SOLID MODELLING

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COMPUTER GRAPHICS

Why solid modeling?

- Recall weakness of wireframe and surface modeling
  - Ambiguous geometric description
  - incomplete geometric description
  - lack topological information
  - Tedious modeling process
  - Awkward user interface

Solid model

- Solid modeling is based on *complete, valid and unambiguous* geometric representation of physical object.
  - Complete → points in space can be classified. (inside/ outside)
  - Valid →vertices, edges, faces are connected properly.
  - Unambiguous → there can only be one interpretation of object

Solid model representation schemes

1. Constructive solid geometry (CSG)
2. Boundary representation (B-rep)
3. Spatial enumeration
4. Instantiation.

Constructive solid geometry (CSG)

- Objects are represented as a combination of simpler solid objects (*primitives*).

- The primitives are such as cube, cylinder, cone, torus, sphere etc.

- Copies or "instances" of these primitive shapes are created and positioned.

- A complete solid model is constructed by combining these "instances" using set specific, logic operations (Boolean)

Constructive solid geometry (CSG)

- Boolean operation
  - each primitive solid is assumed to be a set of points, a boolean operation is performed on point sets and the result is a solid model.
  - Boolean operation → union, intersection and difference
  - The relative location and orientation of the two primitives have to be defined before the boolean operation can be performed.
 - Boolean operation can be applied to two solids other than the primitives.

Constructive solid geometry (CSG)- boolean operation

- Union
  - The sum of all points in each of two defined sets. (logical "OR")
 - Also referred to as Add, Combine, Join, Merge

A   B

A ∪ B
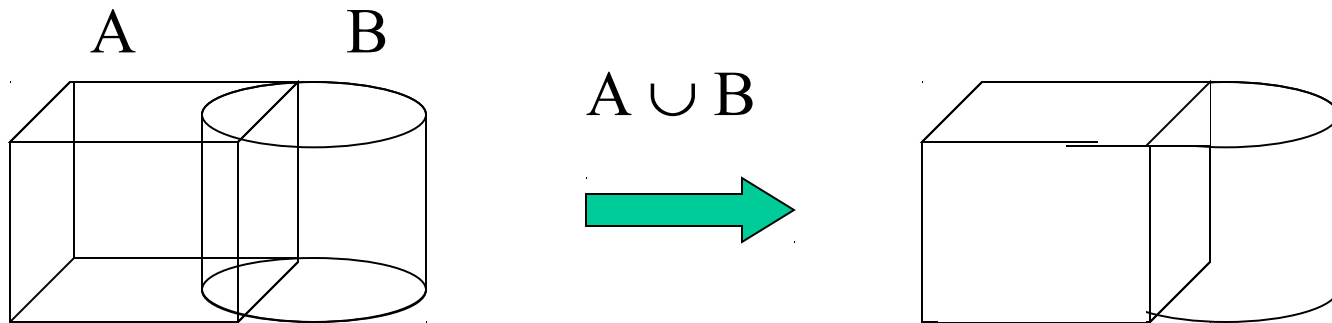
Constructive solid geometry (CSG)- boolean operation

- Difference
  - The points in a source set minus the points common to a second set. (logical "NOT")
  - Set must share common volume
  - Also referred to as subtraction, remove, cut

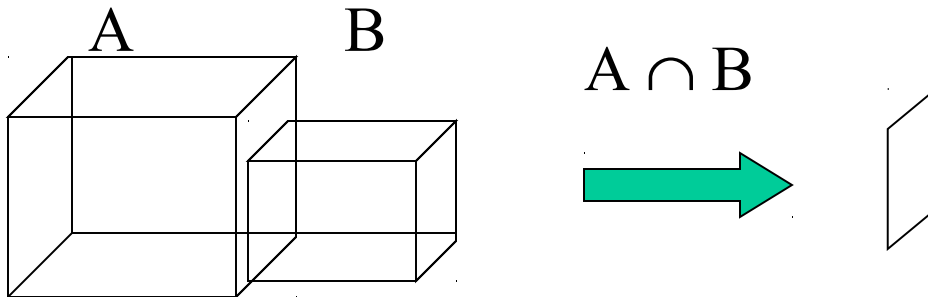A   B   A - B
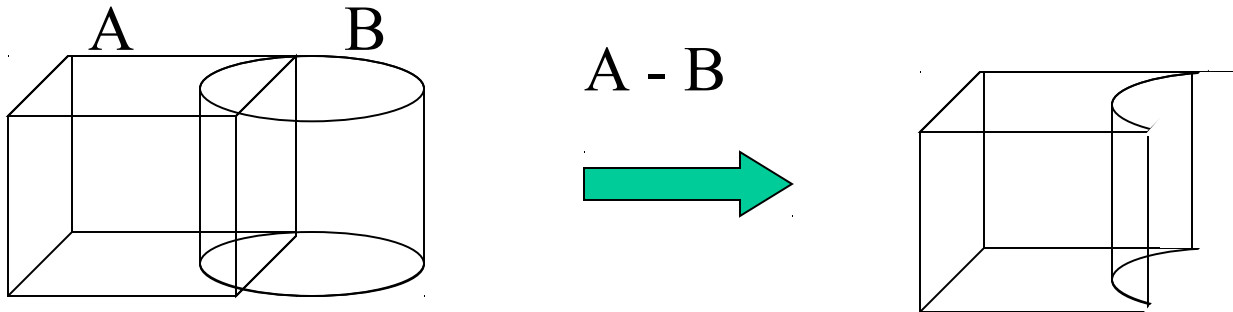
Constructive solid geometry (CSG)- boolean operation

