Modeling

Chapter 8
Intro. to Computer Graphics
Spring 2008, Y. G. Shin

- **Components for Image Synthesis**
  - Scene description
  - Light source
  - Viewpoint
- Scene = an assembly of one or more models
  - A model contains
    - structural description - geometry of the shape
    - surface description - appearance (lighting)
  - For a simulation model we need more
    - physics
    - mechanics - assemblability, reachability

* Some of contents from SigGraph Lecture Notes

- How are models used?
  - Image synthesis
  - Design
  - Manufacturing - part relationships, feasibility
  - Simulation
  - Art
- Levels of Detail
  - visual detail vs. structural detail
  - more detail = more realism/accuracy
    = more resources
  - procedural objects : more detail when
    you need it.

- Issues in Model Selection
  - Computational cost of the model
    - storage space
    - object construction time
    - display time
  - Effectiveness in modeling the desired phenomena
    - geometry
      - looks good for image-making
      - accuracy for simulation
    - appearance
      - looks
      - accuracy

- Implementation Complexity
  - the number of primitives
  - the number of shapes
  - complexity of each instance
- The methods need to acquire (or create) data
- Ease of simulation
  - match to simulator
  - cost of conversion
- Ease of animation
  - physics of motion
  - constraints

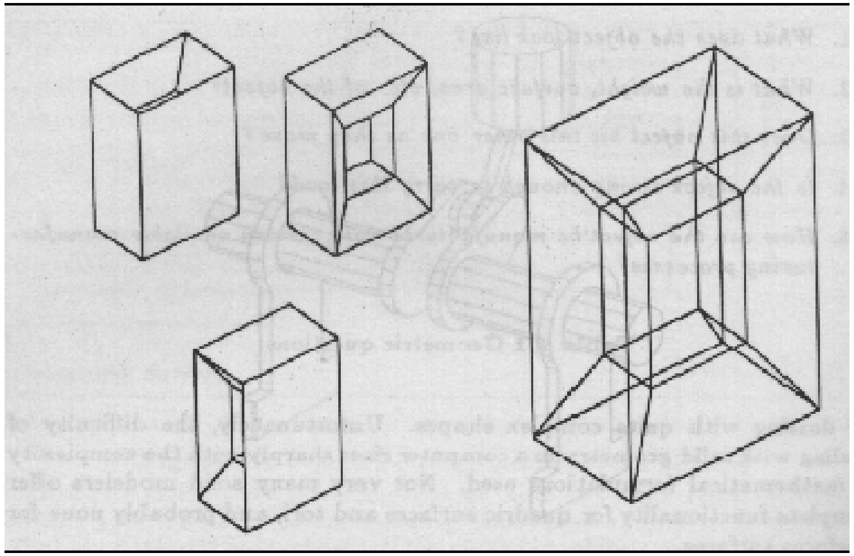
- The difference between models and rendering
  - Models describe the object and its attributes:
    - shape or geometry
    - reflectivity, transmittance
    - surface smoothness, color
    - texture
  - Rendering algorithm transforms the model to a screen-based view from a given:
    - COP or camera position, location, view direction, view up direction projection type, window clipping plane, focal length
    - One or more light sources – location, direction, intensity, color
    - Atmospheric effects - ambient light, fog, depth cuing
    - Image quality parameters – antialiasing, resolution

- Operations on models
  - Transformations
  - Change of detail
    - Interpolation to augment detail
    - Averaging to reduce detail
    - Hierarchy of models of the same object at different levels of detail
  - Measurement
    - topology - connectivity, feature
    - distance
    - volume
    - surface tangent

- Combination
  - union
  - intersection
  - difference
  - cut/slice
- Deformation
  - skew
  - stretch
  - bend
  - perturb (e.g., randomly, stochastically, or fractally)
- Display operation
  - wire-frame
  - visible line/surface
  - ray cast
  - radiosity

