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Real-time collaborative design based on operation semantics in distributed CAD environment

Chen Chun Zhang Shensheng Li Lei Zhang Jingyi

(Department of Computer Science and Engineering, Shanghai Jiaotong University, Shanghai 200030, China)

Abstract: This paper proposes a collaborative design model based on operation semantics in a distributed computer-aided design (CAD) environment. The goal is to reduce time consumption in data format conversion and the requirement of network bandwidth so as to improve the cooperative ability and the synchronization efficiency. Firstly, real-time collaborative design is reviewed and three kinds of real-time collaborative design models are discussed. Secondly, the concept of operation semantics is defined and the framework of an operation semantics model is presented. The operation semantics carries the original design data and actual operation process to express design intent and operation activity in conventional CAD systems. Finally, according to the operation semantics model, a CAD operation primitive is defined which can be retrieved from and mapped to the local CAD system operation commands; a distributed CAD collaborative architecture based on the model is presented, and an example is given to verify the model.

Key words: operation semantics; primitives; collaborative design; computer-supported collaborative work

Product design and development is a complex and iterative process. Nowadays a design task can be hardly accomplished by one or two people, it needs multidisciplinary experts consisting of a workgroup to participate in the task. Real-time collaborative design is the emerging technology to assist workgroups to complete a design task in a geographically distributed computer-aided design (CAD) environment. In the present, the collaborative mode in distributed CAD environment is basically based on sharing product data. However, each CAD system defines its own data format which can hardly be interpreted in other CAD systems. So the shared data must be firstly transformed into a standard common data format such as STEP or IGES, then they can be interpreted and processed. This may consume too much time in data format transformation and model data transfer on the network, which is not very suitable for real-time and synchronous collaboration in a distributed environment.

In order to describe the design with dynamic data, the operation behavior of design is studied in this paper, and a real-time collaborative design model based on operation semantics is proposed. The model provides an understandable common data exchange protocol and defines a set of operation primitives for CAD systems interoperation. In the model, operation semantics can be retrieved from a designer's CAD operations and mapped to one or more pieces of operation primitives according to the given CAD system. The operation primitives can be interpreted to local CAD operation commands and implemented correctly. An experimental system illustrates the implementation of this model and conclusions are shown in the end.

1 Real-Time Collaborative Design

1.1 Reviews and issues

Many studies[1-3] have investigated the feasibility of real-time collaborative technology for the sharing and communicating of information across computer networks. Nam[1] presents a real-time collaborative 3D CAD system which allows distributed designers in a small team to work together to build and edit virtual 3D models. A shared 3D workspace is incorporated in a conventional CAD interface and provides a number of real-time collaborative features in two main interface elements. Tay[2] develops a real-time collaborative design system named CyberCAD to dynamically support large volumes of 3D-CAD data transmission. CyberCAD is built focusing on the features of platform independence and uniform user interface. There appear to be some commercial CAD systems supporting real-time collaborative design such as Alibre design in Alibre corporation and OneSpace in CoCreate corporation. The systems not only provide conventional function modules of a CAD system, but

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Biographies: Chen Chun (1975—), male, graduate; Zhang Shensheng (corresponding author), male, professor, sszhang@ sjtu.edu.cn.

also support several designers discussing and modeling on line. Theoretically the number of participants in such systems is not limited, but the real-time collaborative performance will degrade due to the insufficiency of network bandwidth, as product data exchange consumes lots of bandwidth. In addition, they provide designers with the self-designed product modeling tools that are fresh and unfamiliar to most designers who work on conventional CAD systems such as AutoCAD, CATIA, or Pro/Engineer.

According to the above analysis, the key issues involved in real-time collaborative design in distributed CAD environment are shown as follows[4-7]:

- Provide real-time and online collaboration tools during product design in a distributed environment;
- Reduce the requirement of network bandwidth for communication and data exchange;
- Decrease the time consumption of product data conversion in heterogeneous CAD systems;
- Integrate conventional CAD systems to provide individual and familiar operation interfaces.

The research attempts to address some of the problems mentioned above by discussing real-time collaborative design based on operation semantics in a distributed CAD environment. The focus is on exploring a suitable model of real-time and synchronous collaborative design to support a distributed CAD environment.

1.2 Typical models

There are three kinds of real-time collaborative design models: the sharing views model, the sharing product data model and the sharing operation model.