- intersection
  - Those points common to each of two defined sets (logical "AND")
  - Set must share common volume
  - Also referred to as common, conjoin

A   B $A \cap B$
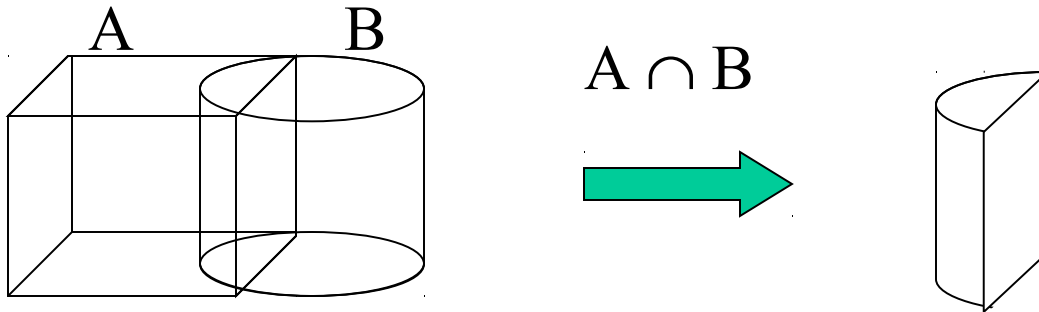
Constructive solid geometry (CSG)- boolean operation

- When using boolean operation, be careful to avoid situation that do not result in a valid solid

A   B

$A \cap B$

Constructive solid geometry (CSG)- boolean operation

- Boolean operation
  - Are intuitive to user
  - Are easy to use and understand
  - Provide for the rapid manipulation of large amounts of data.
- Because of this, many non-CSG systems also use Boolean operations

Constructive solid geometry (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

