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Ontology-based Semantic Interoperability among Heterogeneous CAD Systems

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Abstract: Because the different CAD systems use different concepts, attributes and relations to store data model, it is difficult to implement semantic interoperability among heterogeneous CAD systems. In this study, the Feature Command Ontology Model (FCOM) which is established, includes a number of Neutral Semantic Feature Commands (NSFCs) corresponding to the basic modeling operations of CAD systems. The FCOM which has explicit ontological semantics, provides the uniform representation of heterogeneous information and helps to shield the heterogeneity of data sources. Meanwhile, it is capable of dealing with modification and deletion operations besides common creation operations. Based on the FCOM, a synchronized collaborative design platform upon heterogeneous CAD systems is built; the real-time data exchange among heterogeneous CAD systems is achieved in a semantic way.

Key words: Data exchange, CAD systems, heterogeneous, synchronized collaborative design, FCOM

INTRODUCTION

With the rapid development of network technology and computer technology, the enterprises are facing fierce competitions, inter-enterprise collaboration and resource sharing are needed. Collaborative design of heterogeneous CAD systems is gradually becoming a hot research area. More and more complex CAD products need to be collaboratively developed by multiple departments or groups geographically dispersed. The technology shortens the product development time, makes the best use of remote resources and reduces the design cost (Kim and Han, 2008).

In collaborative design, the different enterprises and departments use different CAD systems for considering the aspects such as function and economy. Therefore, the data is stored by different storage methods among heterogeneous CAD systems and defined by different concepts, attributes and relations, which results in the heterogeneity of data source and brings to difficulties of collaborative design (Huang and Diao, 2008).

In this study, we construct Feature Command Ontology Model (FCOM), which includes a Number of Neutral Semantic Feature Commands (NSFCs) corresponding to the basic modeling operations of CAD systems. The FCOM provides a uniform representation for heterogeneous information, which can deal with modification and deletion operations besides common creation operations. The synchronized collaborative design platform upon heterogeneous CAD systems is built by FCOM, the real-time communication among heterogeneous CAD systems is achieved in a semantic way.

PRELIMINARIES

The data exchange among heterogeneous CAD systems has been researched by academic and industrial circles. At present, the research work for the data exchange among heterogeneous CAD.

Systems includes three types: The data exchange among heterogeneous CAD systems based on geometric data, the data exchange among heterogeneous CAD systems based on parametric feature data, the data exchange among heterogeneous CAD systems based on operation command.

The data exchange among heterogeneous CAD systems based on geometric data is an earliest research method, which implements the geometric information exchange based on uniform exchange standards. However, with the rapid development of collaborative design technology and parametric feature modeling technology, not only the geometric information about the design, but also the high-level semantic information such as feature, constraint and design history are needed by designers. The designers need compile and modify feature modeling by high-level semantic information.

The core idea of the data exchange among heterogeneous CAD systems based on parametric feature

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data is to implement the data exchange of the high-level semantic information, such as feature, constraint and design history and so on. But knowledge about feature definitions of different CAD systems are different. It is difficult to implement the high-level semantic information exchange among heterogeneous CAD systems. Standard for the Exchange of Product Model Data (STEP) have attempted to solve this problem, but it defines only syntactic data representation so that semantic data integration is not possible. Meanwhile, data exchange based on parametric feature data needs to transfer great amount of data, it is difficult to implement real-time data exchange.

The core idea of data exchange among heterogeneous CAD systems based on operation command is to build neutral commands corresponding to the basic modeling operations of CAD systems to implement data exchange. Because of only transferring of operation commands, the amount of data is small, the communication among heterogeneous CAD systems is achieved in real time.

Study on the data exchange based on operation command, Choi proposes a macro-parametric approach to exchange CAD model between different CAD systems (Choi *et al*., 2002). This method exchanges the macro command files between different CAD systems through neutral commands. The method focuses on off-line exchanging of the complete CAD model, not considering exchanging of single operation command required by synchronized collaborative design.

Li *et al.* (2004) analyzes several typical CAD systems and sets up a number of neutral commands. Synchronized collaborative design is realized by real-time capturing and transferring of modeling operations between distributed heterogeneous CAD systems.

The data exchange based on operation command is implemented by command mapping. The mapping relationships of commands are not only single command to single command, but also single command to multiple commands and multiple commands to multiple commands. So the functions of reasoning and judgment are needed by the data exchange system. Then the data exchange is able to be achieved by different mapping relationships.

To exchange data information in a semantic way, an ontology method is applied in the recent years. An ontology is an explicit specification of a conceptualization (Gruber, 1992). Ontology adds relation, rule and constraint to the taxonomy so that semantics can be represented in a data model (Wei *et al*., 2009). So, the integration of information and semantic interoperability are realized by ontologies.

