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ORIGINAL ARTICLE

Multi-level ontology integration model for business collaboration

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Abstract According to the current situation of the enterprise informatization, a large number of legacy systems (databases, programs, etc.) need to be integrated, different application systems (PDM, ERP, SCM, CRM, etc.) need to interact, and enterprise business needs close collaboration. This paper build an architecture to integrate heterogeneous systems for enterprise business collaboration. It proposed product ontology model, software component ontology model and business process ontology model for heterogeneous system integration, to solve the problem of product knowledge heterogeneous, software components heterogeneous, and business process heterogeneous in collaborative business processes. Based on this, a prototype of platform is given. The research of this paper is of important theoretical significance and provides a new architecture and implementation method for the integration of heterogeneous systems based on business collaboration.

Keywords Business collaboration · Heterogeneous system · Ontology integration

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1 Introduction

Big data is a popular term or topic today both in academic and industrial area. A convincing definition of "Big Data" focuses not only on the size of data in storage but also on other important attributes of "Big Data," like data variety and data velocity [1]. Besides, Internet of Things (IoT) has been paid more and more attention recently, because it could provide a promising opportunity to build powerful industrial systems and applications by leveraging the growing ubiquity of RFID, wireless, mobile, and sensor devices, embedded object logic, object ad hoc networking, and Internet-based information infrastructure [2, 3]. During modern manufacturing process, big data is collected by Internet through information communication technology (ICT). The key point is to use and combine them with other business systems such as ERP, PLM, and SCM. Efficient and flexible means of communications and big data processing would carry on intelligent monitoring, automated decision-making, and production management, in order to develop new business models, optimize production and logistics [4]. Increased amount of information increases the challenges in managing and manipulating data. Data integration is a main issue [5, 6].

However, data sources are extremely heterogeneous in their structure, with considerable variety even for substantially similar entities, due to constraints such as complexity of enterprise application system, diversity of heterogeneous data sources, and so on. Especially, when there is a new demand for enterprise applications, enterprise data integration process becomes quite complex. The integration of heterogeneous data sources is a classical problem in database field, although there are already a lot of data integration methods and the corresponding tools putting into practical applications. Figure 1 depicts the relationships among the various heterogeneous systems integration technology.

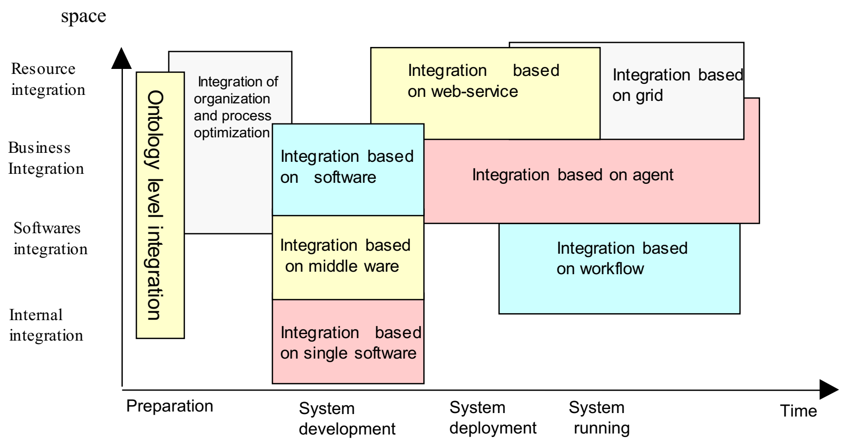


Fig. 1 Relationships among heterogeneous systems Integration Technology

The heterogeneous data source in an enterprise can be classified mainly in three aspects: heterogeneous system, heterogeneous pattern, and semantic heterogeneity. With the development of technologies, the CORBA, DCOM, and different middle-ware products provide enough technical support for resolving heterogeneous system and heterogeneous model problems [7]. The emergence of XML has better solved the above two problems. However, XML does not provide a standard description of data structure and terminology for enterprise information exchange and cannot effectively solve the semantic conflict. A higher category theory or infrastructure is needed to support deep integration in enterprises for business collaboration [8]. This infrastructure has two characteristics: the ontology features and the semantic interoperability.

The key attribute of business collaboration is the loosely coupled integration of data and application, that is, a unified data model without relying on the specific data source. Its key component is the meta-model, which is based on the ontology, and plays a role of interconnecting many kinds of scatter systems [9].

