# A preliminary study on synchronized collaborative design based on heterogeneous CAD systems

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#### Abstract

This paper introduces a preliminary research work of collaborative design synchronized based on heterogeneous CAD systems. By analyzing several typical CAD systems, we set up a number of neutral commands corresponding to the basic modeling operations of CAD systems. Based on the neutral commands, communication between heterogeneous CAD systems is achieved. Furthermore, synchronized collaborative design is realized by real-time capturing and transferring of modeling operations between distributed heterogeneous CAD systems. A prototype of synchronized collaborative design is developed based on two common CAD systems *MDT and SOLIDWORKS with their APIs and VC++. The* preliminary test results show the proposed approach promising.

#### **1. Introduction**

Product development paradigm is changing. More and more products need to be developed by different groups in different sites collaboratively. However, most of current CAD systems, which well support traditional design process, cannot effectively support collaborative design.

In recent years, collaborative design becomes a hot research area of CAD/CAM. The research work in this area can be divided into two kinds, one is about synchronous collaborative design and another is about asynchronous design. And it is recognized that synchronous collaborative design is more difficult to achieve. The current methods usually realize synchronous collaborative design based on homogenous CAD systems because homogenous CAD systems have the same data structures and operation commands and can communicate with each other easily. However, comparing with homogeneous systems, collaborative design based on heterogeneous CAD systems is much more welcome to most users. This is because different designers in different companies or departments are often accustomed to distinct CAD systems, and they prefer to work on their

familiar systems. The challenging problem with synchronous collaborative design based on heterogeneous CAD systems is how to effectively exchange CAD models or modeling operations between CAD systems in real-time regardless of the great differences between the data structures and operation commands of different CAD systems.

There are two kinds of methods for exchanging data between heterogeneous CAD systems. One is to exchange complete solid models among collaborative design systems, which will spend long time to transmit complex models. Especially, different data structures of solid models should be transformed to the same format to enable solid model exchanging between the heterogeneous systems. Another is to directly transmit operation commands to reduce the transmitting time and transferred data. However, different CAD systems have different operation commands, which make it very impossible to exchange operation commands between heterogeneous CAD systems directly.

This paper introduces a preliminary research work about synchronized collaborative design based on heterogeneous CAD systems. By analyzing several typical CAD systems, we set up a number of neutral commands corresponding to the basic modeling operations of CAD systems. Based on the neutral commands, communication between heterogeneous CAD systems is achieved. Furthermore, synchronized collaborative design is realized by real-time capturing and transferring of modeling operations between distributed heterogeneous CAD systems.

## 2. Related Work

Since the mid of 1990's, research on synchronized collaborative design has been paid more and more attentions. Quite a few works have been conducted in this area and several prototyping systems have been developed. According to the architecture, current synchronized collaborative design systems can be divided into two types: central and replicated. A central system includes a single or multi-server, and multi-site. The server is responsible for storing the kernel model and

managing sessions. Each site only communicates with the server. The advantage of the central system is that the system is easy to achieve data consistency and perform concurrency control. The problem of the central system is that the performance of the system will descend when data interchange between site and server is frequent and the interchanged model is complex. The representative central systems include NetDraw [1], NetFeature [2], WebSPIFF [3], and so on.

For the replicated synchronized collaborative design system, there is no server. All sites are in charge of modeling and communication of themselves. Comparing with the central system, the replicated system has much more powerful modeling functions and quicker responsiveness. However, it is difficult for a replicated system to effectively maintain data consistency and perform concurrency control. The representative replicated systems include CoIIIDE[4], Syco3D[5, 6], TOBACO [7], etc.

Yang-Heon et al. developed a collaborative COCADCAM system that enables two geographically dispersed CAD/CAM users to co-edit CAD geometry dynamically [8]. The contribution of the work lies in successfully proposing and implementing the networking strategies and exploring a new data interchange format to extend a traditional single-location CAD/CAM application to a multi-location application. This work is based on homogeneous CAD systems.

Guk-Heon Choi et al. proposed a macro-parametric approach to exchanging CAD model between different CAD systems [9]. By analyzing the general commands of several CAD systems, they set up a series of neutral commands. Instead of directly exchanging CAD models, their 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. Moreover, in order to exchange complex CAD models, their method needs to use ACIS geometric modeling kernel to generate an internal solid model.

Collaboration Gateway is a product of Proficiency Company[10], which can be used to exchange parametric feature models between Pro/E2000i, CATIA V4, UG V16 and I-DEAS V8. The core of the Collaboration Gateway is the Universal Product Representation (UPR) that enables an unprecedented level of CAD interoperability through sharing of design intelligence including features, dimensions, history, assemblies, meta data, and other information. However, the specific UPR is not published yet. And Collaboration Gateway does not support the online exchanging of modeling operations between CAD systems either.

