CSG Tree: Evaluation on Performance between Solid Modelers

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Abstract -

Solid modeling theory and technology are maturing rapidly. We have seen explosive growth in the field's scientific literature, and many solid modelers are commercially available. Commonly a part is represented in the forms of constructive solid geometry (CSG) or Boundary Representations (B-rep). Since it is hard to use the B-rep approach to represent a variable part, the CSG tree approach is widely applied in parametric modeling where features or geometric primitives are its basic building blocks. Many vendors are now offering intuitive 3D browsers that support the review and annotation of 3D models of complex assemblies of solids. These browsers support communication in product data management activities, help illustrate maintenance manuals, or provide interactive virtual-reality experiences for marketing, styling, or ergonomic analysis. In this paper, Constructive Solid Geometry (CSG) is a method used for representing solid objects in many contemporary solid modeling systems. The best CSG tree structure will be presented for representing the performance of the solid model. The complexity of the solid model will be presented by using solid modeler; AutoCAD 2004 and SolidWorks 2001 plus.

***Keywords**: Constructive Solid Geometry (CSG); Binary tree; Solid modeling; Solid modeler.*

1 Introduction

The field of solid modeling deals with design and representation of physical objects. The two major representation schemata used in solid modeling are constructive solid geometry (CSG) and boundary representations (B-rep). Both of these representations have different inherent strengths and weaknesses and for most applications both representations are desired [1]

Constructive solid geometry systems allow the definition of complex three dimensional objects using a combination of simple objects. A CSG tree normally includes a set of solid shape primitives such as cubes, cylinders, cones, etc. which can be defined in a range of sizes and shapes. These primitives are combined using ``set operations", or ``Boolean operations", which allow the shape of an object to be described as the intersection of other objects, or as the union of objects. Inverse sets (or subtractions) are used to make holes in the overall shape. The resulting shapes can in turn be joined, or intersected with other shapes, to describe three dimensional shape of any complexity. Two well known CAD research systems that use CSG methods are GMSolid [2] and PADL-2 [3].

The main difficulty is in evaluating and representing the intersection of parametric surface patches and it has hindered the development of solid modelers that incorporate parametric surface models. The topology of a surface patch becomes quite complicated when Boolean operations are performed and finding a convenient representation for these topologies has been a major challenge [4].

As a result, most of the current solid modelers use polyhedral approximations to these surfaces and apply existing algorithms to design and manipulate these polyhedral objects. Not only does this approach lead to data proliferation, the resulting algorithms are inefficient and inaccurate.

The objectives of this paper are as follows:

i. To evaluate performance of CSG tree of a 3D solid model.
ii. To evaluate complexity and represent the more suitable software for 3D solid model.

2 Literature Review

A solid model is an unambiguous computer representation of a physical object. Research in solid modeling started with a few exploratory efforts in the mid-1960s, but began in earnest in the early 1970s, when several research groups were established in the main industrial nations. Researchers and practitioners recognized that the computer aided design and manufacturing (CAD/CAM) systems of the time required extensive user intervention to perform seemingly routine tasks. A substantially higher level of automation required that all the geometric information about solid objects be captured in computer representations more powerful than the wireframe models then in vogue. Thus solid modelling was born [5]

Early efforts in solid modeling focused on replacing manual drawings with the unambiguous computer models to automate a variety of engineering tasks, for example design and visualization of parts and assemblies, computation of mass, volume, surface of parts, simulations of mechanisms, and numerically controlled machining processes [6]

In a recent article, Ullman [7] discussed the current stage of computer aided design (CAD) systems as a design support system and indicated opportunities for software developers to bridge the gap between how designer activities can be supported better in the concurrent engineering realm. Some of these are as follows:

(i) an ability to visualize function before geometry is fully defined.

(ii) extending CAD systems to provide the designer with information about anticipated material and manufacturing methods.

(iii) generation of a running update of costs as parts and assemblies are changed in real time.

(iv) integration of requirements and constraints into the development of parts and assemblies.

