Ontology Construction from Knowledge Acquisition

Lin-Li Chen[1], Christine W. Chan[2]
[1] Faculty of Engineering, University of Regina
Regina, Saskatchewan, Canada S4S 0A2
Chenli@uregina.ca
[2] Department of Computer Science, University of Regina
Regina, Saskatchewan, Canada S4S 0A2
Christine.chan@uregina.ca

Abstract:
This paper focuses on ontology construction as a foundation for knowledge representation. We present here the processes of knowledge acquisition, analysis, and representation using a conceptual modeling tool, the Inferential Modeling Technique (IMT), as a basis for ontology construction. To illustrate the knowledge modeling process, we apply IMT for knowledge analysis in the domain of petroleum remediation selection process. This paper demonstrates how the Inferential Modeling Technique facilitates the construction of a conceptual model for the domain, which is used as the basis for construction of an ontology.

1. Introduction

Knowledge representation for a complex engineering domain is difficult. In a knowledge-based system, even understanding a single sentence requires extensive knowledge of both language and context. To develop a system, knowledge needs to be represented efficiently and explicitly, so that it is possible to deduce new facts or retrieve existing facts from a knowledge base. In general, knowledge can be represented in systems of general and abstract propositions, organized in a single, coherent, and sharable structure. It is typically represented with a language that tends to be context independent, that is, there is a univocal relation between meanings, words, and object. In the past, ontological issues have been investigated in such areas of AI as theoretical knowledge representation and natural language understanding (Hobbs 1985). Recently, ontological issues are being widely used for the purposes of knowledge sharing and reuse, and object-oriented database design (Hobbs 1985, Hobbs et al. 1987, Monarch and Nirenburg 1987, Wand and Weber 1990). Ontology can also be seen as the study of the organization and classification of knowledge. Ontological engineering in AI has the practical goal of constructing frameworks for "knowledge" that allow computational systems to tackle knowledge-intensive problems such as natural language processing and real-world reasoning. In this paper, we present our efforts at constructing an ontology of an environmental engineering problem domain.

This paper is organized as follows: Section 2 introduces the Inferential Modeling Technique (IMT) for supporting the knowledge acquisition process. The knowledge clarified with the technique was reformatted into an ontology model for knowledge representation. Section 3 describes the problem domain of petroleum remediation selection. Section 4 presents the processes of knowledge elicitation and analysis, and the knowledge models that were developed. Section 5 discusses implementation of the developed ontology using Protégé-2000. Section 6 discusses some preliminary attempts at evaluation of ontologies and the knowledge acquisition user interface. Section 7 concludes the paper.

2. Knowledge Acquisition and Modeling

Knowledge acquisition is an important step in developing a knowledge-based system. The knowledge engineer acquires knowledge from one or more application experts who can explain the problem domain. In this process, detailed information on procedural problem-solving such as input and output, domain knowledge, and the entities and relations in that domain are obtained.

The Inferential Modeling Technique (IMT) was adopted for knowledge analysis during the knowledge acquisition process. The IMT is a systematic technique of cognitive modeling in which the inferential model functions as a template or conceptual map for classifying and organizing the units of knowledge embedded in the verbal or textual data elicited from experts (Chan et al. 1995). The elicited items of knowledge were then reformatted into an ontology, which served as basis for construction of the knowledge base.

2.1 Inferential Modeling Technique (IMT)

The knowledge acquisition process refers to the three stages of knowledge elicitation, knowledge analysis, and knowledge representation. The application of IMT may occur in the collection step (knowledge elicitation), the analysis step, and the interpretation step, and then may iterate back to the knowledge collection and analysis steps. The role of IMT in the knowledge acquisition process is shown in Figure 1.

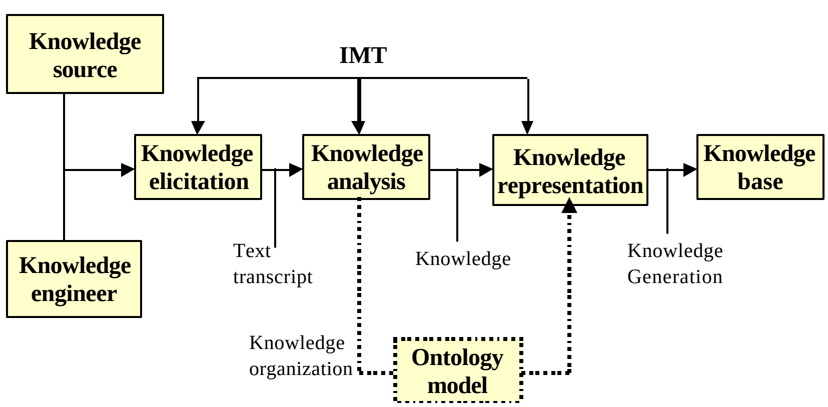

Figure 1. The Roles of the IMT and Ontology in the Knowledge Acquisition Process

The IMT is a procedure, which facilitates the development of the "specific categories" for a given domain by presenting the knowledge engineer with a template of knowledge types. It consists of the following steps (Chan et al. 1995):

1. Specify the physical objects in the domain,
2. Specify the properties of objects identified in (1),
3. Specify the values of the properties identified in (2), or,
4. Define the properties as functions or equations,
5. Specify the relations associated with objects and properties identified in (1) and (2) as functions or equations,
6. Specify the partial order of the relations identified in (5) in terms of strength factors and criteria associated with the relations,
7. Specify the inference relations derived from objects and properties identified in (1) and (2),
8. Specify the partial order of the inference relations identified in (7) in terms of strength factors and criteria associated with the relations,
9. Specify the tasks in the problem,
10. Decompose the tasks identified in (9) into inference relations or structures which invoke units identified in steps (1), (2), (5), and (7),
11. Specify the partial order of the inference or subtask structures identified in (10) in terms of strength factors and criteria,
12. Specify strategic knowledge in the domain,
13. Specify how strategic knowledge identified in (12) is related to task and inference structures specified in (9) and (10),
14. Return to step (1) and repeat until the specification of knowledge types is satisfactory to both the expert and knowledge engineer.