- Model Classification
  - Graphical Model : represent geometric information in terms of points and lines.
  - Surface Model : planar surface
  - Volume Model : voxels

- Wireframes
  - CAD systems
  - Simple BUT ambiguous

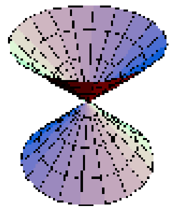


Surface and Boundary Models

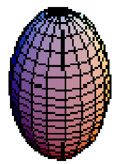
- Points
  - List of coordinate triples (a collection of 3D points)
  - Require a fairly dense distribution of points for accurate modeling
- Polygon mesh (Boundary representation)
  - Vertex, edge, face structure
  - Relatively simple to define, manipulate, and display
  - Commonly used - good for flat surfaces

- Curved surfaces
  - Parametric functions of two variables
  - True mathematical curvature
  - Adjacent patches may be constrained for continuity
  - Shape derived from control points and/or tangent vectors
  - Approximating and interpolating
  - Bezier, Hermite, Bicubic, B-spline, NURBS

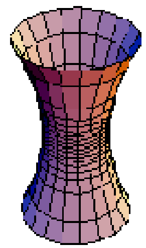
- Implicit surfaces / Algebraic equations
  - The surfaces are defined as the solutions to algebraic formulas.
  - Quadric surfaces
    - Implicit second-order polynomial equations
    - Double cones $$\frac{x^2}{a^2}+\frac{y^2}{b^2}-\frac{z^2}{c^2}=0$$



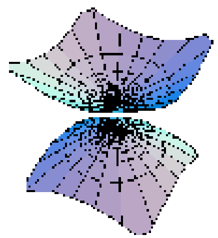
    - Ellipsoids $$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1$$



    - Hyperboloids of one sheet $$\frac{x^2}{a^2}+\frac{y^2}{b^2}-\frac{z^2}{c^2}=1$$

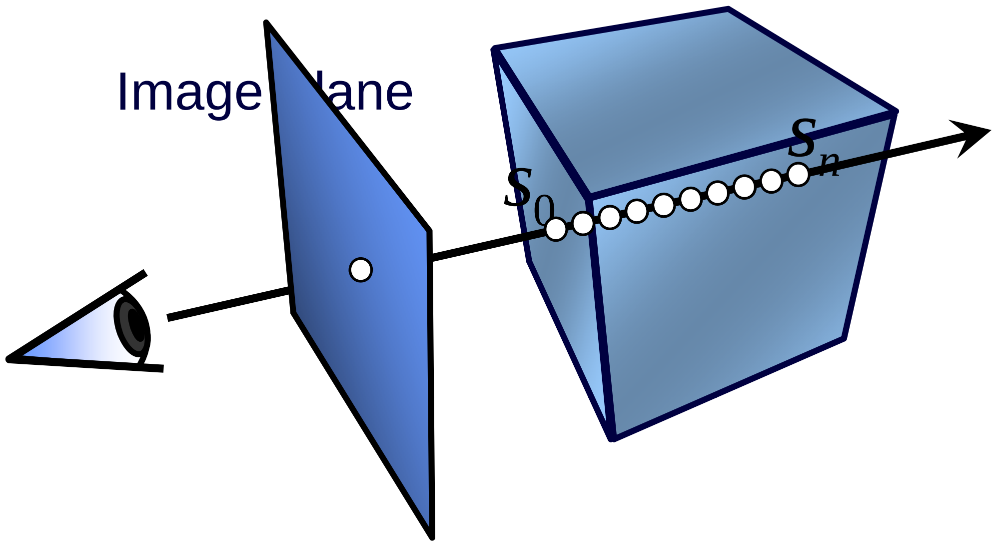


    - Hyperboloids of two sheets $$\frac{z^2}{c^2}-\frac{x^2}{a^2}-\frac{y^2}{b^2}=1$$