In the CSG approach, basic and secondary primitives are constructed by linear and rotational sweeping operations. A 3D solid model is generated by implementing the boolean operations on these volumes. The first study which uses CSG approach was performed by Aldefeld[8]. The algorithm works only for objects with uniform thickness. The algorithm has recognised both straight lines and arcs in input views. The system was based on the identification of members in a set of primitives the combination of which form the model. Bin [9] has considered the basic volume units of many engineering objects as a composition of primitives. In his method translational, conical and rotational sweeping primitives were used. A sweeping process was performed by obtaining a sweeping length from other views. Finally, a 3D solid model is generated by boolean operations.

CSG trees are an example of an *unevaluated* representation. This means CSG tree properties, such as volume or surface area, are implicit. These properties are computationally expensive to find but, because a CSG tree does not force evaluation, less costly transformations (such as pruning the tree) can be applied to reduce the eventual cost of an expensive operation. This means that the evaluation of many aspects of the solid that the CSG tree represents can be done only when, or if, they are needed and with a reduced cost [10].

3 Research Methodology

The methodology for this research has been proposed by Okudan and Rutkowski[11] which is named as Solid Modeler Evaluation and Comparison Cycle (SMECC). Steps of the cycle methodology are amended to suit the requirement:

Step 1: Develop a short list of solid modelers for comparison.

For the first step, a short list of solid modelers was developed for comparison. The lists of solid modelers are as following:

(i) AutoCad 2004
(ii) SolidWorks 2001 plus

Step 2: Determine the solid modeling functions to be compared.

In Step 2, seven functions for comparison was selected as a following :

(i) Extrusion
(ii) Installation, setup, and operating system
(iii) Ease of use, support, and 3D Modeling
(iv) Speed
(v) Flexibility
(vi) Features based design
(vii) CSG tree level

These functions were compiled based on the requirements of the design CSG tree. The complete list of selected functions will be discussed in section 4.

Step 3: Compile a training manual and a schedule for solid modeling learning for the functions determined in Step 2.

A schedule is prepared for learning and understanding the basic operations of each solid modeler. Further operations include basic 3D object drawing by extruding and then involving Boolean operation. Table 1 shows the schedule of the learning basic operations that has been analysed in Section 4.

Step 4: Conduct user performance experimentation.

This step requires a number of users completing a predetermined 3D object using the four solid modelers in comparison. The experimentation involved the same CSG tree for each solid modeler. The pre-prepared learning for each modeler takes about 15 days. User performance is measured for predetermined solid modeling functions as mentioned in Step 2. Solid modelers' strong points and disadvantages are also noted for analysis.

Step 5: Analyze the user performance without data statistically and conclude.

The CSG tree has been analyzed by using different solid modelers. Analysis of the results can be referred to Section 4.

Step 6: Repeat steps 1-5 in regular intervals.

The SMECC cycle has been repeated in predetermined intervals for continuously taking advantage of rapid developments in solid modelers.

4 Experimental Result and Analysis

This section reveals the benchmark test for evaluation of four solid modelers by applying the CSG tree to each modeler.

Comparison on criteria and functions are performed in this analysis. These functions are taken from the ratings that have been published in CADANCE, October 2003. There are 6 parameters to be analyzed. Table 1 shows solid modeler comparison criteria and functions. The comparison will include the following:-

(i) Extrusion
(ii) Installation, setup, and operating system
(iii) Ease of use, support, and 3D Modeling
(iv) Speed
(v) Flexibility
(vi) Features based design
(vii) CSG tree level

This experiment or test was executed in a personal computer. The detail information about hardware / computer used can be referred in Table 2. This computer has been used for testing all the experiment for each solid modeler. The experiment has been conducted by recording a time for an installation and setup solid modeler start from a setup point. A repeat installation and setup for each modeler is done four times to ensure obtaining better time according to the specifications of the computer used. The installation of solid modelers is according to the pre-fixed sequence number 1, 2, 3, 4. After complete installation for each modeler in the sequencer, all the modelers have to be uninstalled and the computer has to be restarted again. Next, the modelers will be re-installed in a new sequence to take a new time reading. The time taken for each installation is based on the average of four separate installations.

