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BETTER CRITERIA FOR THE DEVELOPMENT OF SOLID MODELING SOFTWARE

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Better Criteria for the Development of Solid Modeling Software

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ABSTRACT

The criteria underlying the design of a Hybrid Solid Modeling System, called **GeneSys**, are presented. The system's innovative aspect consists in adopting the criteria pointed out by the recent research on Intelligent CAD (**ICAD**). The paper focuses on the question of cognition and 3D perception. The criteria to measure the quality of the design is also described. The experience with the development of **GeneSys**, the authors believe, provides an extra insight into the question of writing robust engineering software.

INTRODUCTION

A Solid Modeling System is always a central module in CAD Systems. The degree of robustness of this type of software depends on the principles underlying its design. However, writers of engineering software often lack the knowledge and experience needed to establish sound design criteria. This paper presents the design criteria used in the development of a Hybrid Solid Modeling System (**HSMS**), called **GeneSys** (Fischer [5]). Generally speaking, the experience with **GeneSys**, the authors believe, provides an extra insight into the problem of writing robust engineering software.

A good software should provide a good user interface. Usually engineering software also lacks competence in this area. However, this paper does not focus on the usual aspect of this question which can be found somewhere (Foley et al. [4])(Norcio and Stanley [12])(Myers [11]). It focuses on the design criteria pointed out by **ICAD** researchers.

Recent research on Intelligent CAD Systems has revealed a new approach to the development of CAD Systems (Hagen and Tomiyama [7])(Bento et al. [2]) (Fischer [6]), in addition to the well-known question of user interface. The innovative aspect of this approach consists in developing CAD software according to the following general criteria:

(1) to be able to absorb future advances in CAD technology;
(2) to provide robust, efficient and consistent geometric and topological modeling techniques;
(3) to incorporate knowledge representation techniques;
(4) to satisfy the engineer's cognitive needs.

This paper presents the results of this approach in the development of **GeneSys**, with special emphasis on the forth criterion.

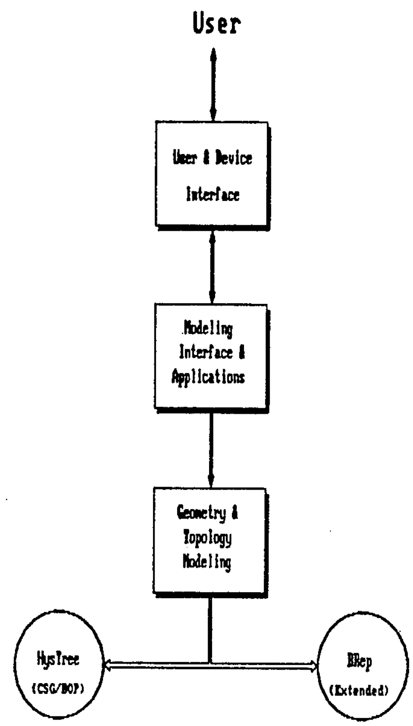

Fig.1 **GeneSys** sub-systems and representation schemes.

THE ARCHITECTURE OF THE SYSTEM

GeneSys is a hybrid system in the sense that it integrates an extended Boundary Representation Scheme (**BRep**) with a modified Constructive Solid Geometry (**CSG**) modeling tree (called history tree), as shown in Fig.1. The domain of both representations is restricted to physical realizable manifold solids, which are the ones that can be manufactured.

GeneSys adopts an extended **BRep** scheme with the following characteristics:

(a) the ordinary **BRep** hierarchy is extended to include the entities **World-Object-Solid** and
(b) attributes/geometry are separated from the topological data structure.

Fig.2 shows the basic assembly hierarchy of **GeneSys**. Fig.3 completes the extended **BRep** data structure of the system presented in Fig.2.