2.2 Ontology Modeling

Traditionally, development of a knowledge base assumes commitment to a single conceptualization and purpose. Often users or software that address the same problem domain cannot share or reuse the knowledge base because they may not share the same implicit conceptualization. An ontology however, is an explicit specification of a conceptualization, which serves as a comprehensive foundation of knowledge. Ontologies are often equated with taxonomic hierarchies of classes, with class definitions, and the subsumption relation ontologies also define the vocabulary with which queries and assertions are exchanged among agents (Gruber 1993). Ontologies can be used as the basis of knowledge acquisition tools for gathering domain knowledge or for generating databases or expert systems (ES). An ontology model can facilitate the knowledge analysis and representation processes. Before discussing the process of ontology construction, we first describe the application problem domain.

3. A Case Study: Petroleum Remediation Selection

Pollution from the petroleum industry is currently a major environmental concern world-wide. To adequately deal with each pollution situation, an appropriate remediation technique has to be selected. The aim of petroleum waste management is contamination remediation. The environmental engineers must make a decision whether to control or reduce the contaminant in the soil and groundwater. However, contaminated sites have different characteristics depending on the pollutant's properties, hydrological conditions, and a variety of physical characteristics such as mass transfer between different phases, chemical, and biological processes. Therefore, remediation techniques for different site conditions can vary significantly. This selection process is difficult and poses as an important challenge for environmental engineers who need support tools in this selection process. Thus, implementing a shareable knowledge base in the domain of remediation selection process can provide support for this decision process.

Petroleum contaminants are chemical substances in petroleum that are hazardous to the environment. Significant attention has been paid to the problems of petroleum-contaminated soil and groundwater. The contaminated sites are affected primarily by nonaqueous phase liquids (NAPLs), which are typically classified as either light nonaqueous (LNAPLs) or dense nonaqueous phase liquids (DNAPLs) from leakage and spillage of petroleum-related facilities such as storage tanks and pipelines. Figure 2 is a diagram that shows soil and groundwater being contaminated from leaking underground storage tanks. The contaminated groundwater directly impacts the drinking water, and poses as a hazard of human health.

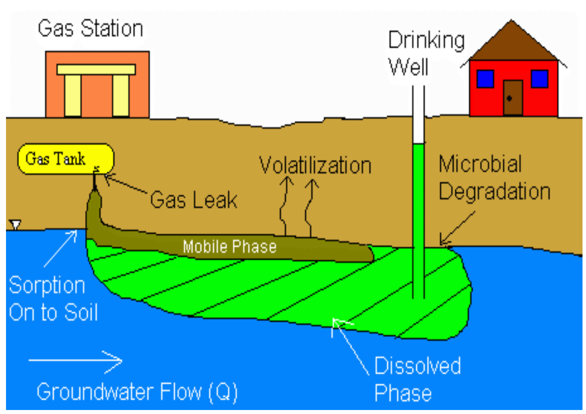

Figure 2. An Overview of the Petroleum Contamination Problem

The remedial technologies that are included in the knowledge base are divided into two categories: in-situ treatment and ex-situ treatment. In-situ treatment refers to treatment of soil or groundwater in place while ex-situ requires the removal by excavation of petroleum-laden soils. Costs and efficiency are dependent on site conditions (Preslo et al. 1990). In-situ remediation techniques are preferred when the contaminated site is large. By contrast, the ex-situ remediations are mostly used if the contaminated site is small. Normally, remediation involves removing contaminants from both soil and groundwater.

Selecting the most suitable method at a given site often requires expertise on both remediation technologies and site hydrological conditions (Sims et al. 1992). Therefore, in acquiring knowledge for this domain, domain experts were interviewed. A description of the domain knowledge as provided by such experts follows.

4. Knowledge Acquisition and Analysis

4.1 Knowledge Elicitation

Knowledge elicitation was conducted primarily through face-to-face interviews and e-mails. The knowledge engineer (the first author) learned about the domain from previously published reports, related projects, and a commercial remediation database on petroleum waste management. The strategy adopted for knowledge acquisition (KA) was based on teaching-learning and teaching-back **(**Neale 1989). Teaching learning was used to obtain the knowledge from the experts including verbal data and references. Then, after organizing the knowledge, teaching-back was used when the experts validated and clarified the knowledge presented to them by the knowledge engineer.

