GEOMETRIC MODELING

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Types of geometric modeling methods

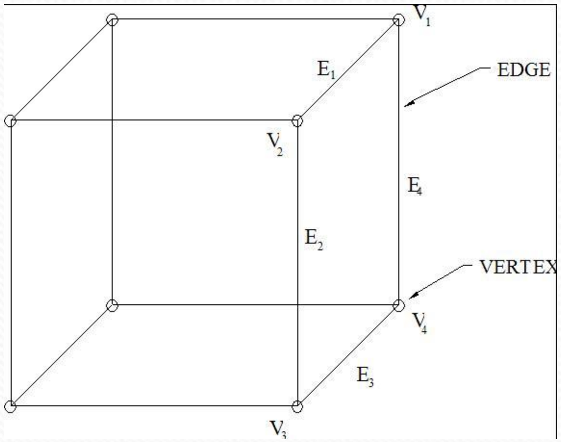
- Wireframe modeling
- Surface modeling
- Solid modeling

Why Geometric modeling is needed

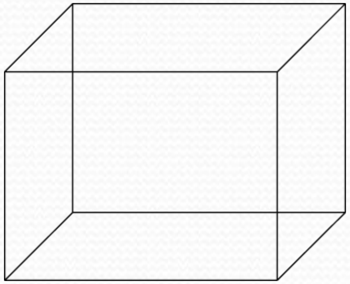
- Geometric (3D) models are easier to interpret.
- Simulation under real-life conditions.
- Less expensive than building a physical model.
- 3D models can be used to perform finite element analysis (stress, deflection, thermal)
- 3D models can be used directly in manufacturing, Computer Numerical Control (CNC).
- Can be used for presentations and marketing.

Wireframe Modeling

- Wire-frame modelling uses points and curves (i.e. lines, circles, arcs) to define objects.
- The user uses edges and vertices of the part to form a 3-D object



Wireframe model



Part

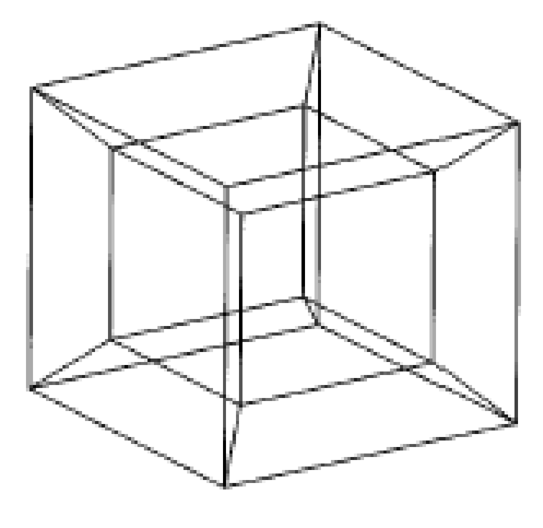
Wireframe modeling - Advantages

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

Wireframe modeling - Disadvantages

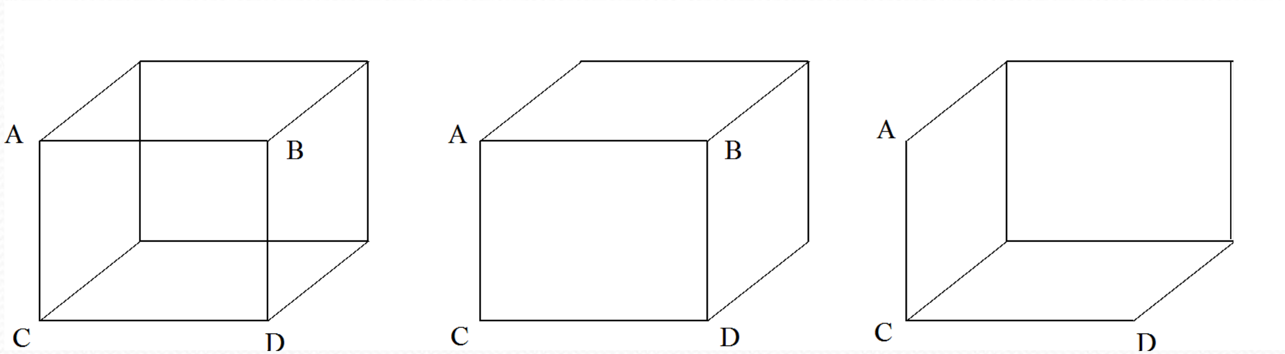
- Tend to be not realistic
- Do not represent an actual solids (no surface and volume).
- Cannot model complex curved surfaces.
- Cannot be used to calculate dynamic properties.
- Ambiguity
  - complex model difficult to interpret.

Wireframe modeling - Disadvantages



What does this object look like?

- Ambiguous views



Surface Modeling

" A surface model represents the skin of an object, these skins have no thickness or material type "

- Surface modeling is more sophisticated than wireframe modeling in that it defines not only the edges of a 3D object, but also its surfaces.
- In surface modeling, objects are defined by their bounding faces.

Surface modeling - Advantages

- Eliminates ambiguity and non-uniqueness present in wireframe models by hiding lines not seen.
- Renders the model for better visualization and presentation, objects appear more realistic.
- Provides the surface geometry for CNC machining.
- Provides the geometry needed for mold and die design.
- Can be used to design and analyze complex free-formed surfaces (car bodies)
- Surface properties such as roughness, color and reflectivity can be assigned and demonstrated.

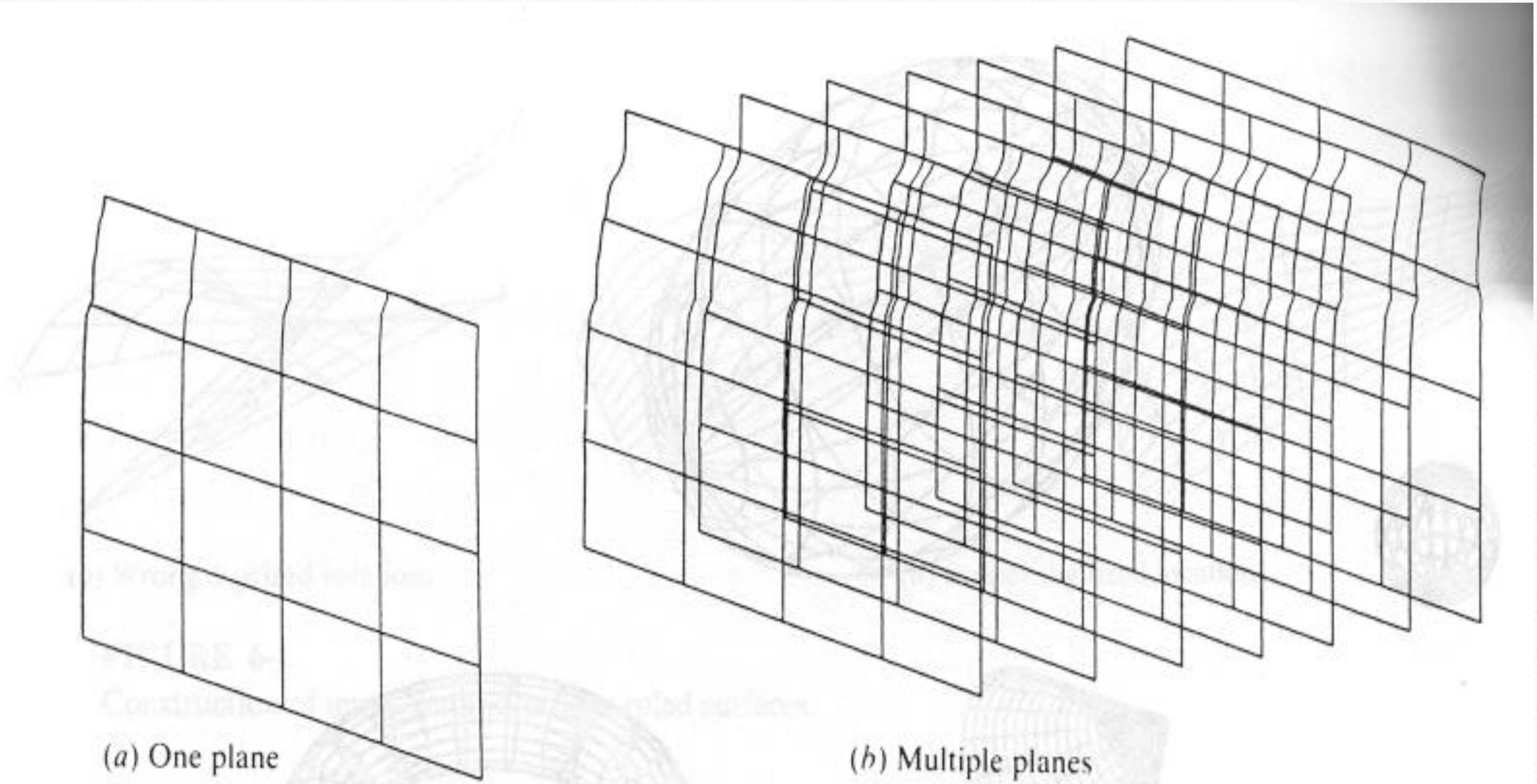
Surface modeling - Disadvantages

- Surface models provide no information about the inside of an object.
- Cannot be used to calculate dynamic properties.

Surface Entities

- **Analytic entities include** :
  - Plane surface,
  - Ruled surface,
  - Surface of revolution, and
  - Tabulated cylinder.
- **Synthetic entities include**
  - Hermite Cubic spline surface,
  - B-spline surface,
  - Bezier surface, and
  - Coons patches.