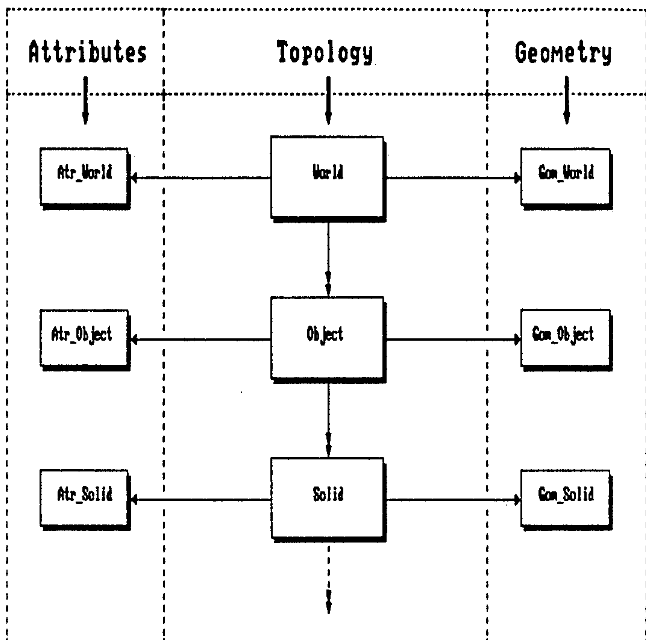

Fig.2 The basic assembly hierarchy of **GeneSys**.

Fig.4 shows the history tree of a modeling session. In the history tree, the user can undo/redo operations followed by the creation of new branches with no loss of information. This process of modeling is often done by users when they are looking for new versions of a specific solid.

The ordinary **CSG** tree has been modified in order to be incorporated into **GeneSys**. The nodes of the modified **CSG** tree store not only boolean operators but also high-level modeling operators. These high-level operators are implemented in terms of basic operations (**BOP's**) which can be topological or geometric operations (Chiyokura [3]). This new **CSG** tree represents not only the history design process of the solid but also its assembly hierarchy.

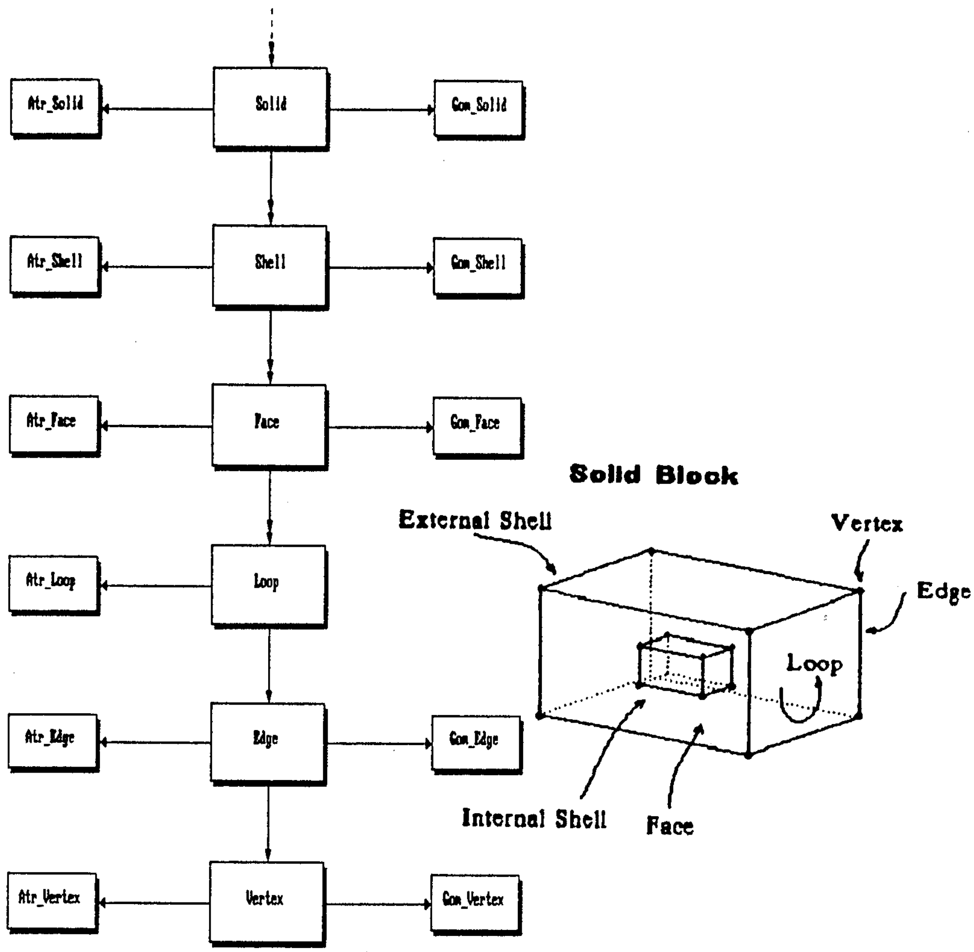

Fig.3 The **BRep** topological representation of a solid.