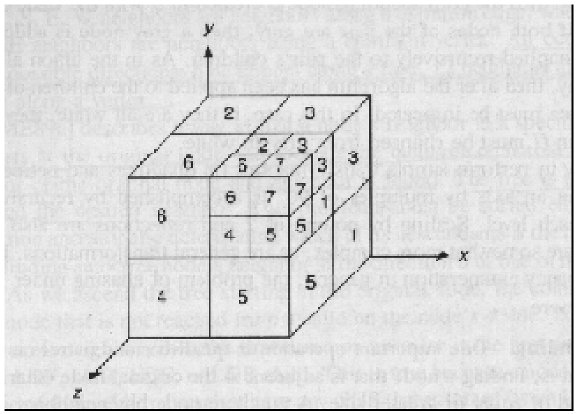


Volume and CSG Models

- Voxels (Spatial-occupancy enumeration)
  - Use identical cells
  - Space-filling tesselation with cubes or parallelpipeds
  - Density or value associated with each voxel
  - Expensive storage but simple data structure
  - Useful for medical imaging – volume visualization
  - Special techniques needed to compute surface normals and shading



- Octree
  - Space subdivision
  - Partition space into 8 cubes, recursively
  - Increases space efficiency of solid tesselations
  - Primarily an indexing scheme for access efficiency



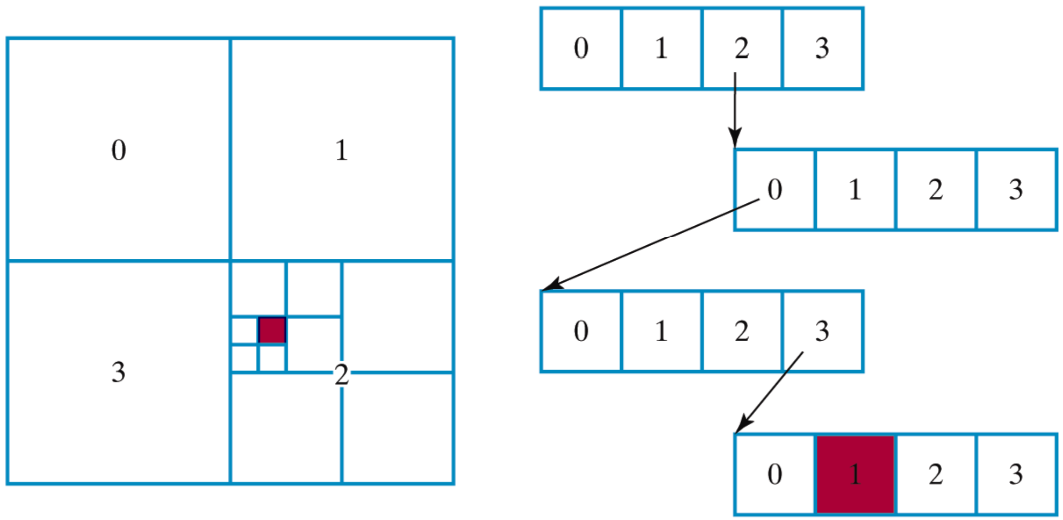
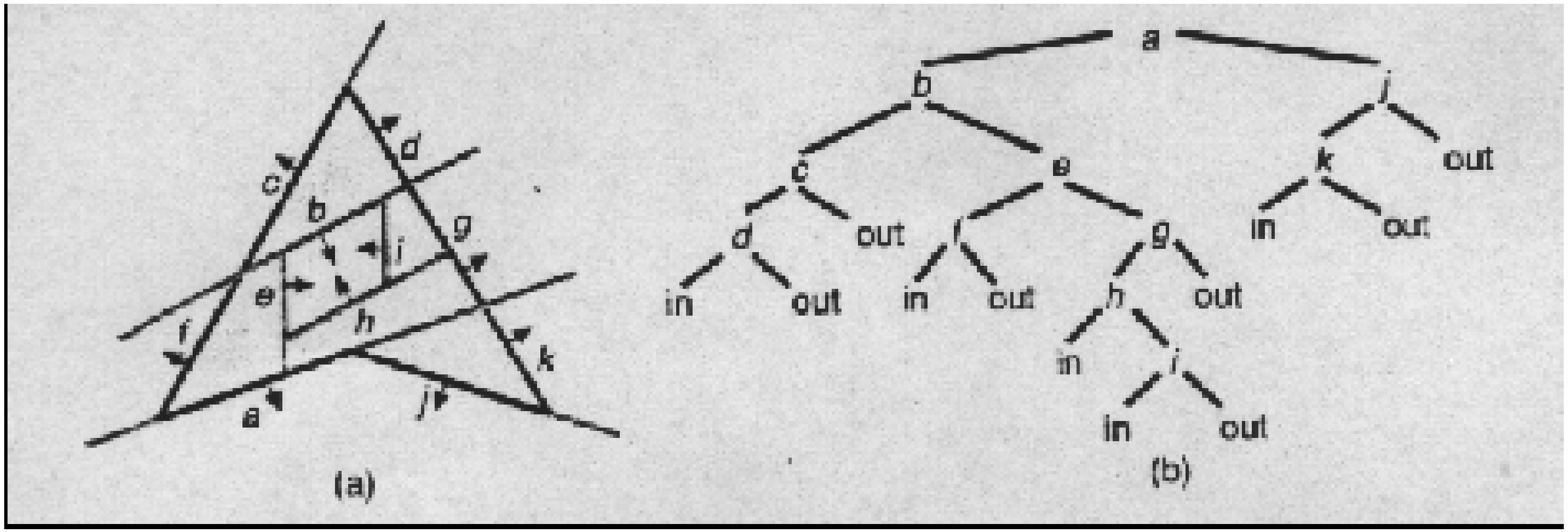