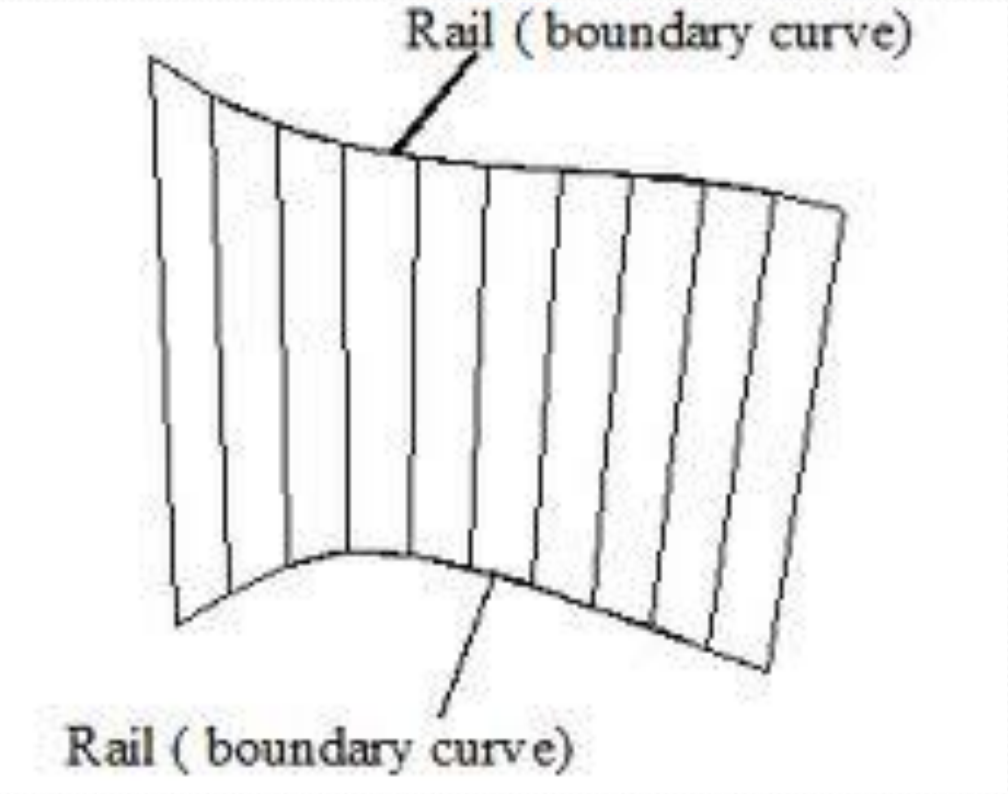
Plane surface



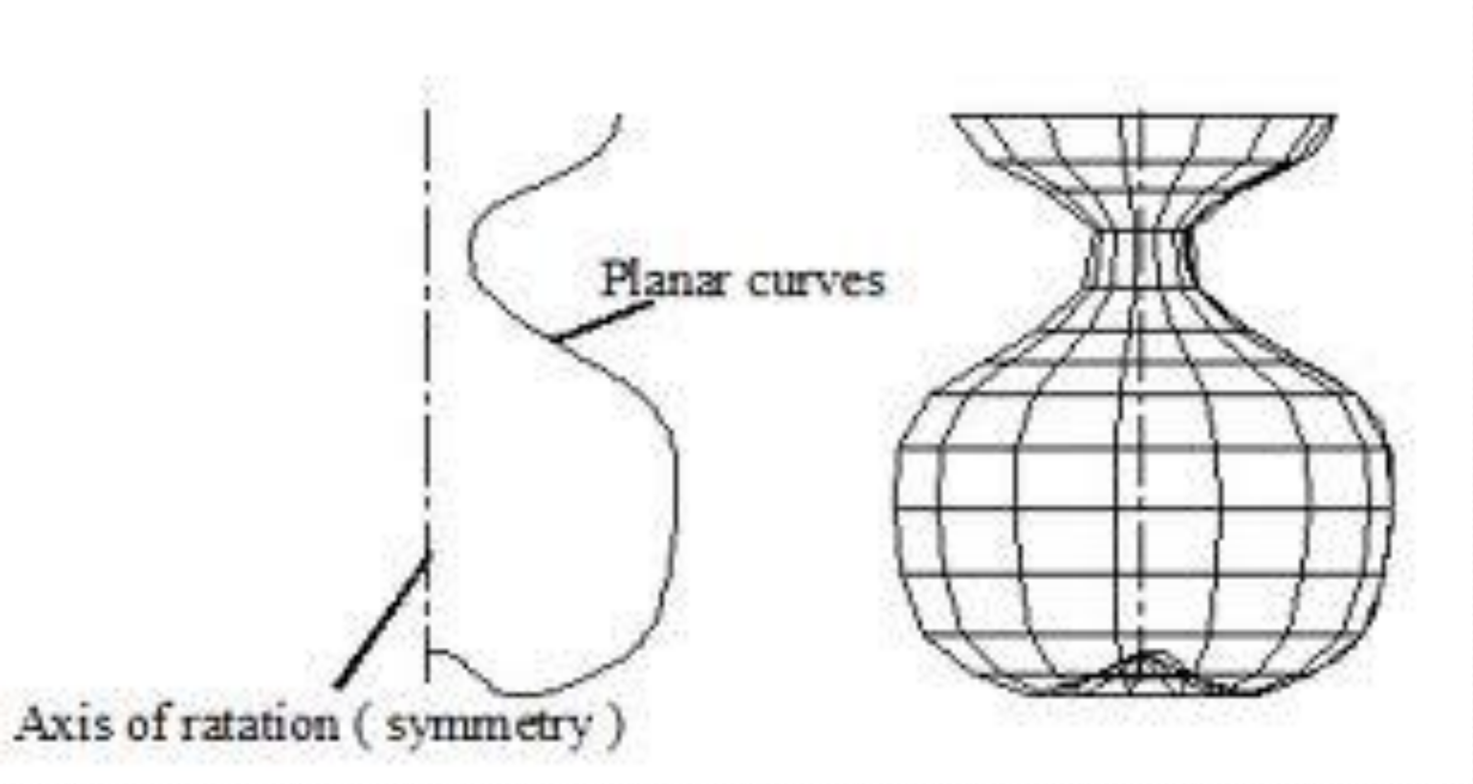
(a) One plane

(b) Multiple planes

Ruled (lofted) surface. This is a linear surface. It interpolates linearly between two boundary curves that define the surface.



Surface of revolution. This is an axisymmetric surface that can model axisymmetric objects. It is generated by rotating a planar wireframe entity in space about the axis of symmetry a certain angle.



Tabulated cylinder. This is a surface generated by translating a planar curve a certain distance along a specified direction (axis of the cylinder).

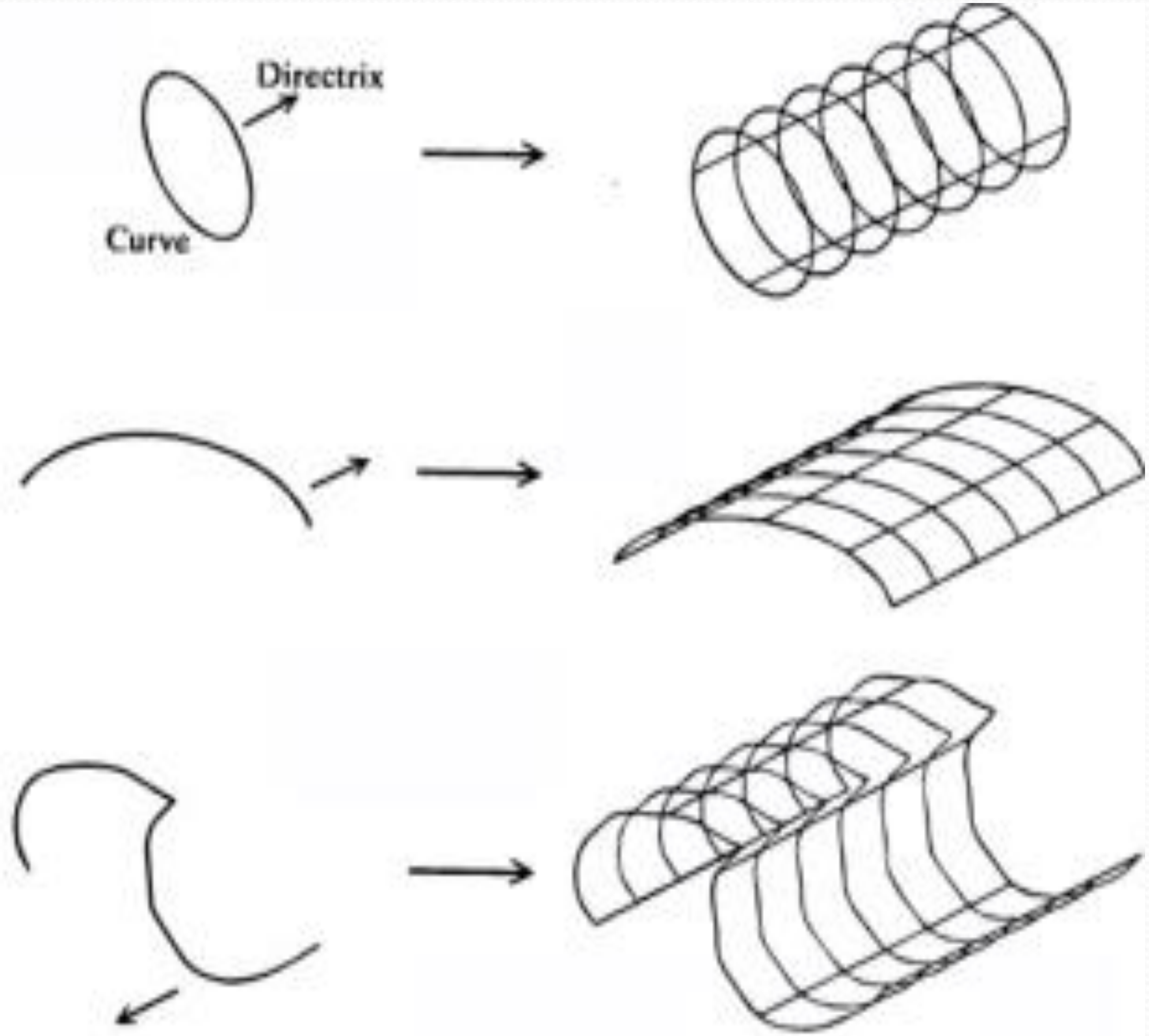


FIGURE 6-7
Tabulated cylinder.

Bezier surface. This is a surface that approximates given input data. It is different from the previous surfaces in that it is a synthetic surface. Similarly to the Bezier curve, it does not pass through all given data points. It is a general surface that permits, twists, and kinks . The Bezier surface allows only global control of the surface.