The implementation of the extended boundary representation scheme is done through a winged-edge data structure (Baumgart [1]). This data structure has proved to offer all the necessary assistance in evaluating topological adjacency relationships. In fact, these topological inquires have been proved to be essential to most of the tasks carried out during the solid modeling process.

CRITERION 1: FUTURE ADVANCES IN CAD TECHNOLOGY

The architecture of **GeneSys** is based upon two principles of software design: Modularity and Information Hiding Mechanisms. Fig.1 mentioned above shows the basic architecture modules. The **User & Device Interface** module is based upon **IntGraf,** a Window Interface System developed by TeCGraf. The portability and standardization of the system are guaranteed since **IntGraf** has been integrated into **GKS/puc** (the TeCGraf implementation of the standard ISO GKS).

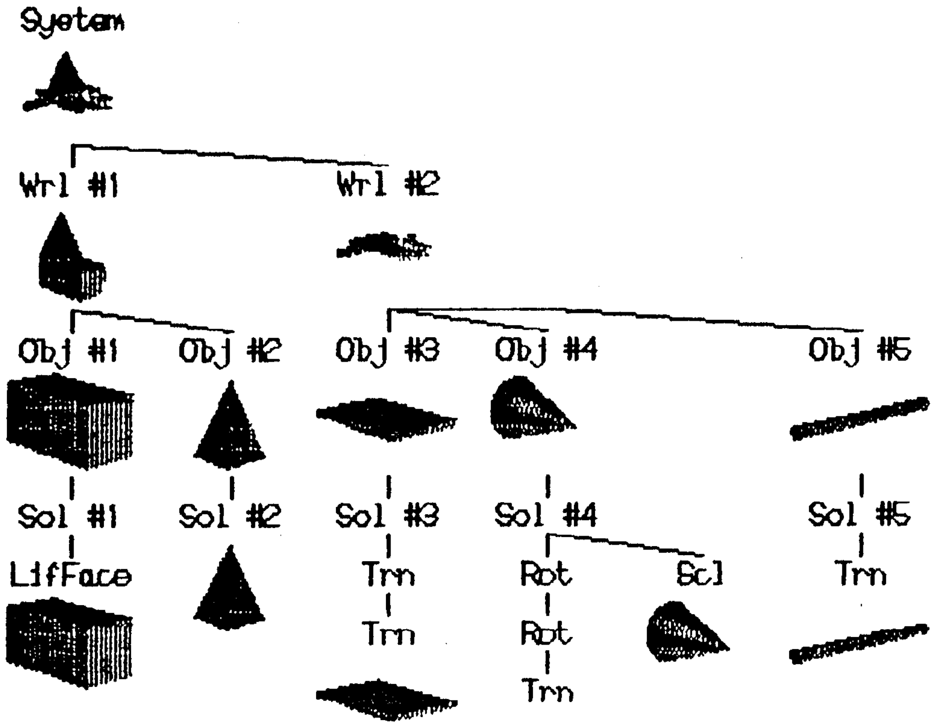

Fig.4 Modified Constructive Solid Geometry Modeling Tree.

The **Interface & Application** module allows the user to incorporate a new part into the system (or a new item into an old part) in a straightforward manner. Therefore, the system is ready to absorb new advances in CAD and Computer Graphics. The data flow of these modules are presented in Fig.5.

CRITERION 2: ROBUST GEOMETRIC/TOPOLOGICAL MODELING TECHNIQUES

The problem of integrating geometry and topology has not been solved yet. Although topological consistency is dealt by the traditional Euler operators (or variations of them), the attempt to achieve geometric consistency at this level is still a vague proposal.

