet allows to indicate to the browser how the user wants to present the content of the elements in the XML document. To present XML documents, ODEd uses XSL (*eXtensible Style sheet Language*) [25], a document transformation and formatting language. In the editor, it was defined a style sheet capable of presenting the documents that represent the ontologies in the hypertext format. Thereby, the hypertexts are presented to the user as HTML documents.

Figure 13 shows the hypertext derived from the software quality ontology. It is possible to visualize all ontology's concepts and relations and their definitions and properties. From the *valuation* relation, for example, the user can browse its concepts and visualize their definitions.

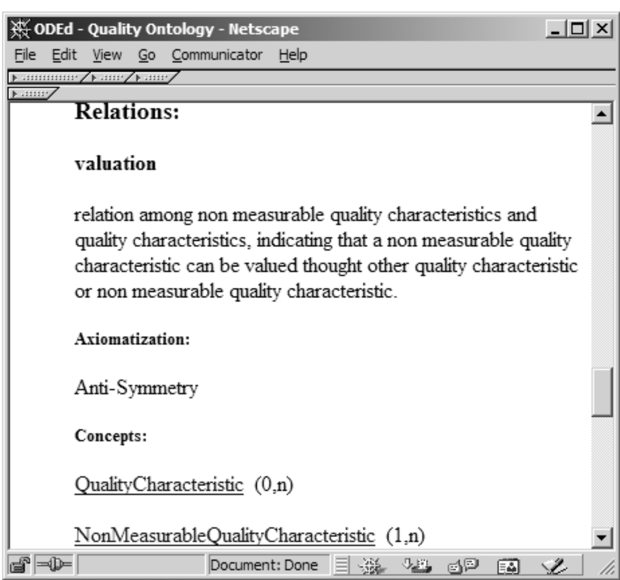


Figure 13: Browsing the Software Quality Ontology.

8 Ontology Instantiation in ODEd

As discussed in section 4, instances of domain concepts and relations can be used to support domain understanding in a DOSEE (R7). Moreover, specially when relations are instantiated, it is possible to check if the constraints imposed by the corresponding axiomatization are the right ones. This is a way to partially evaluate an ontology (R5), though limited.

To support ontology instantiation in ODEd, a set of functionalities was developed, including functionalities to create databases to store the instances, and forms to instance data input. The object infrastructure derived from the ontology (discussed in section 6) is also used, since instances of concepts and relations are, in fact, instances of the corresponding classes and associations in the object infrastructure. So, the classes in the infrastructure must have access to the database created to insert, retrieve, delete and update its instances. But those classes should not have direct access to the database, because this approach would decrease the object infrastructure reuse potential. Thus classes providing the basic services for storing and retrieving objects in the database are also generated. These classes are called shadow classes [26] and their purpose is to isolate the impacts of the technology of data management on the object infrastructure.

Figure 14 shows the database schema generated by ODEd to instantiate the Software Quality Ontology. For each class in the object infrastructure derived from the ontology (see Figure 11), a table is created. Since every concept is described by `name` and `description` properties, a super-class `Knowledge` is created in the object infrastructure, and all classes derived from the ontology's concepts inherit from it. In the database, there is a respective `Knowledge` table that maps this class. Every table derived from a concept is related to the *`Knowledge`* table to map this inheritance, except those that are derived from subclasses in the infrastructure, which are related to the tables that represent their super-types.

In the example shown in Figure 14, table *`QualityCharacteristic`* is related to table *`Knowledge`*, since *QualityCharacteristic* class inherits from `Knowledge` class. *`NonMeasurableQualityCharacteristic`* table, in turn, is related to table *`QualityCharacteristic`*, since `NonMeasurableQualityCharacteristic` class inherits from `QualityCharacteristic` class.