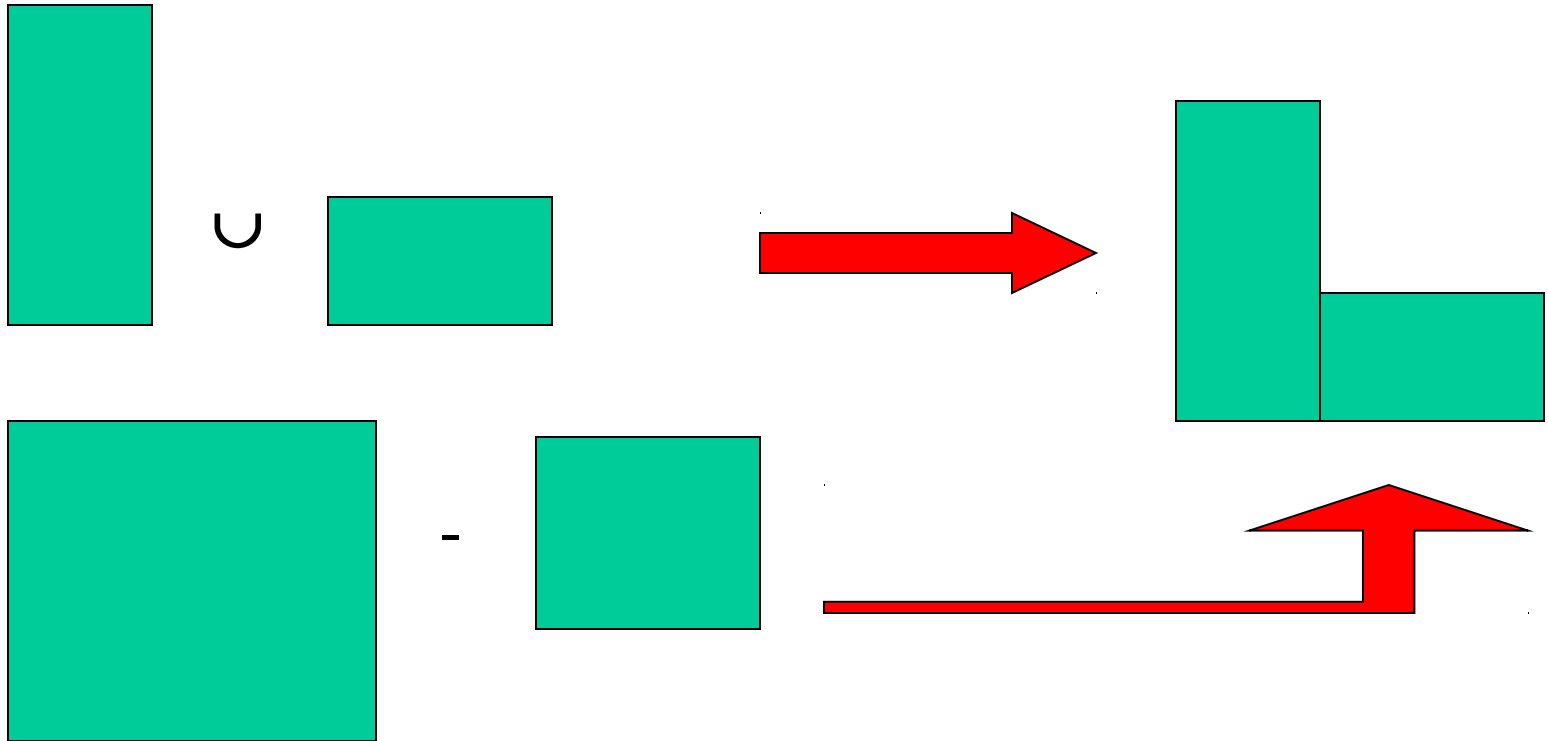# Constructive solid geometry (CSG)- CSG tree

- 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.

Constructive solid geometry (CSG)- CSG tree
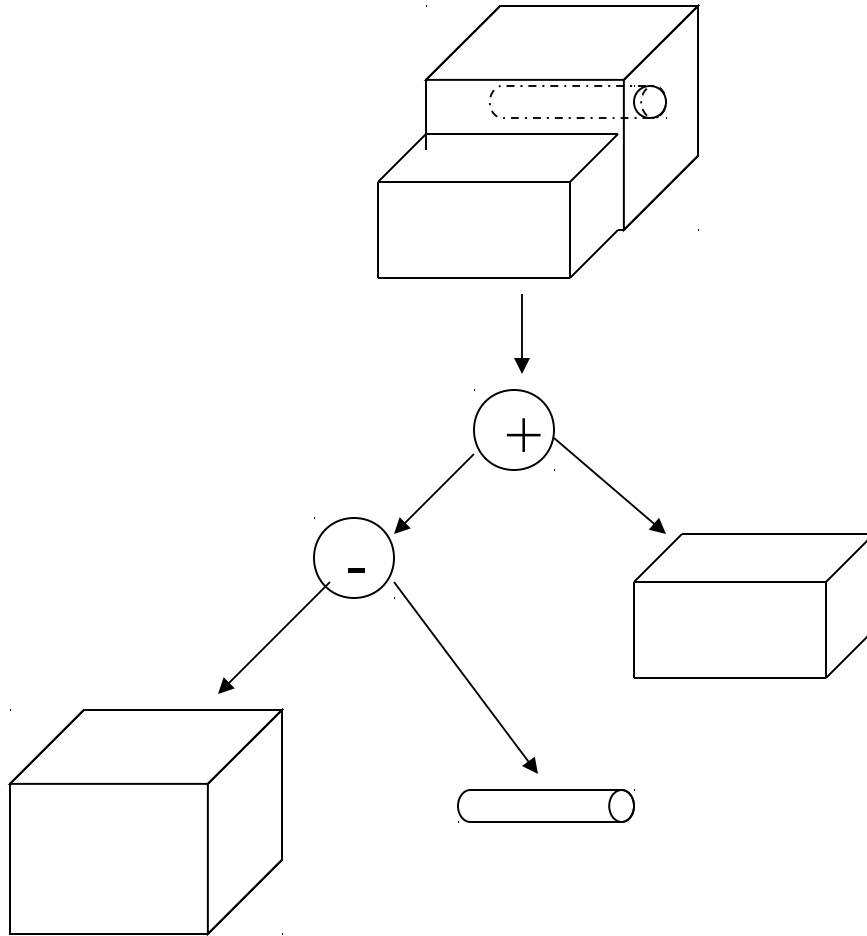
Constructive solid geometry (CSG)- not unique

