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Learning Concept Hierarchy from YANG for Management of Software-Defined Networking based on Theory of Concept Lattices

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Abstract

Nowadays, Software-Defined Networking (SDN) is utilized to improve network management, but the management standardization of SDN itself is still under development. This paper focuses on the integration problem of management information models for SDN, and in order to understand the principles of unified information modeling for SDN management, it tries to apply the theory of concept lattices to learn concept hierarchy from the YANG language for SDN management. Thus, this paper first obtains formal contexts from YANG statements, and then studies formal concepts from the viewpoint of posets so as to learn concept hierarchy from YANG. Case study shows that, the proposed approach is feasible and promising to promote unified information modeling for SDN management.

Keywords: *Software-Defined Networking, network management, concept hierarchy, YANG, theory of concept lattices*

1. Introduction

With the development of Software-Defined Networking (SDN), network management moves from codifying functionality in terms of low-level device configurations to building software that facilitates network management and debugging [1]. Current researches show that, SDN can be utilized to improve network management [2-4]. However, the management standardization of SDN itself is still under development.

Open Networking Foundation (ONF) proposes and develops the Open Flow Management and Configuration Protocol (OF-CONFIG, the newest version is 1.2 up to now) [5] oriented to SDN management. The OF-CONFIG protocol is based on the NETCONF protocol [6] and the YANG language [7] proposed by Internet Engineering Task Force (IETF) respectively to provide network devices with a secure-session network configuration management protocol and to promote the specification of management information.

Considering the integration problem of management information models for SDN, YANG may possibly be the basic meta-schema language, and learning concept hierarchy from YANG will help to understand the principles of information modeling for SDN management in a unified manner.

Our prior work [8] introduces Granular Computing (GrC) into the research on unified information modeling in network management domain, and discusses the problem from the granularity point of view, and our prior work [9] further studies the problem from the ontology point of view and applies the theory of concept lattices into the research on semantic management information modeling. It seems that, as one origin of GrC, concept lattices can be used to formally describe the meta-schemas for management information modeling, and the theory of concept lattices prospects a promising way to learn concept hierarchy from YANG for the sake of SDN management. The aim of this paper is then to apply the theory of

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concept lattices to learn concept hierarchy from the YANG language for SDN management.

The remainder of this paper is organized as follows. Section 2 demonstrates how YANG defines information models for SDN management as a meta-schema language. Section 3 then applies the theory of concept lattices to obtain formal contexts from YANG statements and studies formal concepts from the viewpoint of posets, aiming to learn concept hierarchy from YANG for SDN management. Section 4 discusses case study so as to validate the feasibility of proposed approach for promoting unified information modeling in view of SDN management. Section 5 concludes this paper.

2. YANG as A Meta-Schema Language to Define Information Models for SDN Management

Since OF-CONFIG 1.2 has a companion YANG module for implementation of the OF-CONFIG data model, YANG might possibly be used to define information models for SDN management, and examples are also provided in the specification of OF-CONFIG 1.2. In other words, YANG can be utilized as a meta-schema language to define information models for SDN management. YANG syntax consists of lexical tokenization, identifiers, statements, xpath evaluations and schema node identifier, and especially, statements are core for modeling SDN management information. Figure 1 shows an example of YANG statements specified in RFC6020.

```
leaf-stmt           = leaf-keyword sep identifier-arg-str optsep
                        "{" stmtsep
                            ;; these stmts can appear in any order
                            [when-stmt stmtsep]
                            *(if-feature-stmt stmtsep)
                            type-stmt stmtsep
                            [units-stmt stmtsep]
                            *(must-stmt stmtsep)
                            [default-stmt stmtsep]
                            [config-stmt stmtsep]
                            [mandatory-stmt stmtsep]
                            [status-stmt stmtsep]
                            [description-stmt stmtsep]
                            [reference-stmt stmtsep]
                         "}"
```

Figure 1. An Example of YANG Statements Specified in RFC6020

Taking the definition of information models for SDN into consideration, the YANG language plays the role of meta-schema and specifies the management information mainly by means of statements. As for the example demonstrated in Figure 1, the “leaf” statement can be used to define a simple scalar variable of a particular type in information models for the sake of SDN management.