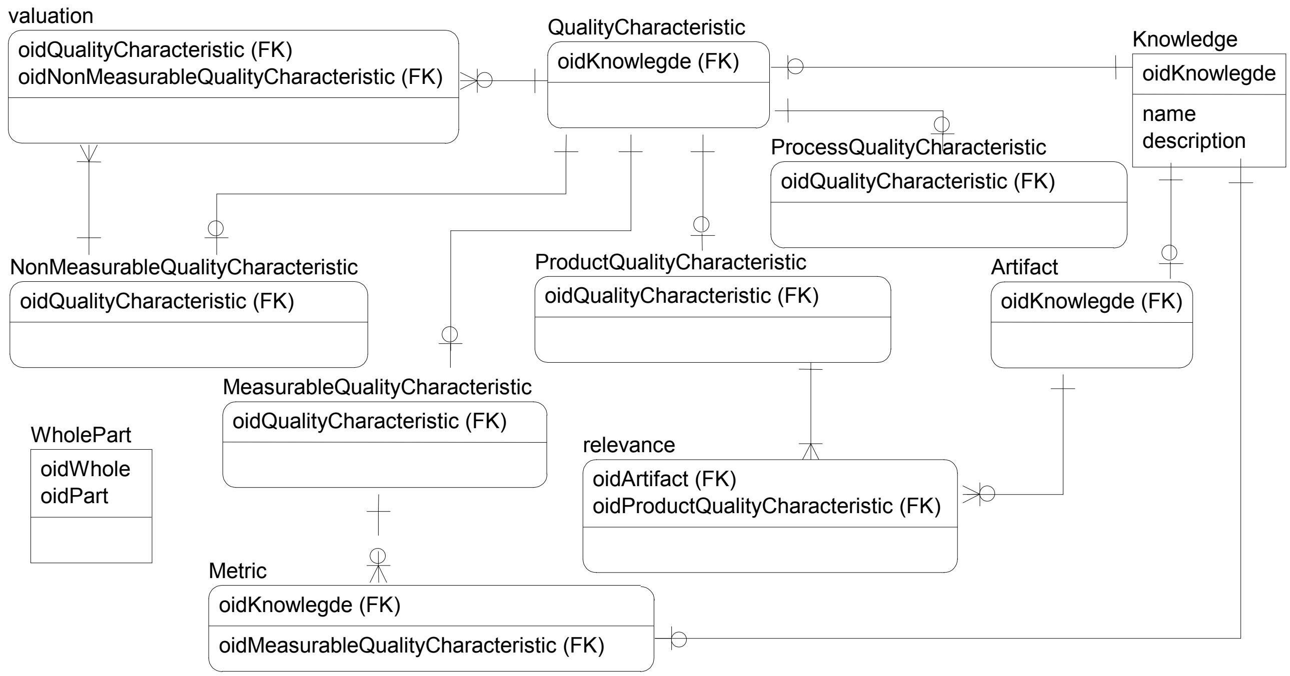


Figure 14: The database of the Quality Ontology.

When an instance of a concept, such as `Metric`, is created, a register is inserted in the corresponding concept's table (*`Metric`* in the example). Also a register is automatically inserted in the table *`Knowledge`* to store the values of the properties *name* and *description*.

One-to-one (1:1) and one-to-many (1:N) binary relations are mapped as foreign keys. In table *`Metric`*, for example, the foreign key *`oidMeasurableQualityCharacteristic`* links a metric to the quality characteristic it quantifies.

Many-to-many (N:N) binary relations, relations with arity bigger than two, and relations with properties are mapped to associative tables, whose primary keys are the identifiers of the classes involved in the relation. In the relation *valuation*, for example, table `valuation` was created with the following composed primary key: *`oidQualityCharacteristic`* plus *`oidNonMeasurableQualityCharacteristic`*.

To treat whole-part relations, a unique table *`WholePart`* was created. In this table the `oid` for each instance that belongs to a whole-part relation is stored. The identifiers *`oidWhole`* and *`oidPart`* represent, respectively, the object whole and its part. For example, to include a quality characteristic `c1` as a sub-characteristc of a non-measurable quality characteristic `c2`, the register (*`oidC2`*, *`oidC1`*) is created in the table *`WholePart`*.

As discussed early, the classes in the object infrastructure must have access to the database generated. To do so, besides generating the database and the domain classes in the object infrastructure, a persistence layer is also automatically generated by ODEd.

For each concept or relation that has a domain class in the object infrastructure, a shadow class is created in the persistence layer. All the operations of the persistence mechanism are encapsulated in the shadow classes. Each one of those classes presents the necessary functionality to implement the persistence of the objects, such as to save, to remove or to update an object, and to retrieve a group of objects. For example, a class `QualityCharacteristicPers` is created. It is responsible for manipulating, in the database, the objects of the class `QualityCharacteristic`.

