Semantic Management: advantages of using an ontology-based management information meta-model

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Abstract:

The multiplicity of Network Management models (SNMP, CMIP, DMI, WBEM...) has raised in the last years the need of defining multiple mechanisms to allow the interoperability among all involved management domains. One basic component of such interoperability is the mapping between the information models that each domain specifies. Usually, these mappings have been carried out with syntactical translations that do not include the semantic aspects of the defined information. These translations could reach the semantic level by using ontologies: these ontologies widely used in Artificial Intelligence, exactly focus on the meaning of those concepts composing an information model.

This article shows how to improve current network management methods with the application of formal ontologies techniques. This will allow the definition of a management information meta-model integrating all the information that currently belongs to different management domains in the same model. In this way, network managers can work and reason with an abstract view of the management information, independent of the specific management model used to interoperate with the managed resource. Another advantage of the use of ontology-based management information meta-models is the ability to include basic semantic behavior for a manager to monitor and control these resources.

Keywords: Ontology, Network Management, Information Models Integration, Behavior Information.

Introduction

Network and service management has been a field in which traditionally proprietary solutions from different vendors have been imposed. These solutions demanded the management of those equipments could only be performed with those vendor products. Then, between the eighties and nineties integrated network management models appeared that defined standard protocols and information models allowing the interoperability between multiple vendors managers and managed elements.

Due to historical reasons, two different management models have survived the standardization process: Internet network management model (also known as SNMP) and OSI network management model (also known as its protocol: CMIP). These models are incompatible, so finally each model has got its own application field, even though both models have to coexist in some environments.

Later on, other integrated network management models have appeared that use other technologies for resources management different to SNMP or CMIP. The most notably example is WBEM and its associated information model, CIM.

Given the heterogeneity of integrated network management models establishing interoperability mechanisms have become essential. Existing studies about this topic divide this problem in two points which are about the communication protocol and the information model: If a rule set can be defined that translates both points, interoperability is possible.

However, there is already one question without an easy answer: What happens when two different domains represent the same concept in a different way? A merely syntactic translation from the source model will not give the existing concept in the destination. A semantic translation is necessary that maps directly both domain concepts.

This paper introduces some issues to facilitate the information model interoperability, explaining the possibilities to reach a semantic translation. For this, the knowledge representation discipline known as Ontology could be the answer to this question: An ontology provides all necessary constructions to add semantics to represented information (see Figure 1).

Applying this discipline to network and service management field could be the key that allows a real integrated management of all resources composing a networked system which usually belong to different management domains: Switches and routers managed with SNMP, computers administered with DMI or CORBA-based electronic services would be managed in a unified way from a manager with one and only information model. These network managers could work and reason with an abstract view of the management information, independent of the specific management model used to interoperate with the managed resource.

Also, declarative capacity given by ontologies would allow the definition of rules to model the manager behavior, adding this feature to the specified management information model, which would detail all management information in a unified way. In fact, ontologies have axioms and rules that define completely the values a concept can have. These axioms could be useful to describe certain behaviors.

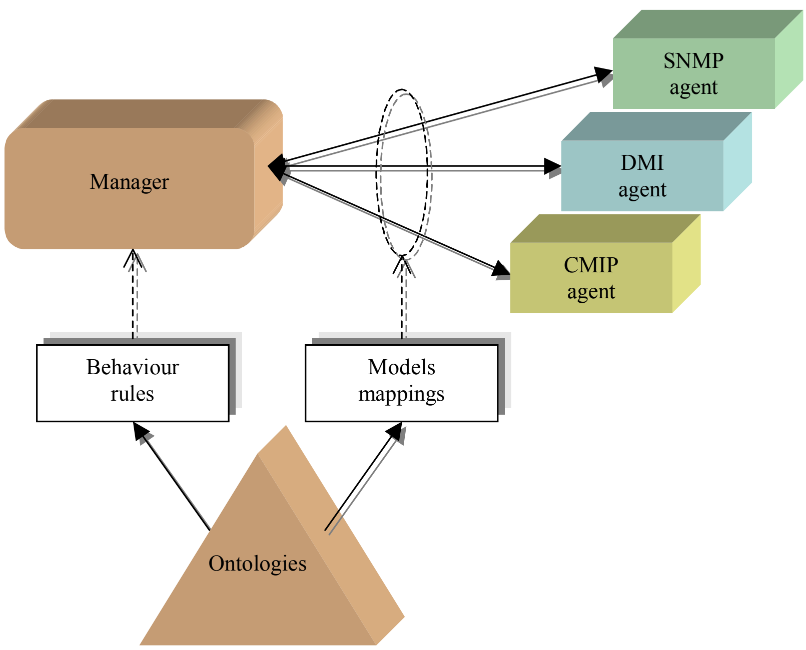

Figure 1. Paper objectives.