In view of the problems of the current enterprise informatization, a large number of legacy systems (databases, programs, etc.) need to be integrated, different application systems (PDM, ERP, SCM, CRM, etc.) need interaction, and enterprise collaboration requires a comprehensive integration. The integration technology based on ontology has the features of large coverage and strong base, which are helpful for solving the problem of heterogeneous system integration fundamentally.

2 Architecture of business collaboration model

With the globalization of economy and manufacturing, business collaboration between enterprises is becoming increasingly widespread, which requires lots of information systems to support and work together. Thus, architecture of business collaboration model is established and shown in Fig. 2.

From Fig. 2, the structure model can be divided into five levels.

(1) Technology layer: in this layer, information technologies are used for heterogeneous system integration when business collaborated, such as CORBA, XML and agent technology, Secure Electronic Transaction (SET) technology, and Standard for the Exchange of Product Model Data (STEP) technology;
(2) Ontology model layer: defines the standard language and standards process specification for business collaboration among enterprises. Its' technical implementation is an information portal, also called e-HUB or registration database. According to different systems and different business cooperation unit, the ontology model is divided into three levels: product ontology model, software component ontology model, and business process ontology model;
(3) Semantic mapping/inference layer: provides some information and function of standard knowledge items, in order to realizing information sharing and integration in the semantic level in all kinds of heterogeneous systems within and among enterprises, finally reach the interoperability between business operations;
(4) Internet layer: standard channels for communication between business operations;
(5) Application layer: faces heterogeneous systems in business collaboration, such as CRM, SCM, and PDM. In general, they are independent developed by enterprises or independent application software by outsourcing.

3 Multi-level ontology model for business collaboration

The heterogeneous in business collaboration is mainly embodies in three aspects: product knowledge heterogeneous,

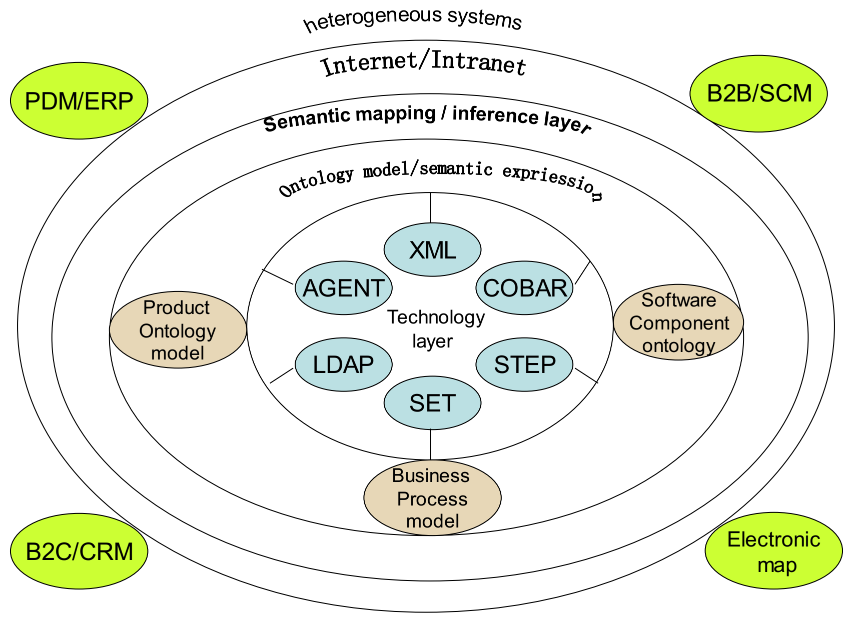


Fig. 2 Architecture of business collaboration model

software components heterogeneous, and business processes heterogeneous [10, 11]. The domestic and foreign scholars already have different degrees of research on the three aspects of ontology modeling and the ontology model. But these studies were carried out from description consistency and reuse aspect of product knowledge, software components, and processes. And particularly the research results of product knowledge are the most abundant. The differences of ontology-based heterogeneous system integration and previous ontology research are in follow three points:(1) A totally business-oriented integrated system needs to be integrated in all above three aspects, none is dispensable. (2) The three levels are interrelated and coordinated and need to study the coordination mechanism. (3) The integration method of heterogeneous systems based on ontology needs to cover the existing technologies and methods.