3. Learning Concept Hierarchy for SDN Management Based On Theory of Concept Lattices

As one origin of GrC, concept lattices are introduced to essentially reflect the relationships between entities and attributes, which are specified as formal contexts, and the theory of concept lattices is a mathematization of the philosophical understanding of concepts defined as formal concepts [10-12]. When applying the theory of concept lattices to learn concept hierarchy for SDN management, formal contexts are first obtained from YANG statements, and formal concepts are then studied from the viewpoint of posets.

3.1. Formal Contexts Obtained From Yang Statements

As is indicated in the section above, information models for SDN management can be specified by the YANG language with the use of statements. These statements may possibly be classified as complex YANG statements with sub-statements and primitive YANG statements without sub-statements. Note that, some complex YANG statements are components of other complex YANG statements. Thus in this case, the complex YANG statements used for direct definition of node(s) in the schema tree representing information models for SDN management can be identified as first-level complex YANG statements, and other complex YANG statements are then identified as second-level complex YANG statements.

According to the classification of YANG statements above, Figure 2 explains the functions of the main first-level complex YANG statements that act as entities for modeling SDN management information, and Figure 3 lists the main second-level complex YANG statements and the main primitive YANG statements, both of which can be used as attributes of these entities shown in Figure 2 to suppose the first-level complex YANG statements.

Furthermore, based on the theory of concept lattices, Definition 1 provides the specification of formal contexts for learning concept hierarchy from the YANG lanauage.

Definition 1 Suppose that, a) the first-level complex YANG statements are entities for modeling SDN management information specified as E, b) the second-level complex YANG statements and the primitive YANG statements are attributes of these entities specified as A, and c) if $e \in E, a \in A, (e,a) \in R$, then it means that R represents the relationships between E and A, namely eRa, thus in this way, the formal context for learning concept hierarchy from YANG is defined as $Y = (E, A, R)$.

3.2. Formal Concepts for SDN Management

On the basis of Definition 1, YANG-based formal contexts reflect the relationships between entities and their attributes for modeling SDN management information. Thus the attribute set for an entity and the entity set for an attribute are then respectively provided in Definition 2 and Definition 3.

the main first-level complex YANG statements act as entities for modeling SDN management information
module: Definition of the module's name, and group of all statements belonging to the module
submodule: Definition of the submodule's name, and group of all statements belonging to the submodule
import: Availability of definitions from a module in another module or submodule
include: Availability of the content from a submodule in its parent module or brother submodule
typedef: Definition of a new type used locally in module by itself or importing from other module
container: Definition of an interior data node in the schema tree
leaf: Definition of a simple scalar variable of a particular type
leaf-list: Definition of an array of a particular type
list: Definition of an interior data node in the schema tree for organizing the entry with many instances
grouping: Definition of a reusable block of nodes
rpc: Definition of a NETCONF RPC operation
notification: Definition of a NETCONF notification
anyxml: Definition of an interior data node in the schema tree for an unknown chunk of XML
argument: Addition of nodes to the schema tree
extension: Definition of new statements within the YANG language

Figure 2. The Functions Of The Main First-Level Complex YANG Statements That Act As Entities For Modeling SDN Management Information

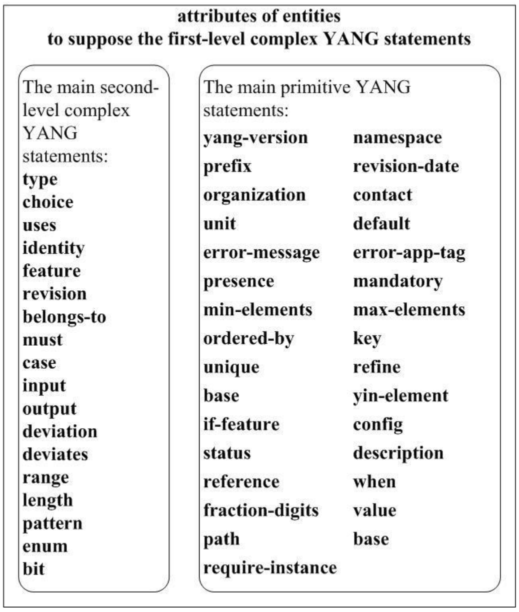

Figure 3. The Main Second-Level Complex YANG Statements And The Main Primitive YANG Statements As Attributes Of Entities Shown in Figure 2

Definition 2 One particular entity for modeling SDN management information $e \in E$ can be associated with some attributes, in other words, e has an attribute set as

$$eR = \{a \in A | eRa\} \subseteq A \tag{1}$$

Definition 3 One particular attribute of entities for modeling SDN management information $a \in A$ can be associated with some entities, in other words, a has an entity set as

$$Ra = \{e \in E | eRa\} \subseteq E \tag{2}$$

In order to learn concept hierarchy from YANG-based formal contexts, Definition 4 first introduces formal concepts for modeling SDN management information, and Definition 5 then demonstrates the possible relationship of two formal concepts.

