Developing an Ontology for Wood-related Industry: An Experience Report

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Abstract

Ontologies are widely used as a technique for representation and reuse of knowledge. This paper summarizes experiences and results of a project within ontology development, with wood-related industry as application sector. One major aspect of the project was the selection of a suitable methodology for ontology development. In a literature study existing methodologies were analyzed with respect to their suitability for small-scale application contexts. As no existing methodology was fully adequate, an improved methodology was proposed. The main intention was to reduce development time and effort to meet the demands of small-scale application contexts. The improved methodology was applied and evaluated in the project, i.e. in the development of an ontology for wood-related industry. The main conclusion is that the methodology was adequate for the project, but some aspects could be elaborated and further investigated, such as reuse of already existing ontologies.

Keywords
Ontologies, ontology development, ontology development methodologies, wood-related industry
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1 Introduction

This project report describes the work in a project at School of Engineering in Jönköping that took place in the autumn of 2003 and spring of 2004. It is part of the research work in the field of information logistics, aiming at demand-oriented information supply and optimized information flow in networked organizations.

In today’s more and more distributed organizations there is a need for support of knowledge-intensive processes. An important issue is to provide exactly the right information for the work context of a user. In order to do this, there has to be a shared understanding and meaning of concepts and terms in the application domain. The project work contributes to supplying the right information by developing an ontology for the application scenario. According to Gruber an ontology is a formal specification of a shared conceptualization [2].

Ontologies have several different application areas. Some of them are mentioned by McGuinness [4]. First of all they provide a controlled vocabulary, meaning that all users, authors, databases and other systems can use the ontology and mean the same thing for a concept. Ontologies can also be seen as “umbrella” structures from which to extend content. For example several different companies can agree on a shared structure, or terminology, and then each of them specify it as is necessary for them. Ontologies may also provide browsing and searching supports.

The application context for the project was the wood-related industry as application sector and Internet-marketplaces as usage scenarios. The ontology reflects the value chain, product structure and organizational structure for a selected part of wood-related industry. Domain knowledge for wood-related industry was available from School of Engineering’s SIDA¹ project. Our intention was to use the ontology as basis for a future Internet marketplace that is supporting to find the “right supplier” for a customer’s need. Thus, requirements from the operator of this marketplace, El mia AB, have been captured and form the basis for describing use cases for the ontology.

The document consists of five sections. The next section describes the results of a literature search in ontology development methodologies. The third section describes the methodology used in the project. The fourth section describes the results of the project, the implemented ontology, and the final section discusses conclusions and future work.

¹ Main objective of this project, which was funded by the Swedish International Development Agency, SIDA, was to bring together SMEs from South America (Chile, Argentina, Colombia and Uruguay) and Sweden, from wood-related industry in joint ventures or development projects.
2 Ontology Development

In order to be able to perform ontology development from scratch, a literature research in the context of ontology development was performed. The approaches selected and described are the ones that seemed most appropriate considering our application context and background.

2.1 The Enterprise Ontology

The Enterprise Ontology was developed to support and enable communication between different people, people and computational systems, and among different computational systems [10].

The method for development of ontologies proposed by Uschold and King in [8] consists of four phases: purpose, building, evaluating and documenting. In the first phase the purpose is identified, i.e. to find out why the ontology is being built and what its intended uses are. Here should also be considered who will use the ontology and how. The second phase is the building of the ontology itself and is divided into three parts: capture, coding and integrating. Capture means to identify the key concepts and relationships, produce text definitions for the concepts and relationships, identify terms to refer to the concepts and relationships, and to agree on the above. Uschold and King propose to first use brainstorming in order to produce all potentially relevant terms and phrases, and then try to group these together to structure them. The next thing to do is to produce definitions for the concepts and relationships that occurred in previous steps. This is done by producing a natural language text definition, as precise as possible, and then checking that this is consistent with already introduced terms. Relationships are indicated with other terms, and separate notes or additional information are provided if necessary. It is also necessary to review definitions and check the consistency again and that no ambiguous terms exist. By coding is meant to take the result from the previous phase and to explicitly represent it in some formal language. This includes committing to a meta-ontology, choosing a representation language, and creating the code. By meta-ontology is meant the main different kinds of terms and concepts that the ontology should capture. Some examples are actors, relationships, and entities. Guidelines to choose representation language can be perspicuity, conceptual distance, expressive power, standards, formal semantics, and more. The third and final part of the building of the ontology regards how and whether to use already existing ontologies, and if it is decided to use an existing ontology then how should this be done. In the evaluation phase it should be checked that the ontology fulfils the requirements and that it does not contain any unnecessary things. The last phase is the documentation phase in which the ontology should be documented in some way. There are (at least not today) no good guidelines about how this should be done.
2.2 TOVE – Toronto Virtual Enterprise

