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Semantic Management Information Modeling based on Theory of Concept Lattices

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Abstract**—With the development of future Internet, it is of great significance to study how to realize unified management information modeling, in order to avoid a lot of repetitive work and standardize information modeling in network management domain. This paper discusses the problem from the ontology point of view and introduces the theory of concept lattices into the research on semantic management information modeling, which includes a) establishing an ontology-driven framework for semantic management information modeling, b) building unified management information modeling ontology based on concept lattices, and c) generating semantic models for network management information modeling using the theory of concept lattices.**

Index Terms**—network management, unified information modeling, semantic interoperability, ontology, concept lattices, formal concept analysis**

I. Introduction

Since US government declared the startup of Next Generation Internet (NGI) [1] plan in 1996, aiming to study basic theories for new generation computer information networks and establish a brand-new Internet architecture, there is an increasing interest by research and industry in future Internet and its management. In the USA, there are initiatives like Future Internet Design (FIND) [2] and Globe Environment for Network Innovation (GENI) [3]. In Europe, there is the Future Internet Research and Experimentation (FIRE) [4] program. And in China, there is the China Next Generation Internet (CNGI) [5] project.

As an important research area, network management should be an indispensable part for the design of future Internet, instead of being a post-accession function in the traditional sense. As to future Internet, network management deals with not only existing conventional managed objects but also new ones including content and context, while the interoperability problem of multiple network management domains becomes more prominent.

Meanwhile, there is an urgent need to address two main problems of information modeling in the field of network management, which are the lack of conformance and low level of formalization. Hence, it is of great significance to study how to realize unified management information modeling, in order to avoid a lot of repetitive work and standardize information modeling for the sack of network management domain.

On the syntax level, management information can not make full use of all the functions and expressive abilities of regulated information specification languages, lacking semantic understandings. In most cases, it is quite essential to study information mediation for network management. And the main reason for this is that, the problem of semantic interoperability is not well solved during the process of developing useful abstractions for physical and logical features of network entities by current network management standards.

Recently, studies on semantic interoperability for network management information and its specification usually focus on ontology. Ontology [6] [7] plays an important role in Semantic Web, and the most general definition of ontology may be that, *an ontology is an explicit and formal specification of a shared conceptualization*. It may be quite useful to apply ontology description languages such as Web Ontology Language (OWL) [8] for special management information mediation problems. However, when describing general management information and their relations by methods in virtue of special languages, it may possibly lack essential systematization and feasibility, not to mention the building of a unified framework.

Philosophically speaking, permanent relationship of Managed Objects (MOs) is always described by not-lasting terms, such as OWL. The fact is that, these terms reflect not only the characteristics of the times but also the fashion of the designers or a particular organization. Furthermore, the structure described by syntax and the one revealed by metaphysics are consistent. In other words, the latter one is just a reconstruction of the former one. One example for this kind of relationship is a Management Information Base (MIB) definition and the corresponding MIB tree. Thus in this case, theory of concept lattices is introduced to network management domain for the purpose of semantic information modeling in a unified manner.

The remainder of this paper is organized as follows. Section II presents related work. Section III establishes an ontology-driven framework for semantic management information modeling. Section IV builds unified management information modeling ontology based on

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concept lattices. Section V discusses the solution for generating semantic models for network management information modeling using the theory of concept lattices. Section VI concludes this paper and prospects future work.

II. Related Work

Taking the problem of unified information modeling for network management into consideration, current studies are generally divided into two main directions.

A. Proposal of a Unified Standard

One direction for unified information modeling in the field of network management is to propose a unified standard, such as SMIng [9] suggested by Internet Research Task Force (IRTF), YANG [10] by Internet Engineering Task Force (IETF), Common Information Model (CIM) [11] by Distributed Management Task Force (DMTF), and so on.

Especially, Reference [12] argues that, the development of information models for important element types may do favor to managers for the access of standard managed objects through a standardized style.

B. Integration in a Unified Manner

The other direction for unified management information modeling is to integrate existing standards using formal methods such as ontology description languages. An example for these methods is application of OWL, Semantic Web Rule Language (SWRL) [13] and Semantic Markup for Services (OWL-S) [14] to ontology-based modeling. An OWL ontology can be used as the integration of all domain information, when at the same time, Merge and Map (M&M) methods must also be taken into account [15] [16] [17]. A step forward in integrating ontology-based information is to add behavior information, to the OWL ontology using SWRL [18] [19]. Moreover, OWL-S is an ontology developed in Semantic Web domain, aiming at the automatic discovery, invocation, composition and interoperation of Web services, and it can be utilized to promote the automation of network management [20].