The raw data in the form of verbal and text data initially obtained from the domain experts is described as follows:

[*In order to select a remediation method for eliminating or removing pollution from industrial petroleum, we need several steps: first, we need to determine what media sites have been contaminated by toxic chemical substances, and the condition of the site. Second, we need to know what types of contaminants are in the site, and the condition of the contaminants. Finally, we need to have information or knowledge on remediation techniques.*]

[*In the first step, there are several sub-tasks that are used to determine the site condition.*

1. *Determine whether the contaminated site is soil, groundwater, or both soil and groundwater. If the media of this contaminated site is soil then further analysis of the soil condition is required as follows.*
2. *Obtain the size of contaminated site including area, volume, and depth of the site.*
3. *Obtain percentages of three major kinds of soils: sand, silt, and clay.*
4. *Determine the type of soil.*
5. *Determine the site hydraulic conductivity: the sub-tasks of this step are determining soil hydraulic permeability, soil heterogeneity, and soil isotropy.*

The size of site can be labeled into three types: small, medium, or large.
The unit that we used for area is square meter (m^2), for volume is cubic meter (m^3), and for depth is feet (ft). These data are input by users.
The soil type is classified into 12 kinds of soils: sand, clay, sandy loam, silt loam, clay loam, sandy clay, silt, loamy sand, loam, sandy clay loam, silty clay loam, and silty clay.
The site hydraulic conductivity is either simple or complex.
The sub-task of determining soil hydraulic permeability can result in a classification of extremely low, low, medium, high, or extremely high.

The sub-task of determining soil heterogeneity can be homogeneous, heterogeneous, or extremely heterogeneous.
The sub-task of determining soil isotropy can result in a classification of isotropic or anisotropic.

If media of this contaminated site is groundwater, then further analysis of the groundwater condition is required as follows.
……]

In the process of elicitation, we transferred the raw data to text. In the above example, we underlined the most important vocabularies, which referred to the central concepts, main objects with their relevant information, and relationships between each object. After the domain knowledge was obtained from the experts, it was analyzed.

4.2 Knowledge Analysis and Representation

4.2.1 Application of Inferential Modeling Technique (IMT)

The focus of this stage is to decompose the text data into the elements in the IMT model. During this analysis phase, we made use of the procedure of the IMT, presented in section 2.1, and identified the objects, attributes, values, tasks, and the relationships between objects. For clarification, a description of each element in the petroleum waste management domain is added. An example of each type of element is given as follows.

Object (O):
O1: site media=>environment in which contaminants are retained or permeated.
Attribute (A):
A1: site size=>the dimensions (depth, length, and width) of contaminated site.
Value (V):
V1: large=>the volume of contaminated site
Task (T):
T1: determine site media=>determine the entire contaminated site belongs to soil, groundwater, or soil and groundwater.
Relation (R):
R1: soil is a site media=>an equivalence relation

4.2.2 Ontology Design for the Domain of Petroleum Waste Management

Ontology design is primarily a categorization process. Good categorizations can facilitate information retrieval. Studies on categorization that pertain to ontology design in the AI field include Sowa's ontology (Sowa 1995), Dahlgren's ontology (Dahlgren 1988), and Gensim (Karp 1993). Since the domain ontology of a knowledge-based system is an explicit specification of the objects, concepts, and other entities that are presumed to exist in some area of interest as well as the relationships that are held among them (Gruber 1993), it defines the set of terms and relations of a domain independent of any problem-solving method. Normally, such method-specific formulation of domain knowledge is difficult to reuse in a different application. Therefore, to separate the potentially reusable domain knowledge from the method-specific knowledge is a consideration that guided our structure of the domain ontology.

The design of the ontology structure for the domain of petroleum waste management is illustrated in Figure 3. Figure 3 consists of three major sub-categories under the root of *Thing*. The three sub-categories are class, process, and relation.

"Class" can be a *Tangible Thing* and an *Abstraction*. There are two major categorizations under *Tangible Thing*: decomposable objects and non-decomposable objects. Basically, the class ontology includes all tangible or abstract concepts or substances that are relevant in the petroleum remediation process, such as chemicals, site media, standards, and experiments.

"Process" consists of simple process, complex process, and combination process. For example, if a task can be accomplished in two steps using objects within a single class hierarchy such as mix and add, then we consider it to be a simple process. If a task is accomplished in more than two steps using objects within a single class hierarchy, we define it to be a complex process. For example, when determining soil type, first, we need to take soil samples, then measure the percentage of each soil type, then measure an axis on the textural classification triangle, which is a soil classification system developed by the United States Department of Agriculture (USDA), and finally, the type of soil representative of the entire site can be determined. The combination process applies when a process involves objects from more than one class hierarchy. In other words, a task is accomplished in more than two steps using objects from different class hierarchies. For example, we want to determine the level of contaminants in soil, that is, we need to collect soil samples from the site, and then test the concentration of each contaminant type; finally, the level of contaminants can be determined. This task involves soil from *site_media* class, contaminant type from *contaminant* class, standard value from *standard* class, and contaminant concentration from *experiment* class. In this case, since the four different class hierarchies of *site_media*, *contaminant*, *standard*, and *experiment* are involved in accomplishing this task of determining the level of contaminants in soil. This is a combination process.

"Relation" covers properties of classes including their internal structure and relationships between classes. A relation can be one of three types: binary relation, multiple relation, and instance relation. Binary relation is a relation between two classes; for example, organic chemical and petroleum contaminant are two classes. *Benzene_B* is an element of these two classes, that is, *Benzene_B* is an organic chemical, and it is also a petroleum contaminant. Multiple relation is a relation involving more than two classes; for example, *John* is a university student, but he has a part job in a bank; besides, he teaches swimming classes during the weekend. In this case, *John* involves three different classes, student, employee, and teacher. Instance relation is a relation of some sets of attributes with certain values to an object. An instance relation is only true for a specific class or instance. For example, "*Saskatchwan*" is a direct instance of the class "standard", which has the attributes of site_media=soil, site_size=small, site_conductivity=simple, contaminant_type=BTEX, contamination_phase=residual, and contamination_level=high.