The TOVE ontology was developed as part of the TOVE Enterprise Modelling project. The goal of the project was to create an Enterprise Model that could deduce answers to queries.

Grüninger and Fox define the goal of an ontology to “agree upon a shared terminology and set of constraints on the objects in the ontology” [3].

The development of a new ontology must be motivated according to a scenario that describes a problem and that also describes possible solutions to the problem. The motivating scenario(s) help developers not only to understand why the ontology is needed but also how it can and will be used. Based on one (or more) motivating scenario a set of questions that the ontology need to be able to answer arise. These questions are in this stage called informal competency questions. It is recommended that the questions are defined such that high level questions require the solution of lower level questions. These questions are used to evaluate the ontological commitments that have been made. The next thing to do is to specify the terminology of the ontology; this is done by using first-order logic. First the relevant objects are identified, then attributes of these objects are defined by unary predicates, and relations among objects are defined by n-ary predicates. The competency questions now need to be defined formally with respect to the axioms in the ontology. These questions can be used to distinguish between ontologies, by looking at what kind of problems they can solve. According to Grüninger and Fox the most difficult aspect in defining ontologies is the process of defining axioms. The difficulty lies in that the axioms must be necessary and sufficient enough to express the competency questions and their solutions. The final thing to do is to create completeness theorems for the ontology. These define the conditions under which the solutions to the questions are complete.

2.3 Unified Methodology

Uschold presents a unified methodology for development of ontologies [9]. He has looked at the two methodologies previously described (EO and TOVE) and combines the “best” parts in each of them into a unified method.

The first step is to define the purpose of the ontology, i.e. why the ontology is being built. This can be done in several ways; to identify the intended users, or as in the TOVE project motivating scenarios and competency questions, or a user requirements document to mention some. Next the developer should decide what level of formality the ontology has to have. This depends on the users and the intended uses of the ontology. In the next phase the developer need to find the concepts that should be in the ontology and the relations among them. This can be done in mainly two ways, either with motivating scenarios and informal competency questions that control what should be and not be in the ontology, or brainstorming and trimming to list the relevant concepts. Uschold prefers to go the middle-out way when defining terms and relationships. When it comes to building the ontology the author describes four possible approaches- The first one is to skip the previous steps and use an ontology editor to
define terms and axioms. Second, do the previous steps and then begin a formal encoding. The third approach is to produce an intermediate document that consists of the terms and definitions that appeared in the previous step, this document can be the final result, or be specification of the formal code or be documentation for it. The fourth and final approach is to identify formal terms from the set of informal terms. The final part that Uschold presents is the evaluation or revision cycle, where the developed ontology is compared to the competency questions or the user requirements, or according to some general criteria such as clarity, consistency and reusability.

2.4 Ontologies for conceptual modeling

Sugumaran and Storey presents a heuristics-based method for developing and creating ontologies [6]. They start by identifying all the basic terms; this is done by using use cases and then revising synonyms and related terms manually or by an online thesaurus. In the next step they identify the relationships among these terms. They define three types of relationships: generalization, synonyms and associations. Generalization corresponds to a “is-a”-relationship. In this step they also consider relationships between ontologies, in order to allow the ontology to evolve. Next thing to do is to identify basic constraints, which means that terms or relationships are related, e.g. one term/relationship depends upon another, one term/relationship must occur before another, one term/relationship requires another for its existence or one term/relationship cannot occur at the same time as another. The final step takes in consideration higher-level constraints, such that domain constraints and domain dependencies.

