Extenics-based Ontology Merging of Hierarchical Information Modeling for Distributed Management

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Abstract

In order to provide a highly formalized ontology merging of hierarchical information modeling for distributed management, the Extenics-based approach is introduced to formalize ontology merging of both Management Information Base (MIB) models and MIB instances. The aim of this paper is then to utilize ontology merging at the meta-schema level based on concept lattices to generate semantic models for ontology merging of MIB models using basic-elements in the form of matter-elements, and realize the formal presentation of both MIB instances for ontology merging and implicit knowledge for MIB instances with the use of the extension theory for basic-elements. The proposed Extenics-based ontology merging approach for both MIB models and MIB instances integrates with the former approach for meta-schema based on concept lattices, and aims to promote the formalization level of hierarchical information modeling for distributed management in *a unified ontology-driven manner.*

Keywords: *Distributed Management, Hierarchical Information Modeling, Ontology Merging, Extenics, Basic-Element, Extension Theory*

1. Introduction

Recently, studies on semantic interoperability for distributed management information and its specification usually focus on ontology. Ontology [1, 2] plays an important role in Semantic Web, and it may be quite useful to apply ontology description languages such as Web Ontology Language (OWL) [3] for special management information mediation problems, which may possibly promote conformance but still have relatively low level of formalization. Thus in this case, a more highly formalized approach should be introduced to distributed management for the purpose of hierarchical information modeling based on the ontology-driven method in a unified manner.

The aim of this paper is then to introduce the Extenics science into the study on ontology merging of hierarchical information modeling for distributed management, and from ontology merging of meta-schema based on concept lattices for hierarchical information modeling, discuss the ontology merging problems of both Management Information Base (MIB) models and MIB instances by utilizing the extension theory for basic-elements.

The remainder of this paper is organized as follows. Section 2 briefly introduces our prior work, and Section 3 discusses issues related to the possibility of Extenics-based ontology merging of hierarchical information modeling for distributed management. Section 4 makes use of the former approach for meta-schema based on concept lattices to generate semantic models for ontology merging of MIB models using basic-elements in the form of matter-elements. Section 5 demonstrates the formal presentation of MIB instances for ontology merging and implicit knowledge for MIB instances by means of the extension theory for basic-elements. Section 6 concludes this paper.

2. Our Prior Work

This section presents our prior work about hierarchical information modeling for distributed management and ontology merging using Formal Concept Analysis (FCA) that is the theory of concept lattices, and points out a promising way to promote the level of formalization for ontology merging.

2.1. Hierarchical Information Modeling for Distributed Management

Current studies on Granularity Computing (GrC) [4, 5] can be reduced to three main perspectives, which include 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 perspectives, hierarchical information modeling for distributed management have been seriously considered and built. Thus the information granularity for distributed management is then divided into meta-schema (information specification language), model or schema (information specification) and MIB (information).

2.2. Ontology Merging of Meta-schema using Concept Lattices

Based on the remarkable benefits of the FCA for visualization by the expression of partial ordering sets, its mathematic formalization can be further applied to the articulation of different management information specification languages [6, 7]. Thus in this case, concept lattices have been applied to describe ontology at the meta-schema level and their translation into schema defined by ontology description languages in view of semantic management information modeling has been possible [8, 9].

However, in order to provide a more highly formalized ontology merging of hierarchical information modeling for distributed management, the Extenics-based approach will be introduced to formalize the translation from ontology at the meta-schema level based on concept lattices to ontology merging of MIB models and then the translation from MIB models to MIB instances.

3. Proposed Extenics-based Approach

This section discusses issues related to the possibility of Extenics-based ontology merging of hierarchical information modeling for distributed management.

3.1. The Extenics-based Formalized Approach

First proposed by Prof. Cai in 1983 [10], the Extenics-based approach prospects a promising way by means of formalization. As a transverse science, Extenics [11] runs through natural sciences and social sciences, which studies the extensibility of things, the rules and methods for opening up things and then uses them for solving problems.

The research objective of Exenics is the solving of contradictory problems of the reality world, and its basic theory is the extension theory containing matter-element analysis [12] and extension mathematics as its two pillars. From the viewpoint of distributed management, the Extenics-based formalized approach is prospective for the study on hierarchical information modeling with the use of the extension theory system.

3.2. Basic-elements for Management Information Modeling

The logic cell of Extenics is basic-elements [13], which include matter-elements, affair-elements and relation-elements, and the formalization by their composition formats is called as composite-elements.