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

Constructive solid geometry (CSG) representation

- CSG representation is unevaluated
  - Faces, edges, vertices not defined in explicit
- CSG model are always valid
  - Since built from solid elements.
- CSG models are complete and unambiguous

Constructive solid 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.

Constructive solid geometry (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.

solution

- CSG representation tends to accompany the corresponding boundary representation → *hybrid representation*
- Maintaining consistency between the two representations is very important.

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.

Boundary representation (B-Rep)

- Why B-Rep includes such topological information?

  - A solid is represented as a closed space in 3D space (surface connect without gaps)

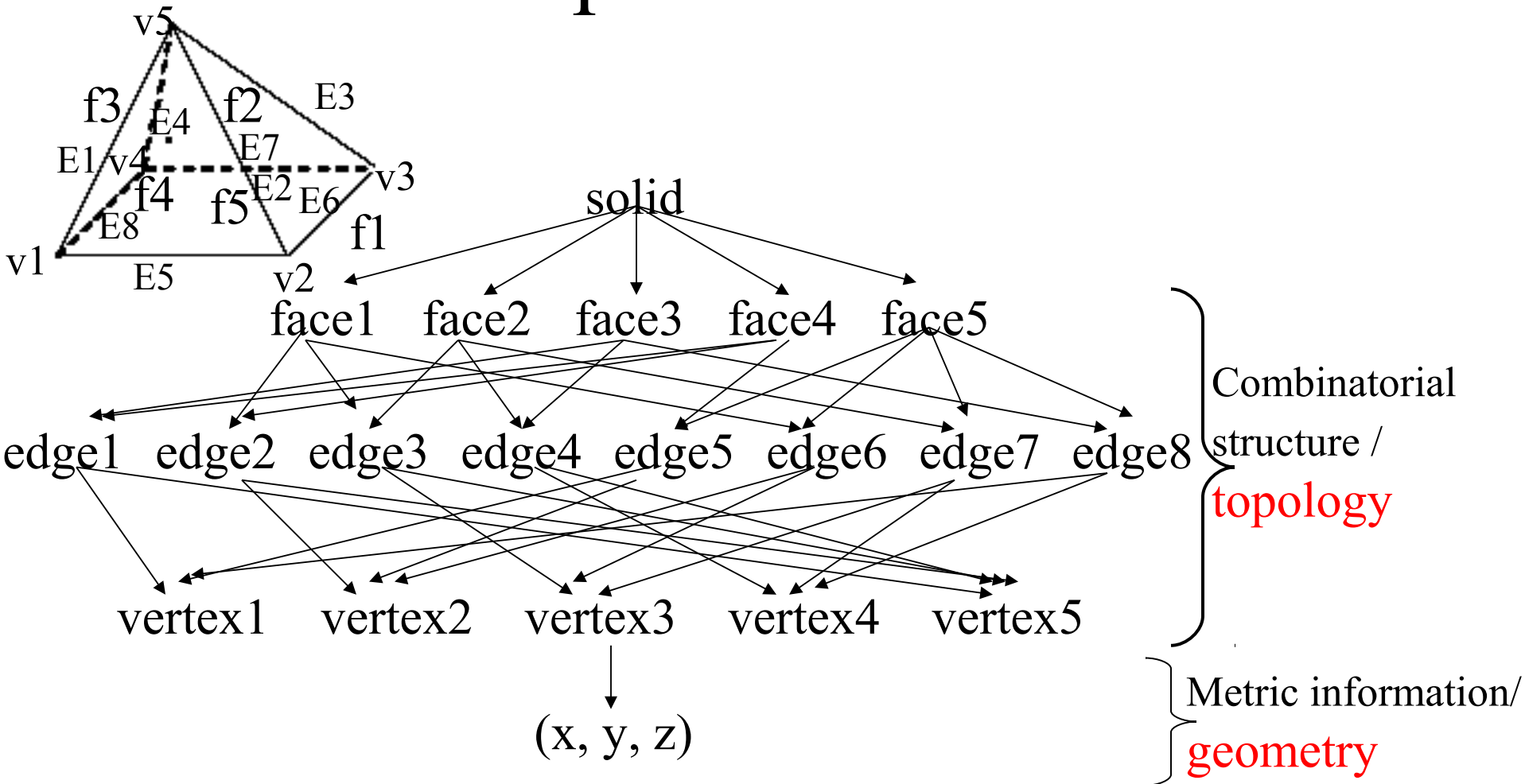 - The boundary of a solid separates points inside from points outside solid.