This paper is structured as follows:

- First of all, a review of existing mapping levels to reach interoperability between different management models is given.
- Then, ontologies are introduced and compared with current network management modeling techniques.
- Next, a new approach to map models with ontologies is explained.
- Also, some examples about how to add behavior to the management information are shown.
- Finally, some conclusions as well as future work lines are given.

Mapping levels

Interoperability issues have been studied since problems caused by different domains have been found. First theoretical work about this topic was [Kalyanasundaram94]. This paper enumerates different aspects that affect the interoperability. These ones are information model, exchange protocol, and transparency levels when crossing from one domain to another. Some interoperability schemas are also proposed as possible solutions: Multiarchitectural managers or agents and management gateways. Similar approaches have been enumerated at [Rivière96, Keller99]

A deeper study about information management interoperability can be found at [Rivière98]. They give different approaches depending on four viewpoints:

- Philosophy: it is referred to the management information level at which the interoperability is obtained. Figure 2 shows this point, that maybe is the most important to understand how important is the way in which the information is translated. This is stressed by the fact that this viewpoint can be also found in chapter 6 (Mapping existing models into CIM) of [DMTF99a], with similar nomenclature.
    - Technique: This approach defines a construct in the source model that defines the meta-construct of the destination model. This approach has been used by DMTF to define the SNMP-DMI gateway [DMTF97]. There are commercial products that define CORBA-SNMP or RMI-SNMP gateways [AdventNet01] based also on this philosophy level.
    - Recast: This approach maps meta-constructs of the source model to meta-constructs of the destination model. It allows a syntactic interoperability. This approach has been used in [NMF93a, NMF93b, NMF93c] and [Open00].
    - Domain: This approach maps model instances from source to destination model. It allows a semantic interoperability. This approach has been partially used in CIM with the MappingStrings qualifier, and it is the better way to reach a better interoperability. However, it cannot be done automatically and this is its most important inconvenient. Then, usual approach taken by vendors [Microsoft01, Sun01] is recast, even though syntax is different to semantics.

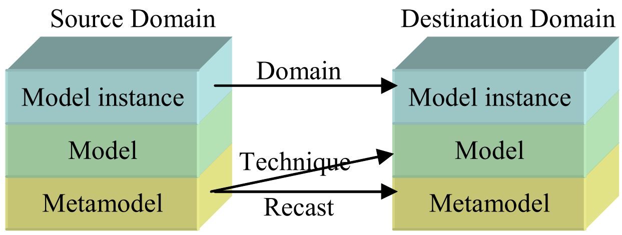

Figure 2. Philosophy viewpoint.

- Principle: it is referred to the degree of heterogeneity that exists between information models. This point is also addressed in [Kalyanasundaram94].
  - Direct Translation: Managed objects of the source model are directly mapped onto equivalent objects of the destination model. This translation is much related to recast translations and appropriate when concepts in both models are fairly homogeneous.
  - Abstract Translation: Source and destination concepts are different and information of the source has to be manipulated to fit in the destination model.
- Mode: it is referred to the kind of information utilized to reach the interoperability
  - Static Mode: The interoperability is solely based on the management information.
  - Dynamic Mode: Other factors, such as instance identification, are also taken into account in a broader context including services and protocols.
- Organization: it is referred to the dependence of the translation to management systems.
  - Independent: It does not depend on management systems of source or destination models. It is usually realized by a proxy or gateway.
  - Dependent: It depends on management systems, adopting approaches such as multiarchitectural managers or agents.

In short, common solutions are usually based on recast philosophy, direct translation principle, dynamic mode and organization independent, although other ones are also possible.