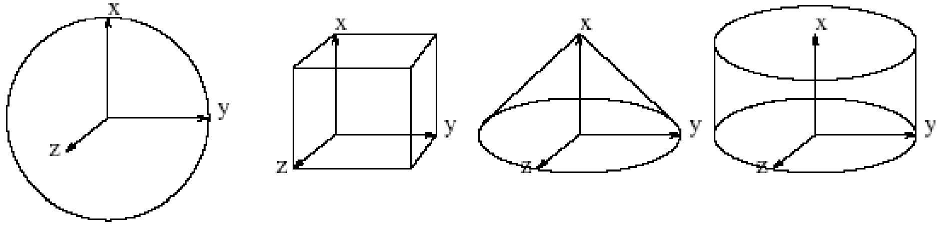
Figure 8-65

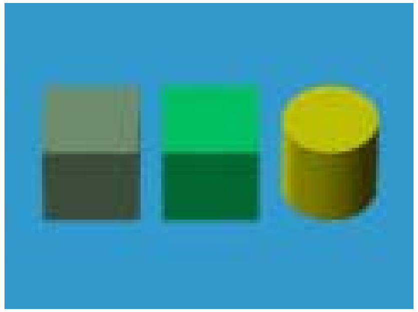
Quadtree representation for a square region of the *xy* plane that contains a single foreground-color area on a solid-color background.

- Binary space partitioning (BSP) tree
  - Subdivide a scene into two sections at each step with a plane that can be at any position and orientation
  - Smaller tree size than octrees

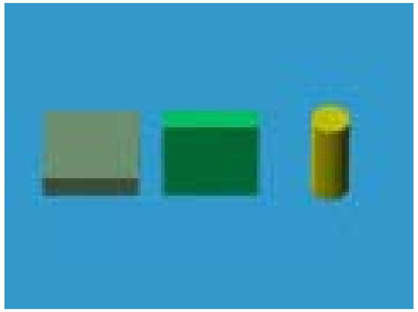


- CSG (Constructive Solid Geometry)
  - Recursively combine simple primitives by boolean operations
  - Simple primitives

