Introduction

Learning Objectives

- Development of Computer Geometric Modeling
- Feature-Based Parametric Modeling
Introduction

The rapid changes in the field of Computer Aided Engineering (CAE) have brought exciting advances in the engineering community. Recent advances have made the long-sought goal of concurrent engineering closer to a reality. CAE has become the core of concurrent engineering and is aimed at reducing design time, producing prototypes faster, and achieving higher product quality. Pro/ENGINEER is an integrated package of Mechanical Computer Aided Engineering software tools developed by Parametric Technology Corporation (PTC). Pro/ENGINEER is a tool that facilitates a concurrent engineering approach to the design, analysis, and manufacturing of mechanical engineering products. The Pro/ENGINEER software allows us to quickly create three-dimensional solid models. Real-life loads can be simulated on the computer to predict the behaviors of the designs under specific operating conditions. The computer models can also be used directly by manufacturing equipment such as machining centers, lathes, mills, or rapid prototyping machines to manufacture the product.

![Diagram of Computer Aided Engineering (CAE)]

Computer Aided Engineering (CAE)

- Computer Aided Design (CAD)
- Computer Aided Manufacturing (CAM)

Computer Geometric Modeling

Finite Element Analysis

Development of Computer Geometric Modeling

Computer geometric modeling is a relatively new technology and its rapid expansion in the last fifty years is truly amazing. Computer-modeling technology advanced along with the development of computer hardware. The first generation CAD programs, developed in the 1950s, were mostly non-interactive; CAD users were required to create program-codes to generate the desired two-dimensional (2D) geometric shapes. Initially, the development of CAD technology occurred mostly in academic research facilities. The Massachusetts Institute of Technology, Carnegie-Mellon University, and Cambridge University were the lead pioneers at that time. The interest in CAD technology spread quickly and several major industry companies, such as General Motors, Lockheed, McDonnell, IBM, and Ford Motor Co., participated in the development of interactive CAD programs in the 1960s. Usage of CAD systems was primarily in the automotive industry, aerospace industry, and government agencies that developed their own programs for their specific needs. The 1960s also marked the beginning of the development of finite element analysis methods for computer stress analysis and computer aided manufacturing for generating machine toolpaths.
The 1970s are generally viewed as the years of the most significant progress in the development of computer hardware, namely the invention and development of **microwprocessors**. With the improvement in computing power, new types of 3D CAD programs that were user-friendly and interactive became reality. CAD technology quickly expanded from very simple **computer aided drafting** to very complex **computer aided design**. The use of 2D and 3D wireframe modelers was accepted as the leading edge technology that could increase productivity in industry. The development of surface modeling and solid modeling technology were taking shape by the late 1970s; but the high cost of computer hardware and programming slowed the development of such technology. During this time period, the available CAD systems all required expensive room-sized mainframe computers that were extremely high in cost.

In the 1980s, improvements in computer hardware brought the power of mainframes to the desktop at less cost and with more accessibility to the general public. By the mid-1980s, CAD technology had become the main focus of a variety of manufacturing industries and was very competitive with traditional design/drafting methods. It was during this period of time that 3D solid modeling technology had major advancements, which boosted the usage of CAE technology in industry.

The introduction of the **feature-based parametric solid modeling** approach, at the end of the 1980s, elevated CAD/CAM/CAE technology to a new level. In the 1990s, CAD programs evolved into powerful design/manufacturing/management tools. CAD technology has come a long way, and during these years of development, modeling schemes progressed from two-dimensional (2D) wireframe to three-dimensional (3D) wireframe, to surface modeling, to solid modeling and, finally, to feature-based parametric solid modeling.

The first generation CAD packages were simply 2D **Computer Aided Drafting** programs, basically the electronic equivalents of the drafting board. For typical models, the use of this type of program would require that several to many views of the objects be created individually as they would be on the drafting board. The 3D designs remained in the designer’s mind, not in the computer database. The mental translation of 3D objects to 2D views is required throughout the use of the packages. Although such systems have some advantages over traditional board drafting, they are still tedious and labor intensive. The need for the development of 3D modelers came quite naturally, given the limitations of the 2D drafting packages.

The development of three-dimensional modeling schemes started with three-dimensional (3D) wireframes. Wireframe models are models consisting of points and edges, which are straight lines connecting between appropriate points. The edges of wireframe models are used, similar to lines in 2D drawings, to represent transitions of surfaces and features. The use of lines and points is also a very economical way to represent 3D designs.
The development of the 3D wireframe modeler was a major leap in the area of computer geometric modeling. The computer database in the 3D wireframe modeler contains the locations of all the points in space coordinates and it is typically sufficient to create just one model rather than multiple views of the same model. This single 3D model can then be viewed from any direction as needed. Most 3D wireframe modelers allow the user to create projected lines/edges of 3D wireframe models. In comparison to other types of 3D modelers, 3D wireframe modelers require very little computing power and generally can be used to achieve reasonably good representations of 3D models. However, because surface definition is not part of a wireframe model, all wireframe images have the inherent problem of ambiguity. Two examples of such ambiguity are illustrated.

