A collaboration ontology modeling method for high level architecture

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Abstract

HLA (High Level Architecture) is the general technical framework for distributed modeling and simulation. But the object model of HLA cannot meet the requirements of semantic data consistency. A collaboration ontology modeling method was proposed for HLA simulation. Firstly, the definition and formal description of collaborative ontology was provided, and constructing method was proposed, it mainly included two critical keys: the ontology template mapping and the conceptual matching degree calculation. Then, the corresponding tasks ontology was generated according to the specific goal of the simulation, and HLA object model was generated, the main structure of federate object model was designed. On the one hand, semantic data consistency in collaborative simulations for complex product development was enhanced and the efficiency of model development was improved. On the other hand, it improved the reusability of the simulation model. Finally, a case was provided to demonstrate the effectiveness and feasibility of the way.

Keywords: high level architecture, collaborative simulation, ontology, complex product, federate object model

1 Introduction

High Level Architecture is a well-known standard of collaborative simulation. HLA is oriented to collaborative simulation for complex product with uniting the simulation model of each field, and it has achieved remarkable results on complex product collaborative development platform [1-3]. But the HLA cannot fully meet the requirements of collaborative simulation for complex product, semantic data consistency of concept and its relationship is realized for each domain simulation model in the process of collaborative simulation, so that confidence of simulation result is enhanced to guide the design and development of complex product. HLA constructs the federation with federation object model (FOM) and simulation object model (SOM), but the consistency and completeness cannot be guaranteed and they are not easy to understand even for professional experts. Although Simulation Interoperability Standards Organization (SISO) added semantic data item to the new revised version HLA Evloved in 2010. It could not be identified and understood by computer, because method of description is based on natural language [4].

Rathnam proposed that based on the simulation ontology SONT to realize the models' semantic consistency in various fields in the process of collaborative simulation, but the establishment of SONT is based on a comprehensive overall ontology-World Ontology, it is difficult to guarantee the flexibility of system integration, and can't reuse the existing SOM. Özdikis and the others proposed a method that is based on the Eclipse framework which mapping the domain ontology for the Federate Object Model [5]. But this method is only mapping for the single field ontology, it is difficult to ensure multi-domain ontology's consistency. Sun and the others based on HLA's interactive ontology achieved a complex product development which is based on semantic collaborate knowledge modeling and cooperative organizations [6]. But the interactive ontology can only describe the interaction semantics, it is unable to describe the concept and the relation of their own simulation members. Through the XML, Rabb and the others described the information of domain simulation modeling which is based on the semantic formalizing description, and they used the description files created FED documents needed by the HLA federation [7]. But this method is only applicable to domain modeling which the semantic information needs interaction, for lack of integrity. Hu and the others used a simulation framework with the combination of HLA and WebService, proposed to use the basic ontology, domain ontology and application ontology all these three levels' ontology to describe the variety knowledge and information involved in collaborative simulation [8], but did not describe how to apply ontology model to create HLA object model.

For the above problems, this paper has put forward a HLA simulation modeling method which is based on collaborative ontology; it not only can complete the semantic consistency in all areas, but also can improve the development efficiency and the re-usable of simulation model.

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2 HLA modeling process based on ontology

The development and design of complex product in many areas have already established the corresponding domain ontology. Domain ontology is a description of concepts and relationships between concepts within the field. Figure 1 is the procedure of the construction of HLA object model which is based on ontology, mainly including three parts: collaborative ontology's creation, task ontology's generation and the object model's construction. Collaborative ontology took HLA/RTI environment as the basis, and also based on a common information interaction specification, reused the domain ontology correspond to the domain simulation model, described the shared conceptual model in all areas, so as to achieve the semantic model mutual understanding in various fields.