1) The sharing views model

In some cases design collaboration proceeds just for the sake of discussion, without any data exchange. The product data are stored in a host computer, which is in charge of data processing and computing. The collaborators receive the displayed data from processor and output to the screens for discussion. No product data are exchanged during communication in the model (see Fig.1). Therefore, this model only maintains view synchronization. Based on the model,

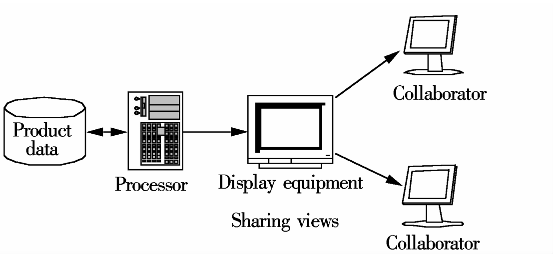

Fig.1 Sharing views model

high speed and wide-bandwidth network is required to support continuous image data transfer. The typical application system is Microsoft NetMeeting, which is just applied in local area network and small collaborative workgroup.

2) The sharing product data model

Different from the sharing views model, the sharing product data model has realized data synchronization. It maintains product data consistency among collaborators (see Fig.2). Any changes of product data will be synchronously reflected in other collaborators' computers. So if one collaborator wants to modify product data, he must firstly get control of the data section. The changed product data are transferred to other collaborators simultaneously when the data are modified. In this model, the collaborators can only see the results of the modified model but not the operation process of modifying. CAD systems with network-oriented database are based on the model of sharing product data.

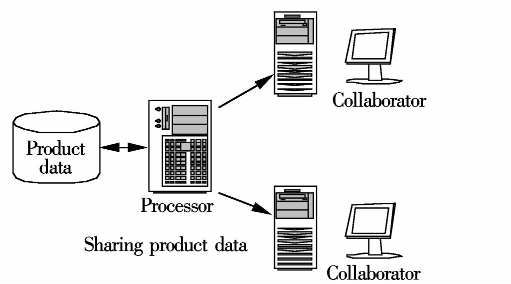

Fig.2 Sharing product data model

3) The sharing operation model

The sharing product data model is a way of sharing modeling results in a collaborative design. It is hard to guarantee view synchronization. The sharing operation model is the way to achieve both data and view synchronizations (see Fig.3). In this model, the dynamic behavior is embodied in the operation semantics' specifications. Details of operation behavior are specified in a textual format attached to the operation such as XML documents. As the operation behaviors are formatted and shared in the model, all the collaborators know what has been done and the same operation sets are executed locally to produce the corresponding data.

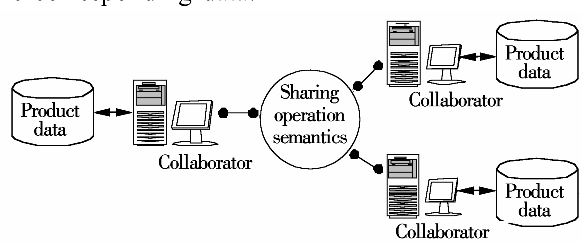

Fig.3 Sharing operation model

2 Operation Semantics Model

2.1 Operation semantics

In product design, design intent and behavior are the abstract concepts that belong to the field of natural knowledge. Clayton[8] presents artificial intelligence (AI) symbolic models to address those concepts. AI symbolic models used in his paper include geometric forms, intended functions and computed and assigned behaviors of design. AI symbolic reasoning methods are also used to analyze design behavior and compare predicted behavior with intended function. However, AI symbolic models require manual activities to interpret some of the symbolic and graphic representations, which will potentially become a bottleneck during the design process. In this paper operation semantics is introduced to describe and denote those concepts. Here we give some discussions on design intent, modeling process and operation behavior:

- Design intent

Many design tools create approximate models without explicitly containing information about their design intent. Actually, by detecting design intent, designers can handle the models on a higher level of abstraction for modification and analysis.

- Modeling process

The modeling process is described as a set of operations in the design. A product design task can be divided into several parts of the modeling process. Each part associated with a specific aim has the characteristics of independence, integrality, significance and understandability.

- Operation behavior

Operation behavior means the action of the designers' operation upon the product design. It is the embodiment of design intention during designing.

In order to represent those concepts accurately and automatically, their semantic information should first be retrieved. This can be done by analyzing the designer's operations. Generally, operation semantics is a semantic description of the designer's operations. When formalized to some primitives, operation semantics can be shared and interpreted by computers. Operation semantics has three characteristics:

1) Possessing a pre-defined format: Operation semantics may be translated into one or more primitives of the understandable format. These primitives can easily be shared and interpreted by the computer.

2) Representing at least one operation: Operation semantics should be mapped in some well-defined way to the designer's operations.

3) Being interpreted and implemented by the computer: Operation semantics should correspond to the instructions of computer to achieve the same operations.

According to the above analysis, operation semantics can be formalized as follows:

$$\text{DesignSem} := \langle C, O, A \rangle$$

where C represents basic semantic concepts and action of operation semantics, O represents the object associated with the operations, and A represents additional information including necessary parameters of value and result.

In order to effectively describe operation semantics and enhance the semantic interoperability, the domain ontology should be introduced in the collaborative design model. It provides a common understanding of the operation semantics and its relationships to be shared in distributed CAD systems communication.