The expression of ontology:

$$\text{Onto} := \{C, A^C, R, A^R, \leq C, \leq R, \sigma, L, X, I\}$$

Where:

- C = Concept sets
- A^C = Attribute sets of each concept
- R = Relation sets
- A^R = Attribute sets of each relation
- $\leq C$ = Concept hierarchy
- $\leq R$ = Relation hierarchy
- σ = Function of $R \rightarrow C^+$
- L = Logic language
- X = Axiom sets
- I = Instance sets

Ontologies endow semantics with data model by including concepts, relations, constraints and axioms, so semantic interoperability are realized among different CAD systems by ontologies (Cho *et al*., 2006). Li *et al*. (2004) defined standard feature command and then exchanges data using a neutral file format according to the standard. Although, the existing method allows mappings between different terminologies, the mappings can be done only grammatically, not semantically. Thus, we construct a FCOM to transfer the semantic information so that heterogeneous data can be effectively managed.

A FRAMEWORK OF FEATURE COMMAND ONTOLOGY MODEL

Ontologies are usually divided into the sharing ontology and the domain ontology. The domain ontology is designed for a specific application, it is a specific functional design ontology repository. The CAD systems are encapsulated into domain ontology. But the domain ontologies themselves could be heterogeneous. The heterogeneities are obstacles to integrate and share product information. So, we need the sharing ontology. The sharing ontology is a functional modeling as a standard intermediate by Web Ontology Language (OWL) (Antoniou and Harmelen, 2004). It provides a uniform representation for heterogeneous information. In this study the FCOM which belongs to the sharing ontology, defines high-level concepts and attributes and shields the heterogeneity of semantic information.

In this study, the data exchange is implemented by the FCOM. The FCOM gives fundamental distinctions of NSFCs and the hierachical relation of NSFCs. The general UML class diagram of NSFCs is showed in Fig. 1.

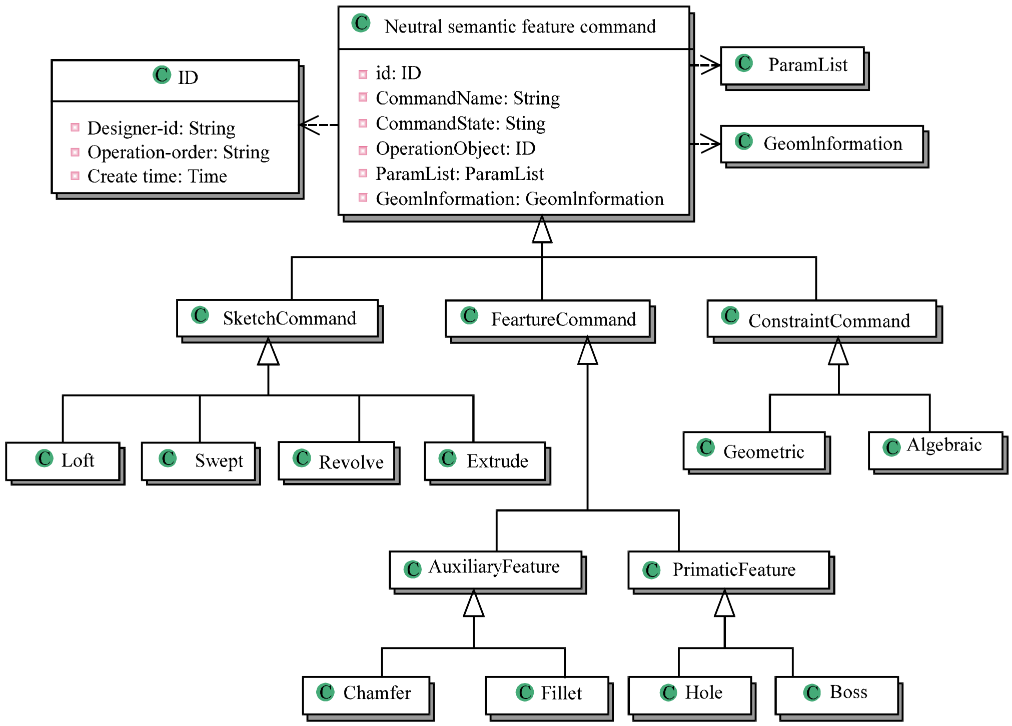

Fig. 1: General UML class diagram of NSFC

The class neutral semantic feature command is the parent of all NSFC classes. The id is an unique identifier that is composed of designer-id, operation-order and createTime. The designer-id is the unique identifier of designer; The operation-order is the operation generation sequence number in local site; The createTime is the created time of the NSFC. The representation method of id makes not only the permanent uniqueness of the id, but also the traceability of the feature operation. The commandName is the NSFC's name and the command state indicates one of three states: Creation, Modification, Deletion. If the commandState is Modification or Deletion, the operationObject is used to record the existing modified or deleted object. The paramList represents the parameters of NSFCs.