#### 3. Overview of Approach

order to effectively realize synchronized In collaborative design with heterogeneous CAD systems, we propose a neutral command based approach. The key idea of the approach is to achieve the real-time exchanging of modeling operations between different CAD systems through neutral commands. Figure 1 shows the system structure adopted by the approach. The system is a replicated one with each site having a distinct CAD system by which the user performs synchronized collaborative design with users in other sites. In each site, besides a distinct CAD system, there are two translators. One is responsible for translating a specific modeling operation (SMO) just carried out locally into one or more neutral commands (NC) that will be sent to other sites immediately, called SMO-NC translator. Another translator called NC-SMO translator, is in charge of translating a neutral command received from other site into one or more corresponding modeling operation command (i.e. API function) of the local CAD system, which will be carried out in the local site at once so as to achieve the effect of synchronized collaborative design.



Figure 1: System Structure

The feasibility of the approach is based on the observation that the essential modeling operations provided by all commercial CAD systems are similar though their interface and maneuverability may be different.

#### 4. Construction of Neutral Command

This research is based on three popular CAD systems, MDT (Mechanical Desktop 6), SolidWorks (SolidWorks 2001Plus) and UG (Unigraphics V18.0). Solidworks and UG use Parasolid as their geometrical modeling kernel, and MDT uses ACIS. By analyzing the modeling commands of these three CAD systems, we construct a number of neutral commands corresponding to the basic modeling operations provided by commercial CAD systems.

#### 4.1. Primary Neutral Commands

A neutral command consists of two parts, one is operation name, and the other is parameters of the operation. The neutral commands that we have constructed are listed below.

# 4.1.1. Creation of Sketch and Sketch Entities.

(Parameter rotation) if refers to the rotation direction of the created arc, -1 for CCW, 1 for CW)

#### 4.1.2. Creation of Constraints.

```
createDimension (
Point3D displayLocation,
double dimValue,
Entity attachedEntity1,
Entity attachedEntity2)
```

(Parameter displayLocation is the location of dimension on the screen, not all systems need it. The type of Entity may be Vertex or Edge.)

#### 4.1.3. Creation of Features.

```
createFeatureExtrusion (
int combineType,
Sketch activeSketch,
int direction,
double draftAngle,
double startLength,
double endLength)
```

(Parameter combineType is the type of extrusion, for example, 1 for Base, 2 for Cut and 3 for Boss. Parameter direction is used to indicates whether the direction of extrusion is consistent with the normal of sketch or not, 1 for the same, -1 for opposite.)

(The edgeList is a collection of edges that will be filleted; the method of expressing an edge in the neutral command will be discussed later.)

#### 4.2. Expression of Topological Entity

For certain neutral commands, their parameters include topological entities. For example, createFeatureFillet has one or more edges as its parameters. In homogeneous systems, transferred entities can be identified by their IDs since the same entity has the same ID. But it won't work for the heterogeneous systems because the IDs of the same topological entity in different CAD systems are usually different. To solve this problem, we directly use entity's type and its geometric information in the World Coordinates System (WCS) to express the topological entity in neutral commands. For instance, a linear edge is expressed by its type and midpoint, and a planar face is expressed by its type, its normal and a point inside it.

The feasibility of this method depends on whether the geometric information of the same topological entity in different CAD systems is equal or not. Fortunately, it is observed that the three CAD systems' WCSs are all Cartesian coordinate systems with right hand rule, and never be changed in design process. Moreover, User Coordinate System (UCS) can be freely transformed to WCS and vice versa. In one word, no matter what UCS used, the geometric information of the same topological entity in WCSs of different CAD systems is always the same.

# 5. Mapping between Specific Modeling Operations and Neutral Commands

As mentioned in Section 3, in this work, two translators, i.e. SMO-NC translator and NC-SMO translator are devised and used to achieve mapping between modeling operations of a specific CAD system and neutral commands. In the following, we describe these two translators in more details.

The SMO-NC translator mainly consists of three functions. One is responsible for listening to the CAD system events, another is used to access the model of CAD system, and the third is in charge of translating specific modeling operations to neutral commands. The primary class diagram of SMO-NC translator is shown in Figure 2.



Figure 2: Primary Class Diagram of SMO-NC Translator

The NC-SMO translator mainly consists of two functions. One is responsible for capturing the incoming commands from network; the other is in charge of translating neutral commands to specific modeling operations and executing it. The primary class diagram of NC-SMO translator is shown in Figure 3.





