OVERVIEW OF THE PRINCIPLES OF 3D MODELING SYSTEMS

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Abstract: Geometric modeling is developing a mathematical development of an object called “model”. This model may be shown in two dimensional (2D) or in three dimensional (3D). Depending on the application, a 2D model may completely satisfy the need, but the ideal form of model representation is the 3D model. It is the base of many CAD /CAM applications such as kinematical analysis of mechanical systems and finite element analysis, NC, CNC programming etc. The geometric modeling plays a major role in full integration and automation of CAD/CAM systems. This paper describes the principles of 3D modeling systems in order of their evolutionary history, including the main advantages and disadvantages of each system. Also solid modeling technique is classified due to its popularity and wide adoption in today’s CAD/CAE systems.

Keywords: wireframe, surface, solid modeling.

1. INTRODUCTION

Geometric modeling is a general term applied to three-dimensional computer-aided design technique. Can be defined as computer compatible mathematical description of the geometry of the object which can be displayed as the image on the monitor of the computer by means of CAD software. Geometric modeling is used to: visualize, analyze, document and produce a product or process. According to definition geometric models are computational (symbol) structures that capture the spatial aspects of the objects of interest for an application.

Designer can create geometric models by using CAD software in three steps:

- *Creation of basic geometric objects*: the designer creates basic geometric elements by using commands like points, lines, and circles.
- *Transformations of the elements*: the designer uses commands like achieve scaling, rotation and other related transformations of the geometric elements.
- *Creation of the geometric model*: the designer uses various commands to form the desired shape.

There are two categories of information for defining geometric object, fig.1:

- *Geometric information* – coordinates and dimensions of the object and its components.
- *Topological information* – the relations between components of the object.

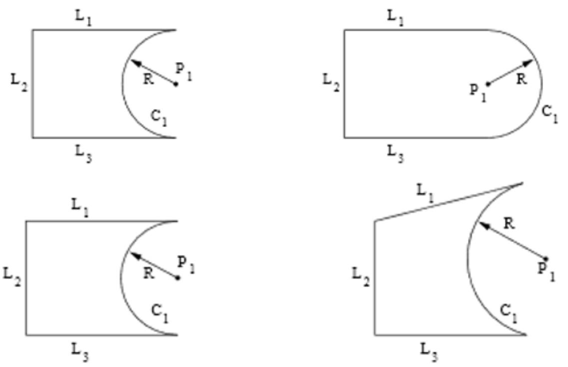


fig.1 Same geometry but different topology and same topology but different geometry

The basic geometric modeling approaches used in today’s CAD/CAM systems are:

1) Wireframe,
2) Surface and
3) Solid modeling.

2. WIREFRAME MODELING

Represent one of the first simplest thus the fastest techniques in the term of processing speed, introduced in the beginning of the 1960s. *Wireframes*, are the simplest 3D geometric representation. In this approach each vertex is defined by x, y, z coordinate, edges by a pair of vertices and faces as three or more edges. This representation is natural for a designer who is familiar with mechanical drawings because it is the lines and curves in a drawing which define 3D space. Wireframes are not complete and surface geometries are not present which may be important for later manufacturing processing and other analyses. They have certain advantages as:

- Can quickly and efficiently convey information than multiview drawings,
- Lines are the intersection of surface,
- Can be used for finite element analysis and as input for CNC machines to generate simple parts,
- Contain information to create surface, solid and higher order models.

Also they have a number disadvantages such as:

- Volume and mass characteristics cannot be specified,
- Not suitable for designing shapes and specifying more complex surface,
- Not ideal for CAM/CAE tasks,
- Representation is ambiguous.

3. SURFACE MODELING

Developed due to the limitations of wireframe modeling, CAD systems were developed *surface models*, further to include bounding surfaces of the object, as well as the edges of objects. Surface entities such as planar, cylindrical, conical and spherical faces can be represented using analytical equations [4]. It enriches the object description by attaching mathematical description of object's surface. In this way, a surface models provide a more complete description of the object in comparison with wireframe models, which enables to design and analyze complex free-formed surface as well as geometry needed for mold and die design.

Main advantages are:

- Hiding lines not seen thus eliminating ambiguity present in wireframe models,
- Surface models play an important role in industry, because they give an accurate description of the surface of an object which, can be used to guide manufacturing applications,
- Support volume and mass calculation, finite element modeling, NC path generation, cross sectioning and interference detection,
- Surface properties such as roughness, color and reflectivity can be displayed,
- Models support shading, making model more realistic, thus yielding better visualization.