Formula 1 demonstrates a common definition of basic-elements, in which $Object$ means a particular object, with its characteristics $c_1, c_2, ..., c_n$ and corresponding values $v_1, v_2, ..., v_n$.

$$B = \begin{bmatrix} Object, c_1, v_1 \\ c_2, v_2 \\ ..... \\ c_n, v_n \end{bmatrix} \quad \ldots (1)$$

Base on Formula 1, the class for a kind of basic-elements can be defined as Formula 2, in which $V_1, V_2, ..., V_n$ describe the value domains of characteristics $c_1, c_2, ..., c_n$ for the set of objects that is $\{Object\}$.

$$\{B\} = \begin{bmatrix} \{Object\}, c_1, V_1 \\ c_2, V_2 \\ ..... \\ c_n, V_n \end{bmatrix} \quad \ldots (2)$$

4. Ontology Merging of MIB Models using Basic-elements

This section will make further use of the FCA approach to generate semantic models for ontology merging of MIB models based on basic-elements in the form of matter-elements.

4.1. Generation from Meta-schema based on Concept Lattices

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. FCA emphasizes the difference of objects and properties, while in the ontology domain, this difference is not so obvious, and objects play a more important role. Figure 1 provides a simplified concept lattice of ontology merging for management information modeling at the meta-schema level using FCA.

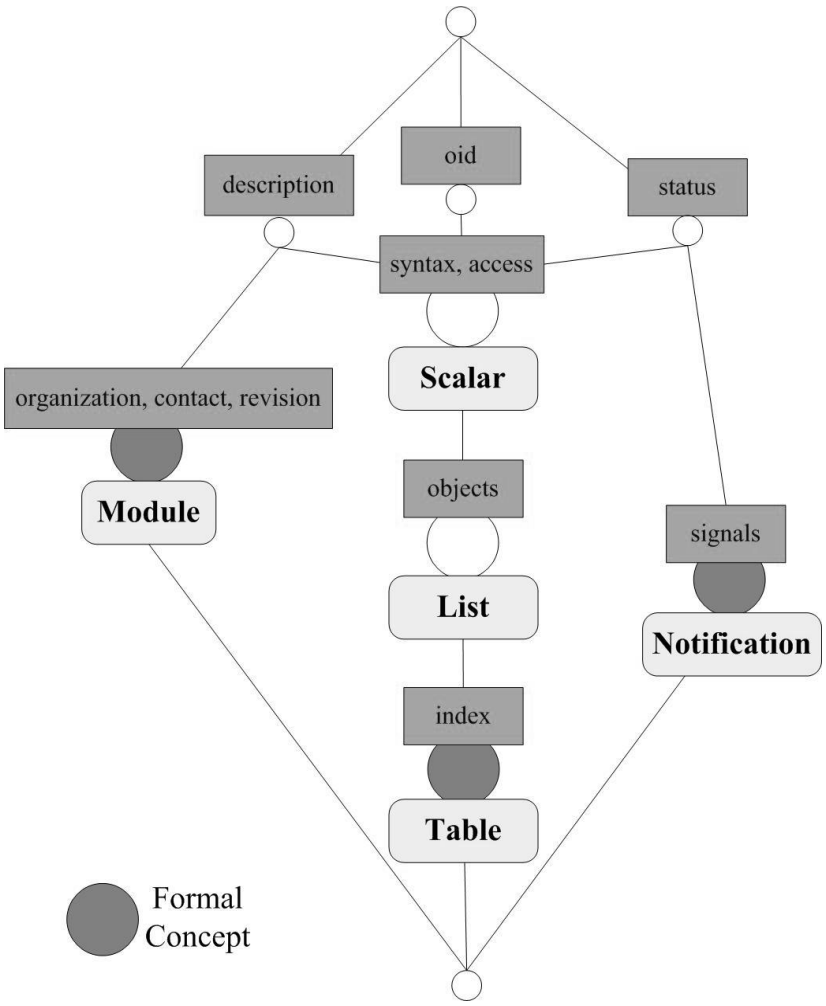

Figure 1. A Simplified Concept Lattice of Ontology Merging for Management Information Modeling at the Meta-schema Level using FCA

As is shown in Figure 1, the meaning of objects for MIB models are explained as follows.

(1) The Module object indicates the information for a particular MIB model.

(2) The Scalar object indicates the Managed Object (MO) with only one instance.