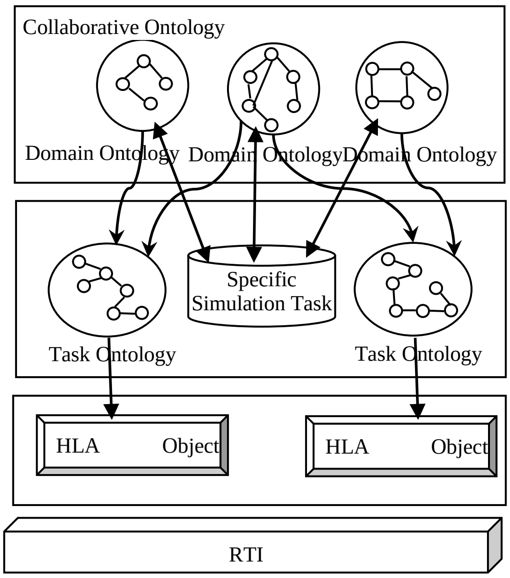

FIGURE 1 The HLA Object Model Procedure based on Ontology

Refer to ontology and HLA specification, the collaborative ontology is defined as "based on a set of common information in interaction and specification form, and the multiple shared conceptual model's formal specification description", set the domain anthologies distribute on different physical nodes, and before the specific simulation tasks, firstly each domain ontology needs realize the semantic consistency, namely through ontology concepts and concept relations' matching to complete the integration of collaborative ontology. Based on the complete of collaborative ontology creation, according to the requirement of simulation target's specific simulation tasks, generated the corresponding task ontology. On the stage of HLA object model's generation, it is mainly to complete the mapping from ontology to HLA object model, and also on the basis of task ontology and domain ontology, generated the procedure of specific simulation task corresponding to FOM/SOM. Please see Figure 1.

For the convenience of study, the formal definition of domain ontology, collaborative ontology and task ontology will be given in the following. And the ontology that related in this paper is built in OWL language.

Definition 1 Domain Ontology.

$$O_D ::=< C, A, R, I, \tau > .$$

Domain Ontology O_D is defined as a five tuple, it describes concepts and their relationships in a specific domain. C denotes concept set in the domain. A denotes a set of attributes on concept set C, used to represent concept's own characteristics. R is relationship set including hierarchical relationship between concepts and the relationship between attribute levels, parent-child relationships, equivalence relations, etc. I is a set of instances in the domain, the living example of a concept; τ is the mapping from concepts relations to the concepts, namely, $\tau : R \to C \times C$.

Definition 2 Collaborative Ontology.

$$O_C ::=< S, E, \tau_{SE} > .$$

Collaborative Ontology O_C can be formalized defined as a three tuple, it describes the shared concepts and their relationships in all domain. S is the domain ontology set, E is a set of relationships of concept equality in the domain, τ_{SE} is the mapping from the relationships of equal concepts to the concepts.

Definition 3. Task Ontology.

$$O_T ::=< S_T, C_T, R_T, \tau_{CR}, I_T > .$$

Task ontology O_T can be defined as a five tuple, it is the ontology which describes a particular task or behaviour, and also describes the concept involved in the simulation and relationships between concepts. S_T denotes concept set involved in the simulation task in the domain, C_T is concept set of simulation model which required for interaction, R_T is concepts' relationships set of the simulation model which required for interaction, τ_{CR} is the mapping from concepts relationships in simulation model which required for interaction to the concepts, namely, $\tau_{CR} : R_T \to C_T \times C_T$, I_T is the concept instances set of the task ontology O_T .

3 Creation of collaborative ontology

Collaborative ontology is created to solve the semantic heterogeneity problem in domain ontology; it is also the basis of HLA object model generation. Firstly using the basic concept within the territory to form an abstract ontology, and then matching domain ontology's concepts, when the abstract ontology can't describe the matching concept in domain ontology, and then expand the abstract ontology, integrated new concepts form collaborative ontology in abstract ontology and domain ontology, and in the meantime save the new matching relations. Collaborative ontology's creation is a constantly iterated, and constantly improved process, not only overcome the ontology's cumbersome in domain ontology, but also overcome the defect of incomplete shared vocabulary, it is able to adapt to large scale, multiple domain ontology collaborative simulation system. Please see Figure 2.

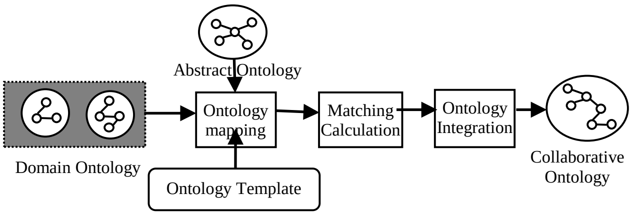

FIGURE 2 Creation process of collaborative ontology

In the creation process of collaborative ontology, the mapping based on domain ontology template and the matching calculation are two important links, the following will be stated respectively.