3.1 Product ontology model

Product ontology is used to describe a collection of product data terms and their definitions in the entire product life cycle. It is the basis for the product-related systems modeling (such as CAX, KBS, MRPII/ERP, PDM, etc.), information integration and interoperability between them, product knowledge modeling and reuse, and design knowledge acquisition.

Product ontology provides an integrated view for the product data scattered in different application systems. Through ontology instantiated, the integration of decentralized and heterogeneous product knowledge can be realized. Based on the ontology logic and the reasoning, it can use the first-order logic specification to express the requirement of product knowledge and capture the product knowledge. When knowledge acquisition across the traditional boundary of the enterprise, knowledge demand and knowledge expression may use different ontologies. Ontology reasoning is used to establish the semantic mapping between the concepts of ontologies in order to achieve the conversion between different ontologies. Figure 3 shows the instance of conceptual model of the product ontology.

3.2 Software component ontology model

The ontology model of the software component is used to describe the terms and definitions of the components which could be reused and shared or to be the integrated in the entire system software, and also include the ontology description of the protocols. For example, the same functional components use different terms or different protocols are represented by ontology and mappings. From the existing research results, the ontology research method of the software components is consistent with the product knowledge in methodology view. However, software components, product knowledge, and business processes are different in their characteristics. For instance, the software components have features of communication and behavior, product knowledge has the feature of concept and data structure [12].

The software components include new Web-based services components, besides reuse and integrate a large number of software components of legacy systems become critical. A preliminary definition of the range of the software component is shown in Table 1.

The construction of software component ontology for heterogeneous systems is divided into two steps:

The first is the research on the common attribute of software component ontology, which requires to establish at least the following concepts: basic properties of the components

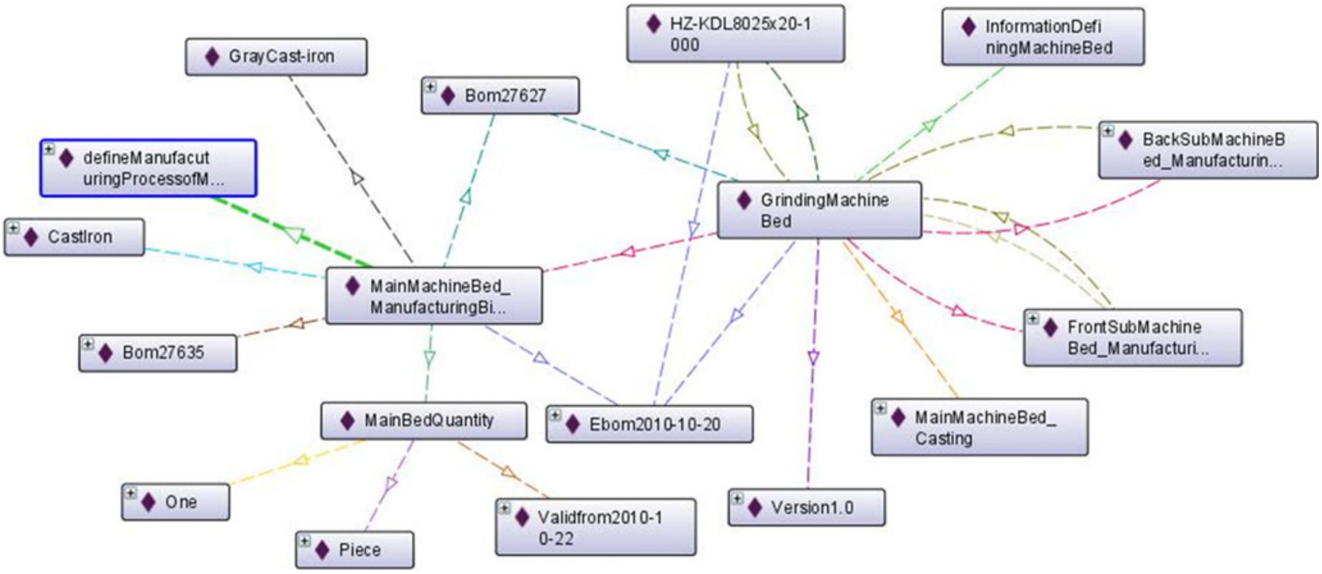


Fig. 3 The instance of conceptual model of product ontology

(including type and version), object representation, relationships with other components (such as the combination and decomposition of components), constraints (including access authority and performance requirements), behavior (including communication mode, protocols, input parameters, parameter objects, parameter attributes, parameter format, and return values), and so on. Figure 4 is an example of the concepts of software component ontology. Table 2 shows parts of the basic properties of software component ontology.