Reference [21] utilizes XML technologies to organize MIB as a tree structure, performs a structural data process, and provides a graphical support for quick access to management information with the use of Virtual Reality (VR) technologies. Reference [22] tries to integrate existing standards in a unified manner, and it proposes semantic mapping implemented between any ontology pair, in order to solve the semantic interoperability problem, since ontology is used as semantic modeling for managed environments. That is to say, it can reduce the interoperability problem in network management domain to ontology mapping tasks between conceptual semantics.

III. Ontology-driven Framework for Semantic Management Information Modeling

Network management has become a critical technology for future Internet, and the basis of hierarchical analysis in the interest of network management is management information.

A. Granularity Computing Viewpoint

As for the problem of unified management information modeling for future Internet, it becomes greatly important to understand and describe this problem from multiple views and multiple levels, and Granularity Computing (GrC) [23] [24] provides a new thinking.

Current studies on GrC can be reduced to three main perspectives, which consist of structural philosophy thinking, structural problem solving and structural information processing. These three basic perspectives relate to each other and also have its own framework, while there is a hierarchy among them.

In accordance with the GrC triangle, the hierarchy of network management information granularity is seriously considered and built, which is divided into the MIB (information) level, the model or schema (information specification) level, and the meta-schema (information specification language) level, with demonstrations as follows.

(1) MIB for instance information. Generally, specific management protocols require MIB of different styles.

(2) MIB definition for model or schema. It is also called as information specification, which includes protocol-neutral information model and protocol-specific data model.

(3) Specification language for MIB definition. It is also named as meta-schema or information specification language, which consists of information modeling language and data modeling language correspondingly.

B. Proposed Ontology-Driven Framework

As to the three-level hierarchy of network management information granularity, the key for applications is the schema level. However, current information specifications in network management domain are in the lack of conformance and have a low degree of formalization. In fact, information models and data models are improved by semantic models, so as to grantee the concepts used in the field of network management and their existing relations formalized [25]. Hence, semantic management information modeling is a prospective way for the study of unified information modeling for the sake of network management.

Furthermore, when taking automation into consideration, there is an urgent requirement to provide a general method for the generation of information in the field of network management. Thus in this case, the meta-schema level needs to be utilized. And an ontology-driven framework is then proposed for semantic management information modeling, as shown in Fig. 1.

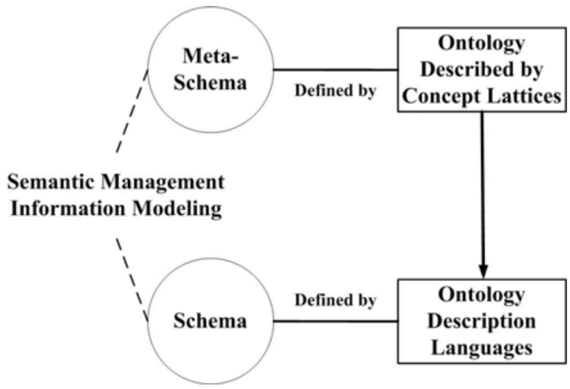

Figure 1. Proposed ontology-driven framework for semantic management information modeling.

As is indicated in Fig. 1, concept lattices is introduced to describe ontology at the meta-schema level and translated into schema defined by ontology description languages in view of semantic management information modeling.

The next two sections will build unified management information modeling ontology based on concept lattices, and discusses the solution for generating semantic models for network management using the theory of concept lattices respectively.

Ⅳ. The Builiding of Meta-schema Ontology for Network Management Information Modeling based on Concept Lattices

As one origin of GrC, concept lattices [26] is an exact mathematic model, essentially reflecting the entity-attribute relationship. And its corresponding Hasse chart can reveal notional hierarchy. It seems that, application of concept lattices may be an effective means to construct ontology as meta-schema for unified information modeling in network management domain.

A. Concept Lattices and its Theory

The problem of semantic interoperability becomes more and more important, especially in the environment of future Internet. And the cooperation of standards for management information specifications can be seen as a way to implement semantic interoperability. However, the fact is that, standards proposed by different organizations remain a competing relationship rather than a cooperative one. From this point of view, the ontology-driven approach provides a unified way to semantic interoperability, while the understanding of ontology by different organizations may be different.

Hence, when applying ontology description languages to realize the integration of management information specifications in a direct way, the ontology building process totally relies on a mass of manual work, and subjective factor may easily play an impact on the quality of the obtained ontology. As the theory of concept lattices, Formal Concept Analysis (FCA) is a mathematization of the philosophical understanding of concepts, and it can be utilized as a learning technique for ontology building [27].