3.1 MAPPING BASED ON ONTOLOGY TEMPLATE

The ontology structure and form that after ontology integration are depending on domain ontology, when the domain ontology's main structure has a big difference, there is also a big difference in integration ontology's main structure. Therefore, it needs to be based on a unified ontology template to complete the process of ontology integration, to form clear and normative integration ontology which can clearly describe complex product's concepts and relationships. On the one hand, it can enhance the readability of the ontology, and on the other hand, and it will benefit the reuse of the HLA simulation modeling. According to different HLA simulation tasks, HLA simulation modeling process should be based on the same design model to create a different HLA simulation model. As a result, the ontology template can have an abstract description of the product's concept relationships in all aspects; so that it can integrate different fields' simulation models which correspond to domain ontology that contains all the concepts and relationships. Please see Figure 3.

Ontology template is a collection of all kinds of concepts for that every concept of domain ontology can find their parent class in this template. Taking the machine tool product as an example, collaborative ontology template and HTC2550hs lathe domain ontology structure's matching process is given, as shown in Figure 3. Ontology template covers all content and related information that possibly need interaction. First analyze the domain ontology, according to IS-A relationship in ontology's concepts forming one or more of the relational tree.

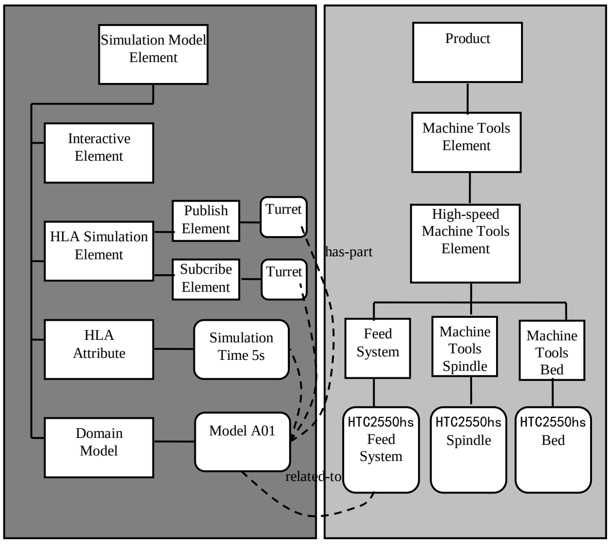

FIGURE 3 Domain model's mapping based on ontology's template

Then using the WordNet semantic software to match its roots' concept and the abstract concept in ontology template thus contained this relational tree into ontology templates' a certain abstract concept.

This template uses the instance of ontology to describe various elements required in collaborative simulation interaction, and as the sub-concept of the root concept in domain ontology which added to the original domain ontology. Ontology template's root concept, "simulation model element" is all the HLA collaborative simulation related concepts' abstract concepts. Example of its sub-concept of "domain model" is the overall description of the scope of current HLA simulation modeling within difference simulation models, through the connection between the "related - to" relationship and a concept in domain ontology, described the specific categories and attributes of simulation model. "Simulation Model" concept instance through "has-part" relationship linked with the "Release Element" concept instance, the "Order Element" concept instance, "HLA conventional simulation element" concept instance, in order to further describe the interaction capacity of current model in collaborative simulation. “Release Element" concept instance used to describe the object that can be published in collaborative simulation (object class or interactive class), through the connection between the “related - to" relationship and a certain concept instance in domain ontology. "Order Element" concept is similar to "Release Element" concept, for describe models in federation that are prepared to be ordered."HLA Attribute Element" is a further attribute description of the object that can be published or can be ordered, and its specific instance can be built alone or can use the same "related - to" relationship which linked to a certain concept in domain ontology. "HLA conventional simulation element" uses "Simulation Time", "Simulation Step" and other date attributive relationships to describe model's general attributes in collaborative simulation, and it plays a guiding role in building the collaborative federation simulation.

If the root concept cannot successfully match, then it will be matched directly to their respective sub-concept, until having a successful match. After domain ontology's parsing which is based on ontology template, it can through calculate the semantic similarity of concept under the same abstract concept in various fields in ontology template. Then eventually determine the domain ontology's concept's equal relationship. This way is according to the classification of ontology template, it only needs to match the similar concept, and it will further enhance the efficiency and accuracy of ontology's concepts' matching.