As referenced previously, different organizations such as Open Group, Tele Management Forum, OMG or DMTF have also proposed different standardized solutions, usually based on gateways. Figure 3 shows a possible scenario based on all these solutions:

- A CORBA manager can access CORBA-based agents with management information defined in IDL, or TMN and SNMP agents with such information defined in GDMO and SMI respectively, and translated into IDL [Open00].
- A TMN manager is quite similar to previous one, because it can manage TMN agents with information defined in GDMO, and CORBA and SNMP agents with information defined in IDL and SMI respectively, and translated into GDMO [Open00, NMF93a, NMF93b].
- When dealing with SNMP managers, access to other domains different to SNMP is restricted: making requests to CORBA-based agents is possible only if management information has been defined in SMI and translated later into IDL [Open00]. Similar thing happens to TMN, where translating from GDMO to SMI is not always possible. [NMF93c]
- In DMI, access from SNMP domain is possible, but using a different translation mechanism, based on an SMI MIB defined by DMTF that allows the access to MIF information [DMTF97]. Commercial products also translate recasting from MIF to SMI [Sun02], but this does not comply with the standard approach.

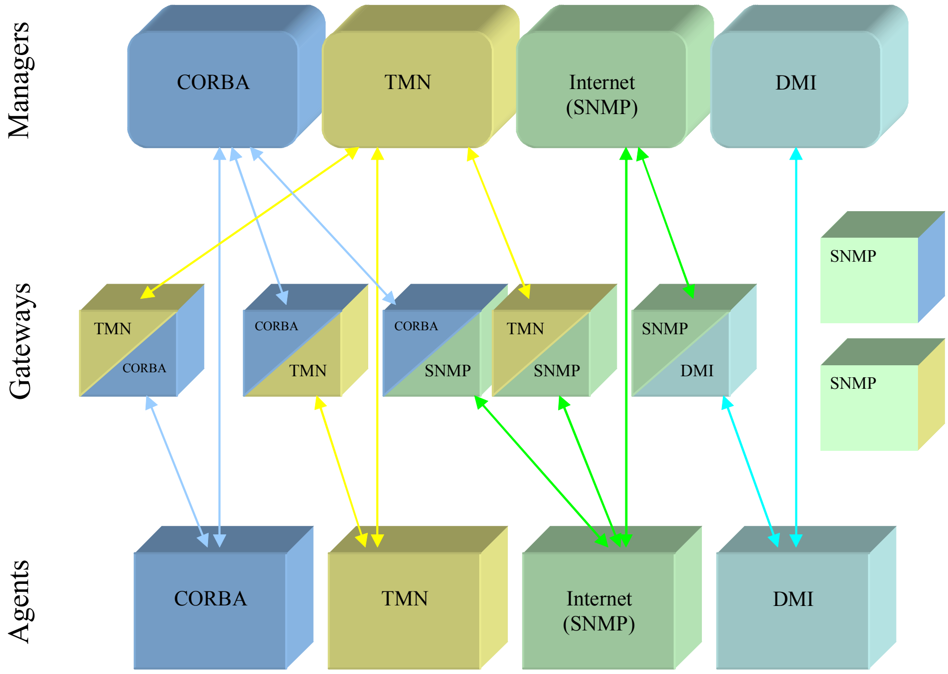

Figure 3. Defined gateways for different management domains interoperation.

As seen, different existing solutions to solve interoperability problems have permitted to carry out a partially integrated network management. Many problems are still unsolved, because both the access method and managed information are still dependent of the managed resource domain. A desirable solution, sometimes called Umbrella Management [Neumair98, Keller99], would have a single information model and a single access interface that could communicate with every enterprise resources, usually managed in terms of its domain. An implementation of this solution is WBEM architecture [DMTF00], defined by DMTF. In WBEM, access interoperation is almost saved; semantic interoperability is still an obstacle:

- Different protocols are integrated through providers. Every provider behaves as a gateway between an independent protocol, HTTP/XML [DMTF99b], and management protocols. The set of possible operations in WBEM is sufficiently complete to access any management domain. Thus, protocol integration can be reached.