GeneSys tackles the problem of geometric consistency at a higher level through the **Geometric Modeling Interface** (**GMI**) module and the **High-Level Operations** (**HOP**) module. The modeling techniques are based upon compact and efficient low-level operators, leaving to **GMI/HOP** all the responsibility to achieve geometric consistency. The **GMI** module is capable of interactively guiding the user during the modeling process. This characteristic of the system inhibits the user to incur into basic geometric mistakes, such as the splitting of a triangular face. The **HOP** module treats the geometric processes that are not interactively done by the user, such as boolean operations. **HOP** also provides high-level modeling tools to

GMI. This approach is much more realistic than any attempt to insert geometric tests in **BOP**'s. Moreover, in this case, the undo/redo basic operations (**BOP**'s) are very efficient.

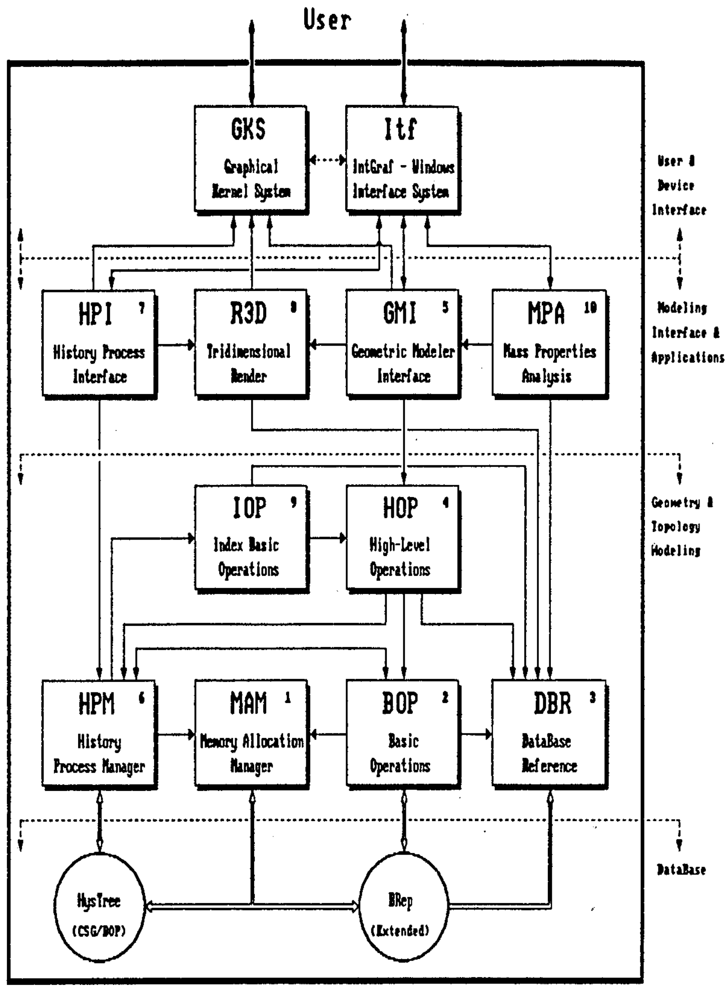

Fig.5 Detailed architecture of **GeneSys**.

In addition, **BOP's** provide a sound and robust foundation for low-level representations. As stated by Mäntylä [10], these operators have the role of an assembly language for Solid Modeling. Moreover, they are reversible.

CRITERION 3: KNOWLEDGE REPRESENTATION

The question of knowledge representation for Solid Modeling Systems comprises topics of Intelligent User Interface, Pictorial Information and Design Automation. These topics are too complex to be presented in this paper. However, the authors believe that the data structure and the history tree of **GeneSys** can be used as a lower level support to the future development of a Knowledge-Based CAD System.

The attributes of the data structure can be used as slots to store parameters for Pictorial Reasoning, Feature Modeling and Product Modeling (Ovtcharova [13]). The history tree can also help the incorporation of semantics into the system. Furthermore, it can be used for both generation and recognition of 3D entities (in contrast to the usual systems that only generate them, as pointed out by Helm and Marriot [9]).