**Wireframe Ambiguity:** Which corner is in front, A or B?

**A non-realizable object:** Wireframe models contain no surface definitions.
Surface modeling is the logical development in computer geometry modeling to follow the 3D wireframe modeling scheme by organizing and grouping edges that define polygonal surfaces. Surface modeling describes the part’s surfaces but not its interiors. Designers are still required to interactively examine surface models to insure that the various surfaces on a model are contiguous throughout. Many of the concepts used in 3D wireframe and surface models are incorporated in the solid modeling scheme, but it is solid modeling that offers the most advantages as a design tool.

In the solid modeling presentation scheme, the solid definitions include nodes, edges, and surfaces, and it is a complete and unambiguous mathematical representation of a precisely enclosed and filled volume. Unlike the surface modeling method, solid modelers start with a solid or use topology rules to guarantee that all of the surfaces are stitched together properly. Two predominant methods for representing solid models are constructive solid geometry (CSG) representation and boundary representation (B-rep).

The CSG representation method can be defined as the combination of 3D solid primitives. What constitutes a “primitive” varies somewhat with the software but typically includes a rectangular prism, a cylinder, a cone, a wedge, and a sphere. Most solid modelers also allow the user to define additional primitives, which are shapes typically formed by the basic shapes. The underlying concept of the CSG representation method is very straightforward; we simply add or subtract one primitive from another. The CSG approach is also known as the machinist’s approach as it can be used to simulate the manufacturing procedures for creating the 3D object.

In the B-rep representation method, objects are represented in terms of their spatial boundaries. This method defines the points, edges, and surfaces of a volume, and/or issues commands that sweep or rotate a defined face into a third dimension to form a solid. The object is then made up of the unions of these surfaces that completely and precisely enclose a volume.

By the 1980s, a new paradigm called concurrent engineering had emerged. With concurrent engineering, designers, design engineers, analysts, manufacturing engineers, and management engineers all work closely together right from the initial stages of the design. In this way, all aspects of the design can be evaluated and any potential problems can be identified right from the start and throughout the design process. Using the principles of concurrent engineering, a new type of computer modeling technique appeared. The technique is known as the feature-based parametric modeling technique. The key advantage of the feature-based parametric modeling technique is its capability to produce very flexible designs. Changes can be made easily and design alternatives can be evaluated with minimum effort. Various software packages offer different approaches to feature-based parametric modeling, yet the end result is a flexible design defined by its design variables and parametric features.
Feature-Based Parametric Modeling

One of the key-elements in the Pro/ENGINEER solid modeling software is its use of the feature-based parametric modeling technique. The feature-based parametric modeling approach has elevated solid modeling technology to the level of a very powerful design tool. Parametric modeling automates design and revision procedures by the use of parametric features. Parametric features control the model geometry by the use of design variables. The word parametric means that the geometric definitions of the design, such as dimensions, can be varied at any time in the design process. Features are predefined parts or construction tools in which users define the key parameters. A part is described as a sequence of engineering features, which can be modified/changed at any time. The concept of parametric features makes the modeling more closely match the actual design-manufacturing process than the mathematics of a solid modeling program. In parametric modeling, models and drawings are updated automatically when the design is refined.

Parametric modeling offers many benefits:

- We begin with simple, conceptual models with minimal detail; this approach conforms to the design philosophy of "shape before size."

- Geometric constraints, dimensional constraints, and relational parametric equations can be used to capture design intent.

- The ability to update an entire system, including parts, assemblies and drawings after changing one parameter of complex designs.

- We can quickly explore and evaluate different design variations and alternatives to determine the best design.

- Existing design data can be reused to create new designs.

- Quick design turn-around.

The feature-based parametric modeling technique enables the designer to incorporate the original design intent into the construction of the model, and the individual features control the geometry in the event of a design change. As features are modified, the system updates the entire part by re-linking the individual features of the model.

Pro/ENGINEER WILDFIRE is the twenty-fifth release, with many added features and enhancements, of the original Pro/ENGINEER software produced by Parametric Technology Corporation (PTC). Pro/ENGINEER is considered the industry leader in setting the standard for the feature-based modeling paradigm. Pro/ENGINEER's Behavioral Modeling and Intent Referencing allow users to concentrate on the design without depending on the associated parameters or constraints. Users can specify how features interact with each other and Pro/ENGINEER will automatically adjust sizes and positions as changes are made.