Relations that generate associative tables and do not have their own shadow classes are handled by the shadow classes of the concepts involved in the relation. The relation *valuation*, for example, is manipulated by the classes `QualityCharacteristicPers` and `NonMeasurableQualityCharacteristicPers`. Each one of these shadow classes has a method, as shown below, to insert a register in the associative table *`valuation`*.

```
public void insertValuation(String
                    obj, String obj1)
{
  String sLocSQL;
  Statement oLocSt;
  try   {
    sLocSQL = "INSERT INTO valuation
      (oidQualChar,oidNonMensQualChar)
       VALUES ('"+obj+"','"+obj1+"')";
    ...
    oLocSt.execute(sLocSQL);
    ...
  }
  catch (Exception e)
  { e.printStackTrace();    }
}
```

Before inserting a register in the table `valuation`, it is necessary to check the theory of the relation *valuation*. Thus, the `QualityCharacteristic` class is associated to the `QualityCharacteristicPers` class and the insertion method of the shadow class is called by the method `setValuation`, which is responsible for checking the valuation theory.

```
public abstract class
      QualityCharacteristic implements
                                  IWhole
{
  QualityCharacteristicPers pers = new
           QualityCharacteristicPers();
  Set valuation = new Set();
   AntiSymmetry s = new AntiSymmetry();

   public Set getValuation()
   { return valuation; }

   public boolean setValuation
        (NonMeasurableCharacteristic c)
   {
     boolean result = false;
      if s.anti_symmetry(this,
                      c,“valuation”)
      {
        result = true;
        valuation.add(c);
        c.setValuation (this);
        pers.insertValuation
                (this.getOID,c.getOID);
      }
      return result;
   }
}
```

Finally, to support instance data input, customized forms are generated, based on the ontology contents, in an approach similar to that implemented in Protégé-2000 [27]. All forms for concept instantiation have text fields to input data concerning the properties *name* and *description*. If a concept has other properties, more complex forms are generated, allowing data input for all properties. One-to-one (1:1) and one-to-many (1:N) binary relations can also be instantiated when the concept is instantiated, in an approach analogous to that applied to properties.

Figure 15 shows the form for instantiating the *Metric* concept. The instance created is named `Test Restartability`. Since *Metric* does not have other properties than *name* and *description*, this form has only the corresponding two text fields. To allow data input for the `quantification` relation (a one-to-many (1:N) relationship), there is a list that enables the user to choose the measurable quality characteristic the metric quantifies. In the example, the *Test Restartability* metric quantifies the *Testability* quality characteristic.

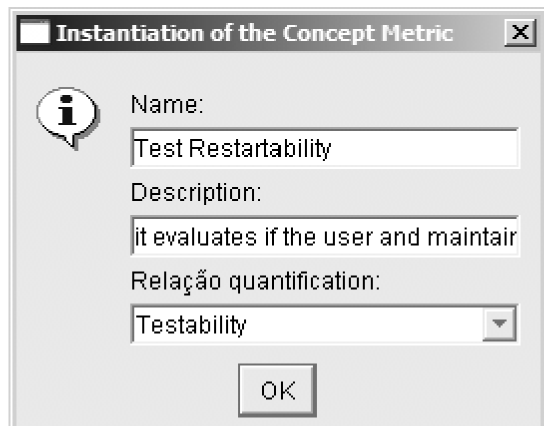


Figure 15: Creating an instance of *Metric*.

For instantiating many-to-many (N:N) relationships, the user should choose an instance of one of the concepts involved in the relation. Then, he/she has to choose, among the instances of the other concept, those that are linked to the first.

Figure 16 presents the instantiation of the *valuation* relation for the *Maintainability* instance. In the example, *Maintainability* can be valuated by several quality characteristics, such as *Analysability* and *Testability*. A list of all quality characteristics already instantiated is exhibited and the user should select those that valuate *Maintainability*.

It could be pointed out, however, that before instantiating a relation, its axiomatization must be checked. For example, since *Testability* was defined as a quality characteristic that valuates *Maintainability* in the previous example, it should not be allowed to relate *Maintainability* as a quality characteristic that valuates *Testability*, because the relation *valuation* is anti-symmetrical.