2.5 Methontology

Fernández et al describes several different types of life cycles that software goes through [1]. The waterfall life cycle describes activities as sequential, meaning that you go through one activity in a time and cannot go back and revise anything in an activity already passed. This model is not so useful for ontologies since developers almost never have a complete requirements specification document at the beginning. Another model is the incremental life cycle where the software grows by layers, in the same way that software often is released in new versions. This means that new definitions and changes only can be done when a new version is being planned. The third and most suitable for ontology development is the evolving prototype life cycle which allows the ontology to grow depending on the needs.

When building an ontology the first thing to do is to specify the purpose of the ontology, the level of formality and the scope of the ontology. Next all the knowledge needs to be collected, there are several ways to do this: brainstorming, structured and unstructured interviews, formal and informal analysis of texts, and knowledge acquisition tools. In the conceptualization phase Fernández et al first proposes to build a Glossary of Terms with all possibly useful knowledge in the given domain. Then terms are grouped according to concepts and verbs, and these are gathered together to form tables of formulas and rules. Next thing to do is to check whether there are any already
existing meta-ontologies that can and should be used. The result of the implementation phase is the ontology codified in a formal language, that can be evaluated (verified and validated) according to some references. The final part consists of the documentation, if the above methodology is followed each phase results in a document that describes the ontology developed so far.

2.6 Ontology Development 101…

Noy and McGuinness describe a way to develop an ontology by using an example, an ontology is created for wines and terms connected to wines [5]. Their methodology is iterative, starting with a rough concept and then revising and filling in the details. The first step in their suggested methodology consists of determining the domain and the scope of the ontology. One way to do this is by use of competency questions. Next thing to think about is whether to use already existing ontologies, and if so, how to use them. A list of all the terms that could be needed or used is then produced. To define the classes and the class hierarchy a top-down, bottom-up, or a combination of these development processes can be used. Which one to use depends on the personal view of the domain. Some guidelines are given for this step. The class hierarchy should represent an “is-a” relation, cycles should be avoided, siblings should have the same level of generality, multiple inheritance could lead to some problems and also guidelines regarding when to introduce new classes or instances are given. Now the classes are defined, i.e. the terms and the relations, next the properties of the classes need to be specified (attributes). Here it is important to check whether some relations are inverse or not, and whether a default value for an attribute could be useful. After this the value type of both the classes and the class properties are defined, this includes cardinality, domain and range. Finally the individual instances are created. Noy and McGuinness also describe some naming conventions and why this is important.

2.7 A Methodology for Ontology-based Knowledge Management

Sure and Studer describe a methodology for ontology development covering the whole life cycle [7]. They define five different phases: feasibility study, ontology kickoff, refinement, evaluation and last a maintenance and evaluation phase. In the feasibility study problem areas and solutions are identified and put into a wider organizational perspective. They also propose to identify use cases in order to identify the scenarios where the ontology should or could be used, users of the systems and other people involved in the project. The kick off phase starts with a requirements specification document containing the domain and goal of the ontology, design guidelines, knowledge sources, users and user scenarios, competency questions and applications supported by the ontology. Two different approaches for modelling are described, top-down approach and bottom-up approach, which one to use depends on how the requirements specification document looks like. The initial draft of the ontology is refined and/or revised in the refinement phase. There is the ontology also created by
formalizing a description of it in a formal representation language. In the evaluation phase the ontology is compared to the requirements, and tested in the target application environment. Another valuable input here are usage patterns of the ontology, meaning the way users use the ontology to search for concepts and relations. This helps to analyze what parts of the ontology which are most frequently used and maybe should be expanded and the correspondingly on the least frequently used parts maybe something could be deleted. The maintenance and evaluation phase contains strict rules for updating/inserting/deleting processes of ontologies, who are responsible for maintenance and for example in which time interval the ontology is maintained.
3 Development Process in the Project

The initial plan was to select a suitable ontology development methodology based on the literature search, but no existing methodology seemed to be suitable. More details were wanted and not all of the methodologies covered the whole lifecycle of the ontology. Therefore an enhanced methodology was proposed. The methodology can be seen as a mix of some of the methodologies described earlier, mainly with Methontology as the basis, taking the relevant parts from each methodology. Below is a short description of the proposed methodology consisting of four different phases, requirements analysis, building, implementation, and evaluation and maintenance.