Secondly, manufacturing software component (MSC) core ontology is built, which is based on the research of the common software component ontology. It uses W3C standards such as RDF, OWL, and SWRL as an expression language; and bases on ISO 16100 (Industrial automation systems and integration-Manufacturing software capability profiling for interoperability), as well as the relevant national and international standards. This software component ontology can meet the requirements of integration of heterogeneous systems in the manufacturing system and has clear and practical features. At the same time, the unified representation of the manufacturing software components in the concept level is achieved, and the semantic consistency of the manufacturing software component ontology is realized. According to ISO 16100, a number of manufacturing software components constitute a manufacturing software unit. The manufacturing software unit is essentially a software component, but it also exhibits different functional features, so it needs to consider specific manufacturing activities in the integration of software components and systems.

3.3 Business process ontology model

The traditional ontology is based on static entities and is not suitable for dealing with the dynamic activity. So process ontology is needed at this time. The essential entities (concepts) in the process ontology are the concepts of abstract or specific process, activity, event and related participants, conditions, etc.; they have different types of relationship, such as relationship between part and whole, inheritance relationship, instance relationship, attribute relationship, etc. [13].

The role of the process ontology for business is illustrated with an example of supply and delivery. Figure 5 shows receive payment and good available are the trigger conditions of delivery request of company B; delivery request has several outputs; action of deliver goods is composed of a number of sub process (Subclass), has

Table 1 Range of software component ontology

Component type	Protocol type	Interface wrapper type	Web type	Profession type
Example	DCOM component	Adapter	Web service component	System research component
	CORBA component	Connector	CORBA component	Reports component
	Java/Bean component	interface wrapper OLE	RPC based component	Access control component
	ODBC/JDBC component	Web service component		NC code generating component
	ActiveX component			Manufacturing software component

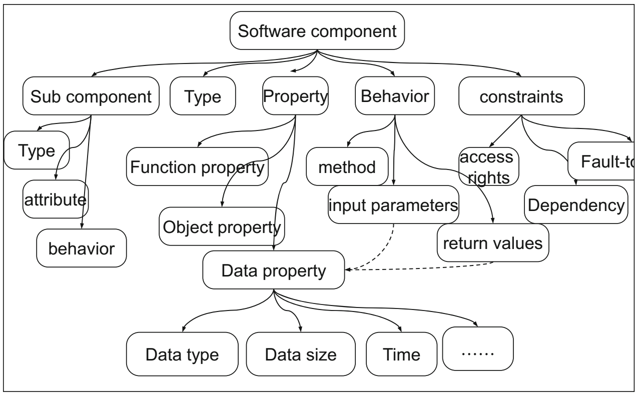


Fig. 4 Sample of software component ontology concept model

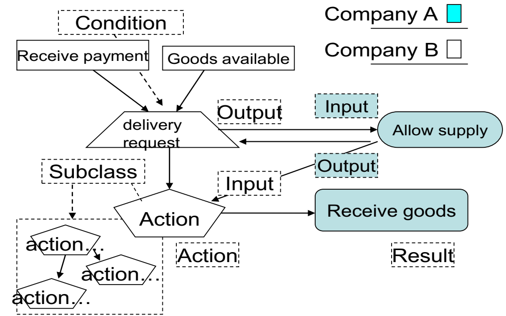


Fig. 5 Part of the process ontology for the process of delivery/receiving

some actions (Action), and will produce results (Result). The company A also has a series of similar processes. If the enterprise uses the process ontology, the semantic mappings among processes can be reached.

4 Ontology mapping and semantic interoperability

In the process of ontology-based integration of heterogeneous systems for business collaboration, there are multiple ontology mapping procedures including data to ontology, local ontology to domain ontology, and domain ontology to domain ontology. The core technology of ontology mapping is semantic similarity computation or namely semantic similarity algorithm.