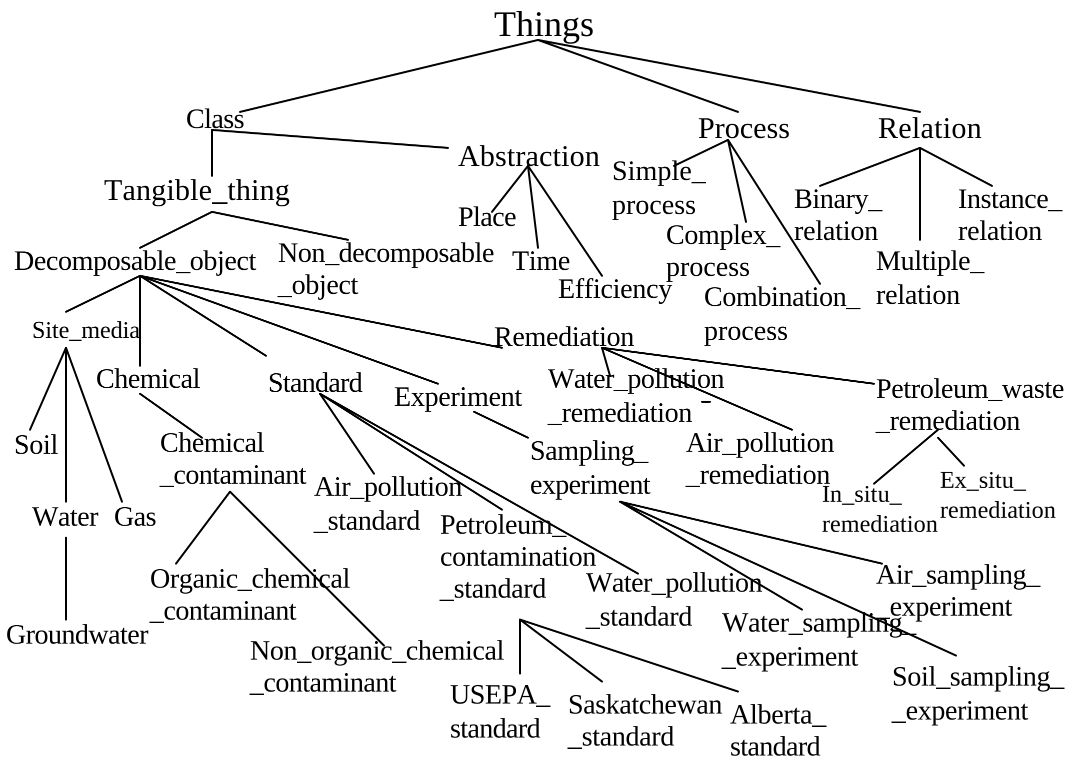

Figure 3. Ontology Design of the Petroleum Waste Management Domain in a Classification Hierarchy

4.2.3 Analysis of the Class Hierarchy

The classification hierarchy shown in Figure 3 is the ontology structure that classifies most relevant knowledge in the petroleum remediation domain, excluded from the diagram are attributes of classes. When an individual class within the classification hierarchy is described in detail, the particular class and its related subclasses and attributes are referred to as a class hierarchy, like the one shown in Figure 4.

There are two types of links in the class hierarchy: “is-a” link and “species” link. Most categories or classes in this model are involved in an *is-a* hierarchy; that is, the links between classes (a category and its sub-category) are mostly *is-a* links. For example, category *A* is-a category *B* if every instance of *A* is also an instance of *B*. By default, all the properties of a category are inherited in its sub-category, unless overridden by a sub-category definition. In our classification, for example, soil *is-a site_media*, that is, every instance of soil is also an instance of *site_media*.