2.2 Operation semantics model in real-time collaborative design

In real-time collaborative design, not only should the magnitude of exchanged information be small enough to meet the capacity of network bandwidth, especially in a narrow bandwidth environment, but also the collaboration granularity should be reduced to a moderate level to assure both the data and view synchronizations. The operation semantics model is presented to address this issue. In the design process, designer's operation is a dynamic behavior, and can be captured and converted into the pre-defined format data. Therefore it is suitable for automatically processing and sharing. Fig.4 depicts the framework of the model.

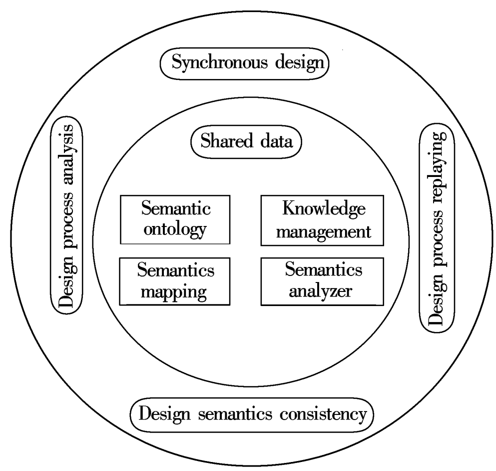

Fig.4 Framework of operation semantics model

The components in the center circle form the core part of the model: shared data, semantic ontology, knowledge management, semantics mapping and semantics analyzer.

- Shared data The shared data component stores the operation event information that is produced during the design. These data will be transformed into operation primitives defined in semantics ontology.
- Semantics ontology Ontology is used to specify the concepts of domain knowledge, their relationships and terminologies[9]. In the semantics ontology component, the semantics description rules and algorithms are defined and stored including semantics mapping tables.
- Knowledge management Knowledge management provides some technologies to improve shared data access ability, such as role-based data access[10]. This component is used to improve the performance of shared data storing and retrieval.
- Semantics mapping For the different CAD systems, operation semantics corresponds to a different set of operation instructions. The semantics mapping component provides a matching mechanism to convert it into the instruction sets of the specified CAD system.
- Semantics analyzer This component first pre-handles the operation information by discarding useless information or error data. Then it produces operation semantics with the rules specified by the semantics ontology.

Around the central core is the application part of the model, which includes five components: synchronous design, design process analysis, design process replaying and design semantics consistency.

- Synchronous design This component provides strategy to assure operation synchronization so as to maintain both the data and view synchronizations.
- Design process analysis During the design, operation events will be captured by the system for processing. Some of them are useless, which are discarded according to the pre-defined rules. However, the component does not analyze the semantic information, so the further processing should be done in the core part.
- Design process replaying This is an assistant tool to replay the modeling process by executing orderly operation semantics. The function provided by this component is necessary for operation synchronization or further discussion in real-time collaborative design system.
- Design semantics consistency Data inconsistency is always an issue to be tackled in a distributed environment. This component provides some methods to detect the inconsistency and corresponding solutions.

3 Experiment

In order to verify the feasibility of the operation semantics model, a prototype system in multi-version AutoCAD system environments has been represented, which demonstrates the method of collaborative design in distributed CAD environment.

3.1 Operation primitives

In order to be recognized and interpreted by computers, operation semantics is mapped to one or more sections of the operation primitive. An operation primitive is described as follows:

[OperationType][ObjectType, ParamSet][UserInf, ObjectHandle][AdditionalParamSet]

There are four sections in an operation primitive. In the first section, OperationType represents the type of operation, for example add, modify or delete. In the second section, ObjectType represents the type of operation object such as line, arc or circle; ParamSet represents the parameters associated with OperationType. In the third section, UserInf stores the information of the designer who produces the operation semantics; ObjectHandle specifies the object information, which is used for matching the operation object. In the last section, additional parameters are given associated with the operation primitive. The following example demonstrates the operation of modifying an arc:

[Modify][Arc, CenterPoint, Radius, StartAngle, EndAngle][UserInf, ObjectID][Color, Layer]

During the design process, as soon as the operation primitive is produced, it will be sent to the distributed sites at once. Then each site will map it into local instructions to execute.