- Even though future management information will take CIM as information model, legacy agents exist with information defined in other language. Recast translations have been defined for SMI [Microsoft01, Sun01], GDMO [Festor99] or IDL [Pablos01]. Thus, syntactic integration can be reached, the same one as obtained by IIMC or JIDM, but semantics is not integrated.

  This is a problem when different management domains have overlapped concepts in their respective information models. The ideal solution would be that those concepts would be reflected in CIM concepts, as it happens in some cases, using the MappingStrings qualifier [DMTF99a]. In [Juanes01, Schott02] other concepts have been identified, but this domain mapping is not very usual.

  Also, none of the management information models integrate those rules that govern the behavior of an intelligent manager being able of answering questions. For that, other declarative language such as Prolog or other similar [Benech99] is usually used. Anyway, these rules are totally independent of the information they need to get the requested information.

Ontologies

As previously seen, WBEM could be a valid integration architecture. However it has problems for semantic integration. Semantic issues are being solved in the Knowledge Management and Artificial Intelligence fields using Ontologies. This subject has recently gained relevance with the appearance of the Semantic Web [BernersLee01], and there are some related standard activities being performed at several projects such as IST OntoWeb [Ontoweb01], DAML [DAML02], and SemanticWeb.org [SemanticWeb02]. Ontological Engineering techniques could help in the information management integration.

To understand how ontologies can be applied to the information management integration it is necessary to explain previously what they are. Ontology could be generally defined as an explicit and formal specification of a shared conceptualization [Studer98]. This definition can be understood in the following way:

- It is explicit because it defines the concepts, properties, relationships, functions, axioms and constraints that compose it.
- It is formal because it is machine readable and interpreted.
- It is a conceptualization because it is an abstract model and a simplified view of the domain phenomena it represents.
- Finally, it is shared because there has been previously a consensus about the information and it is accepted by a group of experts.

Briefly, it can be said that an ontology is the definition of a set of concepts, its taxonomy, interrelation and the rules that govern such concepts.

Ontologies can be classified between lightweight and heavyweight. First ones are those that are able of modeling the information referred to a domain, but they do not include axioms or constraints, and so, it is difficult to reason with them. Last ones include all elements that allow their use to make inferences about the knowledge they contain.

In this way, existing management information models could be understood as lightweight ontologies: Models like CIM define the information of the management domain in a formal manner and consent by working groups. However, they do not incorporate those questions that provide the semantics they lack, and which allow the inference of knowledge based on existing one.

Thus, it is also possible making a certain correspondence between ontologies types architecture [Gómez99] and CIM, as shown in Figure 4. Ontologies are usually based on other ones, following a pyramid structure in which more general and also more reusable ontologies are at the bottom level, and more usable and also more specific and less reusable are at the top. CIM has a similar structure in which only a general common ontology level is not present. Besides, CIM lacks tasks ontologies that allow handling this knowledge through Problem Solving Methods.

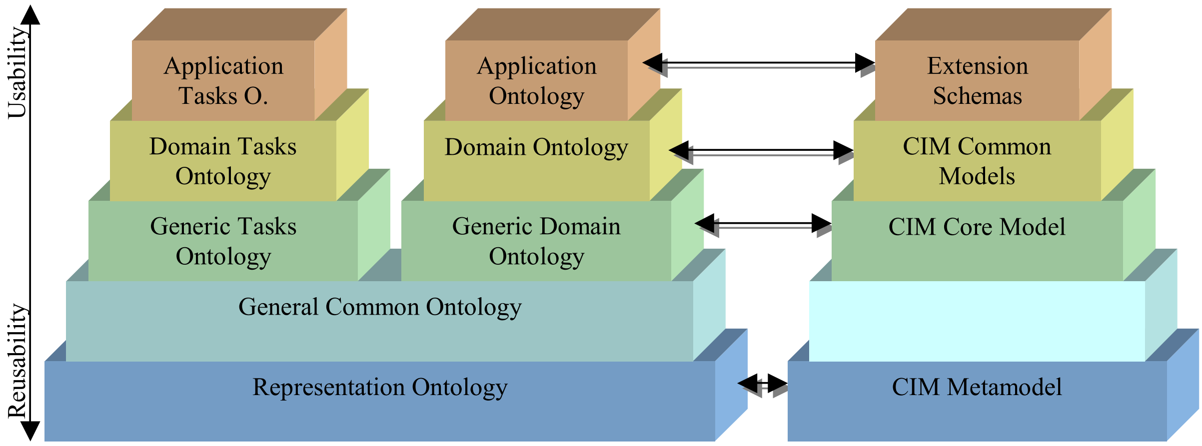

Figure 4. Correspondence between CIM and Ontologies architectures.