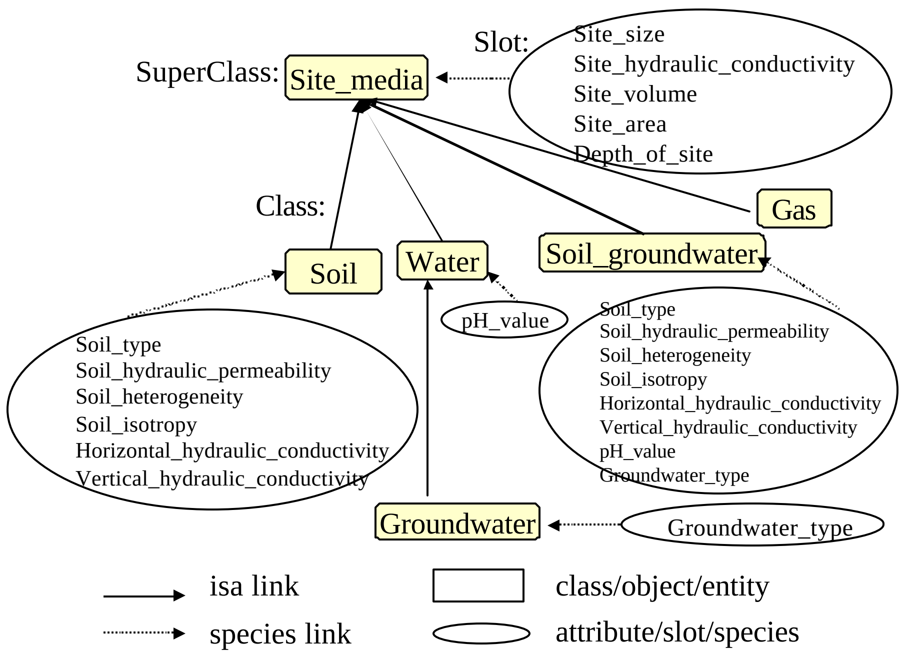

Figure 4. A Sample Class Hierarchy

A species link connects classes to their attributes in the class hierarchy; it can only connect to the leaves of the hierarchy. For example, in the petroleum domain, *Benzene-B* is a specific organic chemical substance belonging to the *petroleum_contamination_standard* class. Therefore, *Benzene-B* is a species of *petroleum_contamination_standard* class because there is no sub-category of *Benzene-B*. Specific instances are not a part of a class hierarchy because they are not categories themselves. All the links at the levels above the leaves are *is-a* links. Links that connect the leaves in the class hierarchy are "*species*" links. For instance, *Benzene-B* is a leaf in the category hierarchy, and there is a species link between *petroleum_contamination_standard* class and the *Benzene_B* slot because there is not any sub-class under the slot.

Detailed information about the classification hierarchy shown in Figure 3 is described in Figure 4, which shows the class *site_media* with its subclasses and attributes. Figure 3 shows classes of the problem domain under the top-level ontologies of class ontology, process ontology, and relation ontology. Detailed information such as attributes of classes is excluded in this classification hierarchy. For example, the class *site_media* is under the category of "*Decomposable_object*" in Figure 3. In Figure 4, we expanded on the details on the superclass of "*site_media*" and its subclasses of soil, water, groundwater, soil_groundwater, and gas. For example, "*site_media*" is a superclass; there are five subclasses under it: soil, water, groundwater, soil_groundwater, and gas. "*Site_media*" has the attributes/slots of *site_size*, *site_hydraulic_conductivity*, *site_volume*, *site_area*, and *depth_of_site*. Each subclass of the superclass "*site_media*" inherits all the attributes from the class "*site_media*", and in addition has its own attributes. For example, water is a subclass of site_media. It has all the attributes described above and in addition, also has its own attributes of *pH_value*. Similarly, "*groundwater*" is a subclass of "*water*" and "*site_media*"; therefore, it has all the attributes of "*site_media*" and the attributes of "*water*", plus its own attribute of *groundwater_type*. Other segments of Figure 3 that show other classes can be similarly expanded.

4.2.4 Entity Relationship Modeling

Another aspect of the ontology design which has not been hitherto discussed is relationships among the classes in the petroleum remediation domain. For this purpose, the Entity-Relationship (ER) model is adopted. ER diagrams are used to provide a convenient framework for database design, development and documentation. It represents relationships among entities involved in an information system.

Figure 5 shows the relations among the classes in the petroleum waste management domain. The classes have been depicted in the classification hierarchy shown in Figure 3 and some sample detailed information on attributes of the classes is shown in Figure 4. Some sample relations in the domain are described as follows. The name of relations is italicized and the entity types involved are in bold.

In the petroleum remediation problem domain, groundwater contains contaminant is represented by a *reside_in* relation between the entity types of "**contaminant**" and "**groundwater**". Other relations shown in Figure 5 include **soil** *is a* **site media**; **contaminant** *resides in* the **soil**; **experiment** *tests and determines* the **site media** that belong to **soil** or **groundwater**, **experiment** *determines* the type, phase, and level of **contamination**; **standard** is used for *comparing and calculating* the level of **contamination**; **remediation** is *applied to* **site media** in order to *eliminate* **contaminants** in site. The entities of "**soil**", "**site_media**", "**contaminant**", '**experiment**", "**groundwater**", "**standard**", and "**remediation**" are classes shown in the classification hierarchy of Figure 3. The relations of "*is a*", "*reside in*", "*test and determine*", and "*eliminate*" describe the relationships among these classes. Cardinalities of the relations are also shown in Figure 5.