B. Ontology Building based on Concept Lattices

In order to get a better abstract effect and reduce the complexity of engineering, management information specification languages for the meta-schema level are selected to be described by ontology based on concept lattices. Generally speaking, ontology building usually contains the following three steps.

a) listing related glossary
b) defining concepts and their hierarchy
c) defining the relations of concepts

Considering the construction of meta-schema ontology, the constructed unified ontology can realize unified description of management information specification languages through knowledge sharing, knowledge reuse and explication of implicit information.

As is indicated in the widely accepted definition of ontology that is an explicit and formal specification of a shared conceptualization, two key points about the ontology design must be seriously considered. On the level of conceptualization, the objects and their relationships contained in the ontology should be confirmed, while on the level of specification, some specified schema or language should be applied to specify these concept models. From this viewpoint, the visualization advantages of concept lattices may provide a promising method for ontology description.

Basic properties, generation algorithms and reduction policies are first discussed for the corresponding concept lattices of management information specification languages [28]. Based on the visualization benefits, concept lattices are optimized to obtain an object-centric ontology description, and a unified ontology is then constructed using the association analysis of concept lattices [29]. And using a combined approach of the merge method [30] and the alignment method [31], Fig. 2 gives the proposed ontology articulation approach by means of concept lattices.

Step 1. Perform the semantic treatment with articulated concept lattices based on the alignment method.
(1.1) Eliminate redundancy of properties.
(1.2) Unify semantic specifications of objects.
(1.3) Compute semantic similarity of objects.

Step 2. Obtain the articulation degree of objects based on their semantic similarity result.

Step 3. Select an appropriate correlation policy according to the articulation degree result of objects

Step 4. Implement the correlation of all objects from source concept lattices in order to construct a unified ontology.

Figure 2. Proposed ontology articulation approach by means of concept lattices.

As is demonstrated in Fig. 2, the definitions of semantic similarity and articulation degree are essential for the proposed ontology articulation approach by means of concept lattices, which are described as Definition 1 and Definition 2. Based on these definitions, Table I provides the object correlation policy in order to build meta-schema ontology for network management information modeling based on concept lattices.

Definition 1. If ontologies B_1, … , B_n described based on concept lattices have objects o_1 , … , o_n respectively, and corresponding properties of these objects are A_1, … , A_n, then as for articulated ontology B, semantic similarity of o_1, … , o_n is defined as

$$Similarity\left(o_1,\dots,o_n\right)=\frac{card\left(A_1\cap\dots\cap A_n\right)}{card\left(A_1\cup\dots\cup A_n\right)} \qquad (1)$$

Definition 2. As for articulated ontology B , if objects o_1, … , o_n from different source concept lattices, then articulation degree of o_1, … , o_n is defined as

$$Articulation\left(o_1,\dots,o_n\right)=\begin{cases}0,\mathrm{Similarity}\left(o_1\dots o_n\right)=0\\1,\mathrm{Similarity}\left(o_1\dots o_n\right)\in\left(0,2/3\right)\\2,\mathrm{Similarity}\left(o_1\dots o_n\right)\in\left[2/3,1\right)\\3,\mathrm{Similarity}\left(o_1\dots o_n\right)=1\end{cases} \qquad (2)$$

TABLE I.
OBJECT CORRELATION POLICY FOR ONTOLOGY BUILDING

Articulation degree	**Object Correlation Policy**
0	Each correlated object keeps the alignment status
1	Choose one of the following two policies according to the practical situation. ① Each correlated object keeps the alignment status ② All correlated objects are merged to an ontology object in a unified way
2, 3	All correlated objects are merged to an ontology object in a unified way

C. Switch Policy

If the number of articulated source ontologies during the building process of unified meta-schema ontology is n , as for the switch of source ontologies B_x and B_y ($1\le x<y\le n$) , the semantic similarity result for B_x and B_y objects by (1) can be used for the establishment of switch policy for articulated source ontologies.

Fig. 3 offers a SQL segment to create $SSTable$ as a semantic similarity table for B_x and B_y objects, which includes $source\_x$ and $source\_y$ representing the B_x object and the B_y object respectively, and $similarity$ for their semantic similarity result.

```
CREATE TABLE SSTable
(source_x VARCHAR(30),
 source_y VARCHAR(30),
 similarity INT);
```

Figure 3. A SQL segment to create SSTable.

During the building process of unified meta-schema ontology, $CRTable$ can be obtained as a semantic similarity table for objects of articulated source ontologies, which includes $source\_1$, … , and $source\_n$ representing the object of each articulated source ontology, and $similarity$ for their semantic similarity result.