The operation commands include four kinds of corresponding relations among heterogeneous CAD systems, so the semantic evaluation is needed in collaborative design. The results of semantic evaluation can be classified into semantic uniform and semantic lossy. The semantic uniform is that a concept or a group of concepts of target ontology is accurately corresponding to a concept of source ontology. When a concept of target ontology, even if a group of concepts, is not corresponding to a concept of source ontology, we define this as the semantic lossy. When semantic lossy occurs, we use the geomInformation to contain such geometric operations. Every NSFC takes a corresponding subclass of class GeomInformation to represent its specific geometric operations.

A synchronized collaborative design system should not only exchange creation operation but also exchange modification and deletion operations in real time. The modification and deletion operations are different from creation operations in that they should find which objects are modified or deleted before they are executed. In order to effectively handle modification and deletion operations, we proposes a method based on the design history. The design history information includes the feature id, the feature command, the parameterization data and the constraints of the CAD¡¡model. We use the XML schema definition to represent the design history of a model. The XML schema is divided into two parts: the id part, by which the modified or deleted object is found; the feature information part, in which all the design history information besides id are represented. Considering that only commands are transported in real time, hence a NSFC is always received instantly after it is sent. And all the NSFCs send and receive in a site sorted by time are exactly the design history. That also means the NSFC with

```
<owl:Class rdf:ID=" NeutralSemanticFeature Command">
 <rdfs:subClassOf>
   <owl:Restriction><owl: allValuesForm rdf:rescource="#featureCommand"/>
     <owl:onProperty><owl:ObjectProperty rdf:ID="hasFeatureCommand"/>
 </owl:onProperty></owl:Restriction><rdfs:subClassOf>
 <rdfs:subClassOf>
   <owl:Restriction><owl: allValuesForm rdf:rescource="#sketchCommand"/>
     <owl:onProperty><owl:ObjectProperty rdf:ID="hasSketchCommand"/>
  </owl:onProperty></owl:Restriction></rdfs:subClassOf>
 <rdfs:subClassOf>
   <owl:Restriction><owl: allValuesForm rdf:rescource="#constraintCommand"/>
     <owl:onProperty><owl:ObjectProperty rdf:ID="hasConstraintCommand"/>
  </owl:onProperty></owl:Restriction></rdfs:subClassOf>
   <owl:Restriction>
     <owl:onProperty rdf: rescource="id">
     <owl:cardinality rdf:datatype="&xsd;NonNegaveInteger">1
   </owl:cardinality></owl:Restriction>
   ......
 </owl:Class >
```

Fig. 2: Basic structured definition of NSFC

the same id is identical. So, we can use id to find the object which is modified or deleted in a remote site. In a local system, a modification operation is executed whose operationState set to Modification. The id of modified feature is acquired by the design history extractor. By traversing the design history schema from top to down and matching the id, we find out the current operated object. Meanwhile, the design history schema is modified. Then the modification operation is transported to the other remote site. By the same id, the object is found and the modification operation is executed in the remote site.

The FCOM applies OWL to describing semantic information in the study. OWL is ontology description language, which is recommended by semantic internet. It is used to clearly express the meaning of terms and the relationship among them as a vocabulary. The basic structured definition of NSFC described by OWL schema is showed in Fig. 2.

AN ARCHITECTURE OF SYNCHRONIZED COLLABORATIVE DESIGN BASED ON FCOM

We have developed a synchronized collaborative design platform upon heterogeneous CAD systems based on the feature command ontology converter. The feature command ontology converter plays an important role in achieving real-time communication within heterogeneous CAD systems. It likes a bridge between different CAD systems. The data exchange is implemented by the feature command ontology converter. The main functions of the feature command ontology converter include: (1) building uniform command terms; (2) providing querying and reasoning mechanism and (3) building uniform data exchange interface between heterogeneous CAD systems. Figure 3 shows the conversion process between heterogeneous CAD systems based on the feature command ontology converter.

Figure 4 and 5 show the result of semantic interoperability between heterogeneous CAD systems.

Two geographically dispersed users, using Pro/E and UG respectively, successfully completed the synchronized collaborative design of the test. When a user using Pro/E creates a feature, the feature operation is captured by the feature command ontology converter and the feature operation is transformed into recognizable feature command in the UG system, then the feature command is sent and executed by UG.