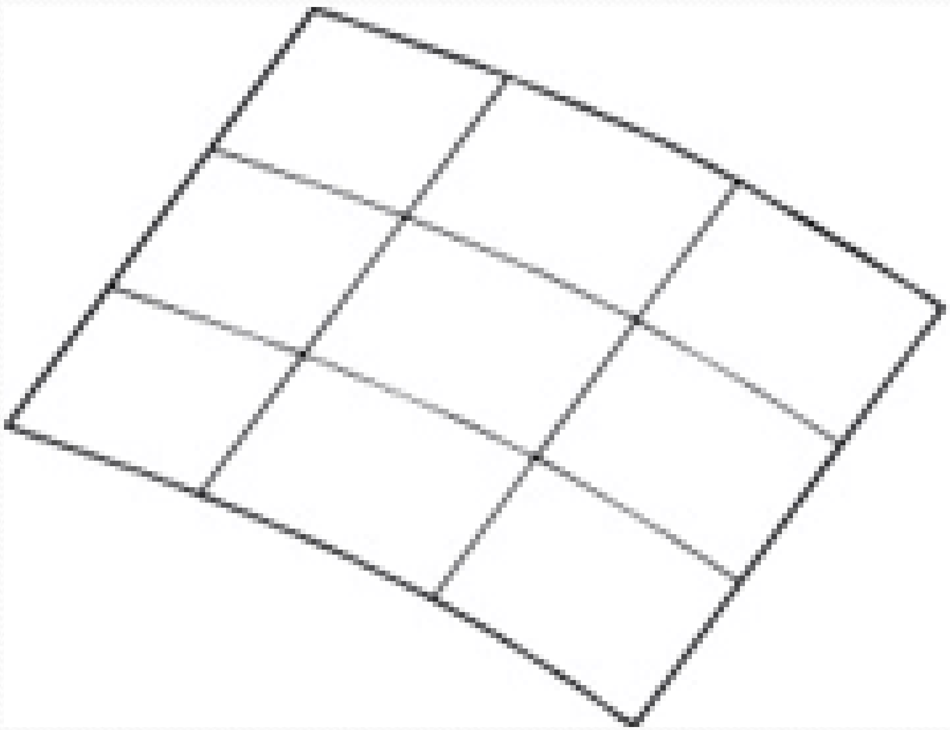
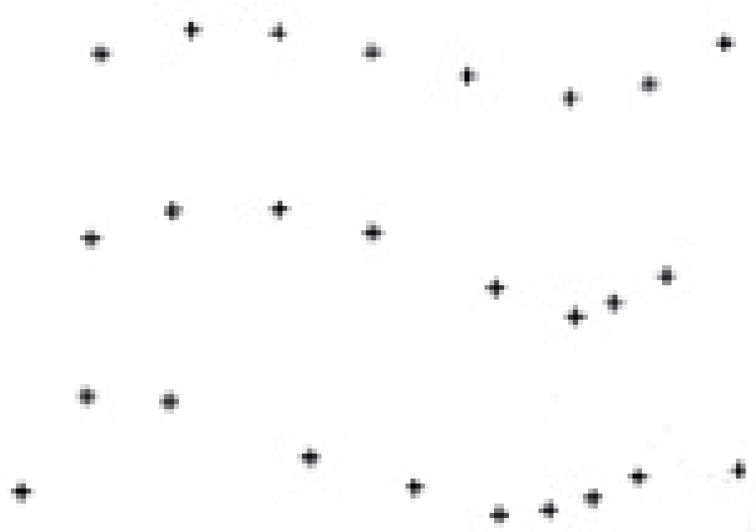
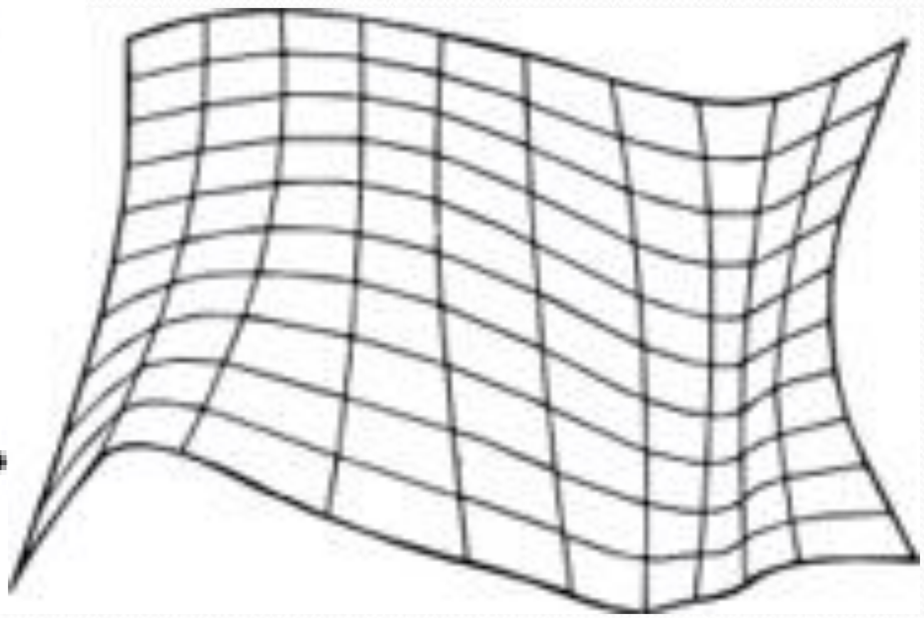


FIGURE 6-8
Bezier surface.

B-spline surface. This is a surface that can approximate or interpolate given input data. It is a synthetic surface. It is a general surface like the Bezier surface but with the advantage of permitting local control of the surface.



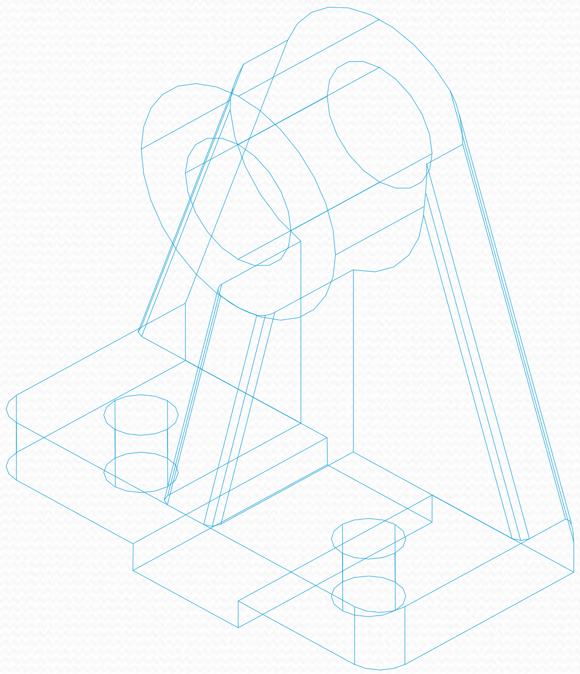
(a) Data points

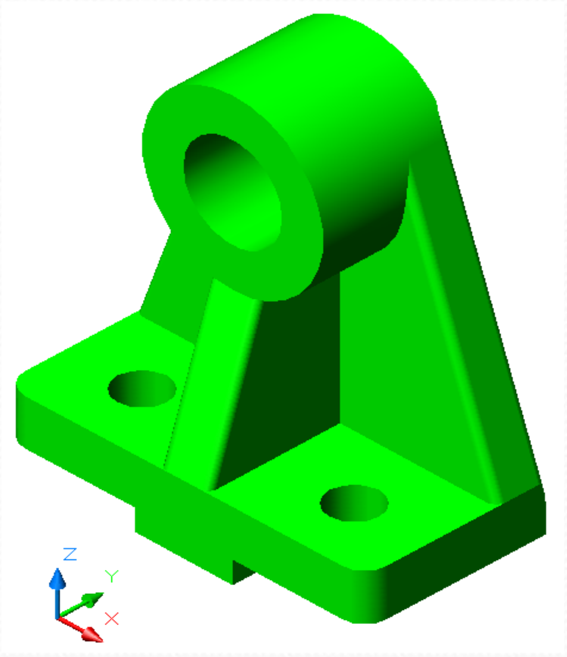


- Coons patch
- Fillet surface
- Offset surface

Solid Modeling

- In the solid modeling, the solid definitions include vertices (nodes), edges, surfaces, weight, and volume. The model is a complete and unambiguous representation of a precisely enclosed and filled volume