Comparison Criteria or Functions	**AutoCAD 2004**	**SolidWorks 2001 plus**
Extrusion	√	√
Installation, setup and operating system	8.5 min	12.5 min
Ease of use, support/help	√	√
3D Modeling	Wire frame, surface, solid modeling	Wire frame, surface, solid modeling
Speed and reliability (in operation Boolean) CPU processing time	3 sec	Not provide operation Boolean
Number of mouse operations to complete a simple 3D cube	3	4
Dimensioning	√	√
Boolean Operations	√	×
Flexibility in command move	√	√
Flexibility adjustable fonts	√	√
Flexibility auto sizing font	×	√
Flexibility auto dimensioning	√	√
Flexibility auto arrow/position	√	√
Number of mouse operation to create a Boolean operation	3	8
Features based Design	√	√

Table 1: Solid Modeler Comparison Criteria and Functions

Specifications Dell Computer Corporation	
System Model	Dimension 4500S
BIOS version	Dell Computer Corporation AOO
Operating System	Microsoft Windows XP Home Edition
Memory (RAM)	384 MB
Processor	Inter® Pentium® 4 CPU 1.70 GHz
System Name	DELL
Local Disk Capacity	37.28 GB
Video Card	Intel ® 82845 G/GL/GE/PE/GV Graphics Controller
Sound Card	SoundMAX Intgrated Digital Audio
Network Card	D-Link DFE-530TX PCI Fast Ethernet Adapter (rev C) – Packet Scheduler Miniport
Floppy Drive (A)	Installed

Table 2 : Hardware and computer information

5 DISCUSSION

In this section, will be more on discussion about the comparison criteria and functions that has been selected.

5.1 Ease of Use, Support/help, and 3D Modeling

Basically, all the solid modelers provide sufficient help on operating the program. The program facilitate can learning from how to construct primitive objects to create complex designs which requires in depth details. The help option in each solid modelers work on their extensive database which can be utilized by entering key words. If the solid modeler does not provide specific help on certain matters, online support is available. Websites may be surfed to obtain further information or assistance from the manufacture of the modeler.

AutoCAD may be easier to use for existing 2D users who are familiar with their menus and key-ins, but new users will find them more unfriendly.

Conventional 2D CAD systems have been changed by advanced solid modeling techniques to aid designer. There are three basic modeling techniques namely, wire frame, surface and solid modeling, which are supported by most CAD/CAM software systems. Wire frame models resemble a raw skeleton of the product. Nearly all solid modeler systems offer the facility of wire frame modeling, but its popularity is waning due to the fact that it consists purely of geometry and lacks physical properties and associatively with the design. The automotive and aerospace industries require bounded areas of continuous surface and have relied mainly upon surface modeling. By appreciating their very nature, surface modelers can be ambiguous even if they do represent an enclosed area of material. This is because some surface modelers do not link surfaces with topological data. In fact, surface modeling is an art modeling and it needs some creativity. Solid modelers solve this problem as they rely on the build up of solid primitive shapes. Addition, union, intersection and subtraction of solids are then performed using Boolean operations to create the desired product shape.

5.2 Speed

All of the solid modelers deliver substantial speed in processing the operations involved in this paper. The test of the speed of each modeler has been conducted by recording the time and by counting mouse operation while doing a Boolean operation process.

SolidWorks 2001 plus does not support this operation. This means, it totally does not support CSG tree to represent how complex objects are formed out of basic objects. Its operation only involves assembling parts to form desired end results without the detail of what objects were involved in constructing it. In other cases, it is able to extrude or extrude cut out desired objects where in Boolean operation these may be considered as union, intersection or subtraction.

5.3 Flexibility in Dimensioning

Most advanced modelers offer some kind of method by which crucial dimensions in the design can be constrained as the model evolves. In parametric modeling there is a strict order dependence of how the model is built up. This can lead to problems when a design is changed.

The basis of dimensioning in AutoCAD2004 is different. User cannot adjust the object's dimension by changing it in the dimensions column. User has to draw a new object with a new set of dimensions. This is difficult to a user because it is not user friendly.