Taking the synchronized collaborative design of the part shown in Figure 4 as an example, the results generated by SMO-NC translator in the design process are described below.



Figure 4: A Test Part



```
Figure 6: Cut Extrusion
```



Figure 5: Base Extrusion Feature



Figure 7: Two Boss Extrusions

When a user creates the base extrusion feature as shown in Figure 5, SMO-NC translator in his or her system translates the modeling operation to the following neutral command:

```
createSketch (passThru=[0,0,0], normal=<0,0,1>)
createSketchLine (
           start=[1.86533e-018,0.08,0], end=[0,0,0])
createSketchLine (start=[0,0,0], end=[0.1,0,0])
createSketchLine (start=[0.1,0,0], end=[0.1,0.025,0])
createSketchLine (
           start=[0.1,0.025,0], end=[0.02,0.025,0])
createSketchLine (
           start=[0.02,0.025,0], end=[0.02,0.08,0])
createSketchLine (
           start=[0.02,0.08,0],
           end=[1.86533e-018,0.08,0])
createDimension (
           displayLocation=[-0.0121992,0.0370248,0],
           dimValue=0.08,
           Entity1=[1.86533e-018,0.08,0],
           Entity2=[0,0,0])
createDimension (
           displayLocation=[0.0490909,-0.0118056,0],
           dimValue=0.1,
           Entity1=[0,0,0], Entity2=[0.1,0,0])
createDimension (
           displayLocation=[0.114908,0.0170317,0],
           dimValue=0.025,
           Entity1=[0.1,0,0], Entity2=[0.1,0.025,0])
createDimension (
           displayLocation=[0.00986301,0.092871,0],
           dimValue=0.02,
           Entity1=[0.02,0.08,0],
           Entity2=[1.86533e-018,0.08,0])
createFeatureExtrusion (
           combineType=1,
           activeSketch={
                         passThru=[0,0,0],
                         normal=<0,0,1>},
           direction=-1,
           draftAngle=0, startLength=0, endLength=0.1)
```

In the last neutral command, the parameter activeSketch takes the Sketch object in the first NC as default active sketch. Parameter combineType's value is 1, which means that this extrusion is a base extrusion. And the long measure in all neutral commands is the meter.

After the user adds the cut extrusion feature as shown in Figure 6, the neutral commands generated by SMO-NC translator are listed below:

```
createSketch (
    passThru=[0.0733333,0.025,-0.0666667],
    normal=<-1.30104e-016,1,0>)
createSketchArc (
    center=[0.07,0.025,-0.03], radius=0.015,
    startAngle=0, endAngle=360, rotationDir=1)
createSketchArc (
    center=[0.07,0.025,-0.07], radius=0.015,
    startAngle=0, endAngle=360, rotationDir=1)
createDimension (
    displayLocation=[0.0864732,0.025,0.0113339],
    dimValue=0.03,
    Entity1=[0.1,0.025,-0.1]->[0.1,0.025,0],
    Entity2=[0.07,0.025,-0.03])
```

```
createDimension (
        displayLocation=[0.110703,0.025,-0.0144113],
        dimValue=0.03,
        Entity1=[0.1,0.025,0]->[0.02,0.025,0],
        Entity2=[0.07,0.025,-0.03])
createDimension (
        displayLocation=[0.0439573,0.025,-0.0496907],
        dimValue=0.04,
        Entity1=[0.07,0.025,-0.07],
        Entity2=[0.07,0.025,-0.03])
createFeatureExtrusion (
        combineType=2,
        activeSketch={
               passThru=[0.0733333,0.025,-0.0666667],
               normal=<-1.30104e-016,1,0>},
        direction=-1.
        draftAngle=0, startLength=0, endLength=0.025)
```