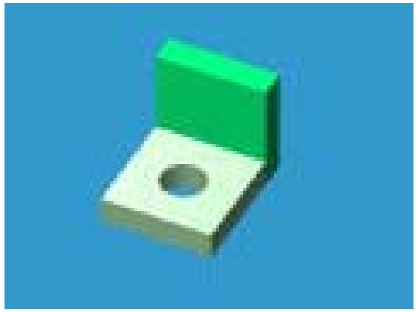




Primitives

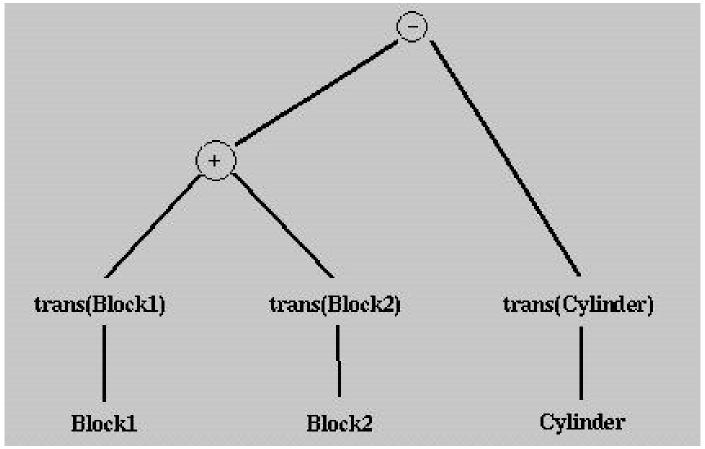


Transformed



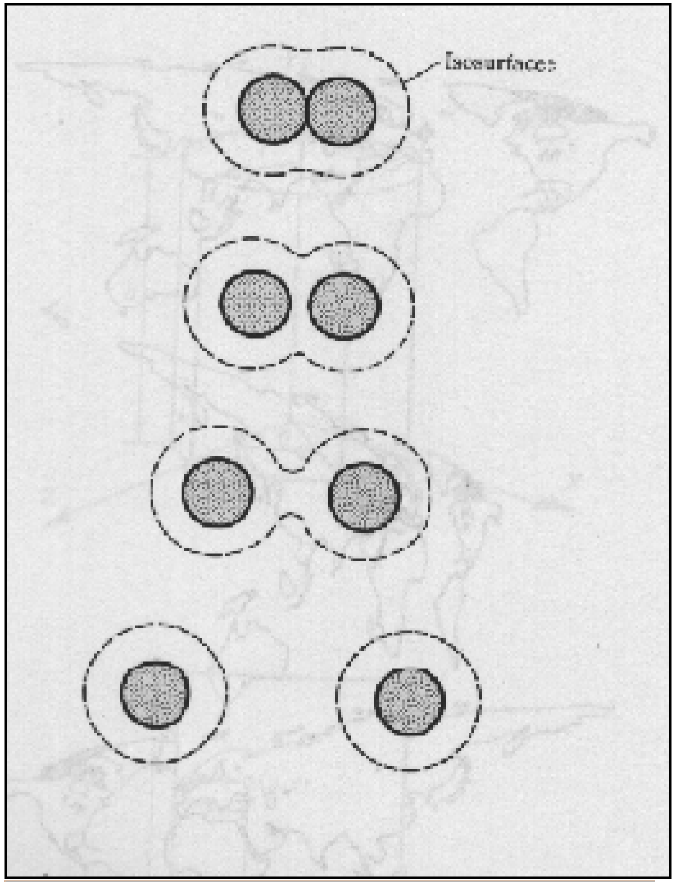
Combined

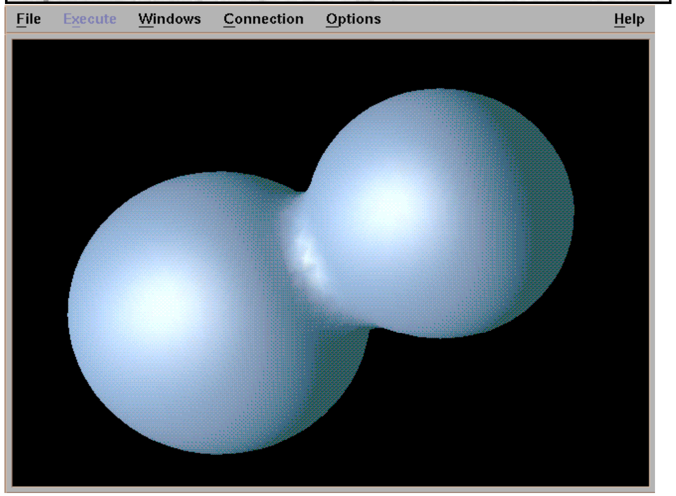
Tree structure



- Specialized (single primitive) systems
  - Ellipsoids
    - Model elongated, symmetric, rounded objects
  - Cylinders
    - Model elongated, rounded objects
  - Spheres
    - Isotropic primitives