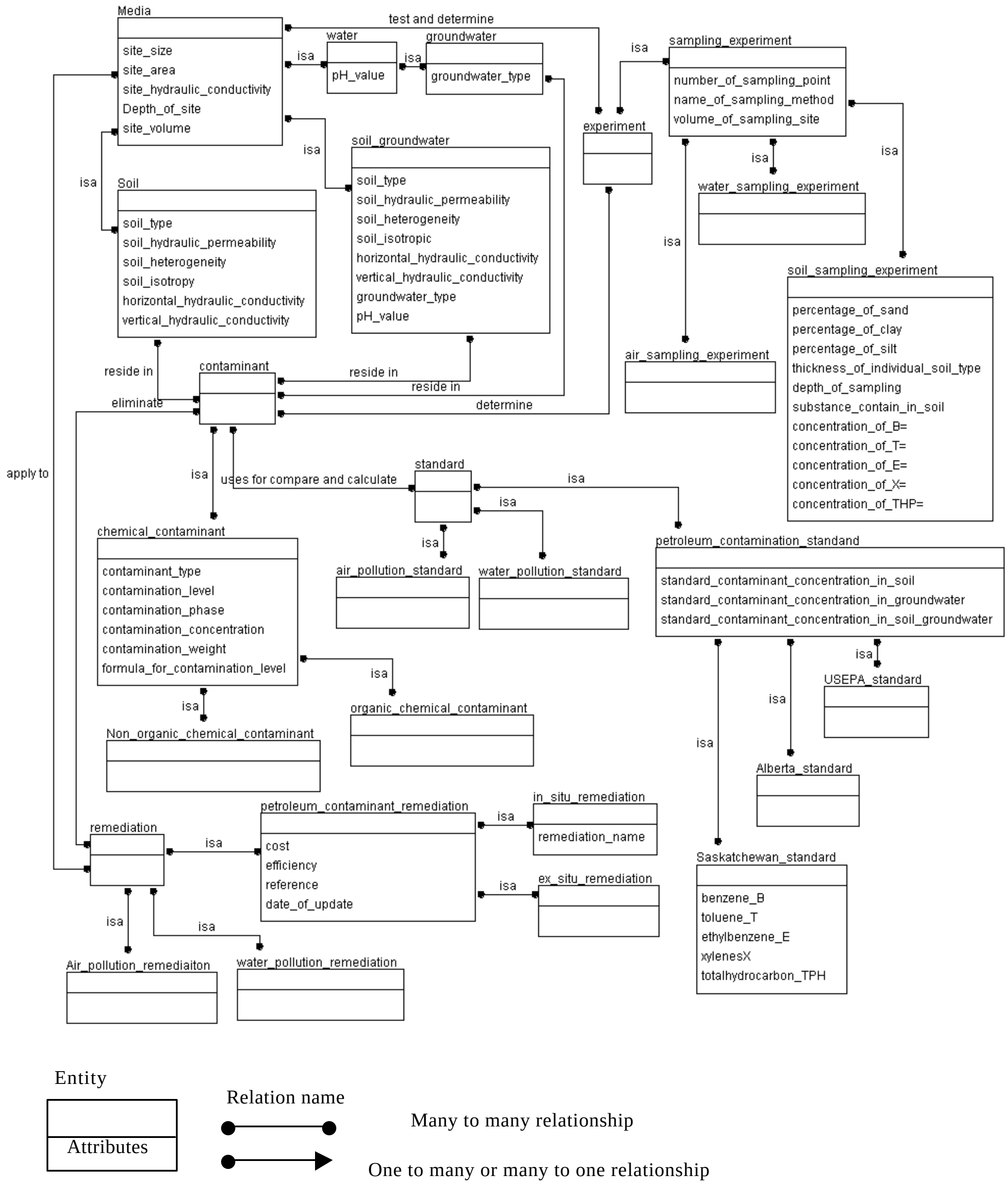

Figure 5. Entities-Relations (ER) Diagram Showing Relations among Classes in the Petroleum Waste Management Domain

5. Ontology Implementation Using Protégé-2000

5.1 Protégé-2000

Protégé-2000 is a Java-based implementation that supports ontology construction. It models knowledge based on class hierarchies. In other words, the Protégé-2000 approach uses the inheritance model provided in the meta-class definitions as the basis for the editor to develop ontologies. By using Protégé-2000, the developer can create a domain ontology and use the ontology as the basis for generating a knowledge-acquisition tool with a meta-tool. Finally, the knowledge-acquisition tool can be used to create instances of the domain ontology (Eriksson, Fergerson, Shahar, and Musen 1999).

The ontology editor in Protégé-2000 supports built-in meta-level classes, slots, and facets, which are the basis for the generation of ontology editors. It provides the platform and a graphical user interface to support customized user-interface extensions, which facilitate system developers and domain experts to develop knowledge-based systems.

5.2 Conversion Between Knowledge Models and Protégé-2000 Ontology Editor

The knowledge on the petroleum domain clarified using the IMT and represented using the classification hierarchy, class hierarchies, and the ER diagram can be directly implemented in an ontology construction tool, Protégé-2000 (Puerta, Edgar, Tu, and Musen 1992). Figure 6 is a brief illustration of the conversion between the results of the knowledge analysis and representation processes and Protégé-2000. For example, classes and subclasses can be taken from the entities of the ER diagram, and become classes and sub-classes in the first column of the Protégé-2000 ontology editor in the "*class*" field shown in Figure 7; the slots are attributes in the ER diagram shown in Figure 5 or class hierarchies as shown in Figure 4. We can then take the slots from class hierarchies to the slot field of Protégé. After all the slots are filled, the values can be added easily by using the "*slot form*", which is provided in the Protégé editor. These values are collected in the knowledge acquisition phase using the IMT. Finally, an ontology classification hierarchy is used for organizing the entire structure in the ontology editor. The instances that are related to classes can be organized by using the "*form*" format, which converts the ontology to the knowledge acquisition user interface shown in Figure 7.

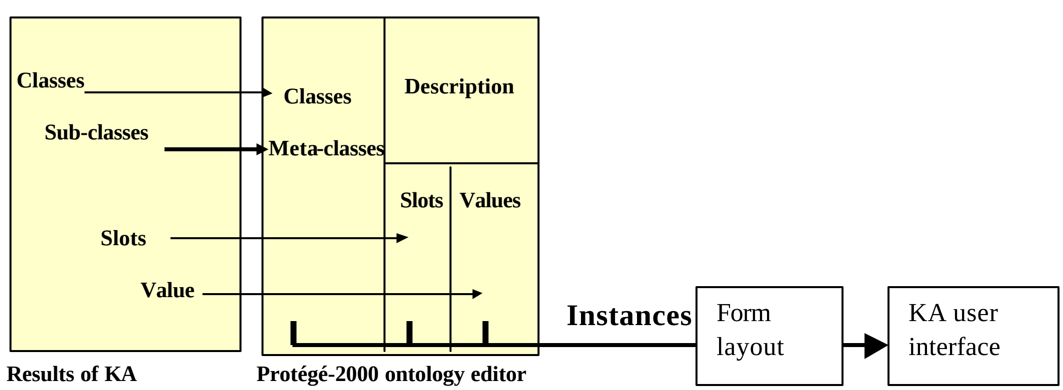

Figure 6. Conversion Between Knowledge Models and Protégé-2000 Ontology Editor

The remediation selection ontology is implemented with Protégé-2000. We converted the knowledge clarified and represented using the class hierarchies and ER diagram as described above into an ontology. In Protégé-2000, the slot is the lowest level of objects. The meta-classes represent concepts in the middle level of the ontology. For example, the meta-class "*soil*" is a sub-class of "*site_media*". In practice, first, we replaced all super classes in the ontology structure then fill in relevant sub-classes (meta-classes or meta-meta-classes). Secondly, we replaced all slots and values, which are related to the class that is highlighted in the ontology platform. Finally, we generated the knowledge acquisition tool thereby transferring the ontology to a user interface. During this task we use the "form" to rearrange the layout of the user interface. The user interface is then used for evaluating the domain knowledge and the system design (see Figure 7).