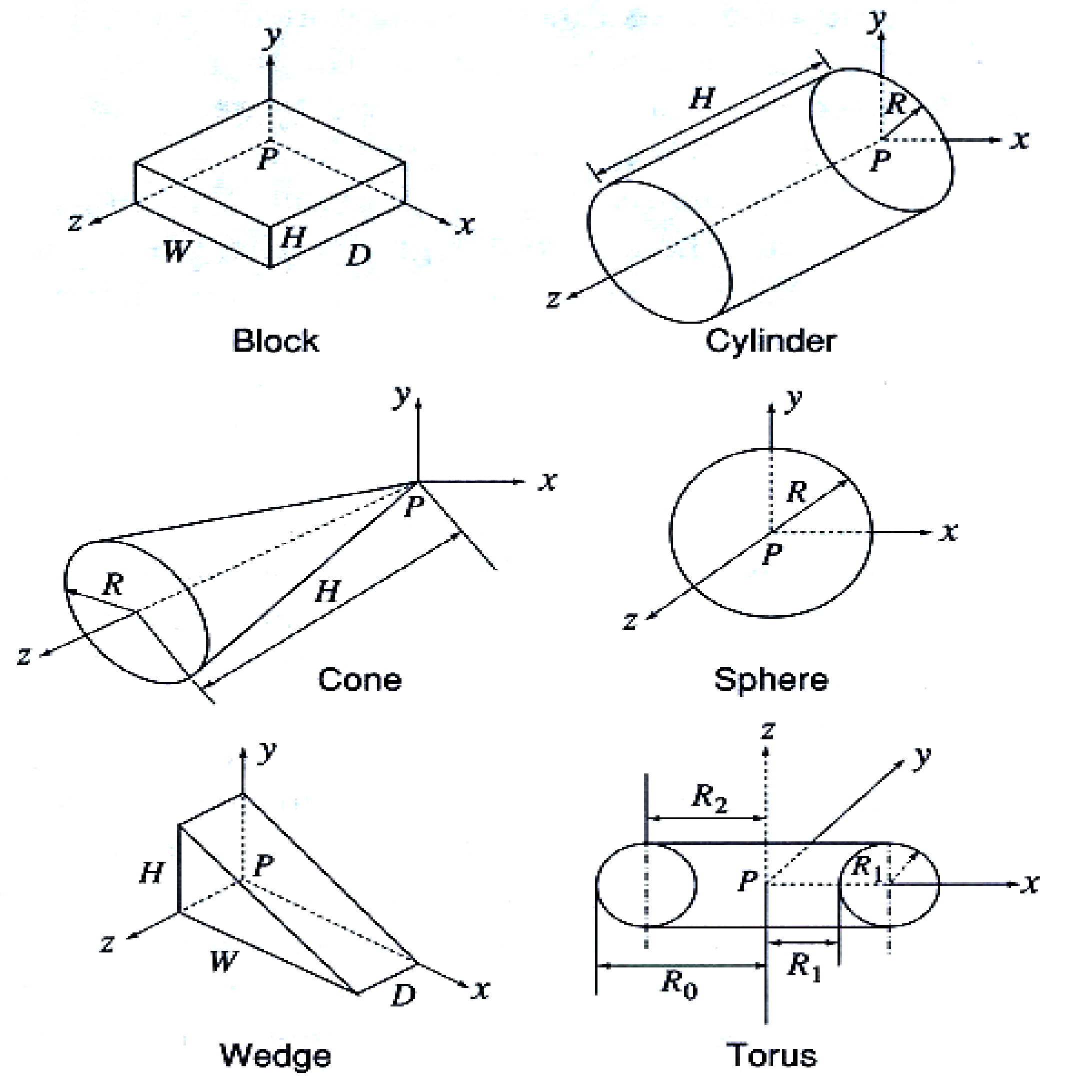
Methods of Creating Solid Models

- Constructive Solid Geometry (CSG), CAD packages; Unigraphics, AutoCAD – 3D modeler.
- Boundary Representation (B-rep), mostly used in finite element programs.
- Parametric Modeling, CAD packages: SolidWorks, Pro/Engineer

Primitive solids

Primitive creation functions:

- These functions retrieve a solid of a simple shape from among the primitive solids stored in the program in advance and create a solid of the same shape but of the size specified by the user



Constructive Solid Geometry, CSG

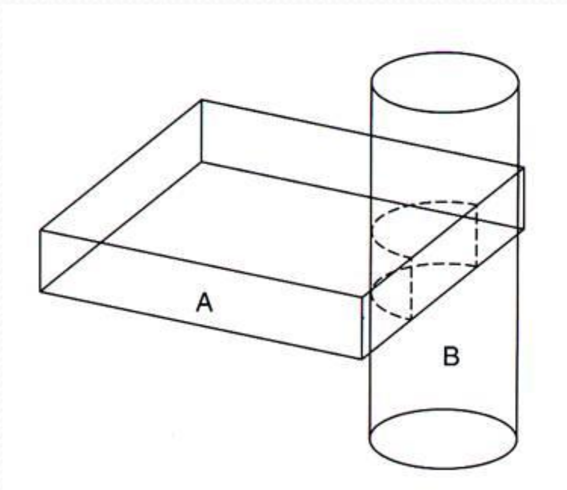
- CSG defines a model in terms of combining basic and generated (using extrusion and sweeping operation) solid shapes.
- Objects are represented as a combination of simpler solid objects (*primitives*).
- CSG uses Boolean operations to construct a model.
- There are three basic Boolean operations:

  Union **(Unite, join) - the operation combines two volumes included in the different solids into a single solid.**

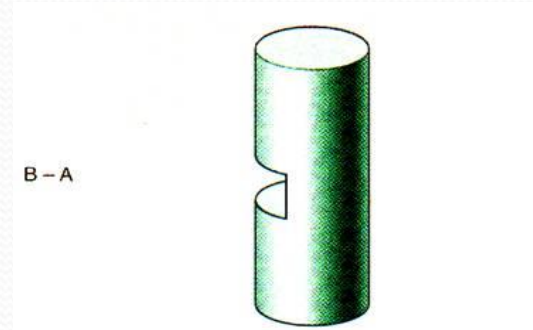
  Subtract **(cut) - the operation subtracts the volume of one solid from the other solid object.**

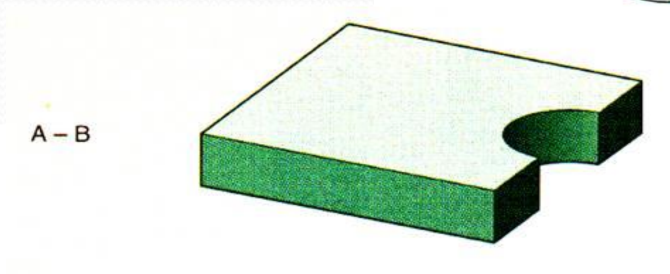
  Intersection **- the operation keeps only the volume common to both solids**