    - Simple geometry
    - Render as shaded spheres or flat disks

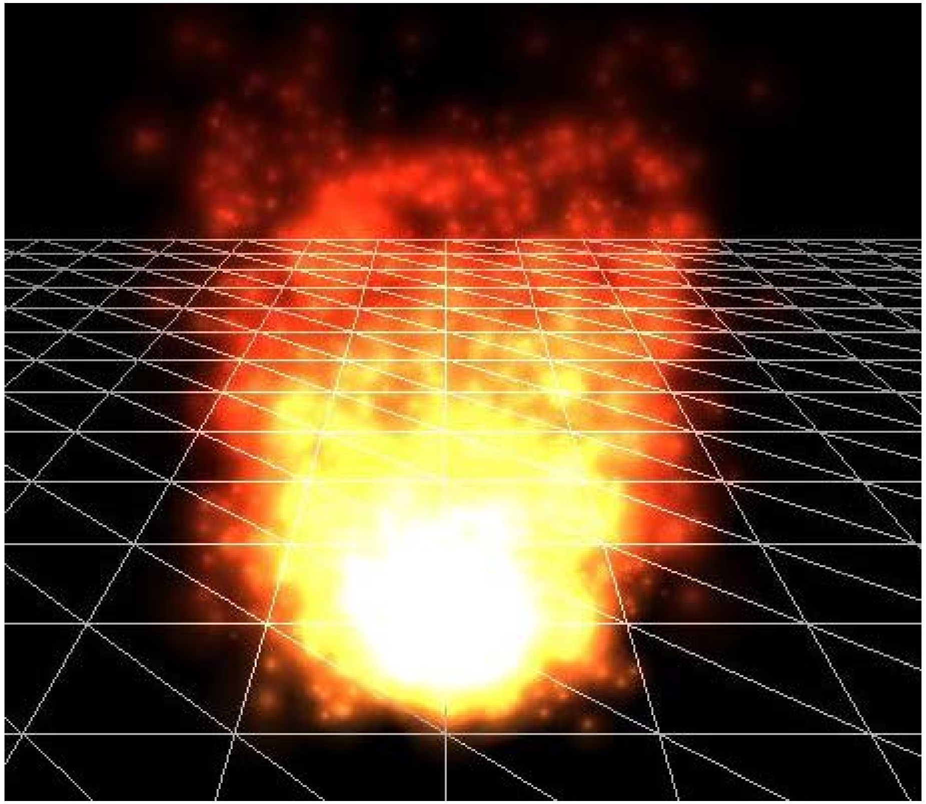
- Potential functions
  - Models for blobby objects (e.g., muscles)
  - Center-point
  - Radius-dependent decreasing value
  - Act like energy sources, summing when overlapping
  - Smooth interfaces between primitives
    e.g., smooth model
    : combination of Gaussian density functions