The concept similarity algorithm is figure out to determine the mapping between ontologies after studying the existing semantic similarity measurement method for ontology concept. It considered the ontology concepts, properties, relations and instances, and integrated schema level, instance level, and structure level method. First, it sets w_1 is the weight of concept similarity, w_2 is the weight of property similarity, w_3 is the weight of structural similarity, and w_4 is the weight of instance similarity. Thus, in the premise of the concept similarity $SC(C_1, C_2)$, property similarity $SP(C_1, C_2)$, structural similarity $SS(C_1, C_2)$, and instance similarity $SI(C_1, C_2)$, the comprehensive similarity of two concepts is then obtained as follows

$$Sim(C_1, C_2) = \frac{w_1*SC(C_1, C_2) + w_2*SP(C_1, C_2) + w_3*SS(C_1, C_2) + w_4*SI(C_1, C_2)}{w_1 + w_2 + w_3 + w_4}$$

w_1,…,w_4 should be determined according to experience. In practical, they can be specified before started. So in practical, each component of similarity is calculated through a set of training samples. And then the comprehensive similarity is integrated after adjusting the w_1, w_2, w_3, and w_4. The rationality of the results is analyzed by the experts.

Table 2 Parts of basic properties of software component ontology

ID;	componentQuality;
Date;	serviceCategory;
Address;	Component Type;
Language;	Reuse Concept;
Platform;	AlgorithmExplain;
Version;	componenlHistory;
User;	Memo;

The mapping transformation between different ontologies uses general ontology as an intermediate transformation format. Integration of the heterogeneous systems is based on ontology mapping, to realize knowledge sharing and integration. The structure of the mapping transformation is shown in Fig. 6.

The ontology mapping is a directed mapping relationship. For the mapping from O1 to O2, the ontology O1 is the source ontology and O2 is the target ontology. The ontology mapping transformation is transforming variables such as concept, property, relationship, axiom, instance, and so on, from source ontology to target ontology aligned in semantic and structure according to mapping rules. The mapping rule is the key to realize the mapping between heterogeneous ontologies, and the mapping rules are based on the mapping relationship. As shown in Fig. 6, the mapping rule base is set up according to the mapping relationship between the

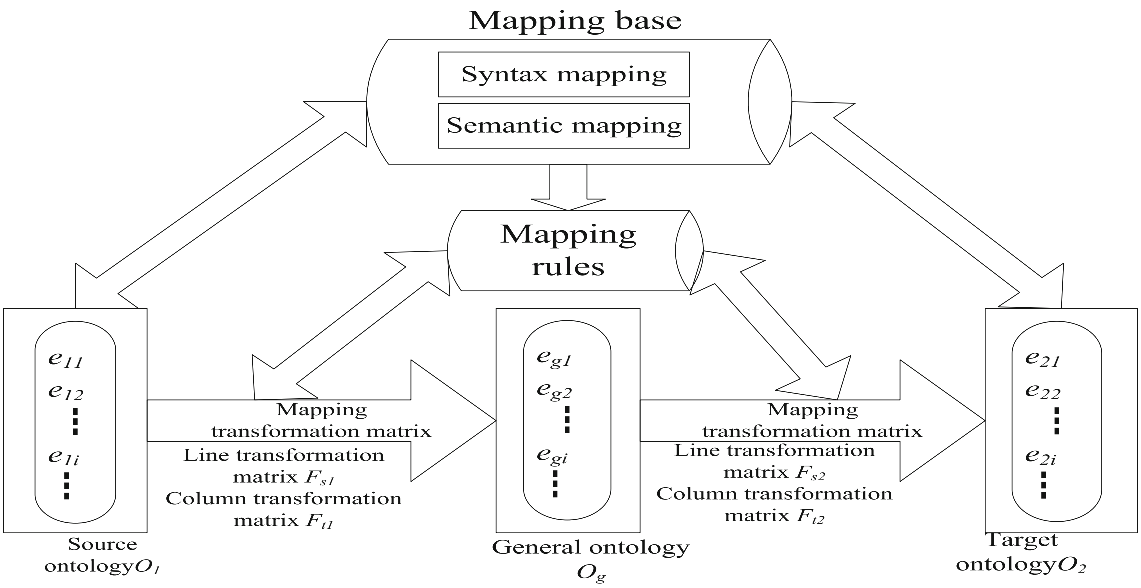


Fig. 6 Structure of ontology mapping transformation

ontologies. In transformation process, the mapping transformation matrix is made up of mapping rules selected from mapping rule base according to the mapping relationship.

