Solid Modeling

A. What is Solid Modeling?
   1. A way to represent, generate, and manipulate *solid* objects.
   2. Necessary for many applications where objects must be maintained as solids. e.g. finite element analysis, computer aided design and machining (CAD/CAM), mass property determination, refraction.

B. Sources:

Foley, van Dam, et al. *Computer Graphics Principles and Practice*. Chapter 12.

Hoffmann *Geometric and Solid Modeling*. Chapters 2 and 3.

Desired Properties of Solid Modeling Systems

A. *Domain* – system can represent all objects desired and perform all operations desired.
B. *Closure* – operations on valid objects produce valid objects.
C. *Unambiguous* – one representation defines one object.
D. *Validity* – only valid objects are stored.
E. *Creation* – easy to create new objects.
F. *Accuracy* – representation and operations maintain the object close to exactly.
G. *Efficiency* – operations are quick and easy to perform.
H. *Compactness* – representation does not use unnecessary space
I. *Uniqueness* – an object can only be represented in one way.

Key Solid Modeling Operations

A. Local Operations
   1. Only affect one (local) portion of the solid.
   2. May need to ensure validity – some local operations have global consequences.
   3. Example operations
      a. Beveling
      b. Rounding
      c. Filleting
      d. Face extrusion

B. Global Operations
   1. Affect the overall solid.
   2. Example operations
      a. Translation
      b. Rotation
      c. Scaling
      d. Operation undo
      e. Offset surface
      f. Boolean operations

Boolean Operations

A. 3 main operations, each takes two valid solids as input and returns one new valid solid.
B. Union, Intersection, and Difference (sometimes Complement is allowed).
C. Natural way of design.
   1. Union – glue/weld operation
   2. Difference – cut/drill operation
D. Basic Boolean operations can produce invalid results. e.g. hanging vertex/face
E. *Regularized Boolean Operations* are used instead.
   1. Perform "normal" Boolean operation.
   2. Take *interior* of the result.
   3. Add the boundary of the interior.
F. Regularized Boolean operations are a conceptual way to understand, not usually implemented that way.

Representations

A. Numerous potential representations – all have various benefits/drawbacks.
B. Often, conversions between representations and hybrid representations are needed or are useful.

Primitive Instancing and Sweeps

A. Primitive Instancing
   1. A certain (limited) set of predefined primitives is allowed.
   2. Each primitive may be governed by parameters.
   3. Set of operations is minimal (e.g. just translation, scale, rotation).
   4. Useful when domain is limited – e.g. furniture placement in home design.

B. Sweeps
   1. Start with a 2D “slice” or a 3D “tool”.
   2. Define a path to sweep along.
   3. The volume traced out by moving the slice or tool along the path defines the solid.
   4. Suffers from many practical problems – few operations, possible invalid objects.
   5. Common examples are solid extrusion, rotational sweep, CAM tool paths.

CSG

A. **C**onstructive **S**olid **G**eometry.
B. Direct representation based on Boolean combinations.
C. Begin with simple, easy to define primitives, often algebraically defined.
D. Solid is stored as a tree of Boolean operations. Primitives are at the leaves, the interior nodes are Boolean operations.
E. Transformations may be stored as unary nodes in the tree.
F. Easy to understand, modify, design, and perform certain queries.
G. Especially useful in ray-tracing applications.

Spatial Decomposition

A. Decompose space into simple, easy to represent parts.

B. Uniform subdivision
   1. Space divided into a regularly spaced grid, each voxel is either in or out.
   2. Useful when data is given that way – e.g. MRI data

C. Octree
   1. Analogous to quadtrees in 2D.
   2. Hierarchical tree is created – each node of the tree corresponds to a region of space.
   3. Each node is either in, out, or both.
   4. Nodes which are both have 8 children, representing the 8 suboctants of that region.

D. Binary Space Partition
   1. Hierarchical binary tree which subdivides space.
   2. Interior nodes are associated with a plane, children describe each side of plane
   3. Leaf nodes are either “in” or “out”