3.2 CALCULATION OF CONCEPT MATCHING DEGREE

After the parsing of ontology, the domain ontology by calculating the similarity to determine matching relationships among concepts, the similarity is used to measure the similarity degree of two elements, and thus to determine whether two concepts may have the same or similar semantic features. Calculating the elements' degree of similarity, first of all, we need to quantify the similarity. Please see Definition

$sim(x,y) \in [0,1](x \in O_{D1}, y \in O_{D2})$.

x, y represent O_{D1}, O_{D2} two concepts in domain ontology, $sim(x,y)$ represents the matching degree. $sim(x,y)=1$ represent two concepts are completely match, and $sim(x,y)=0$ represents not match at all.

Based on the above definition, we use the name of concept, the concept instances, and the parent and sub-class of concept all these three features to gain a comprehensive judgement of matching.

We use Levenshtein method to judge the concept's name. The function is:

$$sim_L(x,y) = \max(0, \frac{\min(|x|,|y|) - ed(x,y)}{\min(|x|,|y|)}) .$$

Function $ed(x,y)$ is the edit distance of two strings. $\min(|x|,|y|)$ is the minimum value of concept name's length.

Concept instance, the concept of the direct parent class and subclass use Dice Coefficient method, the function is:

$$sim_D(x,y) = \frac{f(x \cap y)}{f(x \cup y)} .$$

$f(x \cap y)$ represents a probability that a random instance belongs to the concept x and y, and it is the intersection of these two, $f(x \cup y)$ indicates the probability that a random instance belongs to the concept x or the concept y, it is the union.

After obtained the feature matching degree of the concepts, using the weighted average to calculate the total matching degree of two concepts.

$$sim_D(x,y) = \lambda_1 sim_{L1}(x,y) + \lambda_2 sim_{D3}(x,y) + \lambda_3 sim_{D3}(x,y)$$

and $\lambda_1 + \lambda_2 + \lambda_3 = 1$, $\lambda \in [0,1]$.

After obtained the total matching degree between two concepts, we can judge whether these two concepts exist equal relationship according to the threshold value which set by the user. If the matching degree exceeds the threshold value, then the two concepts are considered to be equal. If it is less than the threshold value, then integrated domain ontology and shared ontology integrated into a new sharing ontology. And because this process is an iterative process, so in the end, the user could also adjust the threshold value of specific task, based on recall rate and accuracy after completed algorithm for matching. At this time, the sharing ontology holds the equal relationships of domain ontology's concepts, formed the common understanding on the concepts of which domain ontology corresponds to the simulation model.

4 Generation of task ontology

After creating collaborative ontology, depending on the specific simulation task requirements, such as domain model information that participate in the simulation, interactive conceptual relations, and the accuracy of the simulation and so on, generate task ontology. Task ontology is generated on the basis of collaborative ontology; it can be regarded as a special form of collaborative ontology. In the process of task ontology's generation, as the collaborative ontology has completed the semantic consistency, therefore every time when different task ontology are established, it doesn't need re-unified the semantic consistency, thereby increasing the efficiency.

Task ontology according to the different needs of specific simulation task, dynamically integrated the domain ontology corresponded to model which participated in the simulation. It described various concepts which under a particular simulation object that the simulation model required interaction, its main structure as shown in Figure 4.