3.2 System architecture

The system architecture based on an operation semantics model is shown in Fig.5. It consists of four

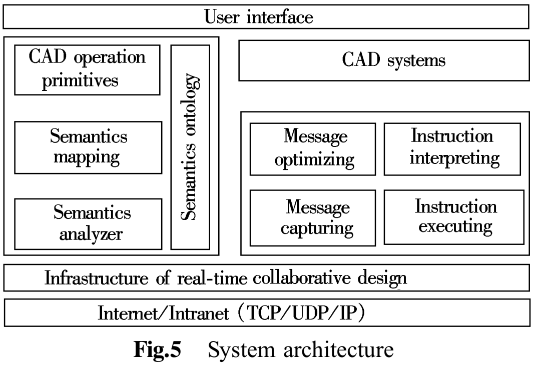

Fig.5 System architecture

components: user input interface, middle module, infrastructure of real-time collaborative design, Internet/Intranet. These components are as follows:

- User interface This component includes two interfaces: product design interface and collaborative tool interface. The product design interface integrates the conventional CAD system to provide the designer a familiar interface, and the collaborative tool interface provides some essential functions of inter-operation.
- Middle module This component consists of three parts. The first part integrates conventional CAD systems. The second part is used for message processing, including message capturing, message optimizing, instruction interpreting and instruction executing. All the CAD operation events will be captured and pre-processed, and all the operation primitives will be interpreted into local CAD instructions to execute. The third part provides operation semantics processing functions, such as semantics ontology, CAD operation primitives, semantics mapping and a semantics analyzer.
- Infrastructure of real-time collaborative design. This component provides the fundamental functions, such as synchronization detecting, data management, and collaborative roles and strategies.
- Internet and Intranet In this component some communicating protocols are provided for information exchange.

3.3 A prototype system

A prototype system based on the above architecture with two versions of AutoCAD system is proposed. The system is built with client/server structure. The server is to manage the data of operation semantics and provide controlling and coordinating functions. As shown in Fig.6, there are two designers at different locations undertaking the collaborative design for an axis. Before beginning the design, one of them must first apply for the control of the operation. During the design, the operation events are captured by the client program, and the semantic information of operations is retrieved and sent to the server. Fig. 6 shows some pieces of operation information in the server. As the operation is performed step by step, the operation semantics are handled one by one, which results in preferable synchronization between the two sites.

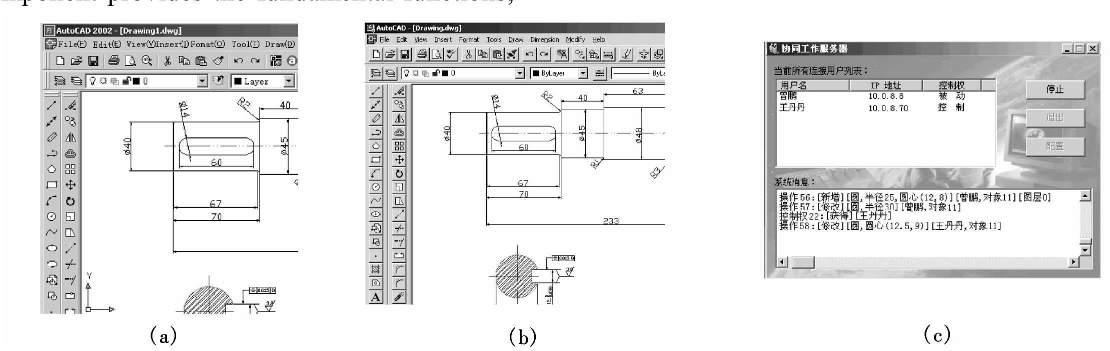

Fig.6 Prototype system. (a) Designer A; (b) Designer B; (c) Server

4 Conclusion

In this paper a real-time collaborative design model based on operation semantics is proposed to enable the designers in different geographical locations to work simultaneously and collaboratively. In order to avoid data format conversion and reduce a large number of product data transfer, a sharing operation semantics model is presented and the framework is discussed. In the experiment evaluation, the operation primitive is well defined in detail, and a prototype system is developed. The example shows that the real-time collaborative design based on operation semantics can achieve both data and view synchronization. Further research is needed on CAD object nominating roles, semantic collision and recovery, and new operation primitives definition.

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分布式 CAD 环境中基于操作语义的实时协同设计

陈 纯 张申生 李 磊 张敬谊

(上海交通大学计算机科学与工程系, 上海 200030)

摘要: 提出了一种应用于分布式 CAD 环境中的基于操作语义的协同设计模型. 主要目的是为了减少数据转换的耗时量以及降低对网络带宽的需求, 从而改善协作能力, 提高实时同步的效果. 首先回顾了实时协同设计的发展现状, 讨论了 3 种实时协同设计模型. 其次, 给出了操作语义的定义, 并提出了一个操作语义模型框架. 操作语义包含原始设计数据和实际操作过程, 表达 CAD 系统中的设计者意图和操作活动. 最后, 根据操作语义模型, 定义了 CAD 操作原语, 该原语可以从 CAD 操作中提取也可以映射成 CAD 操作命令; 给出了一种基于该模型的分布 CAD 协同体系结构, 并通过一个实例加以验证.

关键词: 操作语义; 原语; 协同设计; 计算机支持协同工作

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