Based on the multi-level ontology semantic mapping mechanism and the implementation method, the mapping between local ontology and domain ontology and the mapping between local ontologies are both solved.

5 Development of heterogeneous system integration platform

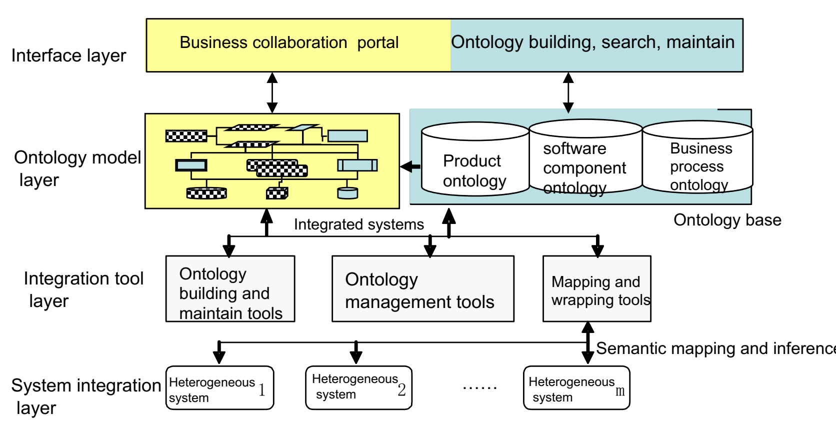
Enterprise heterogeneous systems integration platform implements the interoperability mechanism. Different ontology models are registered in the registration center, top-level ontology coordinates mutual understanding between the enterprise ontology. The enterprise ontology communicates with the top-level ontology through semantic mappings. And the top-level ontology also works as a maintainer and translator for different ontology, to realize the communication between ontologies. The method is based on the establishment of the top-level ontology and the unified semantic representation and realizes the semantic integration of the loosely coupled heterogeneous systems through semantic mapping and reasoning.

Heterogeneous system integration platform works, on the one hand, to constantly improve the top-level ontology library and to establish domain standards; on the other hand, it acts as a business collaboration portal to achieve integration of heterogeneous system for business collaboration. The platform is composed of three levels, as shown in Fig. 7

Ontology model layer: For areas involved in business collaboration, a multi-level ontology model is established, consisting of product ontology, software component ontology, and business process ontology. This layer is the core of the integrated platform.

Integration tool layer: The layer is as the bridge between the worlds of business and software in the

Fig. 7 Prototype framework of the heterogeneous system integration platform



platform, containing a large number of software tools, the mappings between the same domain and different domain ontology, business process coordination, etc. The multi-layer ontology building and maintain tools and ontology management tools are used to construct multi-layer ontology model.

System integration layer: The layer is the ultimate implementation of heterogeneous systems integration for business collaboration.

The prototype system is implemented by Java development tools, based on the B/S three level architecture in order to achieve the requirements of distributed collaboration. It also can realize the rapid deployment, convenient use, remote support, and cross platform facility. The distributed component technology is used to construct the system, which can not only expand, restructure, and improve the re-usability of software modules, but also reduce the deployment complexity of large-scale system, reduce the system maintenance and upgrade costs.

The ontology-based heterogeneous system integration platform acts as a service for heterogeneous systems integration. At the same time, the prototype platform includes the above tools, such as ontology mapping. It also contains some interfaces, including the tracking of the integrated process, human-computer interaction interface, data interface, etc.

The system integration platform is running in the way of Socket service, which can provide the instance publication, query, conversion, and the update of the similarity of ontology mapping.

6 Conclusion

The integration of heterogeneous systems for business collaboration is integrating complex systems. In this paper, the implementation of integration is abstracted to three levels that have both clear boundaries and interrelated relationships. It provides a practical way to study the integration of heterogeneous systems in different levels. In ontology research on product knowledge and business process, the research team has had a good accumulated work. Construct and use of software module in heterogeneous system integration is a challenging study and are the key job in heterogeneous system integration. In the preparatory work of component-based open technology and component reuse technology, the construction of software ontology is focused, in order to resolve the consistency problem of software component communication in the integration of heterogeneous systems.

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