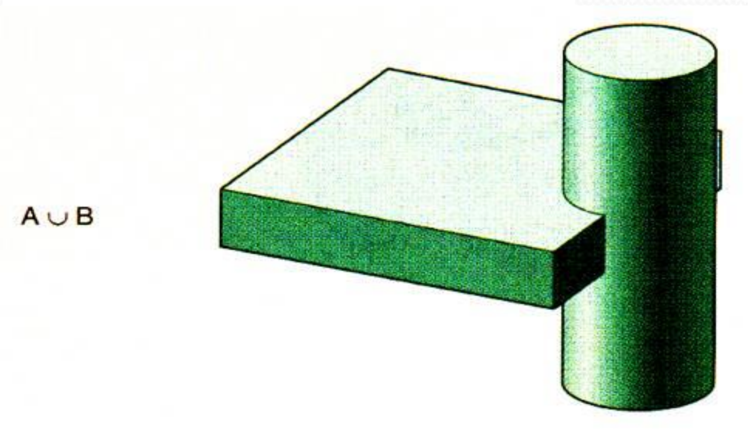
Boolean Operations

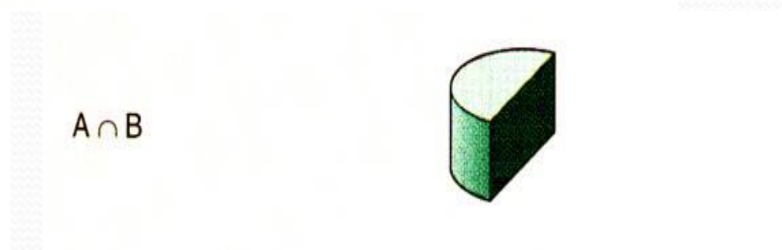


Subtract





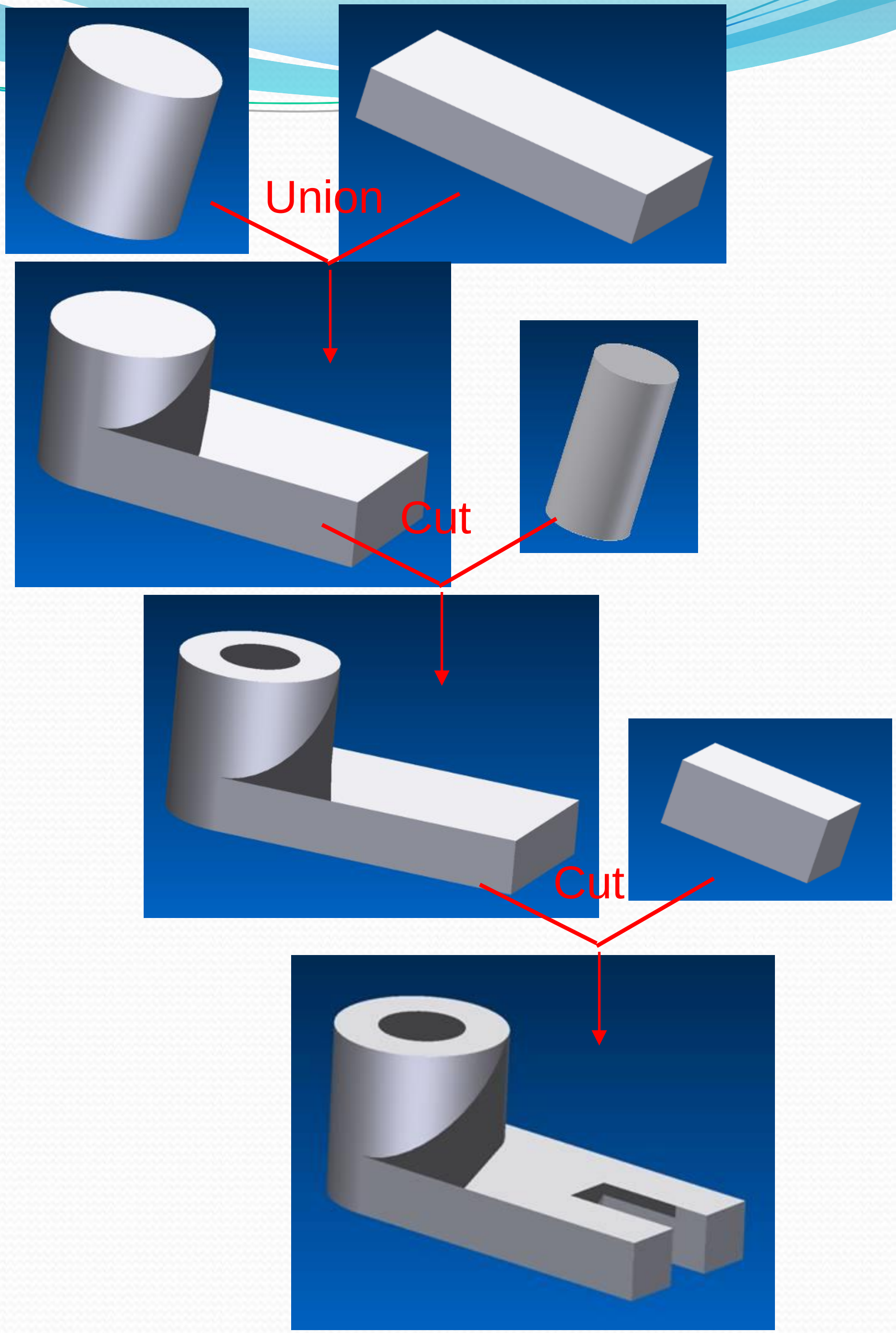




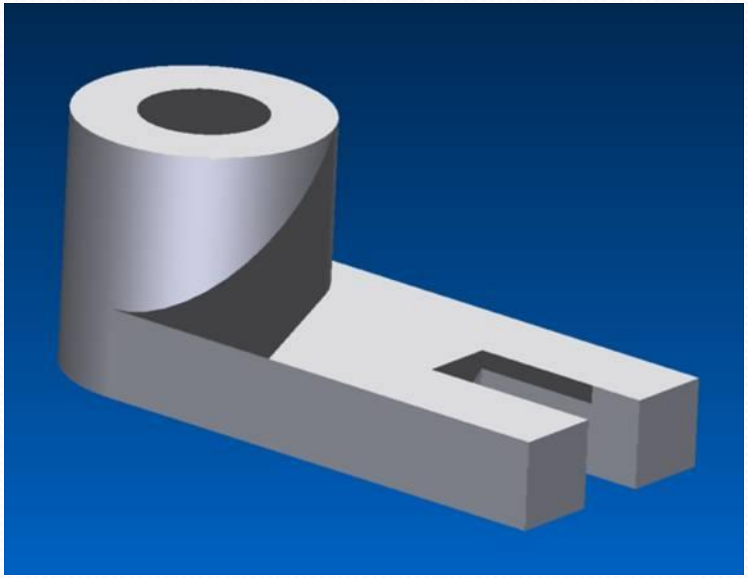
Union

Intersection

Solid Modeling Example Using CSG



Plan your modeling strategy before you start creating the solid model

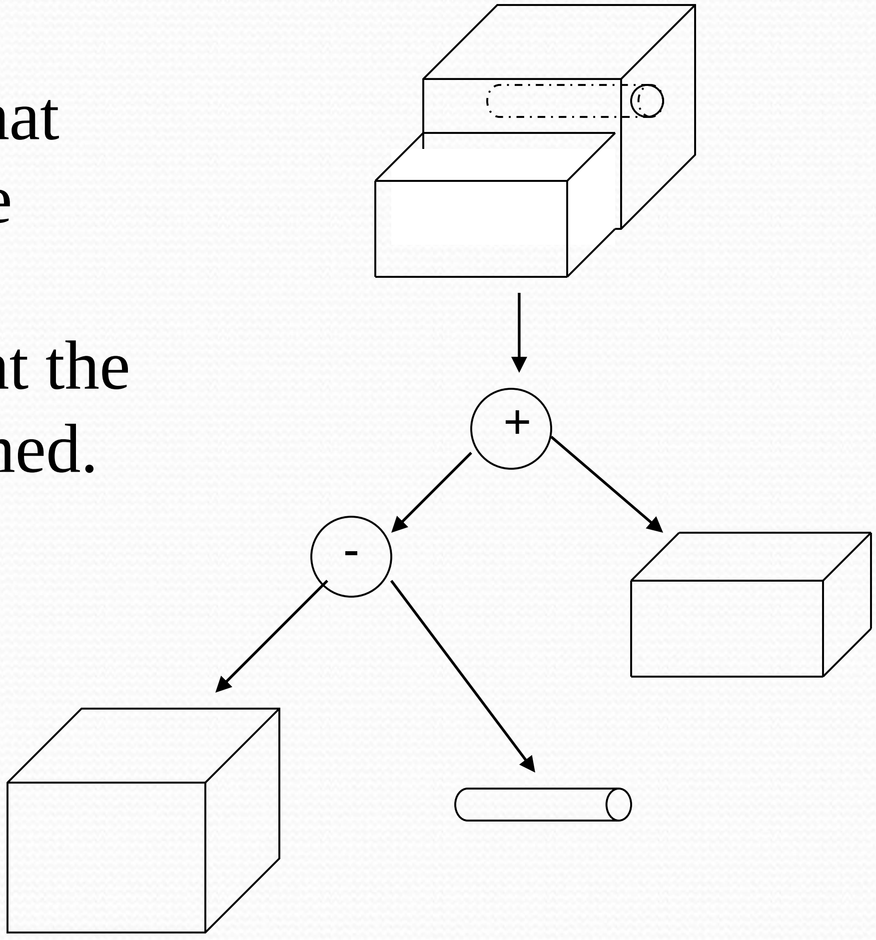


(CSG)- data structure

- Data structure does not define model shape explicitly but rather implies the geometric shape through a procedural description
  - E.g: object is not defined as a set of edges & faces but by the instruction : *union primitive1 with primitive 2*
- This procedural data is stored in a data structure referred to as a CSG tree
- The data structure is simple and stores compact data → easy to manage

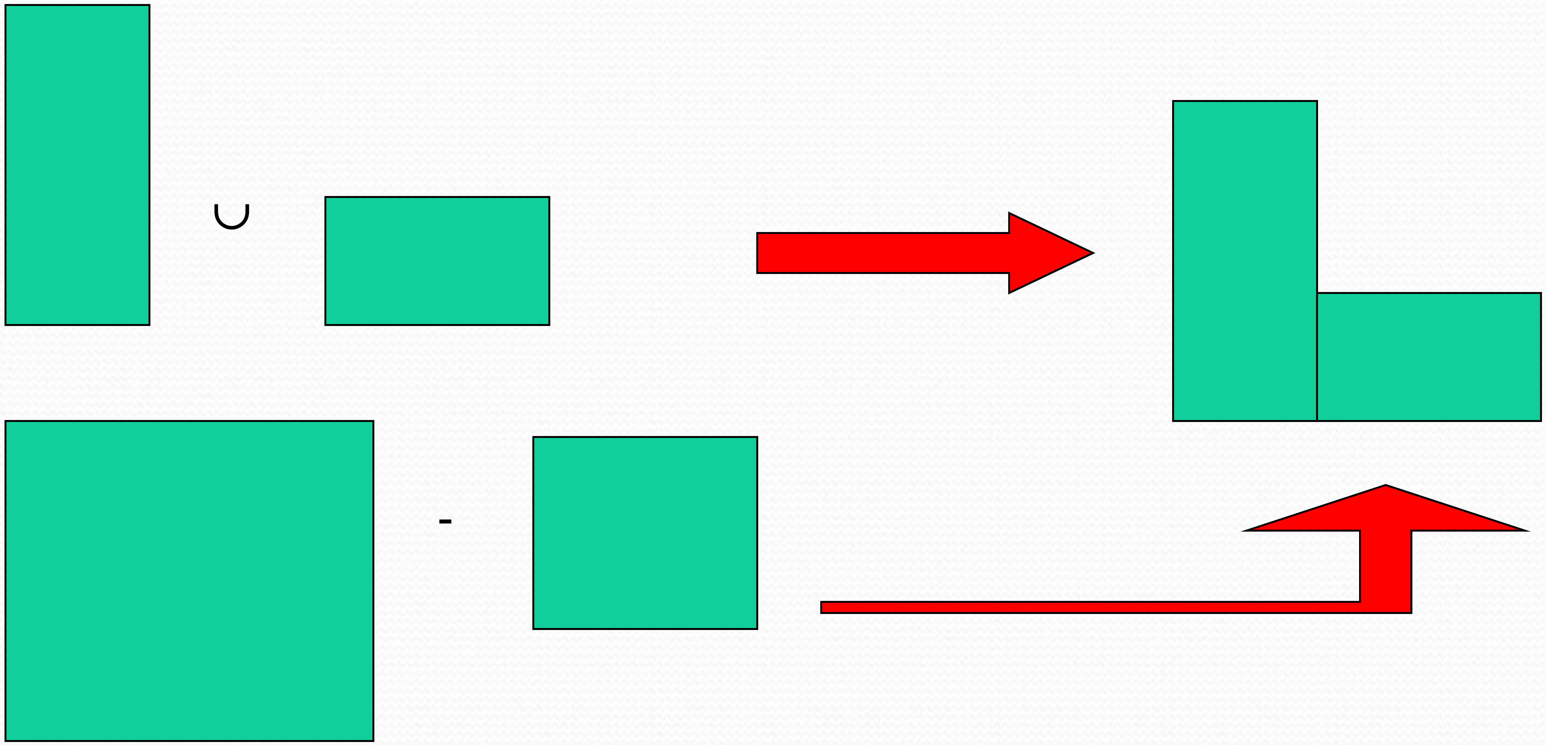
CSG Tree

- CSG tree → stores the history of applying boolean operations on the primitives.
  - Stores in a binary tree format
  - The outer leaf nodes of tree represent the primitives
  - The interior nodes represent the boolean operations performed.



CSG - Nonuniqueness of solid model

- More than one procedure (and hence database) can be used to arrive at the same geometry.



CSG - Advantage

- CSG is powerful with high level command.
- Easy to construct a solid model – minimum step.
- CSG modeling techniques lead to a concise database→ less storage.
  - Complete history of model is retained and can be altered at any point.
- Can be converted to the corresponding boundary representation.