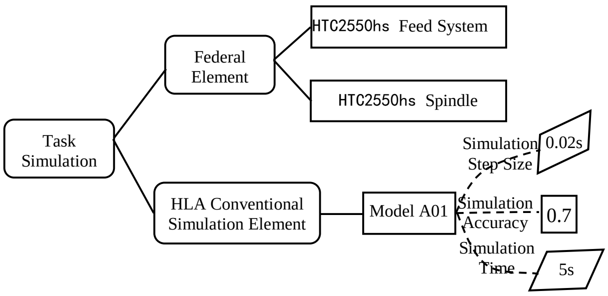

FIGURE 4 Main structure of task ontology

In task ontology, "federal element" concept instance is mainly to describe various simulation models that schedule simulation tasks required, it can through "interact" object relationship to further describe what object that simulation tasks need to interact. "HLA conventional simulation element" through "precision", "simulation-time", "simulation-step" to describe the specific tasks' simulation accuracy, simulation time, the simulation step size and so on. Figure 4 illustrates the current collaborative simulation tasks require "HTC2550hs Feed System", "HTC2550hs Spindle" such simulation models, while "HTC2550hs Feed System", "HTC2550hs Spindle" two simulation models exchange the date. In terms of the simulation parameters, it requires the simulation time for 5s for collaborative simulation, the simulation step size is 0.02s, and the simulation precision is 0.7. Task ontology integrated the domain ontology related to specific simulation tasks, and the domain ontology is a description of its corresponding node simulation model and its interaction information, so the task ontology describes the involved participated simulation model and the mapping relationship of models under specific tasks. After the formation of the task ontology, the system will build the HLA object model that required by federation which is based on task ontology and domain ontology.

5 HLA object model

Because the task ontology contains kinds of information that needs interaction in simulation tasks, and determines the members that participated in federal simulation, so the FOM performed by federation can be directly generated by task ontology, transforming domain ontology's attribute input/output concepts into the category that need to be ordered/released.

Because the design model information, domain ontology information required by HLA domain simulation model can be transformed by the collaborative ontology through federation, so the FOM in collaborative ontology should standardize the definition. In addition, the FOM and SOM of specific simulation task federation can also be built on the basis of domain model semantics' mutual understanding in collaborative ontology, so FOM should also contain the related date concepts of specific simulation task. But the interactive information that required in building HLA domain simulation model and HLA object model should be instantaneous exist in federation, thus this kind of data concepts in the FOM of collaborative ontology should describe in the form of HLA interaction category. According to the above principles, the main structure of object category and interactive category of FOM in collaborative ontology is shown in Figure 5.

The object categories, interactive categories' top parent class in FOM are "HLA object and root class" and "HLA object and root class". The subclass is used to describe the interactive date which in the matching process of concept or relationship in domain ontology, and it is the core content of FOM. The "matching concept" is used to describe the concepts that need to match which released by members, its main attributes include: " concept name", "attribute name", "direct parent class name collection" and "direct subclass name collection". Concept matching in domain ontology is mainly based on the following attributes to complete: "matching relationship" is used to describe the relationships that need to match which released by members, its main attributes include "relationship name" and " related concepts' name", the matching in concepts is mainly based on related concept names' collection to complete. The sub-class of "HLA interaction and root class" is "domain modeling element" and "simulation task element", they are respectively to describe the interactive date which required in the process of HLA domain simulation modeling and building the specific simulation tasks. These two classes are all included HLA specific attributes: "limited release and order", "semantic", "dimension", "transmission mechanism", in which the attribute of "limited release and order" is used to describe whether. This object can be released or be ordered; "semantic" attribute using a text to describe the specific content of this object classes; "dimension" attribute is for the management of RTI data; "transmission mechanism" attribute is for time management of RTI.

6 Application instance

This paper taking multidisciplinary collaborative simulation modeling in development of high-speed CNC Machine Tools HTC2550hs as an example, illustrate this method in detail. Numerical control machine's structure and function are complex, its development and design need the participation of the multidisciplinary, multiple node design staffs, ADAMS simulation model, MATALAB simulation models that involved in collaborative simulation are distributed on different physical nodes, the model has more semantic heterogeneous information, the development efficiency is low, and the post-maintenance is complex, and difficult to reuse. To solve these problems, based on HLA/RTI distributed mode, apply the methods proposed in this paper to solve the problem of semantic heterogeneous, as shown in Figure 6 and Figure 7. It is the ADAMS simulation model's corresponding part of the domain ontology and MATALAB simulation model's corresponding part of the domain ontology, through the creation of collaborative ontology, generation of task ontology and the mapping of HLA object model to realize semantic consistency, Table 1 is part of concept's equivalent element which after matching concepts.

