Procedural Models

- How to easily generate complex data?
- Data from parameterized procedure and/or digitized
- Data amplification
- Ray trace directly v. convert to polygonal models and use z-buffer
Basic Procedural Approaches

- composition from primitive shapes
- extrusion
- surface of revolution
- lofting
- sweep operator
Composition

Procedurally generated

Controlled randomness
Extrusion
Surface of revolution
Lofting
Sweep Operator

Combines extrusion, lofting, and surface of revolution
More sophisticated approaches

- CSG
- Subdivision surfaces
- Curves & surfaces
- Fractals
- Implicit functions
CSG:
constructive solid geometry

- primitive shapes
- union, difference, intersection
- tree structure representation
- Ray trace directly
- Evaluate to polyhedron with Boolean operators
- OpenGL rendering using stencil buffer
  - [http://www.opengl.org/resources/code/samples/advanced/advanced97/notes/node11.html](http://www.opengl.org/resources/code/samples/advanced/advanced97/notes/node11.html)
Subdivision surfaces

- Initial coarsely defined geometry
- Refine geometry by
  - rounding corners,
  - subdividing faces and edges,
  - smoothing faces

What is resulting limit surface?
- What is continuity of limit surface?
Subdivision surfaces

- Round corners
- Catmull-Clark
- Doo-Sabin
- Loop
- Butterfly
Catmull-Clark Subdivision
Loop Subdivision
Curved surface patches

- Hermite curve & patches
- Bezier curve & patches
- Catmull-Rom spline
- B-spline
Hermite Curve

- Given: starting and ending points and tangents
- Determine cubic equation that satisfies constraints

\[ P(0) = p_0 = d \]
\[ P(1) = p_1 = a + b + c + d \]
\[ P'(0) = t_0 = c \]
\[ P'(1) = t_1 = 3a + 2b + c \]

\[ P(u) = au^3 + bu^2 + cu + d \]
\[ P'(u) = 3au^2 + 2bu + c \]

\[ P(u) = UMB = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix} \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} p_0 \\ p_1 \\ t_0 \\ t_1 \end{bmatrix} \]
Hermite Patch

- Given: starting and ending points and tangents
- Determine bicubic equation that satisfies constraints

\[ P(u, v) = uMBM^T v \]
Fractal geometry

- Objects that exhibit similarity under scale
- e.g., Koch curve

Mathematically curious - continuous, infinite length, nowhere differentiable, bounded
Serpinski Gaskets
Other fractal shapes

- Mandelbrot set
- Coastlines
- Mountains

statistically self-similar under scale
Create mountains

1. Subdivide triangle
2. Displace upward
3. Reduce amplitude of displacement
4. Recurse on subdivisions
Implicit functions & isosurfaces

- $f(x,y,z) = 0$
- “density” function
- distance-based implicit functions
- Marching Cubes algorithm
Marching Cubes: convert to polygons
Implicit functions & isosurfaces