Another question to be remarked is that ontologies can be applied not only to define information, but also to add expressiveness and reasoning with those that use first order or descriptive logics. A management system that has an inference engine, like in [Benech99], could use the same ontology for both defining all management information and also define its behavior rules in a unified way.

Mapping models with ontologies

When mapping information models there are two possibilities. The first one is to define translations between every two models. The second one is to define a new information model, a kind of meta-model over existing ones. The second approach is better if the number of models is high, being proved that 2n translations are just needed, instead of n^2-n.

In this way, the definition of CIM has been a good approach. In fact, [Cranefield01] proposes UML joint with OCL as an ontology definition language, and CIM is UML-based, although its meta-model is quite different to UML meta-model [LópezDeVergara01]. Nevertheless, as shown previously semantic interoperability is not completely achieved in CIM and thus, it should be extended. The approach being studied is the creation of a network management model based on formal ontologies. The resulting ontology would be based on CIM, adding the necessary axioms and constraints to obtain a heavyweight ontology.

Working with ontologies is better than working directly with management information models, because there are some works about how to map or merge different ontologies [Hovy98, Noy00, Stumme01, Noy01b]. They do not provide a completely automated mapping algorithm, but give some heuristics which can be used for a semiautomatic mapping.

A first step to solve the problem is to try to express a MIB in ontological terms, and then, add a set of formulae or axioms to complete it. To experiment this approach HOST-RESOURCES MIB has been used as source MIB. This is a good MIB because there are some MappingStrings in CIM that can be useful. Another question that can be useful to capture its concepts is to use SMI reverse engineering algorithms [Schönwälder01], supposing *augments* and *sparses* associations as subsumptiom relationships, and *expands* association as an aggregation relationship.

Working with ontologies is not very complicated if one thinks in terms of objects. The only difference is that terminology is wider, and sometimes it differs from object-orientation: classes are also called concepts or frames; and attributes are also known as slots. Also, other facets such as cardinality or range are usually specified. Another thing is that slot names are usually unique, so SMI naming schema (using prefixes, such as hrDevice or hrPrinter) is good to differentiate slots from different concepts. Finally, operational qualifiers such as *readable* or *writable* or the OID of each slot cannot be expressed in terms of ontologies, but some ontology languages allow the addition of new meta-tags [Fensel01], which could be used for this purpose. Having this in mind, it is possible to translate from SMI and CIM to a particular ontology, and then, try to merge both ones using ontology tools like Protégé 2000 [Noy01a], which has been used in this paper.

Figure 5 and Figure 6 show an ontological view of a subset of the CIM model and the HOST-RESOURCES MIB respectively. The translation to these views has been done by hand, but it could be automated doing a syntactic translation from MOF and SMI to the ontological language.