(3) The List object indicates a set of MOs with only one instance.

(4) The Table object indicates a set of MOs with more that one instances.

(5) The Notification object indicates that the MO will be sent actively from Agent to Manager.

Thus in this case, meta-schema formalized by concept lattices can be utilized to generate formal characteristics of objects for MIB models, as demonstrated in Table 1.

Table 1. Generation of Formal Characteristics of Objects for MIB Models from Meta-schema Formalized by Concept Lattices

Formal Characteristics of Objects for MIB Models	Module	Scalar	List	Table	Notification
description	√	√	√	√	√
oid	√	√	√	√	√
status	√	√	√	√	√
organization	√				
contact	√				
revision	√				
syntax		√	√	√	
access		√	√	√	
objects			√	√	
index				√	
signals					√

4.2. Formal Presentation of Objects for MIB Models based on Matter-elements

When considering Table 1, the class of matter-elements to formalize objects for MIB models, which are Module, Scalar, List, Table and Notification, can be presented respectively as Formula 3-7, according to Formula 2.

$$\{M_{Module}\} = \begin{bmatrix} \{Object_m\}, description, V_{m1} \\ oid, V_{m2} \\ status, V_{m3} \\ organization, V_{m4} \\ contact, V_{m5} \\ revision, V_{m6} \end{bmatrix} \quad \ldots (3)$$

$$\{M_{Scalar}\} = \begin{bmatrix} \{Object_s\}, description, V_{s1} \\ oid, V_{s2} \\ status, V_{s3} \\ syntax, V_{s4} \\ access, V_{s5} \end{bmatrix} \quad \ldots (4)$$

$$\{M_{List}\} = \begin{bmatrix} \{Object_l\}, description, V_{l1} \\ oid, V_{l2} \\ status, V_{l3} \\ syntax, V_{l4} \\ access, V_{l5} \\ objects, V_{l6} \end{bmatrix} \quad \ldots (5)$$

$$\{M_{Table}\} = \begin{bmatrix} \{Object_t\}, description, V_{t1} \\ oid, V_{t2} \\ status, V_{t3} \\ syntax, V_{t4} \\ access, V_{t5} \\ objects, V_{t6} \\ index, V_{t7} \end{bmatrix} \quad \ldots (6)$$

$$\{M_{Notification}\} = \begin{bmatrix} \{Object_n\}, description, V_{n1} \\ oid, V_{n2} \\ status, V_{n3} \\ signals, V_{n4} \end{bmatrix} \quad \ldots (7)$$

In this way, MIB models defined by different management information specification languages at the meta-schema level, such as Structure of Management Information (SMI) with its different versions for Simple Network Management Protocol (SNMP), Structure of Management Information, next generation (SMIng) for both SNMP and Common Open Policy Service usage for policy provisioning (COPS-PR), XML Schema and YANG for the network configuration (NETCONF) protocol, Common Information Model (CIM) proposed by Distributed Management Task Force (DMTF), can be formally presented as matter-elements by a unified formalization.

5. Ontology Merging of MIB Instances using the Extension Theory

This section will apply the extension theory to the formal presentation of both MIB instances for ontology merging and implicit knowledge for MIB instances.

5.1. Formal Presentation of MIB Instances for Ontology Merging by Extension Analysis

From the viewpoint of hierarchical information modeling for distributed management, extension analysis based on divergence principles for matter-elements can be utilized for the formal presentation of objects for MIB instances.

First of all, the definition of divergence for matter-elements is provided as follows, which means that M extends to M_e by means of divergence.

Definition 1 As for matter-element $M = (O, c, v)$, the divergence of M to M_e through extension can be defined by $M - | M_e$.

Extension analysis contains several divergence principles [13] [14] that grantee both one-variable divergence analysis and two-variable divergence analysis for matter-elements. If a MO of the Scalar type for distributed management is formalized by matter-element

as $M_{MO} = \begin{bmatrix} Object, description, v_1 \\ oid, v_2 \\ status, v_3 \\ syntax, v_4 \\ access, v_5 \end{bmatrix}$, using the divergence principle for extension analysis that is $M_{MO} - |\{M_{Instance1}, M_{Instance2}, ...\}$, $M_{Instance1} = [Object, resourceID, v_6]$, $M_{Instance1} = [Object, instanceValue, v_7]$, then the class of matter-elements to formalize objects for such type of MIB instances can be presented as Formula 8.