CRITERION 4: PERCEPTION AND COGNITIVE NEEDS

As far as software development is concerned, Foley et al. [4] pointed out the need to understand prospective users and have quoted Hansen [8]: "Know the user - watch him, study him, interact with him, learn to understand how he thinks and why he does what he does". Foley et al. [4] also noticed that interacting with a computer involves three types of basic human processes: perception, cognition, and motor activity. Perception is the process whereby physical stimuli are received and recognized by humans. Cognition is the process of acquiring, organizing, retrieving and understanding information. These guidelines were taken very seriously in the development of **GeneSys**.

In the present context, the fundamental idea underlying the design of **GeneSys** is the question of satisfying perception and cognitive needs of the engineer. In the case of Solid Modeling Systems this question is quite clear: engineers do not adapt themselves to the three-dimensional environment provided by CAD systems. The reasons are twofold:

- The engineers' great difficulty to manipulate 3D objects on a 2D screen;
- The skill that engineers have developed to manipulate 3D objects through their projections (i.e. technical drafting) along many years;

A solution to this problem is to encourage engineers to develop new skills based on their cognitive needs for 3D perception. This is the keystone to achieve effectiveness and to induce engineers to place reliance upon CAD Systems. The characteristics of **GeneSys** that follow this approach are presented in the next two sections.

GeneSys modeling process

The authors have confirmed the strong inclination engineers have to organize the world in a sound and simple hierarchy. The basic hierarchy of **GeneSys** (i.e. **World-Object-Solid**) satisfies this need. However, the most important characteristic of **GeneSys** is the possibility to manipulate solids by walking in a dynamic history tree (which produces updated visual versions of 3D entities as shown in Fig.4). Moreover, they can undo/redo operations like in a flexible and real 3D world.

GeneSys hybrid architecture gives more flexibility to the modeling process and extends the domain of the modeling space that the system can represent. Although sometimes it is natural for engineers to proceed with global operations like the union of two solids, most of the time the solids are more easily modified through direct transformations (local operations). **GeneSys** supports both techniques.

GeneSys special features

Some special features have been developed in order to satisfy cognitive needs of the user concerning 3D perception, such as: **Dynamic Manipulation** and **Solidness Perception**.

One of the basic assumptions of **GeneSys** is that the user is static and the solids are manipulated by his/her hands. For instance, the user can rotate a solid and then bring it closer to his/her eyes. This feature is called **Dynamic Manipulation**. A box wrapping the object (called **MinBox**) can be manipulated in real time.

Solidness Perception disables the user to get inside the solids. Any attempt to pass through a solid causes the **MinBox** face to flash and to produce a noise. The user has the sensation of moving around solid objects. Even when this feature is not active, **MinBox** faces still flashes when the locator passes through them. This last characteristic, called **MinBox Intersection Feeling**, has revealed itself as an essential aid to navigate in the pseudo-3D/world. The intersection with object faces (instead of **MinBox** faces) is discarded because the computational cost would make this test impracticable in real-time (and, consequently, jeopardizing the solidness feeling).

HOW TO MEASURE THE DESIGN QUALITY

The following criteria can be used to measure the design quality:

1. Learning time;
2. Recall time;
3. Memory load;
4. Fatigue susceptibility.

Learning time is the time a user takes to reach an initial skill level. Recall time is the time a user takes to regain competence after a period of disuse of the system.

There are two types of memory: short-term and long-term. They are related to the amount of time required to keep information related to a particular task.

An informal evaluation of the design quality has been carried out by the authors with a group of students with no experience in Solid Modeling. The analysis revealed low values of learning time, recall time and memory load.

CONCLUSIONS

The design of **GeneSys** considers the general criteria pointed out by **ICAD** researchers, as follows:

- The architecture of **GeneSys** follows two general principles of software design: Modularity and Information Hiding Mechanisms, which make it ready to absorb future advances in CAD technology.

- The architecture of **GeneSys** provides robust, efficient and consistent geometric/topological modeling techniques implemented via the **GMI→HOP→BOP** pipeline.

- The system's extended **BRep** and history tree seem to be quite appropriate to incorporate knowledge representation.

- The system takes into account the engineer's cognitive needs for a better 3D perception environment and a hierarchical assembly methodology.

The innovative approach presented in this paper leads to a more robust, reliable and efficient Solid Modeling system suitable to any Engineering Software based on Computer Graphics.

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