Such disadvantages can be listed:

- Surface model does not contain topological information, and can therefore be ambiguous when determing the volume of an object,
- Depending on the number of surfaces, computation can be complicated.

4. SOLID MODELING

Solid modeling was introduced in the beginning of the 1970s. Unlike wireframes and surface representations which contain only geometrical data, the solid model uses topological information in addition to the geometrical information which enables complete, valid and unambiguous description of physical objects. Solid models support calculation of weight or volume, moments of inertia, stress analysis, dynamic analysis as well as heat conduction calculations. Can be implemented for CNC codes generation and robotic and assembly simulation. A single object can be represented with different solid modeling technique so that interpretation of such representation gives exactly the same physical object.

Advantages of solid modeling:

- Has all advantages of surface models plus volumetric information,
- 3D model can be used to generate 2D standard drawings, assembly drawing and exploded views,
- Solid model results in accurate design and can be used in computer integrated manufacturing (CIM), computer aided manufacturing (CAM) and design for

manufacturability and assembly (DFM, DFA).

Disadvantages of solid modeling:

- More intensive computation than wireframe and surface modeling,
- Processing is the most expensive in comparison to other modeling techniques but with today computers the cost of it is not excessively high any more.

Two basic techniques are used to represent solids in the computer database: Constructive Solid Geometry (CSG) and Boundary Representation (B-Rep), fig.2.

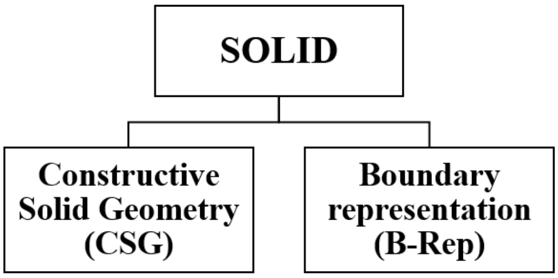


fig.2 Basic technique to represent solids: Constructive Solid Geometry and Boundary representation (B-rep)

Constructive Solid Geometry (CSG), (fig.3a) represent an effective way to construct a solid model by a collection of primitives, such as cuboid, cylinder, cone and sphere and a set of transformations and Boolean operations. The primitives as well as the results of Boolean operations (union, difference and intersection) can be modified by geometric transformations like translation, rotation and scaling. The final shape of a component is described and maintained internally by a tree structure of simpler shapes of primitives.

CSG method has certain advantage and disadvantage. It is relatively easy to construct a topologically corect and precise solid model from the primitives. Also is compact in its storage requirements, but slow at producing images. Due to the limited number of primitives, CSG models are unable to represent objects with complex surfaces.

Boundary representation (B-Rep), **(**fig.3b) method represents a solid as a collection of boundary surfaces. A B-Rep solid is represented as a volume contained in a set of faces together with topological information i.e. vertices, edges, faces, shells and geometric information i.e. points, curves, surfaces. Boundary representation can be divided in three classes:

- Facetted – a solid is bounded by planar surfaces. Points, planes and planar polygons are implicitly represented by their vertex points,
- Elementary – surfaces are planar, quadric and toroidal,
- Advanced – surfaces includes also spline surfaces (B-Spline, Bezier, NURBS, etc.)

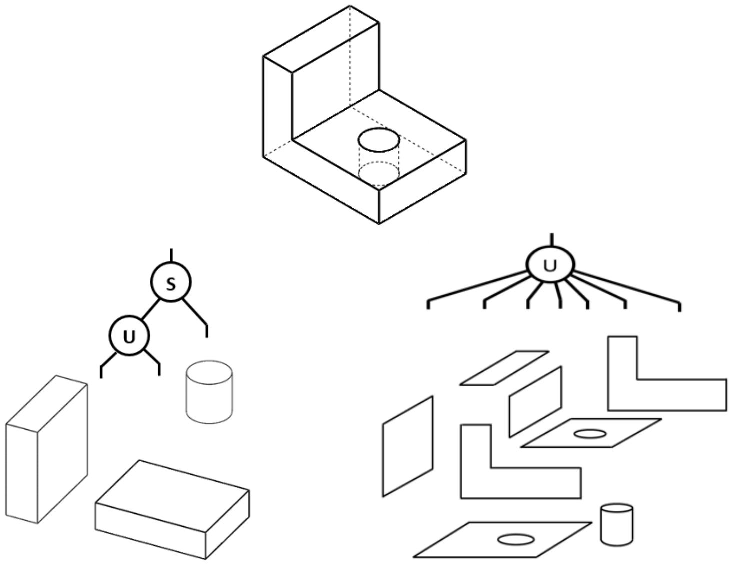
Boundary representation method gives more freedom in building complex models, but the validity of the models could be destroyed in the process. Also it requires a large memory space which is their disadvantage.