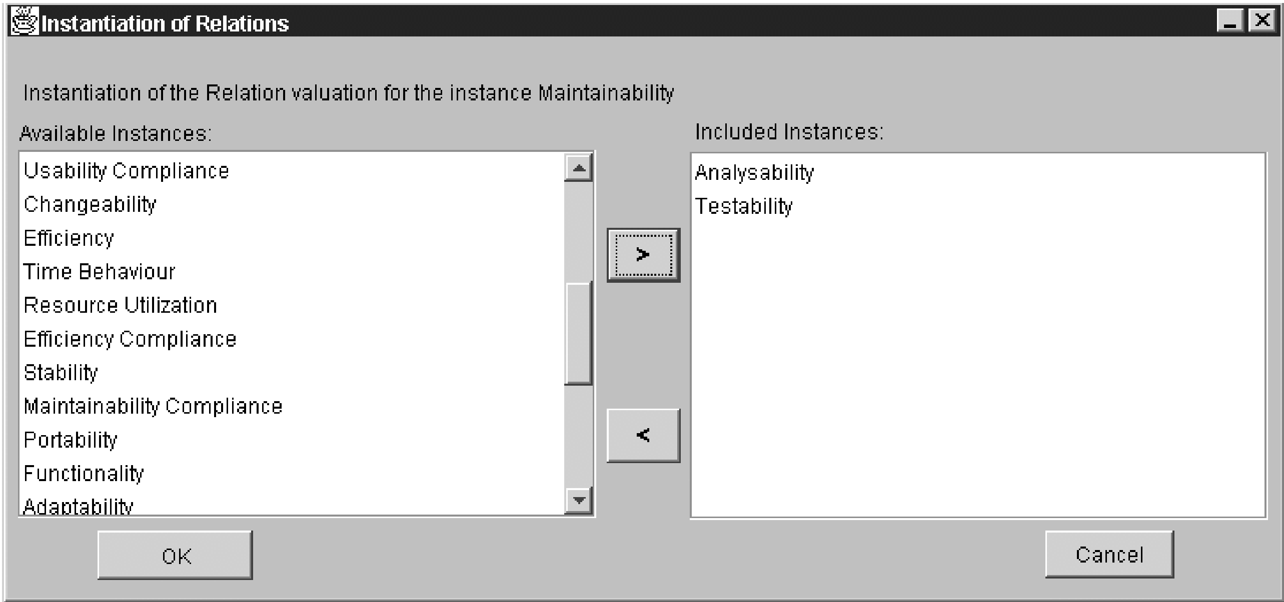


Figure 16: Instantiation of the relation *valuation*.

9 Related Work

There are many ontology editors presented in the literature, such as Ontolingua Server, OntoEdit, OILEd, JOE, Protége-2000 and WebODE.

Ontolingua Server [28] supports ontology development and sharing. It provides access to a library of ontologies, and allows new ontologies to be created. Remotely distributed groups can use their web browsers to browse, build and maintain ontologies stored in the server.

OntoEdit [21] pursues an approach such that graphical means exploited for modeling of concepts and relations scale up to axiom specifications (using RDFS). The core idea is to use an axiom categorization. This categorization is centered around axiom semantic meaning rather than syntactic representation.

OILEd [29] supports the construction of ontologies in OIL. The editor allows defining concepts and relations and also supports the definition of some pre-defined axioms. OILEd has reasoning services that supports ontologies construction, integration and verification.

The *Java Ontology Editor* (JOE) [30] was developed to help users build and browse ontologies. It enables query formulation at several levels of abstraction. JOE provides a graphical user interface for editing ontologies. It uses Entity Relationship diagrams to represent them.

Protége-2000 [27] aims to support knowledge acquisition, and to reach interoperability with other knowledge representation systems. It has classes, instances of these classes, slots representing attributes of classes and instances, and facets expressing additional information about slots. Protégé-2000 generates knowledge-acquisition forms automatically based on the types of the slots and restrictions on their values, allowing ontology instantiation.

Ontobroker [31] provides languages to annotate web documents with ontological information, to represent ontologies, and to formulate queries. The tool set of Ontobroker enables users to access information and knowledge from the web and to infer new knowledge with an inference engine.