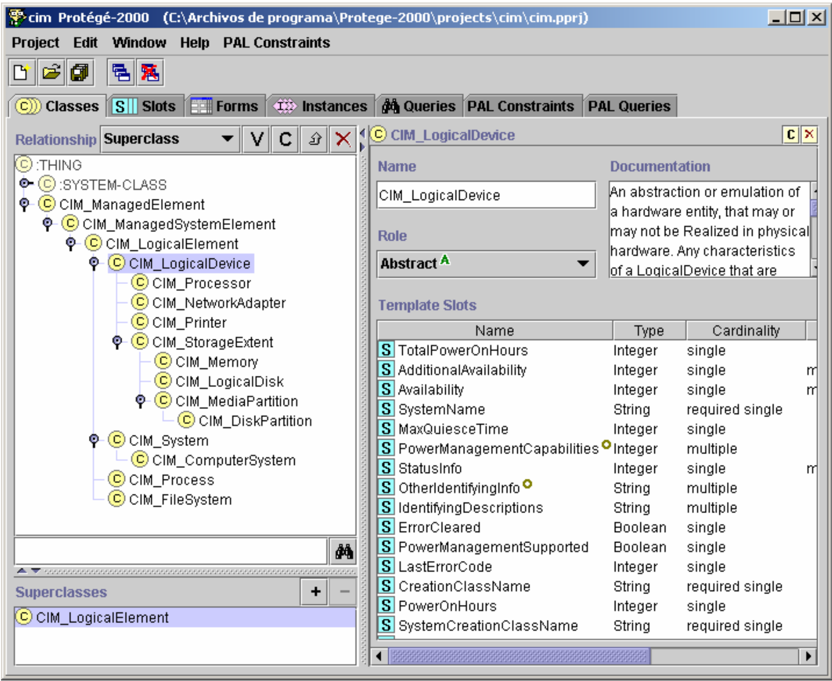

Figure 5. Ontological view of a CIM subset.

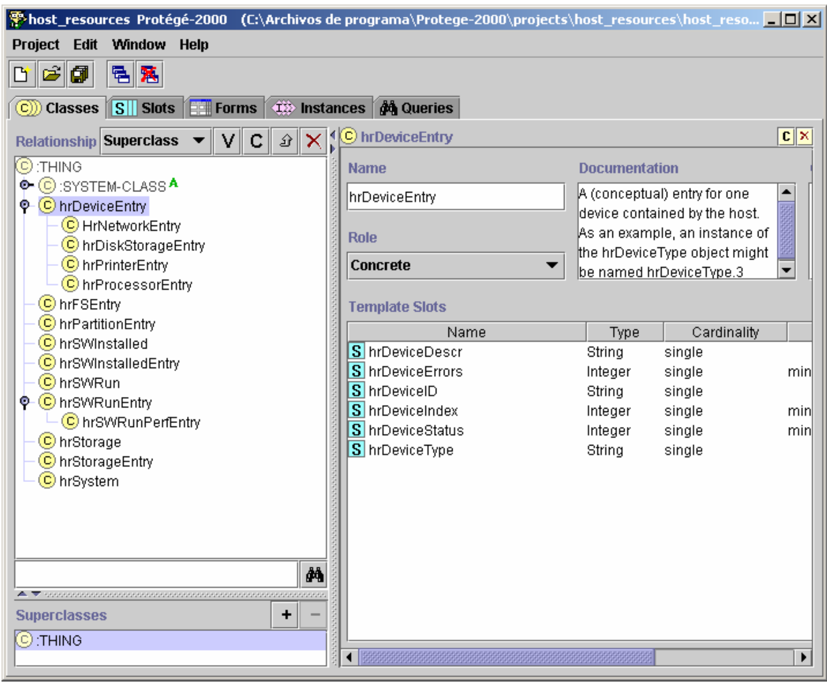

Figure 6. Ontological view of the HOST-RESOURCES MIB.

Figure 7 shows how this tool has also been used to merge or map both ontologies. Some merging has been done again by hand, but the tool aids in this task: it gives some suggestions based on heuristics. Also, both ontologies can be shown in parallel, so that it is easier to map them, being able to map both concepts and slots. Suggestions are given every time a manual operation is performed. In this way, if two slots are manually merged, a suggestion about merging the classes they belong is given; or if two classes are merged, another suggestion about merging their parent classes is also given.

