Geometric Modeling Systems

- Wireframe Modeling
  - use lines/curves and points for 2D or 3D
  - largely replaced by surface and solid models

- Surface Modeling
  - wireframe information plus surface definitions
  - supports shading, toolpath generation, etc.
  - verification of surface normals, curvature, etc.

- Solid Modeling Systems
  - closed volumes. Includes surface information.
  - Any point: inside, outside or on surface.
  - Solid information can be derived (e.g. mass, centre of gravity, etc.)
  - can be used for further analysis or processing (e.g. finite element meshing, NC machining)
  - much more complicated data structure including geometry and topology.
  - Modeling functions designed to relieve operator of the complexity of the data required.

- Modeling functions
  - almost all solid modeling systems provide the same set of modeling functions for object creation.
    - Primitive Creation
    - Boolean Functions
    - Sweeping/Swinging
    - Lofting/Skinning
    - Rounding/Blending
    - Lifting
    - Boundary Modeling
    - Feature based Modeling

- Primitive Creation
  - retrieve previously defined primatives
    - block, cylinder, cone, sphere, etc.
  - usually parametric in nature with dimensional input required upon retrieval.

- Boolean Operations
  - union, intersection and difference
  - can include cutting with planes, etc.
  - avoid invalid solids (e.g. 2 blocks just touching)

- Sweeping/Swinging
  - translating or revolving a planar closed loop results in a solid (i.e. the swept volume).
  - If the shape is not closed, a surface is generated instead of a solid. Some modelers allow this and some do not.

- Lofting/Skinning
  - create a “skin” over prespecified cross-sectional planar sections.
  - The “ends” must be closed to make a solid.

- Rounding/Blending
  - modifying existing solids to remove a sharp edge or vertex and replace with smooth curved surface.
  - Filleting is a special case where the rounding occurs with the addition of material.

- Lifting
  - pulling a portion or an entire face of a solid in a certain direction.
  - Avoid creation of improper solids.
• Boundary Modeling
  – similar to surface modeling.
  – Modification of vertices, edges and faces directly.
  – Must create a fully bounded volume
  – surfaces must then be “stitched” together.
  – Allows for solids with specific complex surface definitions.
  – Perfecting edge connections can be challenging.

• Feature Based Modeling
  – creation of features on objects which are similar to manufacturing tasks.
  – E.g. chamfer, drill a hole, cut a slot, etc.
  – provides potential for automated process planning (e.g. CAPP).
  – Captures knowledge of designer.
  – Integrates design and manufacturing
  – requires designers to think differently
  – doesn’t suit certain geometries and tasks.
  – May limit manufacturing options.

• Parametric Modeling
  – a refinement on all of the other approaches.
  – Allows dimensional constraints to maintained as variables which permits creation of part “families” based on underlying design.
  – Constraints must capture the design “intent” so that resized instances are correctly configured.
  – Can provide significant time savings through re-use of existing models.
  – Requires more training to ensure a proper constraint set.

• Representation of Curves
  – coordinate systems (WCS).
  – Analytic curves
    – e.g. lines, arcs, circles, parabolas, ellipses, etc.
  – Synthetic curves
    – e.g. splines
    – Parametric representation avoids issues of infinite slope, dependence on coordinate system and display as points or line segments
      \[ P(u) = [x(u), y(u), z(u)]^T, \ u_{\text{min}} < u < u_{\text{max}} \]

• Synthetic curves have progressed through stages of development
  – general (Hermite) cubic spline (interpolation)
  – Bezier Curves (approximation)
    • shape controlled by defining points (not derivatives)
    • order/degree is variable to allow higher order continuity.
    • Generally smoother because of higher order derivatives.
  – B-Spline Curves
    • generalization of Bezier Curves.

• Parametric Curves (continued)
  • degree is separated from number of control points
  • Basis (blending) functions of desired degree.
  • Provide further control over curve, including tangency at start and end points.
  • Can use multiple coincident “knots” or control points to affect characteristics of curve.

• NURBS
  • non-uniform rational B-splines
  • a unified representation which is widely used
  • still an approximation and not always the best choice for simple (analytical) shapes.
• Representation of Surfaces
  – parallels curve representation
  – Analytic surfaces (planes, ruled, revolved, etc.) are represented parametrically.
  – Synthetic surfaces have developed in step with curve representation.
    • Hermite bi-cubic
    • Bezier
    • Coons patches
    • B-Spline
    • NURBS

• Representation of Solids
  – many different representations have been tried or proposed.
    • Primitive Instancing
    • Spatial Occupancy Enumeration
    • Cell Decomposition
    • Sweeping
    • Constructive Solid Geometry
    • Boundary Representation (B-Rep)
  – the last two listed have gained wide acceptance in commercial software.

• Constructive Solid Geometry (CSG)
  – uses primitive shapes and boolean operators
  – represented as a tree structure where branches end with primitives, dimensions, and coordinate transform.
  – Works well for user input and rendering
  – doesn’t explicitly define surfaces.

• Boundary Representation (B-rep)
  – objects represented by bounding faces
  – faces are subdivided into edges and vertices
  – it is possible to build a solid from B-rep, but it is laborious for the operator.
  – Excellent surface representation

• Combination CSG and B-rep
  – this is typical of current software which store and manipulate based on CSG, but use boundary evaluation to generate B-rep data.
  – Storage vs calculation trade-offs are made.

• CAD Data Translation
  – geometry, topology, auxiliary information
  – DXF is a commonly used standard
    • developed by Autodesk for AutoCAD
    • ASCII data file with headers and data points
    • not particularly well constructed or efficient.
  – Initial Graphics Exchange Standard (IGES)
    • international effort first available in 1980
    • adopted by ANSI and ISO
    • developed for 2D, 3D and surface model data
    • reasonably standard, although “flavours” exist.

• Standard for Exchange of Product Data
  – STEP is another international initiative
  – goal is to define a file format including all information necessary to describe a product from design to production
  – it is huge, somewhat unmanageable and largely unproven, but probably the future of data exchange.