WebODE [32] is a workbench for ontological engineering that provides a scalable architecture for the development of other ontology development tools and ontology-based applications. WebODE's ontology editor allows the collaborative edition of ontologies at knowledge level, supporting the conceptualization phase of METHONTOLOGY [33] and most of the activities of the ontology's life cycle (reengineering, conceptualization, implementation, etc). It provides several services as ontology import/export, translation of ontologies, ontology browser, inference engine and axiom generator. The graphical user interface allows browsing all the relationships defined on the ontology as well as graphical-pruning these views with respect to selected types of relationships. Mathematical properties such as reflexive, symmetric, etc. and other user-defined properties can be also attached to the "ad hoc" relationships.

All editors previously mentioned were developed to support ontology design in the context of Semantic Web. None of them was developed aiming to support a domain engineering process. ODEd's main purpose is to fill this lacuna. Thus one striking feature of ODEd is to support ontology-to-objects mapping.

Despite of being an important requirement for ontology design, few ontology editors address adequately the existence of graphical facilities for ontology capturing. Most of them allow creating concept taxonomies and some of them relations. Generally, no semantics is associated with the meta-ontology that underlies the graphical language used. JOE and WebODE, for example, use some graphical language to represent ontologies. But the first one uses Entity Relationship models, and the second one does not define any special notation for the kinds of relations supported by the editor. ODEd adopts LINGO, a graphic language specially designed for ontology's representation. However, ODEd does not ignore the importance of other graphical languages available. Therefore it also supports ontology capture using UML, but using LINGO's semantics.

Concerning constraints definition, a very interesting initiative is the creation of axioms templates in OntoEdit [21]. This approach was considered in ODEd in order to facilitate axioms definition. But it is still necessary to define how to represent other types of axioms as provided in WebODE [32].

Reasoning services are an important feature [30, 33] because they can be used in ontology evaluation. Other desirable services provided by some of these tools are the support to the cooperative work and the automatic generation of ontology documentation in HTML [28, 30, 33]. This last feature is addressed by ODEd but no reasoning service is available.

Finally, in ontology instantiation, ODEd uses a similar approach to Protégé-2000 [27].

10 Conclusions and Future Work

In this paper, we presented ODEd, an ontology editor that supports ontology development using graphical representations, besides promoting automatic inclusion of some classes of axioms and derivation of object infrastructures from ontologies. ODEd was built to support an ontology based approach for domain engineering in ODE, a software engineering environment.

Table 2 summarizes how ODEd's requirements (presented in section 4) were addressed in the current version.

Requirements		ODEd	Comment
R1	Competency question definition	Limited	Only informal competency questions
R2	Ontology capture using graphical notation	Yes	Using LINGO and UML
R3	Axiom definition	Partial	Only certain axiom types
R4	Ontology integration	Limited	Manual, with no check
R5	Ontology evaluation	Limited	Through ontology instantiation
R6	Documentation of the ontology development process	No	-
R7	Ontology instantiation	Yes	Java code generation
R8	Domain investigation	Yes	XML and hypertexts in HTML
R9	Generating software assets from ontologies	Yes	Object infrastructure in Java

Table 2: Requirement support in ODEd..

Although most phases of ontology development process are supported by ODEd, there are many aspects to be improved.

First, ODEd should also support defining formal competency questions. This feature is related to ontology evaluation. Once competency questions could be formally captured, they can be used to evaluate if the ontology satisfies its requirements. To support these features, reasoning services are necessary.

Second, in its current version, only certain types of axioms can be captured in ODEd. Other axioms which do not fit in these axiom categories are not treated. We are now working to improve this aspect [23]. In the new approach, axioms can be defined in KIF [34], and checked using the JTP (Java Theorem Prover) [35] inference engine. Since JTP reads DAML + OIL [36] sentences, the ontologies are translated to this standard. This way, ontology exchanging will be considered.

There are other aspects to be improved in ODEd. Ontology integration, for instance, is limited, since ODEd does not deal with inconsistencies among imported concepts and existing concepts. Although ODEd supports ontology capture using graphical notations, this process is manual. ODEd does not offer any facility to support automatic capture of ontology concepts and relations.

In spite of its limitations, ODEd is an important step ahead towards domain orientation in software engineering environments. It supports an ontology-based domain engineering process and can be used to support knowledge reuse in a DOSEE.

11 Acknowledgments

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