- Particle systems
  - Sets of many points moving in spatial paths.
  - Shape description is combined with physical simulation

X (position)
v (velocity)
f (Force accumulator)
m (mass)

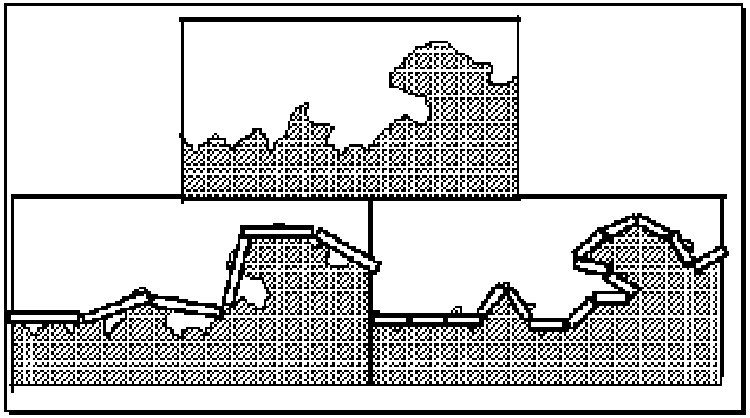


- Comparison of Representation
  - accuracy
    - spatial-partitioning, polygonal b-rep : approximated
    - CSG with non-polyhedra primitives, curved b-rep : accurate
    - tradeoff : resolution and space or time
  - domain
    - primitive instancing, sweeps : limited
    - b-rep : more wide
  - uniqueness :
    - octree, spatial-occupancy-enumeration : unique representation
    - primitive instancing : does not guarantee uniqueness

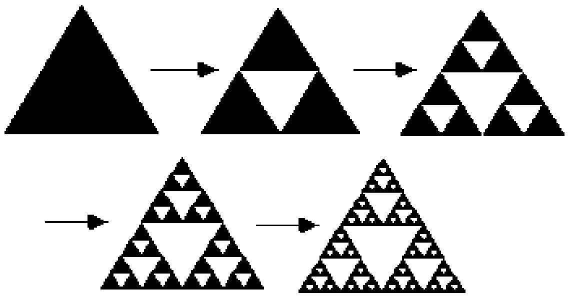
- validity
  - b-rep : most difficult to validate
  - BSP tree : represent valid spatial set
  - CSG tree : needs local syntactic checking
- closure
  - simple sweep : not closed under Boolean operation
  - b-rep : hard to maintain closure after Boolean operation of non 2-manifolds
- compactness and efficiency
  - octree, BSP-tree, CGS : unevaluated model
  - b-rep, spatial occupancy enumeration : evaluated model

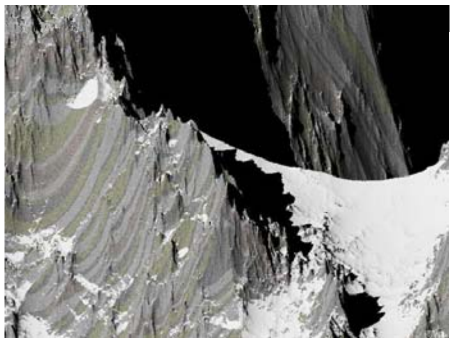
◆ Fractals

- Birth of fractal geometry: Benoit B. Mandelbrot (IBM) published his seminal book “The Fractal Geometry of Nature” in 1977.
- the geometry best describing most natural objects is not traditional 3D Euclidian geometry, but rather what Mandelbrit describes as the *fractal geometry of nature*.