In the requirements analysis phase all formalities for the ontology are specified, e.g. the intended users and uses of the ontology, the purpose and scope of the ontology, what should be in the ontology and what should not be in it. Why the ontology is being built is an important question to answer and what the users require and expect from the ontology. It is necessary to here plan the main tasks that should be done, including how they will be performed, a time plan and what resources that are needed. Usage scenarios of how the ontology can be used should be developed. The available knowledge sources should be identified including a decision how these should be used in the building phase. This could be interviews, text analysis, databases etc. Applications supported by the ontology should be documented. In order to shorten the development time one step is to check whether there are any ontologies that can be integrated with the one being built as soon as possible. Other things that should be specified are the level of formality (depends on the uses) and the level of detail (depends on the user requirements and available information). Before continuing with the building phase the developers should decide on a naming convention that should be used consistently. Any other things that could help to clarify the goals and purpose of the ontology should be specified in this phase. The result of this phase should be a user requirements document containing everything that needs to be specified before the ontology itself is built.

The building phase is iterative, meaning that the developers start with a rough concept and then specify and generalize from this. First, some basic terms are identified, for example by the use cases developed in the requirements analysis phase, by using a middle-out approach. These terms are then expanded and specified into more terms and then generalized if the level of detail obtained is too specific. How these terms are found should be clear from the requirements analysis. Next, relationships among these terms are specified. This includes is-a-relations, associations and synonyms. Now each term is described in natural language, this definition should be as precise and unambiguous as possible. The next thing to do is to add constraints among the terms and relationships. This includes pre-requisites, temporal, mutually inclusive and mutually exclusive constraints. If the requirements analysis resulted in one or more ontologies that should be integrated with the one being built this should be done now, it should be checked what parts that could be reused and which not. Also the properties of the terms (attributes) need to be specified, this includes cardinality, value type, domain and range. During this phase it is recommended to follow the rules and guidelines given by Noy and McGuinness [5]. The result so far should be a document containing all terms and
relationships that should be in the ontology, with a text definition of each term/relationship, constraints among these terms/relationships and properties of the term/relationships. Finally the ontology should be reviewed and revised.

The implementation phase primarily consists of implementing the ontology in an appropriate ontology tool, like Protégé, OntoEdit or SNet-Builder.

The implemented ontology needs to be evaluated and tested to check that it fulfils the requirements given in the requirements document (evaluation and maintenance). It should also be evaluated according to criteria such as clarity, the ontology and its terms should be clear and unambiguous, consistency, the ontology needs to be consistent without contradictions, and reusability, define the possibilities to reuse the ontology and the extent of reuse. It is also important to specify who should update and maintain the ontology and how and when this should be done.

Documentation should be done after each phase, the requirements analysis results in a user requirements document, the building phase results in a document containing all the terms, relationships and properties, the implementation itself is a kind of documentation, and an evaluation and maintenance document.

The whole methodology and its resulting documents can be seen in Figure 1.

Figure 1: Proposed methodology - Phases and resulting documents
4 Ontology for Wood-related Industry

The project started with an interview with Peter Scott from Elmia\(^2\), where existing solutions and use cases were defined. Elmias wish was to improve the communication between visitors and exhibitors at trade fairs. Their existing solution is a fair catalogue, where visitors can see information about the exhibitors. The intended users would be people involved in the selected area of interest. It is assumed that they are familiar with computer usage and with concepts and terms in the ontology. The interview also resulted in a motivating scenario, described below.

- **Users**
  - *Exhibitors and visitors at trade fairs*

- **Use case**
  - *Visitors fill in a taxonomy, with what they are interested in looking at (subject, capacity, etc.), the system does match-making and this results in a hit list, where a company can have 100% correct matching to what the visitor wants, and the hits may lead to a pre-booked meeting at the fair.*

- **Applications**
  - *Use the Internet for the visitors to fill in a taxonomy and do match-making*

Example of questions the ontology should be able to answer:

*A company looks for a supplier of fibre boards with a certain capacity.*

*A newly started company wants to know where they can turn to in order to get answer to import/export questions.*

The knowledge sources available for ontology development were a presentation from the SIDA project, mainly reflecting the value chain in wood-related industry. The SIDA project also had a report describing value chain, important companies/organizations etc. A reference was also given to Tullverkets classification over products made out of wood. Furthermore, Elmia has a dictionary in six languages, and of course, Internet was also going to be used in the building phase.