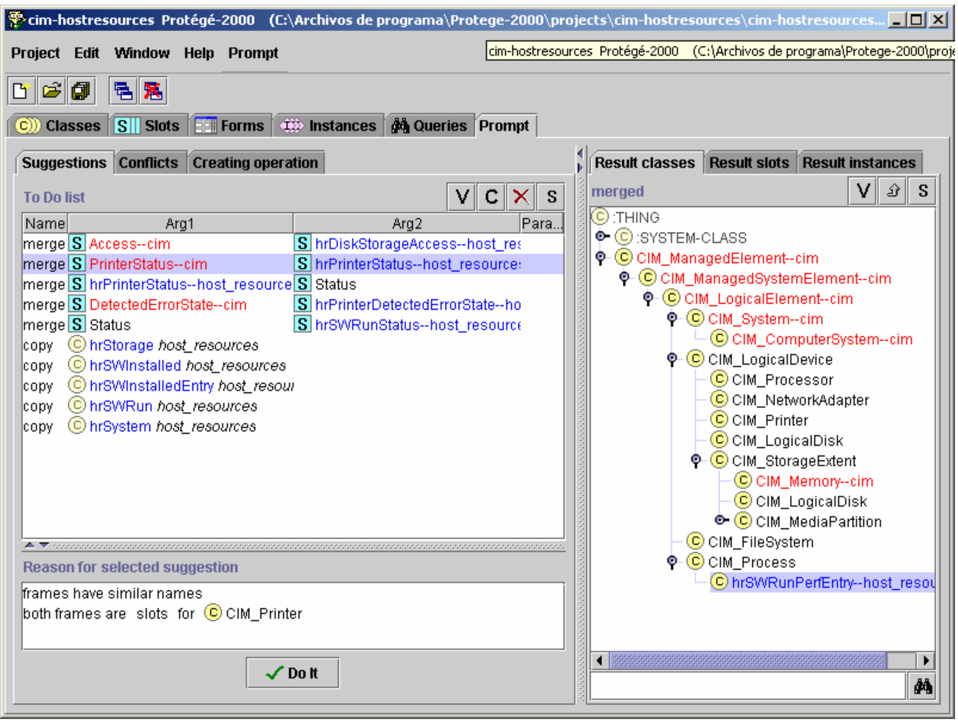

Figure 7. Ontologies merging tool applied to CIM and HOST-RESOURCES.

Defining behavior with ontologies

Adding behavioral information to management models is not a new issue. In fact, GDMO included a BEHAVIOR template, although it did not specify how to define such behavior. Different approaches have been defined since then, including extensions to GDMO [Keller95], creating a specific behavior language [Hasselmeyer99] or using other specification languages such as SDL [Rodríguez99]. However, the addition of behavior to other management models such as CIM has not been proposed until now, as far as known.

Ontologies are intimately related to behavior: Axioms and rules usually provide such functionality, formalizing the concepts that belong to a certain domain. For instance, during translation in last section, some constraints were identified in the description of some CIM models, such as "`a language that is used as a default by the Printer should also be listed in LanguagesSupported`", contained in `CIM_Printer` class. However, these constraints were not enforced by any constraint language. This could be solved using ontologies axioms. The inclusion of this sentence in the ontology would be in a KIF-like language [Crubézy02] something like:

```
(defrange ?printer :FRAME CIM_Printer)
(forall ?printer
      (element-of (DefaultLanguage ?printer)
                  (LanguagesSupported ?printer)
      )
)
```

Even though this language is a predicate logic language, depending on the ontology language, other logic languages, such as descriptive logics could be used [Gómez02]. OCL [Warmer99, OMG01] could be another alternative: if the ontology language is directly CIM, which is a UML-based model, OCL is the extension to UML that allows the definition of constraints. Last sentence could be defined in OCL as:

```
context CIM_Printer inv:
self.LanguagesSupported->includes(self.DefaultLanguage)
```

Other behavioral definitions could also be added to these constraints. Figure 8 shows how the following rule could be defined in the previously used ontology tool: "`The AvailableSpace of a CIM_FileSystem instance should be bigger than a 10% of the FileSystemSize`". Then, once this rule is defined, the ontology tool would check for every `CIM_FileSystem` instance that this rule is fulfilled. Otherwise, a notification would be raised.