B-Rep vs surface modeling

- ## Surface model
  - A collection of surface entities which simply enclose a volume lacks the connective data to define a solid (i.e topology).

- ## B- Rep model
  - Technique guarantees that surfaces definitively divide model space into solid and void, even after model modification commands.

B-Rep 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

solid

face1 face2 face3 face4 face5

edge1 edge2 edge3 edge4 edge5 edge6 edge7 edge8

vertex1 vertex2 vertex3 vertex4 vertex5

(x, y, z)

Combinatorial structure / topology

Metric information/ geometry
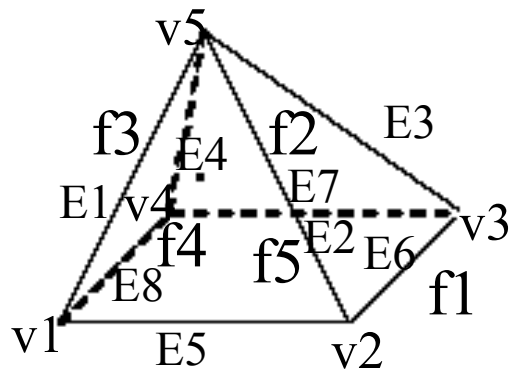
Boundary representation- validity

- System must validate topology of created solid.
- B-Rep has to fulfill certain conditions to disallow self-intersecting and open objects
- This condition include
  - Each edge should adjoin exactly two faces and have a vertex at each end.
  - Vertices are geometrically described by point coordinates

Boundary representation- validity

- This condition include (cont)
  - At least three edges must meet at each vertex.
  - Faces are described by surface equations
  - The set of faces forms a complete skin of the solid with no missing parts.
  - Each face is bordered by an ordered set of edges forming a closed loop.
  - Faces must only intersect at common edges or vertices.
  - The boundaries of faces do not intersect themselves

Boundary representation- validity

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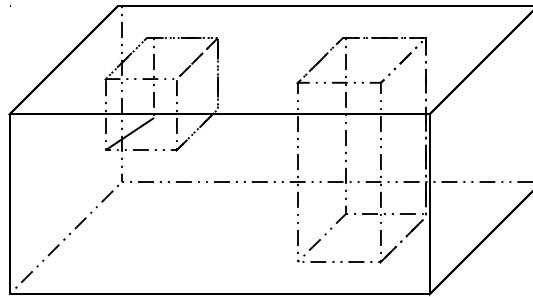 - $V - E + F = 2$ V-vertices E- edges   F- face loops

$V = 5, \quad E = 8, F = 5$

$5 - 8 + 5 = 2$

v5

f3 E4 f2 E3

E1 v4 E7

f4 f5 E2 E6 v3

E8

v1 E5 v2

f1

Boundary representation- validity

- Expanded Euler's law for complex polyhedrons (with holes)

- Euler-Poincare Law:
  - $V-E+F-H=2(B-P)$
  - 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

Boundary representation- ambiguity and uniqueness

- Valid B-Reps are unambiguos
- Not fully unique, but much more so than CSG
- Potential difference exists in division of
  - Surfaces into faces.
 - Curves into edges

Boundary representation-advantages

- Capability to construct unusual shapes that would not be possible with the available CSG→ aircraft fuselages, swing shapes

- 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 object construction method

- Sweeping

- Boolean

- Automated filleting and chambering
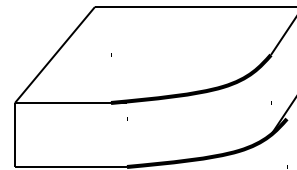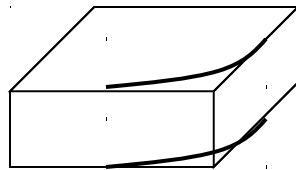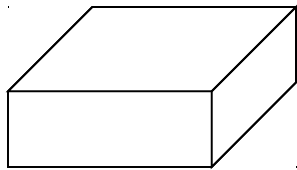
- Tweaking
  - Face of an object is moved in some way