It was decided that the formality of the ontology was going to be structured-informal, which means a restricted and structured form of natural language. The level of detail was decided to be based upon the available information, i.e. decided later on, in the

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\(^2\) Elmia is an organizer of trade fairs located in Jönköping. Important fairs include “Elmia Subcontractor”, which is one of the biggest marketplaces for bringing together producers and suppliers in Northern Europe.
building phase. Regarding the scope of the ontology, the ontology should capture three dimensions: product structure, processes, and organizations, and also relations between these three dimensions. The checking for already existing ontologies in the subject area by searching the Internet resulted in nothing. Finally, it was decided to follow the naming convention described by Noy and McGuinness [5]. This resulted in a requirements analysis document which can be seen in Appendix 1.

So for the building phase, now it should be clear in order how to get the necessary information. Unfortunately the presentation and report from the SIDA project were not what was expected, i.e. they covered only a very small part of the area with an insufficient level of detail. In the methodology it is assumed that a middle-out approach is used in the building phase, this means that the building should start with the is-a hierarchy, and then specialize and generalize from there. When building the product structure, Tullverkets hierarchical classification was used to build up a hierarchy. To construct the processes, mainly the presentation given from the SIDA project was used. The organizations were a bit trickier, but from the information and companies in the SIDA presentation and report some groupings were made as a basis. This all lead to three different class hierarchies, one for product structure, one for processes and one for organizations.

Due to the lack of information in the knowledge sources this was decided to be enough concerning the level of detail. According to the methodology, now synonyms, associations and inverse relations should be defined. Due to information lack it was decided to just try out some relations and not spend a lot of time trying to make a complete, correct ontology without expertise in the domain. For the same reason, the remaining part of the building phase was not carried out, except for some examples.

Originally, this should result in a document with all the terms, relationships and properties, but this seemed unnecessary, instead the ontology was implemented directly into OntoEdit.

The organization and process hierarchies can be seen in Figure 2. One relation can also be seen, from the process Education to the organization Universities.

<table>
<thead>
<tr>
<th>Concept hierarchy</th>
<th>Relations</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education Universities</td>
<td>Universities</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Snapshot from OntoEdit – Organization and Process hierarchies
Figure 3 shows another view of the hierarchies and relations. In the middle you can see the root concept, and below that, with a ring, is the concept Universities which is an organization, and also has a relation to the process Education.

The revision and evaluation of the ontology could not be performed as planned, due to the lack of domain expertise. If the requirements were fulfilled is difficult to decide, but the ontology built can be seen as a small example of how an ontology could look like and be used, and it is extendable if more information should be given. Also regarding the other evaluation criteria it is difficult to decide if the ontology is correct or not.

The maintenance of the ontology has been left out in total, since the ontology will not be used in practice.
5 Conclusions

This section describes the evaluation of the methodology followed by a short section on future work.

5.1 Evaluation of the methodology

The evaluation of the methodology will be divided into the four different phases in the development methodology.

Requirements specification phase

The requirements specification phase went rather well. The most important lesson learned was that it is best to specify as much as possible, in order to be able to plan and cost-estimate the rest of the development. One aspect to change is to more thoroughly evaluate the knowledge sources, to see what information is there, and if more information is needed. This is crucial though, since in the requirements analysis you may not know what information is needed to build the ontology. This means you could easily make the conclusion that the information is sufficient, and then in the building phase this turns out to be wrong since information is missing. The methodology could also be enhanced with more guidelines regarding where to look for ontologies to integrate with. This could be done by adding links to ontology libraries etc. Furthermore, there is need for some kind of integration rules, so the ontology developer knows how to integrate other ontologies.