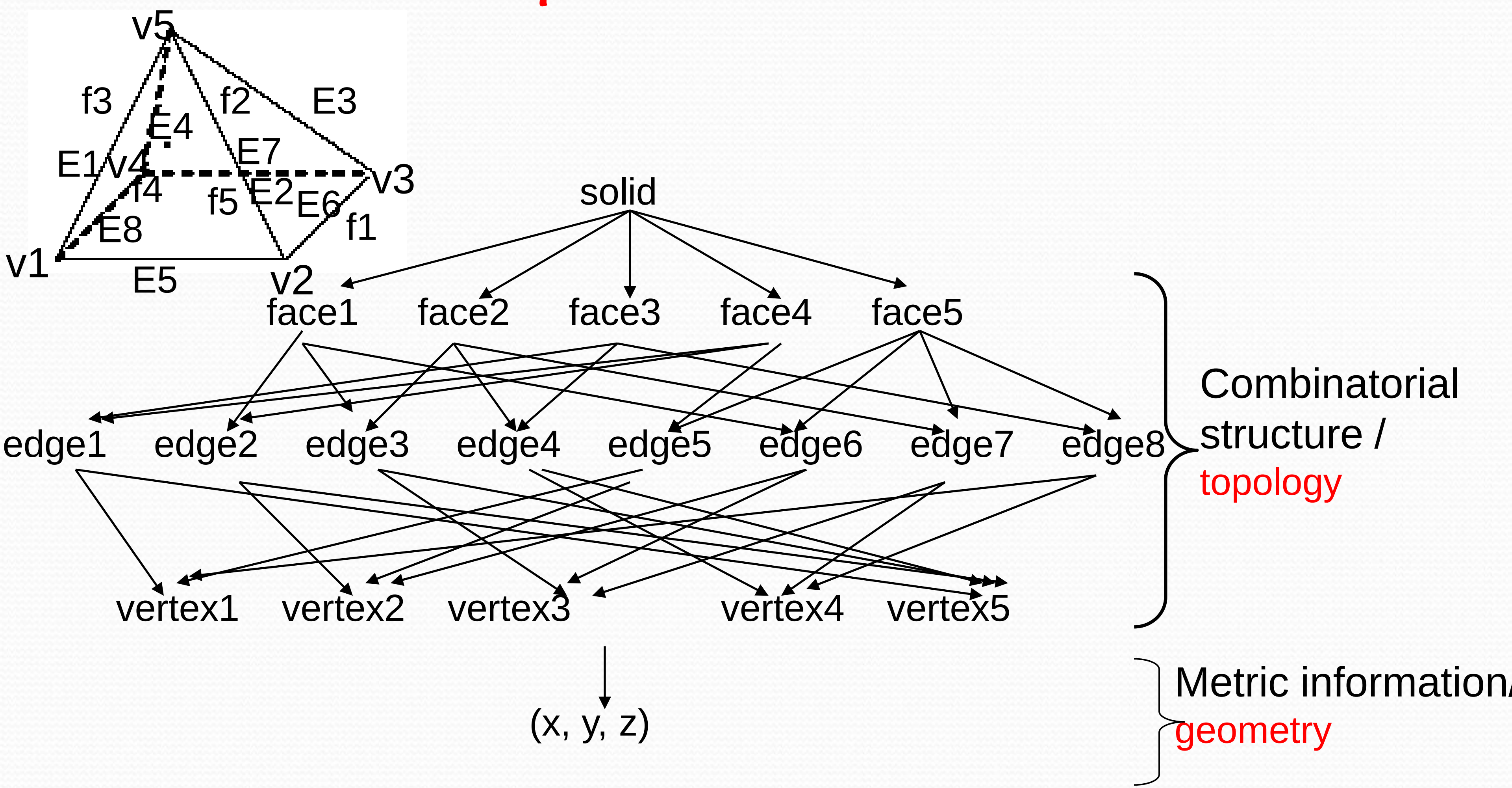
CSG - Disadvantage

- Only boolean operations are allowed in the modeling process → with boolean operation alone, the range of shapes to be modeled is severely restricted → not possible to construct unusual shape.
- Requires a great deal of computation to derive the information on the boundary, faces and edges which is important for the interactive display/ manipulation of solid.

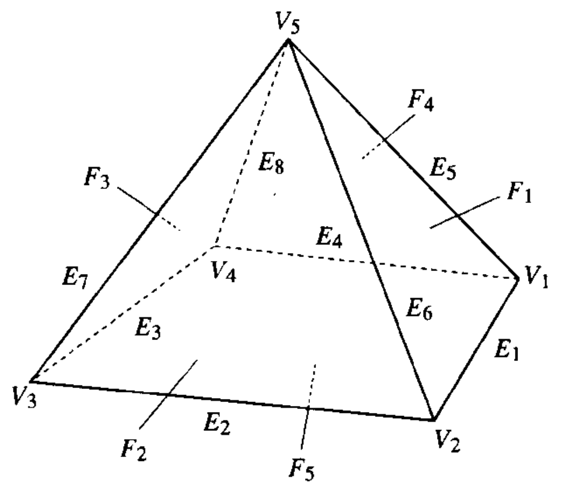
Boundary Representation (B-rep)

- Solid model is defined by their enclosing surfaces or boundaries. This technique consists of the geometric information about the faces, edges and vertices of an object with the topological data on how these are connected.
- B-rep model is created using Euler operation
- *Data structure :*
  - B-Rep graph store face, edge and vertices as nodes, with pointers, or branches between the nodes to indicate connectivity.

B-Rep data structure



B-Rep data structure



Face Table

Face	*Edges*
F_1	E_1, E_5, E_6
F_2	E_2, E_6, E_7
F_3	E_3, E_7, E_8
F_4	E_4, E_8, E_5
F_5	E_1, E_2, E_3, E_4

Edge Table

Edge	*Vertices*
E_1	V_1, V_2
E_2	V_2, V_3
E_3	V_3, V_4
E_4	V_4, V_1
E_5	V_1, V_5
E_6	V_2, V_5
E_7	V_3, V_5
E_8	V_4, V_5

Vertex Table

Vertex	*Coordinates*
V_1	x_1, y_1, z_1
V_2	x_2, y_2, z_2
V_3	x_3, y_3, z_3
V_4	x_4, y_4, z_4
V_5	x_5, y_5, z_5
V_6	x_6, y_6, z_6

Boundary representation-validity

- System must validate topology of created solid.
- For topology consistency, certain rules have to be followed
  - Faces should be bound by a simple loop of edges and should be not intersected by itself.
  - Each edge should exactly adjoin two faces and each edge should have a vertex at each ends.
  - At least three edges should meet at each vertex.

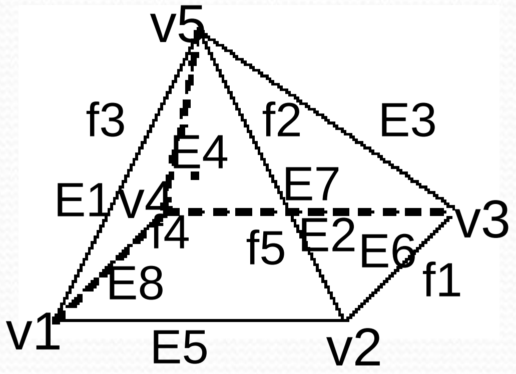
Boundary representation-validity

- Validity also checked through mathematical evaluation
  - Evaluation is based upon Euler's Law (valid for simple solid – no hole)
  - V – E + F = 2

V- number of vertices

E- number of edges

F- number of faces

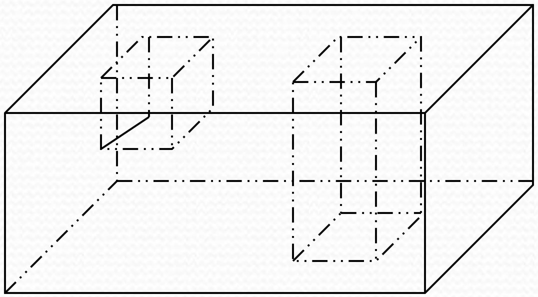


V = 5, E = 8, F = 5

5 – 8 + 5 = 2

Boundary representation-validity

- Expanded Euler’s law for complex polyhedrons (with holes)
- Euler-Poincare Law:
  - V-E+F-H+2P=2B
  - H – number of holes in face,   P- number of passages or through holes, B- number of separate bodies.

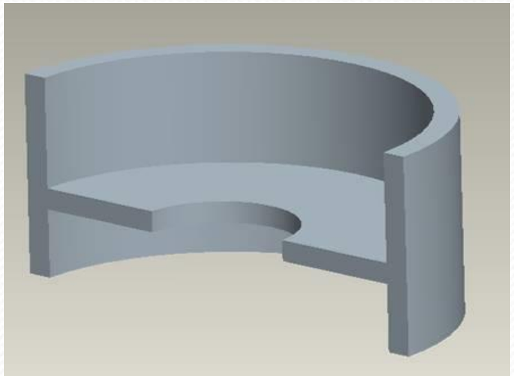


V = 24, E=36, F=15, H=3, P=1,B=1

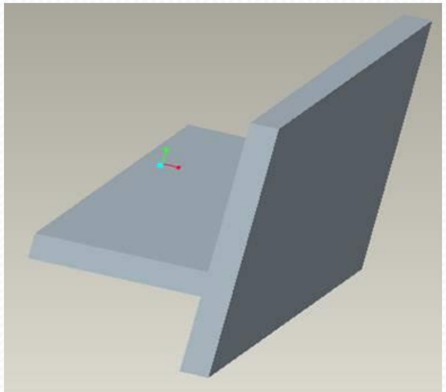
Operation performed

(Extrude Feature, Revolve Feature, Sweep, Loft, Fillet, Chamfer)

- " Feature" --- (shape & operation)
  - Operation --- (Sweep, extrude, Revolve, Boolean)
- *Sketched Feature*
  - ➢ Create a 2D sketch.
  - ➢ Create a feature from the sketch by extruding, revolving, sweeping, lofting and blending.