$$\{M_{Instance}\} = \begin{bmatrix} \{Object_i\}, description, V_{i1} \\ oid, V_{i2} \\ status, V_{i3} \\ syntax, V_{i4} \\ access, V_{i5} \\ resourceID, V_{i6} \\ instanceValue, V_{i7} \end{bmatrix} \quad \ldots (8)$$
$$= (\{Object_i\}, c_i, V_i)$$

5.2. Formal Presentation of Implicit Knowledge for MIB Instances by Extension Functions

When expressing the implicit knowledge for MIB instances, extension functions are introduced to formalize the implicit knowledge in order to promote the automation of distributed management. The definition of extension functions for the case of MIB instances as Formula 8 is then presented as follows.

Definition 2 If the source-object for transformation is $S \in \{\{M_{instance}\}, \{Object_i\}, c_i, V_i\}$, the extension functions of transformation from S to the target-object $S^{'}$ can be defined as $S^{'} = Func(S)$.

As is indicated in Definition 2, the extension function $S^{'} = Func(S)$ essentially reflects the implementation of the extension transformation method [15] as $T : S \rightarrow S^{'}$, which can be formalized by the class of basic-matters labeled as $\{B_F\}$. Formula 9 then demonstrates the formalization of $\{B_F\}$, in which $\{T_q\}$ means a particular set of objects, with its characteristics $c_{q1}, c_{q2}, ..., c_{qn}$ and corresponding value domains $V_{q1}, V_{q2}, ..., V_{qn}$.

$$S^{'} = Func(S)$$
$$\Leftrightarrow T : S \rightarrow S^{'} \qquad \ldots (9)$$
$$\Leftrightarrow \{B_F\} = \begin{bmatrix} \{T_q\}, c_{q1}, V_{q1} \\ c_{q2}, V_{q2} \\ \ldots\ldots \\ c_{qn}, V_{qn} \end{bmatrix}$$

In order to validate the feasibility of proposed Extenics-based approach applied to implicit knowledge for MIB instances, two typical scenarios will be discussed using extension functions. Figure 2 and Figure 3 show respectively these two typical scenarios of implicit knowledge from the Interfaces Group MIB (IF-MIB) [16].

```
ifAdminStatus OBJECT-TYPE
    SYNTAX  INTEGER {
                up(1),        -- ready to pass packets
                down(2),
                testing(3)    -- in some test mode
            }
    MAX-ACCESS  read-write
    STATUS      current
    DESCRIPTION
            "The desired state of the interface.  The testing(3) state
            indicates that no operational packets can be passed.  When a
            managed system initializes, all interfaces start with
            ifAdminStatus in the down(2) state.  As a result of either
            explicit management action or per configuration information
            retained by the managed system, ifAdminStatus is then
            changed to either the up(1) or testing(3) states (or remains
            in the down(2) state)."
    ::= { ifEntry 7 }
```

Figure 2. The First Scenario of Implicit Knowledge for MIB Instances from IF-MIB

Scenario 1 *ifAdminStatus: The desired state of the interface. The testing(3) state indicates that no operational packets can be passed. When a managed system initializes, all interfaces start with ifAdminStatus in the down(2) state. As a result of either explicit management action or per configuration information retained by the managed system, ifAdminStatus is then changed to either the up(1) or testing(3) states (or remains in the down(2) state).*

As for management scenarios such as Scenario 1, the formal presentation of implicit knowledge for MIB instances can be realized by extension functions from the viewpoint of the class of affair-elements presented as Formula 10.

$$S^{'} = Set(S)$$
$$\Leftrightarrow Set : S \rightarrow S^{'} \qquad \ldots (10)$$
$$\Leftrightarrow \{A_{Set}\} = \begin{bmatrix} \{Object_s\}, primitive, V_{s1} \\ instanceValue, V_{s2} \end{bmatrix}$$

According to Formula 10, the implicit knowledge for MIB instances indicated in Scenario 1 can be formalized as a set of affair-elements $\{A_1, A_2, A_3, A_4\}$,

$$A_1 = \begin{bmatrix} \text{ifAdminStatus}, \textit{primitive}, \text{no operational packets can be passed} \\ \textit{instanceValue}, \text{testing}(3) \end{bmatrix},$$

$$A_2 = \begin{bmatrix} \text{ifAdminStatus}, \textit{primitive}, \text{a managed system initializes} \\ \textit{instanceValue}, \text{down}(2) \end{bmatrix},$$

$$A_3 = \begin{bmatrix} \text{ifAdminStatus}, \textit{primitive}, \text{explicit management action} \\ \textit{instanceValue}, \{\text{up}(1), \text{down}(2), \text{testing}(3)\} \end{bmatrix},$$

$$A_4 = \begin{bmatrix} \text{ifAdminStatus}, \textit{primitive}, \text{configuration information retained by the managed system} \\ \textit{instanceValue}, \{\text{up}(1), \text{down}(2), \text{testing}(3)\} \end{bmatrix}$$