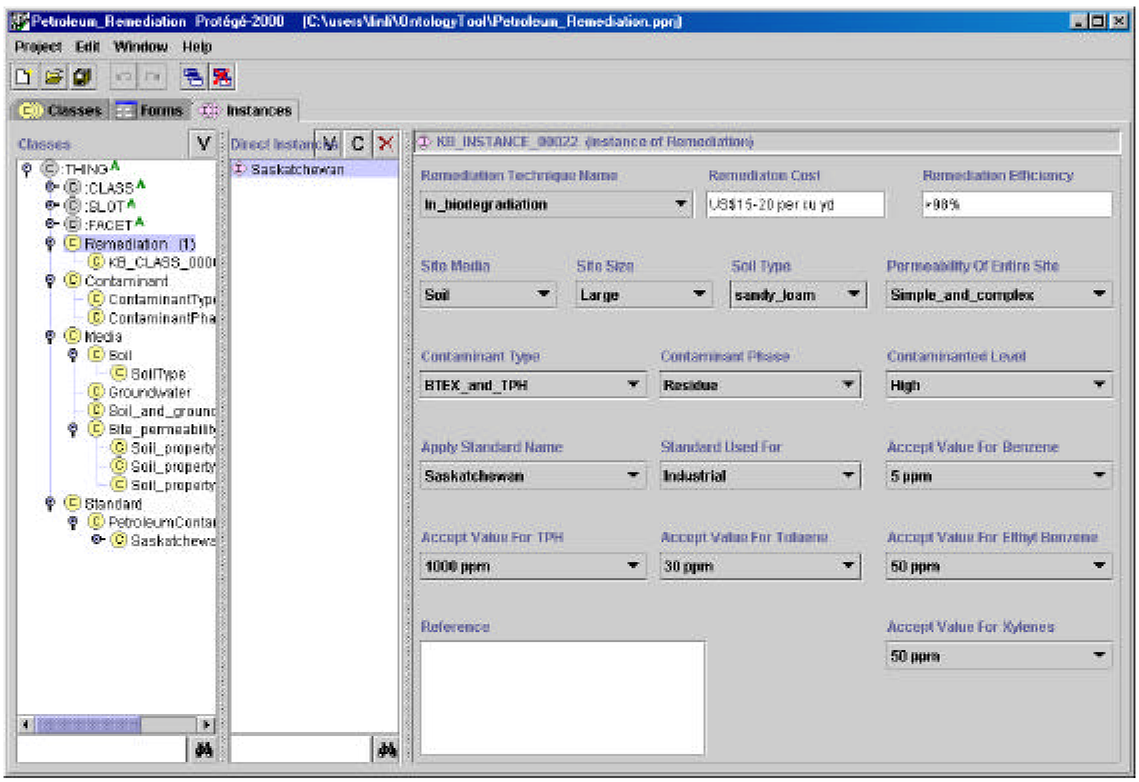

Figure 7. A Sample User Interface Screen From Protégé-2000

In Figure 7, all classes and meta-classes appear on the left side of the figure. The "*direct instance*" shown in the second column of "*Saskatchewan*" is attached to the highlighted class of "*Remediation*". The related classes, slots, and values in the "*Saskatchewan*" instance appear on the right side of the figure. For example, if we look at the class "remediation", there is a direct instance "*Saskatchewan*", which is a subclass of "*standard*". The attributes which are related to this direct instance of "*Saskatchewan*" are: remediation_technique_name=in_biodefradiation, remedation_cost=US$15-20 per cubic yard, remediation_efficency=98%, site_media=soil, site_size=small, site_permeability=simple, contaminant_type=BTEX/THP, Contamination_phase=residue, contamination_level=high.

The user interface enables the experts to (1) fill in the domain knowledge, (2) evaluate the quality and quantity of domain knowledge, and (3) measure feasibility of reuse of domain knowledge. In addition, it can be used for knowledge maintenance.

6. Preliminary Evaluation of Ontologies and the Knowledge Acquisition User Interface

Some measures for the "goodness" of an ontology and the knowledge acquisition user interface include expressiveness of its representation, how understandable is the user interface, and the feasibility of knowledge reuse or sharing.

The user interface is evaluated in terms of the display layout to see if it is easy to enter information and select values. For example, is it better to use a pull down menu or radio bottom to display the values? The textual descriptions in the user interface are evaluated to ensure that they properly represent the information in that domain. Attributes and instances are evaluated to ensure they are suitable and describe a condition related to that class in the user interface; for example, some attributes such as "site hydraulic conductivity" might not belong in a class on "gas". Evaluating the conceptual coverage of the knowledge base includes assessing what percentage of sentences is fully and correctly represented. This involves an assessment on the number of sentences, the number of concepts, attributes of the concepts, and their properties that are represented. Some criteria for evaluating reusability of the ontologies include whether they use an explicit classification scheme, general terms, class inheritance, and appropriate attributes.