Definition 4 When considering the formal context $Y = (E, A, R)$ for learning concept hierarchy from YANG, as for the set of entities $M \subseteq E$ and the set of attributes $N \subseteq A$, assume that

$$M^* = \{n \in A | \forall m \in E(m \in M \Rightarrow mRn)\} = \{n \in A | M \subseteq Rn\} \tag{3}$$

$$N^* = \{m \in E | \forall n \in A(n \in N \Rightarrow mRn)\} = \{m \in E | N \subseteq mR\} \tag{4}$$

, and if $M = N^*, N = M^*$, then $C = (M, N)$ is called as a formal concept for $Y = (E, A, R)$ aiming at modeling SDN management information, in which M means the extension of this formal concept and N means the intension of this formal concept, and $\bigcup(Y)$ is also introduced to represent the set of all the formal concepts for $Y = (E, A, R)$.

According Definition 4, if $M_1, M_2 \subseteq E$ are two sub-sets of entities and $N_1, N_2 \subseteq A$ are two sub-sets of attributes, there are

$$M_1 \subseteq M_2 \Rightarrow M_2^* \subseteq M_1^* \tag{5}$$

$$N_1 \subseteq N_2 \Rightarrow N_2^* \subseteq N_1^* \tag{6}$$

Definition 5 As for the formal context $Y = (E, A, R)$ for learning concept hierarchy from YANG, suppose that $C_1 = (M_1, N_1), C_2 = (M_2, N_2)$ are two formal concepts, and there is

$$C_1 \leq C_2 \Leftrightarrow M_1 \subseteq M_2 \Leftrightarrow N_1 \supseteq N_2 \tag{7}$$

, then C_1 is named as the child-concept of C_2 and C_2 is named as the super-concept of C_1.

As is indicated in Definition 5, the relationship ≤ is a partial order in $\bigcup(Y)$, and Definitions 6-9 then introduce some basic conceptions of posets for the sake of learn concept hierarchy from YANG-based formal contexts.

Definition 6 Assume that, $\bigcup(Y)$ is a set of all the formal concepts for SDN management information modeling, $s_1, s_2, s_3 \in \bigcup(Y)$ and the relationship ≤ is a partial order for $\bigcup(Y)$, if following conditions (8-10) are satisfied

$$s_1 \leq s_1 \tag{8}$$

$$s_1 \leq s_2 \wedge s_2 \leq s_1 \Rightarrow s_1 = s_2 \tag{9}$$

$$s_1 \leq s_2 \wedge s_2 \leq s_3 \Rightarrow s_1 \leq s_3 \tag{10}$$

, then $\bigcup(Y)$ is a poset, recorded as $(\bigcup(Y), \leq)$.

Definition 7 Suppose that, $(\bigcup(Y), \leq)$ is a poset, $X \subseteq \bigcup(Y)$ is a sub-set for $\bigcup(Y)$, and $s \in \bigcup(Y)$, if as for $\forall x \in X$, there is $s \leq x$, then, s is named a lower bound for X. Furthermore, if there is a largest element in $\{s\}$, this element is called as the greatest lower bound for X, record as $\wedge X$.

Definition 8 Suppose that, $(\bigcup(Y), \leq)$ is a poset, $X \subseteq \bigcup(Y)$ is a sub-set for $\bigcup(Y)$, and $s \in \bigcup(Y)$, if as for $\forall x \in X$, there is $x \leq s$, then, s is named a upper bound for X. Furthermore, if there is a smallest element in $\{s\}$, this element is called as the least upper bound for X, record as $\vee X$.