Fig. 4 shows a SQL segment to totally evaluate $SSTable$ from $CRTable$ when $n=2$, while Fig. 5 gives a SQL segment to partially evaluate $SSTable$ from $CRTable$ when $n\ge 3$.

```
INSERT INTO SSTable
 SELECT * FROM CRTable
  WHERE similarity<>0;
```

Figure 4. A SQL segment for total evaluation of SSTable from CRTable.

```
INSERT INTO SSTable (source_x, source_y)
 SELECT source_x, source_y FROM CRTable
  WHERE similarity<>0;
```

Figure 5. A SQL segment for partial evaluation of SSTable from CRTable.

V. APPLYING THE THEORY OF CONCEPT LATTICES TO GENERATE SEMANTIC MODELS FOR NETWORK MANAGEMENT INFORMATION MODELING

It seems that FCA and ontology have no direct associations. But both of them root from philosophy, and from knowledge representation point of view, both of them are used to model concepts and their relations. Hence, this section will make further use of the FCA approach to generate semantic models for network management information modeling.

A. Mapping Outline

Note that, FCA emphasizes the difference of objects and properties, while in ontology domain, this difference is not so obvious, and objects play a more important role. Thus in this case, meta-schema ontology described by based on concept lattices can be translated into schema defined by ontology description languages in view of semantic management information modeling, with the use of mapping outline, as displayed in Fig. 6.

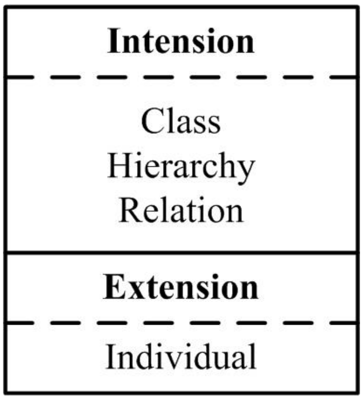

Figure 6. Mapping outline for meta-schema ontology described by concept lattices translated into schema defined by ontology description languages in view of semantic management information modeling.

B. Generation of Semantic Models

Considering the generation of semantic models for network management information modeling, Table II provides some corresponding relations of formal property for meta-schema ontology and OWL construction or tag based on the mapping outline shown in Fig. 6.

Ⅵ. CONCLUSIONS AND FUTURE WORK

This paper introduces the theory of concept lattices into the research on semantic management information modeling. On one hand, it opens up a new era for the applications of concept lattices. On the other hand, it provides an innovative methodology for the problem of unified information modeling in the field of network management from an ontology-driven viewpoint. This methodology establishes the theoretical foundation for studies on semantic management information modeling, and it is greatly beneficial to finally achieve the goal of standardizing information modeling for the sake of network management.

Future work includes further considerations of uncertain factors to describe information modeling in network management domain by introducing fuzziness into formal concept analysis.

TABLE II.
SOME CORRESPONDING RELATIONS OF FORMAL PROPERTY FOR META-SCHEMA ONTOLOGY AND OWL CONSTRUCTION OR TAG

Formal Property for Meta-schema Ontology	**OWL Construction**	**Example for OWL Tag**
description	Capability for Comments	rdfs:comment
oid	Specified Name	rdf:id
status	Version Control	owl:DeprecatedClass owl:DeprecatedProperty
organization	Capability for Comments	rdfs:comment
contact	Capability for Comments	rdfs:comment
revision	Version Control	owl:priorVersion owl:versionInfo
object	Enumeration Structure	owl:oneOf
syntax	Restrictions of Property	owl:allValuesFrom owl:Restriction
access	Enumeration Structure	owl:oneOf
index	characteristics of Property	owl:FunctionalProperty
signals	Enumeration Structure	owl:oneOf

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REFERENCES

[1] NGI Program. Available: en.wikipedia.org/wiki/Next_Generation_Internet_Program
[2] Future Internet Design. Available: www.nets-find.net