.

```
ifOperStatus OBJECT-TYPE
    SYNTAX  INTEGER {
                up(1),          -- ready to pass packets
                down(2),
                testing(3),     -- in some test mode
                unknown(4),     -- status can not be determined
                                -- for some reason.
                dormant(5),
                notPresent(6),      -- some component is missing
                lowerLayerDown(7) -- down due to state of
                                  -- lower-layer interface(s)
            }
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
            "The current operational state of the interface.  The
            testing(3) state indicates that no operational packets can
            be passed.  If ifAdminStatus is down(2) then ifOperStatus
            should be down(2).  If ifAdminStatus is changed to up(1)
            then ifOperStatus should change to up(1) if the interface is
            ready to transmit and receive network traffic; it should
            change to dormant(5) if the interface is waiting for
            external actions (such as a serial line waiting for an
            incoming connection); it should remain in the down(2) state
            if and only if there is a fault that prevents it from going
            to the up(1) state; it should remain in the notPresent(6)
            state if the interface has missing (typically, hardware)
            components."
    ::= { ifEntry 8 }
```

Figure 3. The Second Scenario of Implicit Knowledge for MIB Instances from IF-MIB

Scenario 2 *ifOperStatus: The current operational state of the interface. The testing(3) state indicates that no operational packets can be passed. If ifAdminStatus is down(2) then ifOperStatus should be down(2). If ifAdminStatus is changed to up(1) then ifOperStatus should change to up(1) if the interface is ready to transmit and receive network traffic; it should change to dormant(5) if the interface is waiting for external actions (such as a serial line waiting for an incoming connection); it should remain in the down(2) state if and only if there is a fault that prevents it from going to the up(1) state; it should remain in the notPresent(6) state if the interface has missing (typically, hardware) components.*

As for management scenarios such as Scenario 2, the formal presentation of implicit knowledge for MIB instances can be realized by extension functions from the viewpoint of not only the class of affair-elements as Scenario 1 but also the class of relation-elements depicted as Formula 11.

$$\begin{aligned} & S^{'} = Correlate(S) \\ \Leftrightarrow\ & Correlate : S \to S^{'} \\ \Leftrightarrow\ & \{R_{Correlate}\} = \begin{bmatrix} \{Object_c\}, target Value, V_{c1} \\ condition, V_{c2} \\ sourceMO, V_{c3} \\ sourceValue, V_{c4} \end{bmatrix} \end{aligned} \quad \ldots (11)$$

According to Formula 11, part of the implicit knowledge for MIB instances indicated in Scenario 2 can be formalized as a set of relation-elements $\{R_1, R_2\}$, $R_1 = \begin{bmatrix} \text{ifOperStatus}, target Value, \text{down}(2) \\ condition, NULL \\ sourceMO, \text{ifAdminStatus} \\ sourceValue, \text{down}(2) \end{bmatrix}$,

$$R_2 = \begin{bmatrix} \text{ifOperStatus}, target Value, \text{up}(1) \\ condition, \text{the interface is ready to transmit and receive network traffic} \\ sourceMO, \text{ifAdminStatus} \\ sourceValue, \text{up}(1) \end{bmatrix}$$

.

6. Conclusions

The main contribution of this paper is to introduce the Extenics science into the field of distributed management for the purpose of hierarchical information modeling to solve existing main problems that are the lack of conformance and low level of formalization, generate semantic models for ontology merging of MIB models using basic-elements in the form of matter-elements from ontology merging at the meta-schema level based on concept lattices, realize the formal presentation of both MIB instances for ontology merging and implicit knowledge for MIB instances with the use of the extension theory for basic-elements.

The proposed Extenics-based ontology merging approach for both MIB models and MIB instances takes the FCA approach for meta-schema into consideration, and aims to promote the formalization level of hierarchical information modeling for distributed management by means of a unified ontology-driven manner.

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