Revolved feature



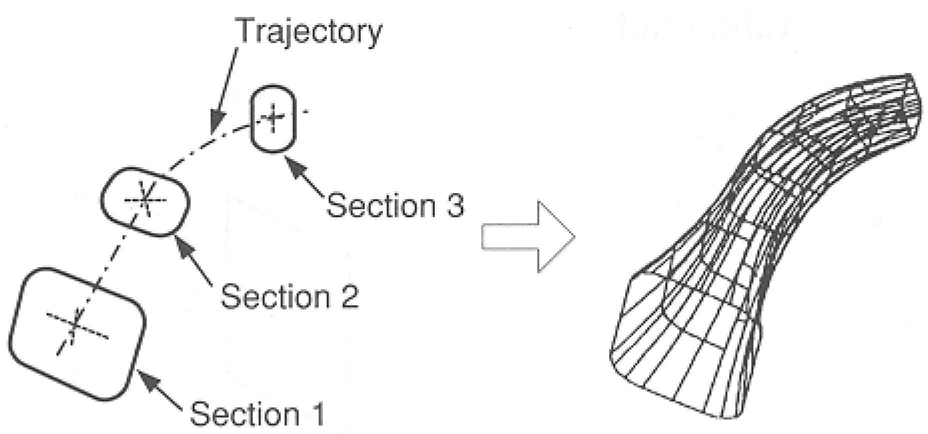
Extruded (Protruded) feature

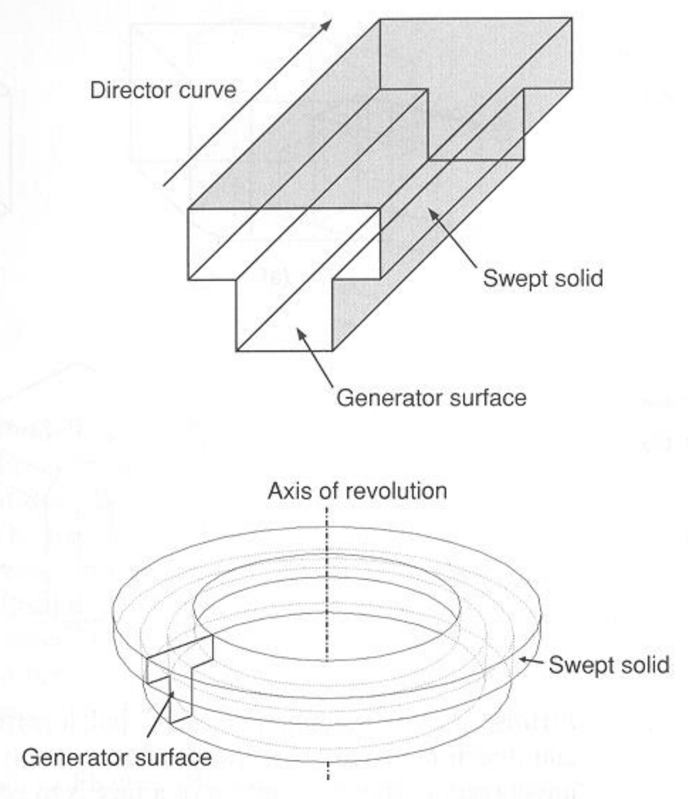
Sweeping

- Linear
  - Extrusion
- Non – linear
  1. Sweep a cross section along a guide curve
  2. “BLEND” two cross section linearly.(linear sweep between two section)
  3. Sweep two cross section along a guide curve.
  4. “LOFT” – to blend two cross section. (like 2 & 3))

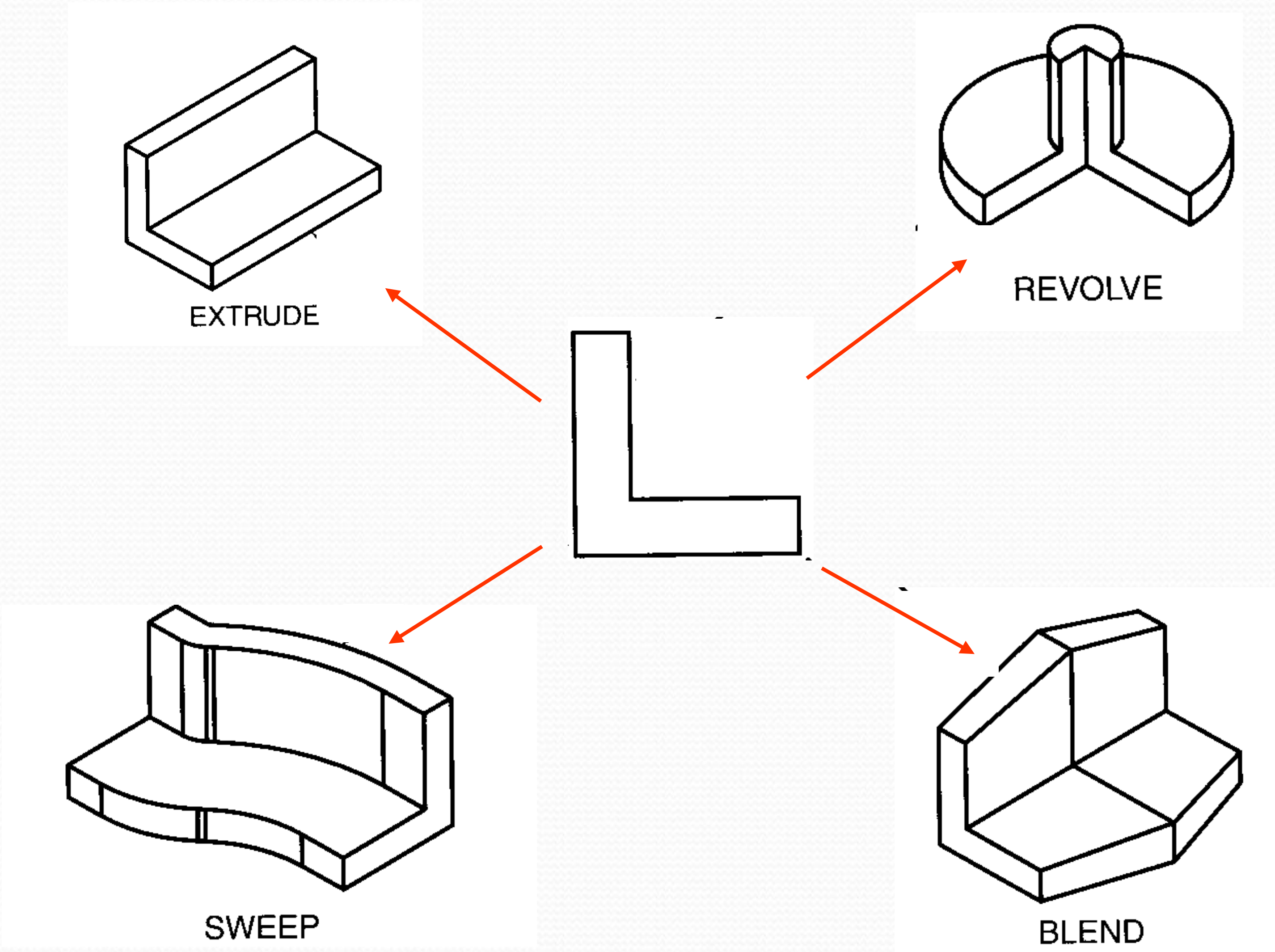
Operation performed

- **Sweeping:** *Sweeping* is a modeling function in which a planar closed domain is translated or revolved to form a solid. When the planar domain is translated, the modeling activity is called *translational sweeping;* when the planar region is revolved, it is called *swinging*, *or rotational sweeping.*



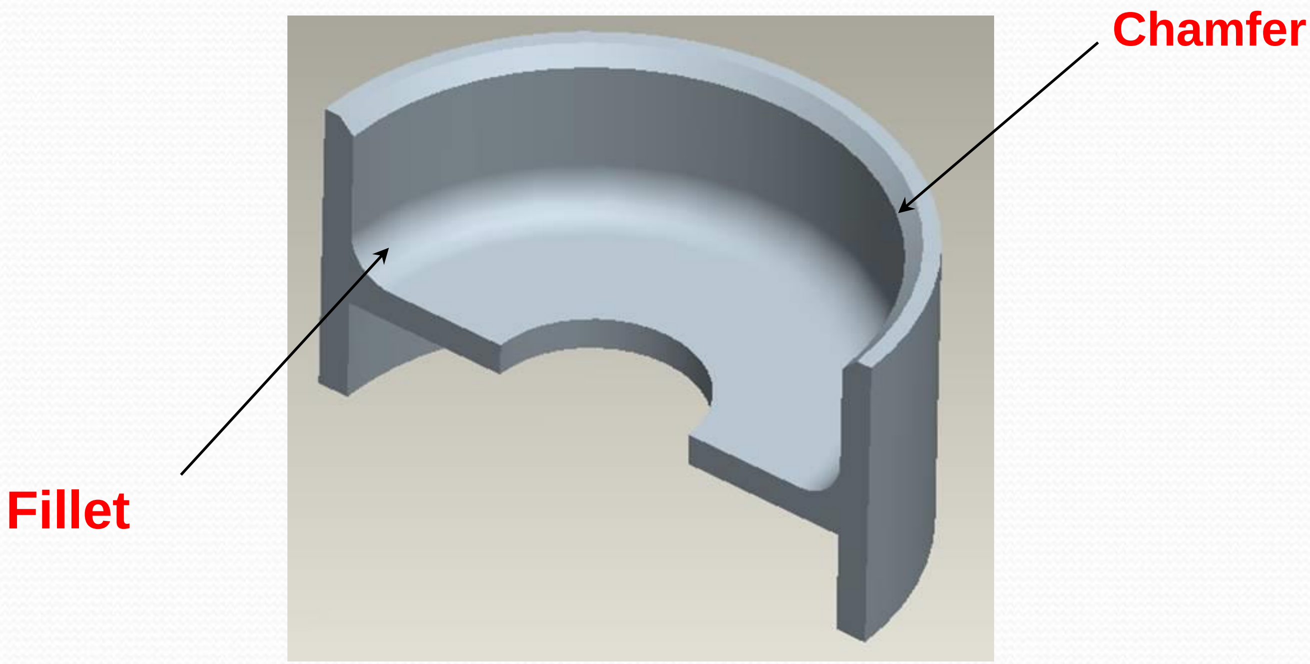


Creating Features from Sketches



Applied Feature

- Applied feature does not require a sketch.
- They are applied directly to the model.
- Fillets and chamfers are very common applied features.