Based on the receiving base and cut extrusions, another user starts to create two boss extrusions as depicted in Figure 7 to strengthen the part. The generated neutral commands are as follows:

```
createSketch (
        passThru=[0.0733333,0.0166667,-0.1],
        normal=<0,0,-1>)
createSketchLine (
        start=[0.02,0.025,-0.1],
        end=[0.02, 0.055, -0.1])
createSketchLine (
        start=[0.02,0.055,-0.1],
        end=[0.1, 0.055, -0.1])
createSketchLine (
        start=[0.1, 0.055, -0.1], end=[0.1, 0.025, -0.1])
createSketchLine (
        start=[0.1,0.025,-0.1],
        end=[0.02,0.025,-0.1])
createDimension (
        displayLocation=[0.0132532,0.0383635,-0.1],
        dimValue=0.03,
        Entity1=[0.02,0.025,-0.1],
        Entity2=[0.02,0.055,-0.1])
createDimension (
        displayLocation=[0.0534935,0.0139324,-0.1],
        dimValue=0.08,
        Entity1=[0.02,0.025,-0.1],
        Entity2=[0.1,0.025,-0.1])
createFeatureExtrusion (
        combineType=3,
        activeSketch={
                 passThru=[0.0733333,0.0166667,-0.1],
                 normal = <0, 0, -1>
        direction=-1.
        draftAngle=0, startLength=0, endLength=0.01)
... (Another similar boss creation codes are omitted.)
```

# 6. Implementation

We have developed a preliminary prototype system of synchronized collaborative design based on MDT6.0 and SolidWorks 2001Plus. For each of the two CAD systems, both SMO-NC and NC-SMO translators are implemented with Visual C++ 6.0 and the open programming APIs of the CAD systems. The translators are compiled into the plug-in of native CAD system, running as background process after system starts to work. The communication between different CAD systems is achieved by Transmission Control Protocol (TCP), which can provide the reliable data exchanging across WAN.

Using the developed prototype system, two geographically dispersed users, using Solidworks and MDT respectively, successfully completed the collaborative design of the test part shown in Figure 4. One user uses Solidworks and the other uses MDT. The specific process of the collaborative design is as follows.

Firstly the user using SolidWorks creates one base extrusion feature in his or her site. At this moment, the LocalCADListenerImpl object of the local SMO-NC translator is notified by the modelChanged event fired by SolidWorks application. And then it gets the new created feature using LocalCADStateDetectorImpl object and captures the geometric information of the sketch and sketch segments, the values of dimensions and the parametrical information of the extrusion feature. Finally, object LocalCADNcTranslatorImpl translates these operations to neutral commands and sends them to the other site using NcSenderImpl object.

The NetListener object of the NC-SMO translator in the other site, which keeps on detecting network, checks every package sent to the appointed port and selects the right package to deliver to the LocalCADNcParserImpl object. The LocalCADNcParserImpl object parses the package into neutral command which is further translated to a specific modeling operation by calling corresponding function of LocalCADSmoExecuterImpl object. Then the modeling operation is executed in current site.

After all the sites complete the build of base extrusion, the views of the two systems are shown as Figure 8.



a) Solidworks 2001Plus View

b) MDT 6.0 View

Figure 8: The views of the two systems after base extrusion is completed

When the user using MDT sees the base extrusion feature, he or she creates a cut extrusion feature on it. At the same time, the user using Solidworks creates one boss extrusion feature on the base solid to strengthen the part. The Figure 9 shows the views of the two systems after the two operations have been executed in all sites.



a) Solidworks 2001Plus View b) MDT 6.0 View

Figure 9: The views of the two systems after cut extrusion and one boss extrusion are created

Further, the user using Solidworks continues to create another boss extrusion feature. After that, the views of the two systems are shown in Figure 10.



a) Solidworks 2001Plus View b) MDT 6.0 View

Figure 10: The views of the two systems after another boss extrusion is created

# 7. Conclusion

Collaborative design based on heterogeneous CAD systems has been paid more and more attentions in recent years. This is because the CAD systems that different companies or different departments use are often different. On the other side, due to the fact that different CAD systems differs from each other in both data structures and modeling commands, the real-time exchanging of CAD models or modeling operations is very difficult, which makes synchronized collaborative design based on heterogeneous CAD systems a big challenging issue.

In this paper, we have introduced our preliminary research work on synchronized collaborative design based on heterogeneous CAD systems. The main results of the work include: 1). By analyzing several CAD systems, we construct a number of neutral commands corresponding to the basic modeling operations of CAD systems. 2). Mechanisms for translating a specific modeling operation to a neutral command and translating a neutral command to a specific modeling operation are put forward, which enable the real-time exchanging of modeling operations between heterogeneous CAD systems. 3). A preliminary prototype system of synchronized collaborative design based on MDT and SolidWorks is developed. For each of MDT and SolidWorks, two translators (SMO-NC and NC-SMO) are implemented. The preliminary test results show the proposed approach promising.

Future work will focus on following aspects: 1). Extend the neutral commands to cover most modeling operations of most commercial CAD systems. 2). Explore the methods for achieving one-more mapping between modeling operation and neutral command. 3). Extend the prototype system to include more CAD systems such as UG, CATIA, Pro/E, etc.

# 8. Acknowledgement

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