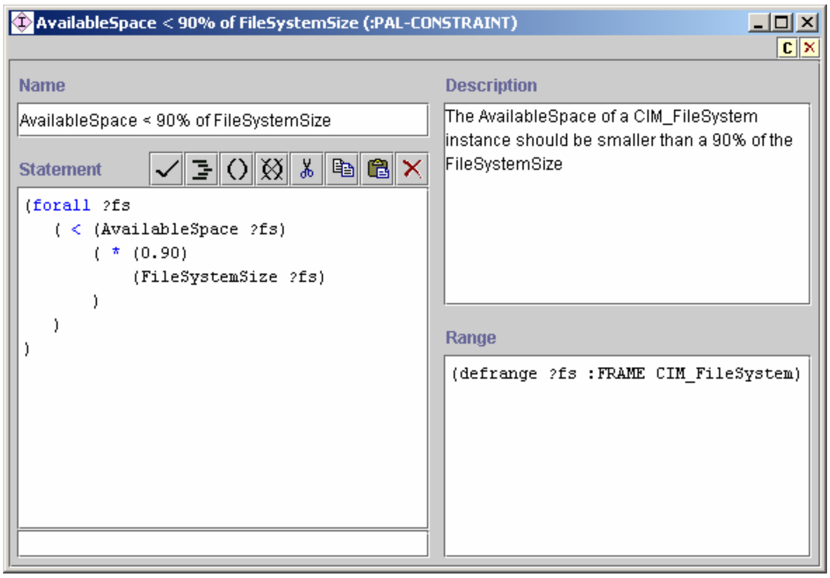

Figure 8. Constraint definition about a concept of the ontology.

Figure 9 shows how to define a query about a similar rule: "`Find all CIM_FileSystem instances in which the AvailableSpace is less than a 10% of the FileSystemSize`". In this case, instead of raising a notification, a list of all instances fulfilling this requirement would be generated.

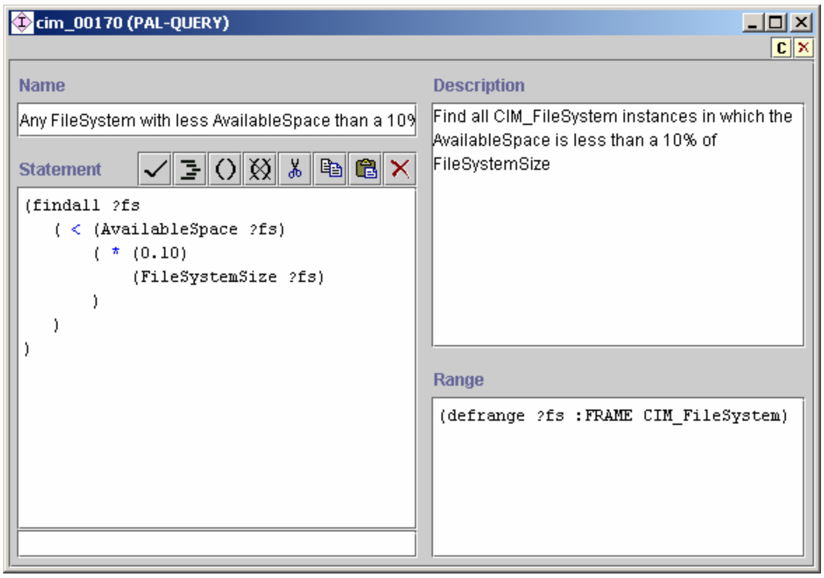

Figure 9. Query definition about a concept of the ontology.

Conclusions and further work

This paper has presented a novel approach in which the definition of an ontology-based management information meta-model has been proposed. The advantages of this approach can be applied when trying to map different management models from a semantic viewpoint. Also, ontology axioms and rules provide a way to define the behavior related to an information model.

CIM has been pointed out as lightweight ontology: It defines a set of shared concepts of the network management world, but it does not provide constructs to formalize constraints or define behaviors. Therefore, CIM should be expanded in the way that a CIM model could be generated from an ontology tool. OCL could be the proper language that helps in this issue, as it is part of the UML specification and CIM uses the UML class diagram.

Ontology tools can aid in the task of mapping and merging information from different domains, obtaining finally a semantically integrated model. Such tools currently work with ontology languages, so that a translation from the management models to an ontology is necessary. These tools can also help in the definition of rules or constraints that add behavioral aspects to the model.

Another point to be studied is the difference between knowledge systems and management systems. Former systems usually work with well-known instances while the latter ones usually obtain such instances when polling or receiving notifications from managed systems. Thus, a proxy that obtains the instances to be reasoned and put them into the ontology reasoning system should be developed. In this way, a manager could be an ontology engine that performs management based on defined rules. For this, the definition of such rules that model the behavior of the system is important.

Finally, a comparison with policy-based management [Sloman02] should be also a good idea, because ontologies can act as the bridge between management models and policies, thanks to the union of management and behavior information.

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