Boundary representation-advantages

- Capability to construct unusual shapes that would not be possible with the available CSG→ aircraft
- Less computational time to reconstruct the image

Boundary representation-disadvantages

- Requires more storage
- More prone to validity failure than CSG
- Model display limited to planar faces and linear edges

  - complex curve and surfaces only approximated

Solid modeling - Advantages

- Has all the advantages of surface models (uniqueness, non-ambiguous, realistic, surface profile) plus volumetric information.
- Allows the designer to create multiple options for a design.
- 2D standard drawings, assembly drawing and exploded views are generated form the 3D model.
- Can easily be exported to different Finite Element Methods programs for analysis.
- Mass and volumetric properties of an object can be easily obtained; total mass, mass center, area and mass moment of inertia, volume, radius of gyration

Solid modeling - Disadvantages

- More intensive computation than wireframe and surface modeling.
- Requires more powerful computers (faster with more memory and good graphics)

Creating Solid Models
Parametric Modeling Concept

- ***Parametric*** is a term used to describe a dimension's ability to change the shape of model geometry if the dimension value is modified.
- ***Feature-based*** is a term used to describe the various components of a model. For example, a part can consists of various types of features such as holes, grooves, fillets, and chamfers.
- Parametric modeler are featured-based, parametric, solid modeling design program: **SolidWorks, Pro-Engineer, Unigraphics (CSG and parametric),** …..

Design Intent

- In parametric modeling, dimensions control the model.
- Design intent is how your model will react when dimension values are changed.

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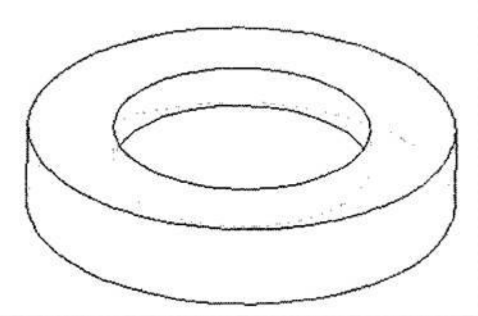
Boolean Versus Parametric Modeling

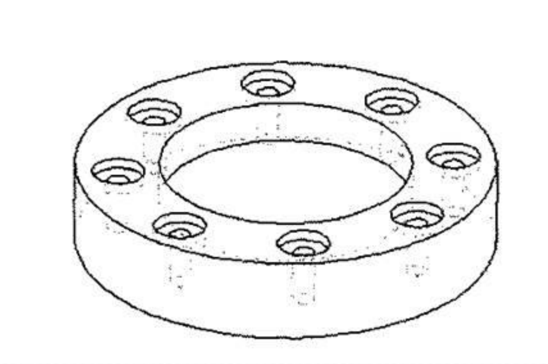
The ability to go back on some earlier stage in the design process and make changes by editing a sketch or changing some dimensions is extremely important to a designer. This is the main advantage of a ***parametric*** (SolidWorks, Unigraphics, Inventor, Pro-Engineer) over a ***non-parametric*** modeler (AutoCAD 3D modeler – Boolean operation)

Boolean Versus Parametric Modeling

Example:

Let's assume that it is desired to design a part consisting of a ring with a certain thickness and a series of counter bore holes along the perimeter.

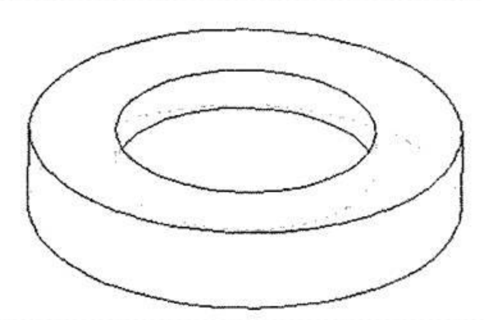




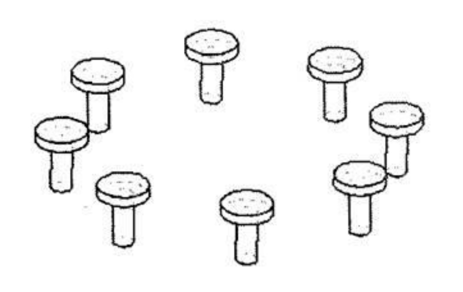
Boolean Versus Parametric Modeling

Boolean operation

Make the base part by creating two cylinders and subtract the small one from the large one

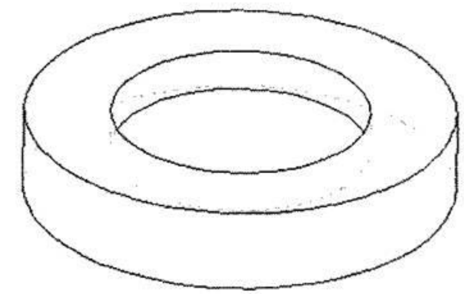


Create the solid geometry that will become the counterbore holes and generate the pattern.

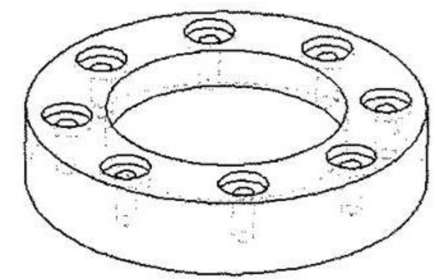


Boolean Versus Parametric Modeling

Position the pattern about the perimeter of the base part. Locating the holes is critical to creating an accurate solid model.



Subtract the pattern from the base part to create the actual holes.



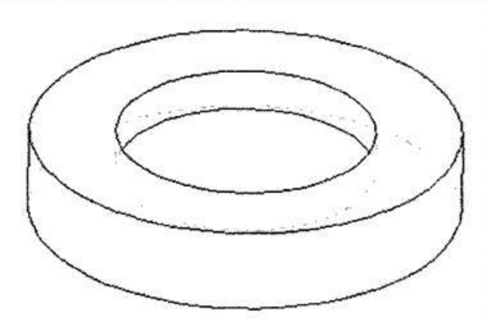
What would happen if you had to come back to this part to change the thickness of the ring or size of the counterbore holes?

Since Boolean operation was used to create the part, changing the thickness would not increase the height of the holes. There is no association between the thickness and the hole pattern location.

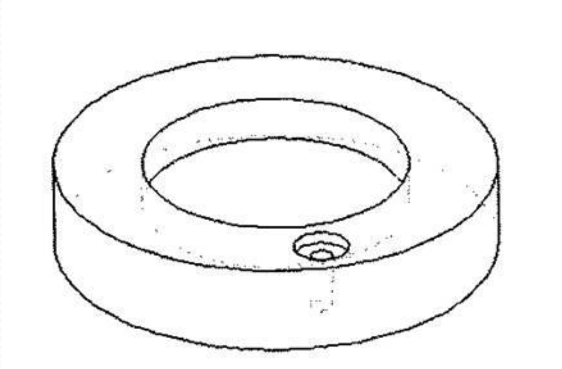
Boolean Versus Parametric Modeling

Parametric modeling (SolidWorks, ProE, UG, …)

Create the initial base, the ring, by extruding the profile (circles) in a particular direction (Pro/E or SolidWorks) or use primitive solids and Boolean operation (UG).

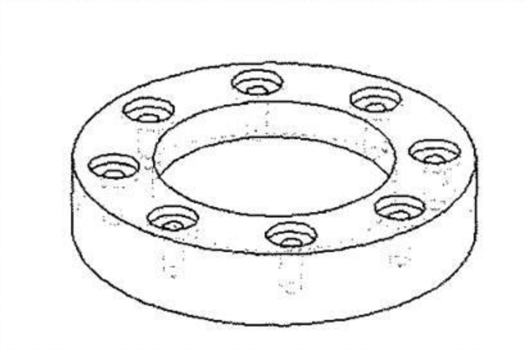


Create the counterbore as a feature. Select the top surface of the ring and either sketch the two holes and extrude at different depth or use the hole feature option.



Boolean Versus Parametric Modeling

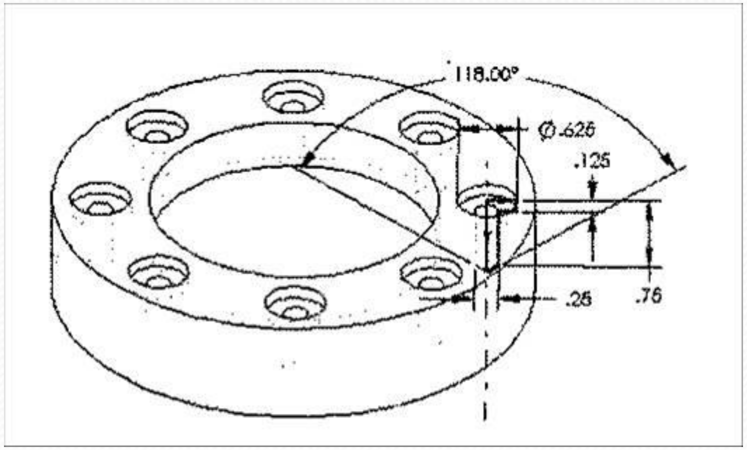
The next step would be to pattern the hole. The pattern would actually be considered a feature in itself, and would have its set of parametric variables, such as the number of copies and the angle between copies.



The model created would be identical to the one created using Boolean operation, **but with intelligence built into the model.**

Boolean Versus Parametric Modeling

The true power of parametric modeling shines through when ***design changes*** need to be made. The design modification is made by simply changing a dimension.



Since the counterbore is associated with the top surface of the ring, any changes in the thickness of the ring would automatically be reflected on the counterbore depth.

Sketching and Features

When discussing the mind-set needed for working with parametric modelers, there are two topics that need to be expanded: ***Sketching and Features***

Sketching

- Take the word sketch literally. A sketch should be just that, a *sketch*.
- When sketching, it is not necessary to create geometry with accuracy. Lines, arcs, and additional geometry need not be created with exact dimensions in mind.
- When the dimensions are added, the sketch will change size and shape. This is the essence of Parametric Modeling.

In short, the sketch need only be the approximate size and shape of the part being designed. When dimensions and constraints are added, they will drive the size and the shape of the geometry.

Summary - Solid Modeling Methods

- **Primitive creation modeling**

  A solid model is created by retrieving primitive solids and performing Boolean operations

- **Sweeping function**

  Creates a solid by translating, revolving or sweeping a predefined 2D shape ***(Sketching)*.**

  If geometric and dimensional constraints are imposed, it is called ***Parametric Modeling***.

- **Feature-based Modeling**

  Models a solid by using familiar shapes; holes, slots, grooves, pockets, chamfers, fillets…..