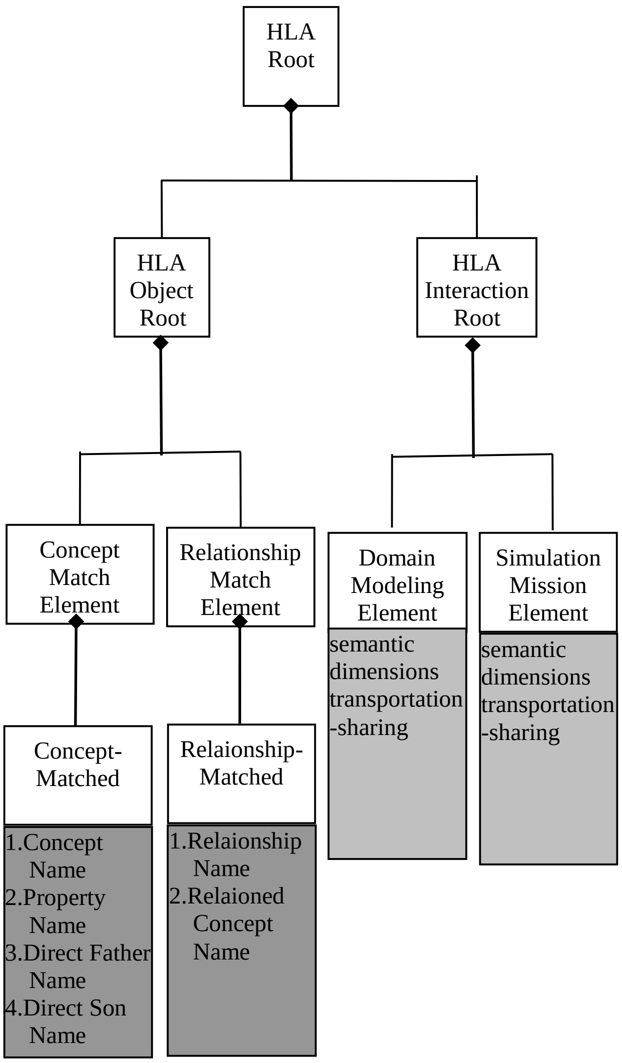

FIGURE 5 Main Structure of FOM

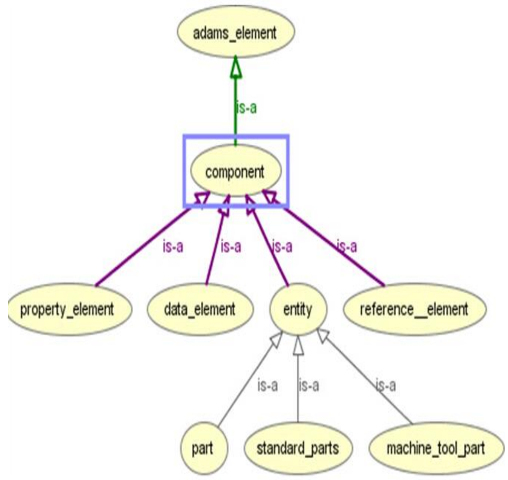

FIGURE 6 ADAMS ontology main structure

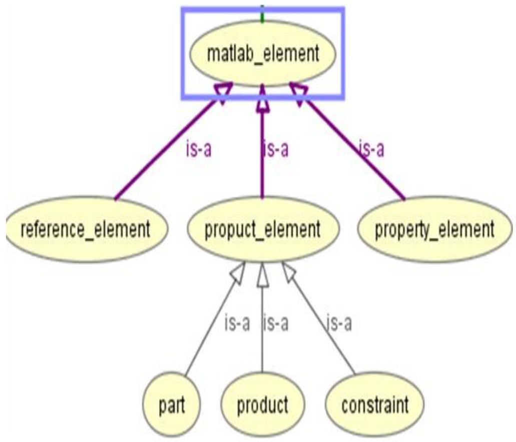

FIGURE 7 MATLAB ontology main structure

TABLE 1 Part of concepts equal element between ADAMS ontology and MATLAB ontology

No.	ADAMS	MATLAB	Comment
1	Property element	Property element	equal in
2	Entity	Product element	equal in
3	Reference	Reference element	equal in
4	Part	part	equal in

7 Conclusions

The modeling method for HLA simulation based on collaborative ontology realized the semantic consistency in the process of complex product's development, on the one hand, after the collaborative ontology's creation, HLA simulation domain model and object model can directly created under HLA/RTI environment which in the specific requirements of simulation tasks, it improved the efficiency of HLA simulation modeling. On the other hand, through the reuse of the domain ontology which corresponded to simulation model, it can achieve the purpose of model reuse, and it guaranteed the independence of the domain ontology.

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