Definition 9 Assume that, $(\bigcup(Y), \leq)$ is a poset, if as for any $s_1, s_2 \in \bigcup(Y)$, both $s_1 \wedge s_2$ and $s_1 \vee s_2$ exist, $(\bigcup(Y), \leq)$ is called as a lattice, and if as for any sub-set $X \subseteq \bigcup(Y)$, both $\wedge X$ and $\vee X$ exist, then $(\bigcup(Y), \leq)$ is called as a complete lattice.

Furthermore, Definition 10 introduces the definition of the clarified formal context, and Definitions 11-12 then demonstrate the relationships of partial ordering respectively for the set of entities and the set of attributes.

Definition 10 Suppose that, $Y = (E, A, R)$ is the formal context for learning concept hierarchy from YANG, if the following conditions are satisfied, then $Y = (E, A, R)$ is a clarified formal context.

a) As for any entity $e_1, e_2 \in E$, if $e_1^* = e_2^*$, then $e_1 = e_2$

b) As for any attribute $a_1, a_2 \in A$, if $a_1^* = a_2^*$, then $a_1 = a_2$

Definition 11 Assume that, $Y = (E, A, R)$ is the clarified formal context for learning concept hierarchy from YANG, and $e_1, e_2 \in E$, then the relationship of partial ordering for the set of entities E is defined as

$$e_1 \leq e_2 \Leftrightarrow e_1^* \supseteq e_2^* \tag{11}$$

, the corresponding poset of which is named as E poset.

Definition 12 Assume that, $Y = (E, A, R)$ is the clarified formal context for learning concept hierarchy from YANG, and $a_1, a_2 \in A$, then the relationship of partial ordering for the set of attributes A is defined as

$$a_1 \leq a_2 \Leftrightarrow a_1^* \subseteq a_2^* \tag{12}$$

, the corresponding poset of which is named as A poset.

4. Case Study

In order to validate the feasibility of the proposed approach to promote unified information modeling for SDN management; two typical statements are selected from YANG, which are the leaf statement and the leaf-list statement, acting as entities shown in Figure 2. Table 1 then provides a formal context for this case, in which the label * means that the column entity has the row attribute and conversely, the column entity does not have the row attribute.

Table 1. A Formal Context For The Leaf Statement And The Leaf-List Statement from YANG

	leaf	basics	leaf-list
config	*	*	*
default	*		
description	*	*	*
if-feature	*	*	*
mandatory	*		
max-elements			*
min-elements			*
must	*	*	*
ordered-by			*
reference	*	*	*
status	*	*	*
type	*	*	*
units	*	*	*
when	*	*	*

As is shown in Table 1, an assisted entity named basics is introduced for the sake of better explaining the relationship of partial ordering of not only entities that are the leaf statement and the leaf-list statement but also attributes for these entities. According to Definition 10, the formal context shown in Table 1 is improved to be a clarified one, as is displayed in Table 2.

Table 2. A Clarified Formal Context For The Formal Context Shown In Table 1

	leaf	basics	leaf-list
cdimrstuw	*	*	*
dm	*		
mm			*

Note that, as shown in Table 2, the attribute "cdimrstuw" means a combination of attributes "config", "description", "if-feature", "must", "reference", "status"," type", "units" and "when" from YANG, the attribute "dm" means a combination of attributes "default" and "mandatory" from YANG, and the attribute "mm" means a combination of attributes "max-elements" and "min-elements" from YANG.

According to Definitions 11-12, Figure 4 and Figure 5 respectively reveal the structure of E poset and A poset for the clarified formal context depicted in Table 2.

Figure 4. The Structure of E Poset For The Formal Context Depicted in Table 2

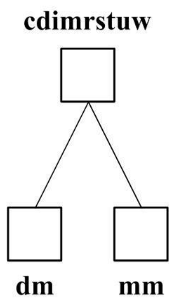

Figure 5. The Structure Of A Poset For The Formal Context Depicted In Table 2

Thus in this way, the proposed approach utilizes the theory of concept lattices and does favor to learn concept hierarchy from YANG, in order to promote unified information modeling for SDN management.

5. Conclusions

The main contribution of this paper is to apply the theory of concept lattices to learn concept hierarchy from YANG for SDN management, by first obtaining formal contexts from YANG statements and then studying formal concepts from the viewpoint of posets, so as to understand the principles of information modeling for SDN management in a unified manner, finally aiming to solve the integration problem of management information models for the sake of SDN.

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