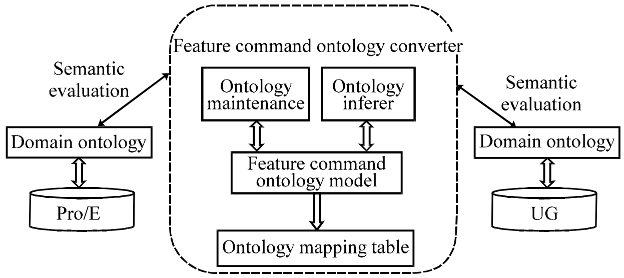

Fig. 3: Conversion process between heterogeneous CAD systems

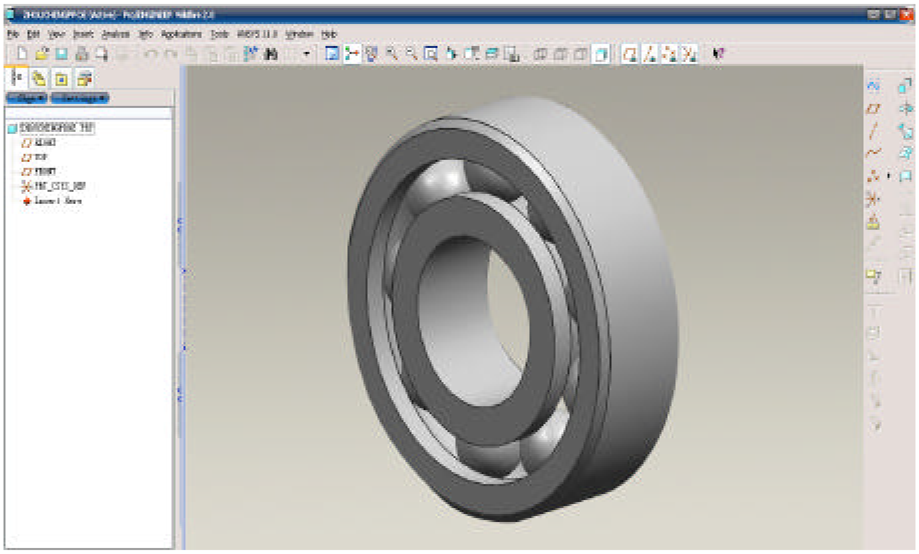

Fig. 4: Pro/E Wildfire 2.0 View

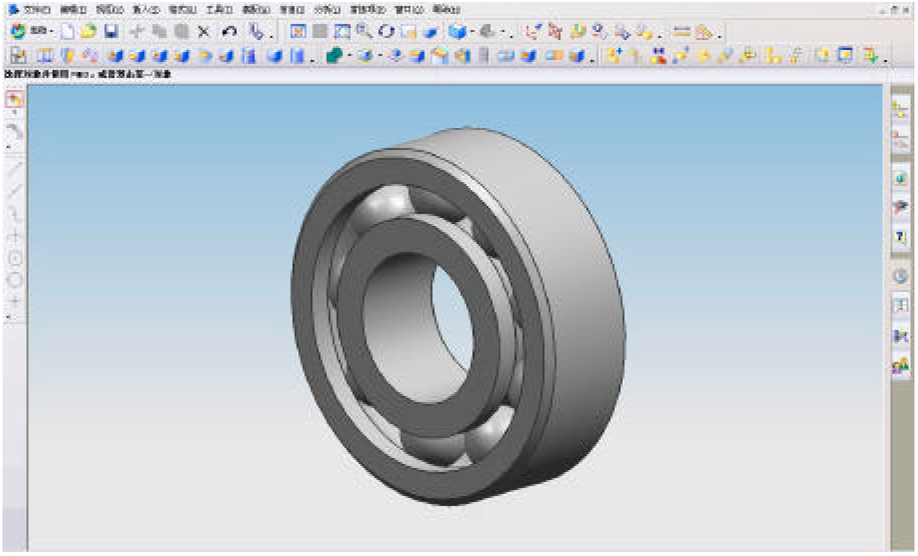

Fig. 5: UG NX4.0 View

CONCLUSION

In this study, we present a data exchange method between heterogeneous CAD systems based on FCOM. By FCOM, the uniform representation of different knowledge of CAD feature models is realized. And this exchange data method only transfers NSFC between the source ontology and the target ontology, which implements real-time data exchange. Meanwhile, it is capable of dealing with modification and deletion operations besides common creation operations. Finally, a synchronized collaborative design platform upon heterogeneous CAD systems is built, communication between heterogeneous CAD systems in a semantic way is proved to be available and effective.

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