4.1 Feature based modeling

Geometric modeling techniques such as constructive geometry (CSG) and boundary representation (B - rep) are widely used in solid CAD systems. Consequently, it can be difficult to integrate CAD with any other higher level process planning. In effort to overcome this shortcoming, enhance the productivity of designers and achieving better CAD/CAPP integration, feature technology has been introduced.

For creating a geometrical components this technique uses predefined combinations of functionalities. Features are created as model-building primitives, which are related to reference systems or to existing solid geometry. This type of modeling uses associative design methods to create pockets, holes, ribs, slots, etc., whereby the referencing and geometrical characteristics can be controlled by associated rules and attributes. The creation of geometrical components is performed by interlinked sequences of functions, which include the definition of the feature type, the selection of reference elements, the input of required dimensions and the composition of the desired geometry models. Feature can also include additional information for organizational, manufacturing or distribution processes and support the derivation of data and information for subsequent engineering processes.

Feature based modeling also allow designers to define their own sets of features. Thus the set of of features needed to design castings is different from those used for machined parts.



a) b)

fig.3 Constructive Solid Geometry method (a) and Boundary representation (B-rep) method (b)

4.2 Parametric modeling

Parametric modeling can be split into dimension driven modeling and constraint based modeling, (fig.4). Parametric modeling means that parameters of the model may be modified to change the geometry of the model. A simple example of a parameter is dimension. When a dimension during the design is changed, the geometry of the part is updated. Thus the parameter drives the geometry. Parametric models can be used for adaptive design such as families of parts or optimizations well as tolerance analysis, (fig.5).

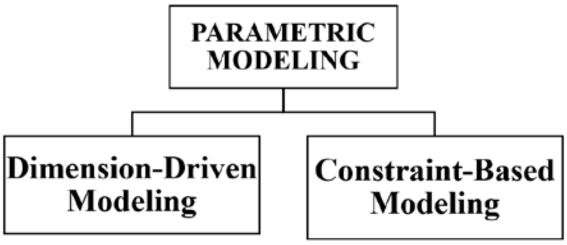


fig.4 Types of parametric modeling

Another feature of parametric modeling is that parameters can reference other parameters through constraints. Modeling constraints can be classified as four types: ground, dimensional, geometric and algebraic, [3].

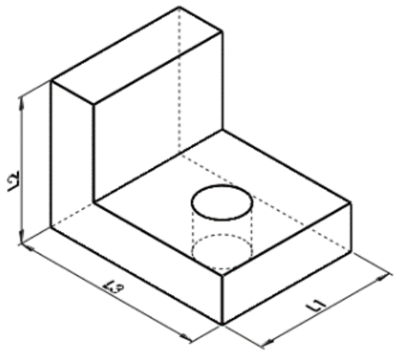


fig.5 Parametric model with dimesion equation

Ground constraints provide reference between part and the global coordinate system. Dimensional constraints provide numerical values for basic geometric entities. A geometric constraint imposes relationships between geometric entities such as tangency, collinearity, parallelism, perpendicularity, coincidence of points, symmetry, etc. and algebraic constraints impose restrictions on design dimensions in the form of mathematical equations. Algebraic constraints may be equalities, inequalities or conditional statements. The power of this approach is that when the dimension is modified, all linked dimensions are updated according to specified mathematical relation, instead of having to update all related dimensions individually.

5. CONCLUSION

This paper gives an overview of the principles of 3D modeling systems in order of their evolutionary history, including the main advantages and disadvantages of each system. The emphasis is on solid modeling technique which enables complete, valid and unambiguous description of physical objects and due to its popularity and wide adoption in today's CAD/CAE systems. The steps by which designer can create geometric models by using CAD software and categories of information are also mentioned, since geometric model has central importance for product lifecycle based on specification and requirements from result of initial design steps and for further steps in product development like FEA, simulation, mockups, production planning, manufacturing, etc.

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