[3] Globe Environment for Network Innovation. Available: www.geni.net
[4] Future Internet Research and Experimentation. Available: cordis.europa.eu/fp7/ict/fire
[5] China NGI. Available: en.wikipedia.org/wiki/China_Next_Generation_Internet
[6] T. R. Gruber. A Translation Approach to Portable Ontology Specifications. Knowledge Acquisition, Vol. 5, No. 2, pp. 199-220, 1993
[7] T. R. Gruber. Towards Principles for the Design of Ontologies Used for Knowledge Sharing. International Journal of Human-Computer Studies, Vol. 43, No. 5/6, pp. 907-928, 1995
[8] P. E. Patel-Schneider, P. Hayer, I. Horrocks eds. OWL Web Ontology Language Overview. W3C Recommendation, 2004
[9] F. Strauss, J. Schönwälder. SMIng - Next Generation Structure of Management Information. RFC3780, 2004
[10] M. Bjorklund ed. YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF). RFC6020, 2010
[11] Common Information Model. Available: http://dmtf.org/standards/cim
[12] A. Pilz, J. Swoboda. Network Management Information Models. International Journal of Electronics and Communications, Vol. 58, pp. 165-171, 2004
[13] I. Horrocks etc eds. SWRL: A Semantic Web Rule Language Combining OWL and RuleML, W3C Member Submission, 2004
[14] D. Martin ed. OWL-S: Semantic Markup for Web Services, W3C Member Submission, 2004
[15] J. E. López de Vergara, V. A. Villagrá, J. Berrocal, J. I. Asensio, R. Pignaton. Semantic Management: Application of Ontologies for the Integration of Management Information Models. Proceeding of 8th IFIP/IEEE International Symposium on Integrated Network Management, pp. 131-134, 2003
[16] J. E. López de Vergara, V. A. Villagrá, J. I. Asensio, J. Berrocal. Ontologies: Giving Semantics to Network Management Models. IEEE Network, Vol. 17, No. 3, pp. 15-21, 2003
[17] J. E. López de Vergara, V. A. Villagrá. Applying the Web Ontology Language to Management Information Definitions. IEEE Communications Magazine, Vol. 42, No. 7, pp. 1-7, 2004
[18] H. Xu, D.B. Xiao. A Common Ontology-based Intelligent Configuration Management Model for IP Network Devices. Proceeding of 1st International Conference on Innovative Computing, Information and Control, pp. 385-388, 2006
[19] D.B. Xiao, H. Xu. An Integration of Ontology-based and Policy-based Network Management for Automation. CD-ROM Proceeding of 2006 Computational Intelligence for Modelling, Control and Automation, pp. 27, 2006
[20] H. Xu, D.B. Xiao. Applying Semantic Web Services to Automate Network Management. CD-ROM Proceeding of 2nd IEEE Conference on Industrial Electronics and Applications, IEEE Press, pp. 461-466, 2007
[21] B. Grand, M. Soto. Navigation in Huge Information Hierarchies Applications to Network Management. Proceeding of 1999 Workshop on New Paradigms in Information Visualization and Manipulation in conjunction with 8th ACM International Conference on Information and Knowledge Management, pp. 56-61, 1999
[22] A. Wong, P. Ray, N. Parameswaran, J. Strassner. Ontology Mapping for the Interoperability Problem in Network Management. IEEE Journal on Selected Areas in Communications, Vol. 23, No. 10, pp. 2058-2068, 2005
[23] Y. Y. Yao. Perspectives of Granular Computing. Proceedings of 2005 IEEE International Conference on Granular Computing, Vol. 1, pp. 85-90, 2005
[24] Y. Y. Yao. The Art of Granular Computing. Proceeding of 2007 International Conference on Rough Sets and Emerging Intelligent Systems Paradigms, Lecture Notes in Artificial Intelligence, Vol. 4585, pp. 101-112, 2007
[25] A. Pras et al. Key Research Challenges in Network Management. IEEE Communications Magazine, Vol. 45, No. 10, pp. 104-110, 2007
[26] B. Ganter, R. Wille. Formal Concept Analysis: Mathematical Foundations. Berlin: Springer, 1999
[27] P. Cimiano, A. Hotho, G. Stumme, J. Tane. Conceptual Knowledge Processing with Formal Concept Analysis and Ontologies. Proceeding of 2rd International Conference on Formal Concept Analysis, pp. 189-207, 2004
[28] H. Xu, D. B. Xiao. Building Information Specification Ontology for Computer Network Management based on Formal Concept Analysis. Proceeding of 2009 IEEE International Conference on Information and Automation, pp. 312-317, 2009
[29] H. Xu, D. B. Xiao. Visualization-based Study on Information Specification Languages for Network Management using Formal Concept Analysis. Communications in Computer and Information Science, Vol. 71, pp. 19-30, 2010
[30] G. Stumme, A. Maedche. FCA-Merge: Bottom-Up Merging of Ontologies. Proceeding of 17th International Joint Conference on Artificial Intelligence, pp. 225-230, 2001
[31] K. Souza, J. Davis. Aligning Ontologies through Formal Concept Analysis. Proceeding of 6th International Conference on Information Integration and Web-Based Applications and Services, pp. 123-132, 2004

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