As for SolidWorks 2001 plus, user can easily adjust the dimensioning of the object by clicking the dimension button.

5.4 Features

Another technology that has gained popularity is feature based design. Features accelerate design by enabling the user to model common form features like holes, bosses, slots, pockets, extrude and Boolean operation are used to offer increased flexibility and ease of use. Once placed in a model, features become integral, associative elements of the design. Assembly modeling consists of several parts located relative to each other in space. Assembly models used for interference checking, rendered and exploded visualization, animation and mechanism analysis as well. SolidWorks and AutoCAD give good features in creating the CSG tree.

5.5 CSG Tree Level

An object model for CSG tree by Kumar and Yu[12] is applied to all modelers as shown in figure 1. Parameter comparison has been tested based on these CSG tree. The level of CSG tree is counted by combining primitive shape in each solid modeler. This combining process uses Boolean operation.

Most simple parts of CSG tree can be formed from combinations of geometric shapes, known in modeling terms as primitives (spheres, cones, cylinders, cubes). There are 6 primitive shapes in AutoCAD while SolidWorks does not introduce any primitive shapes.

When primitives are not enough or unavailable in designing the model, the most economical and intuitive method for creating a solid is to use a technique called extrusion. An extruded solid is formed by projecting a closed 2D profile orthogonally from its construction plane. Extrusions are particularly useful for creating solids from irregular cross sections where no single primitive or readily conceivable combination of primitives would do.

As for SolidWorks 2001 plus, it does not support Boolean operation but the features in this modeler are very attractive because even new users can easily navigate within the menus easily and its GUI is user friendly. This modeler is suitable for mechanical drawing works.

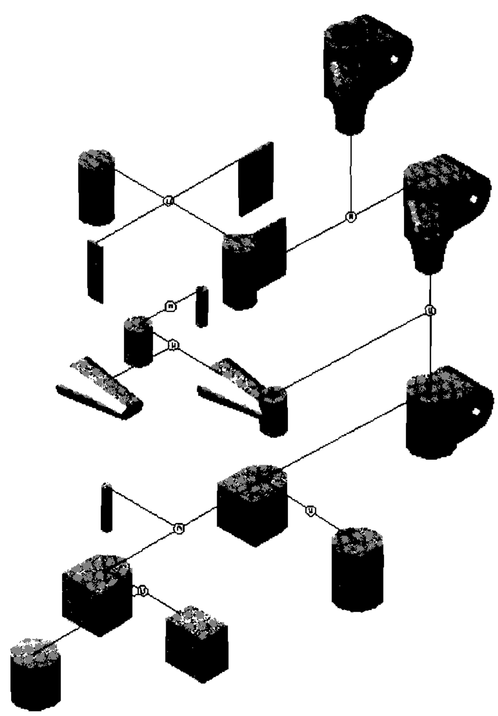

Figure 1: CSG Tree using Boolean Operation for AutoCAD 2004.

6 CONCLUSION

After analyzing and comparing the two solid modelers, it can be concluded that SolidWorks 2001 plus offers interactive GUI for mechanical drawings, but it does not support Boolean operations. SolidWorks gives users flexibility in designing parts. SolidWorks is a mechanical design software that provides feature level control over multiple bodies.

AutoCAD 2004 is an interactive drawing system designed to permit a user to construct or edit a drawing on a graphics display screen. From the comparison of functions that has been analysed in Table 1, AutoCAD has been giving a good performance compared to SolidWorks 2001 plus.

Hence, user will most probably be comfortable using SolidWorks in constructing 3D model. Although SolidWorks do not provide Boolean operator but the objects still can be operated using extrude technique, cut out and split. These techniques are the same as Boolean operation function but uses a different command. SolidWorks also can share drawing file with AutoCAD when user from AutoCAD has to convert file from .dwg or .par file to .swj file. Table 1 shows the comparison criteria and functions for AutoCAD 2004 and SolidWorks 2001 plus.

The set of outcomes of the study is expected to assist companies and design educators in making slid modeler selection decisions. Comparison between solid modelers will also facilitate solid modeler providers in producing software that fulfil users' needs and requirements.

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