Building phase

No problems were experienced in the beginning, the methodology seemed good. However, the methodology was not followed in total here, so it is difficult to evaluate it. Building up the class hierarchies was a good starting point. For a small ontology it seems to be unnecessary to have a document with all concepts, terms and their relationships, constraints, axioms, etc. This might be useful if you have a more complex ontology.

Implementation

No problems were experienced, the ontology was implemented in OntoEdit without any difficulties. This phase should also consist of deciding what ontology tool to use. This could result in e.g. constraints or axioms that are not expressible in all languages used for ontology building, and therefore not possible to implement in all ontology tools.

Evaluation and maintenance

This phase was almost not carried out, so it is difficult to give any opinion on the methodology here. More guidelines are needed in order to know how to evaluate the ontology, what are the evaluation criteria?
5.2 Next Steps

The methodology needs a revision according to the evaluation above. After that it should be used again, in more test cases, to further define and specialize it. The methodology should be further specialized for small-scale application contexts, this could be small and medium-sized enterprises (SMEs) or networks of SMEs. In such contexts it is not usual to have an ontology expert, so the methodology needs to be easy to follow even though you are not an expert on ontologies. The methodology should also be very detailed, in order to be able to cost-estimate the development of an ontology, since small-scale application contexts often have limited resources. Another requirement of such a methodology is to be able to reuse already existing ontologies in order not to re-invent the wheel.
References


Appendix A – Results of Requirements Analysis

- Domain – a part of wood-related industry
- Goal – to try out this new methodology, and development of an ontology. Knowledge obtained in this project could be a basis for the PhD work.
- Design guidelines – into what direction?
  - Clarity – communicate the intended meaning of defined terms
  - Coherence – sanction inferences that are consistent with the definitions
  - Extendibility – anticipate the uses of the shared vocabulary
  - Minimal encoding bias – encoding bias results when a representation choice are made purely for the convenience of notation or implementation
  - Minimal ontological commitment – make as few claims as possible about the world being modelled.
- Strategy for building phase
  - Knowledge sources
    - What knowledge sources are available and how will these be used?
      - Interviews
        - Companies in the selected area
          - Elmia
        - What should be the benefits of using an ontology, i.e. what do you want to improve?
          - The communication between visitors and exhibitors at trade fairs
        - What is the existing solution?
          - A fair catalogue, where visitors can see information about the exhibitors
        - Who are the users, and their familiarity with computer uses, the concepts and terms in the ontology?
          - The users are people involved in the selected area of interest
          - There are familiar with computer uses and of the concepts and terms in the ontology
        - What material exists in the selected area of interest?
          - Tree Hierarchy (from Tullverket)
          - Elmia has a dictionary in six languages
  - Text analysis
    - Presentation
    - Glossary
    - Tree Hierarchy
Developing an Ontology for Wood-related Industry

- Dictionary (Elmia)
- Internet

- Motivating scenarios + solutions, competency questions
  - Users
    - Exhibitors and visitors at trade fairs
  - Use cases
    - Visitors fill in a taxonomy, with what they are interested in looking at (subject, capacity, etc.), the system does match-making and this results in a hit list, where a company can have 100% correct matching to what the visitor wants, and the hits may lead to a pre-booked meeting at the fair.
    - Tamagotchi
      - Each person at the fair gets a “tamagotchi” in which the persons needs and interests are specified. Then the system makes match-making and the tamagotchis beeps when to people match and are close to each other.
  - Applications
    - Use Internet for having the visitors fill in a taxonomy and doing match-making

- Formality
  - Highly informal – loosely in natural language
  - Structured-informal – restricted and structured form of natural language
  - Semi-formal – artificial formally defined language
  - Rigorously formal – formal semantics, theorems and proofs of such properties as soundness and completeness

- Scope
  - Level of detail – based on available information
    - Not so very detailed, depending on the knowledge sources
  - What should be in and NOT be in the ontology
    - Wood-related industry, three dimensions:
      - Product structure
      - Process
      - Organizations

- Check for already existing ontologies in the subject area – did not find anything

- Naming convention
  - Follow the naming convention described in [Ontology Development 10: A Guide to...]

- Resulting document – ontology requirements specification
  - Concision
  - Partial completeness
  - Consistency