7. Conclusion

The knowledge models developed from the phases of knowledge acquisition, knowledge analysis, and knowledge representation have been presented in this paper. We have demonstrated how these models can be utilized in constructing an ontology for the domain of petroleum waste management. The IMT gives an early categorization of the domain. However, the IMT is not suitable for large problem domains because applying it for knowledge classification is time consuming. The classification of knowledge in the ontology better defines the concepts of object relations and gives an overview of the classification hierarchy in the domain. The ER model was used to represent the objects and attributes, and relations among all objects in the classification hierarchy. Combining the ER model, ontology classification hierarchy, and class hierarchy solves the problem of expressiveness that only using the class hierarchy and the ER diagram would introduce.

Protégé-2000 offers a graphical assembly editor that implements our design of the ontology. If the association between two classes is complex, Protégé cannot represent it. An alternative way to represent this is to create a new association class. For example, in two classes “soil” and “soil_sampling_experiment”, the slot “soil_type” in the class “soil” is determined by the three slots of “percentage_of_sand”, “percentage_of_silt”, and “percentage_of_clay” in the class “soil_sampling_experiment”. If we want to represent this relationship, we have to create a new class for example “experiment_determine_soil_type”, which includes the slots from both classes of “soil” and “soil_sampling_experiment”. However, the class “experiment_determine_soil_type” should not be in the ontology classification or class hierarchy. Otherwise, it will obscure the classification because the slot “soil_type” would represent both a value and a relationship at the same time. That is, if we connect the slot “soil_type” of the class “soil” with other three slots in the class “soil_sampling_experiment”, then we cannot represent the twelve values of soil types in the slot “soil_type”.

The knowledge acquisition user interface generated from the developed domain ontology is useful for collecting instances or cases of problem solving scenarios for a specific domain. Each case or instances contributes to a case base. The case can also be included in a database, which can then be used for building an expert system for decision support.

8. Acknowledgment

We are grateful for the financial support of Natural Sciences and Engineering Research Council (NSERC) of Canada. We are also grateful for the assistance X. Wang, Z. Hu, and S. Cheng have given us in this project.

Reference:

1. Chan, C., Tontiwachwuthikul, P., and Cercone, N., “Knowledge Engineering for a Process Design Domain”. *International Journal of Expert Systems*, Vol.8, pp.47-76, 1995.
2. Dahlgren, K., “Naive Semantics for Natural Language Understanding”. Boston, MA: Kluwer Academic, 1988.
3. Eriksson, H., Fergerson, R.W., Shahar, Y., and Musen, M. A., “Automatic Generation of Ontology Editors”. *Twelfth Banff Knowledge Acquisition for Knowledge-based System Workshop*, Banff, Alberta, Canada, 1999).
4. Gruber, T.R., “Toward Principles for the Design of Ontologies Used for Knowledge Sharing”. *International Workshop on Formal Ontology*, Padova, Italy, Technical Report KSL 93-04, Knowledge Systems Laboratory, Stanford University, 1993.
5. Gruber, T.R., “A Translation Approach to Portable Ontology Specifications”. *Knowledge Acquisition*, Vol.5, pp.199-220, 1993.
6. Hobbs, J.R., “Ontological Promiscuity”. In Proceedings of ACL, Vol. 85, pp.61-69, 1985.
7. Hobbs, J.R., Croft, W., Davies, T., Douglas, E., and Laws, K., “Commonsense Metaphysics and Lexical Semantics”. *Computational Linguistics*, Vol.13, pp.241-250, 1987.

8. Karp, P.D. and Hunter, L., "A Qualitative Biochemistry and Its Application to the Regulation of the Trytophan Operon". *In Artificial Intelligence and Molecular Biology*, AAAI Press/The MIT Press, pp.289-325, 1993.
9. Monarch, I. and Nirenburg, S., "The Role of Ontology in Concept Acquisition for Knowledge-based Systems". In Boose, I., Addis, T., and Gaines, B. (eds.), *Proceedings of EKAW-87*, University of Reading. 1987.
10. Neale, I.M., "First Generation Expert System: A Review of Knowledge Acquisition Methodologies", *The Knowledge Engineering Review*, pp.105-145, 1989.
11. Puerta, A.R., Edgar, J.W., Tu, S.W., and Musen, M.A., "A Multiple-Method Knowledge-Acquisition Shell for the Automatic Generation of Knowledge-Acquisition Tools". *Knowledge Acquisition*, Vol.4, pp.171-196, 1992.
12. Preslo, L. M., Robertson, J. B., Dworkin, D., Fleischer, E. J., Kostecki, P. T., Calabrese, E. J. "Remedial Technologies for Leaking Underground Storage Tanks". *Lewis Publishers*, INC. Michigan, USA, 1990.
13. Sims, J.L., Suflita, J.M., and Russell, H.H., "In-situ Bioremediation of Contaminated Ground Water". *Ground Water Issue, EPA/540/S-92/003*, U.S.EPA, R.S. Kerr Environ. Res. Lab., Ada, OK, Vol.11, 1992.
14. Sowa, J.F., "Distinctions, Combinations, and Constraints". *In Workshop on Basic Ontological Issuers In Knowledge Sharing*. Montreal, Canada, 1995.
15. Wand, Y. and Weber, R., "An Ontological Model of an Information System". *IEEE Transactions On Software Engineering*, Vol.16, No.11, pp.1282-1292, 1990.