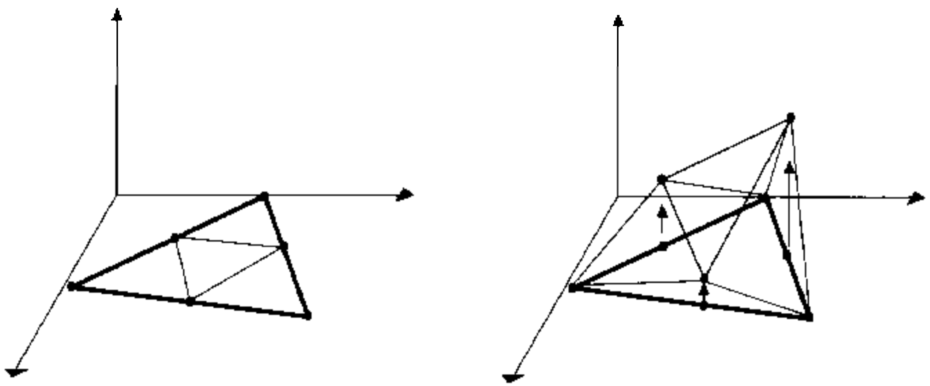


How long is the coast of Britain?"

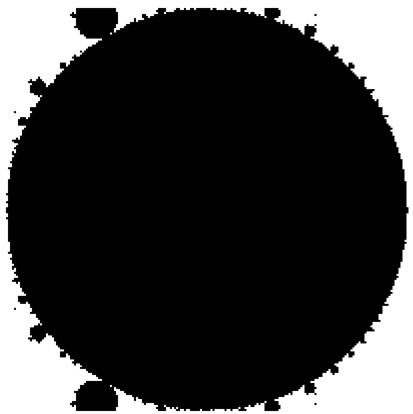




- Properties of Fractals
  - Self-similarity or statistical self-similarity
  - Shapes repeat themselves exactly at different scales
  - Simple algorithms but complex results
  - Iterative procedure
  - Noninteger dimension

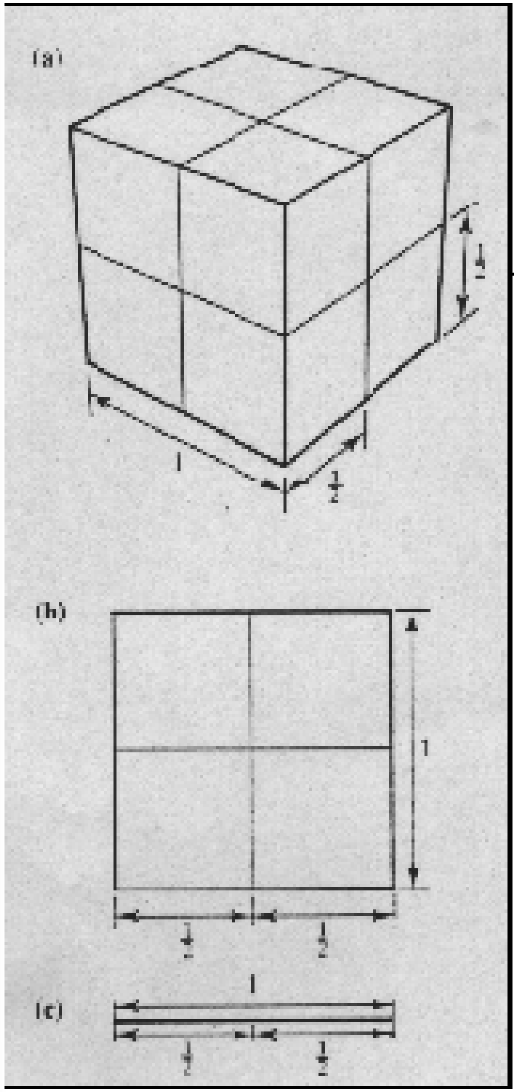


Generating Mountains



Mandelbrot zoom
(from Wikipedia)

Fractal Dimension



Dimension (D)	Self-similar parts (N)	Scaling factor (S)
1	2	1/2
2	4	1/2
3	8	1/2

$$N = 1/S^D$$

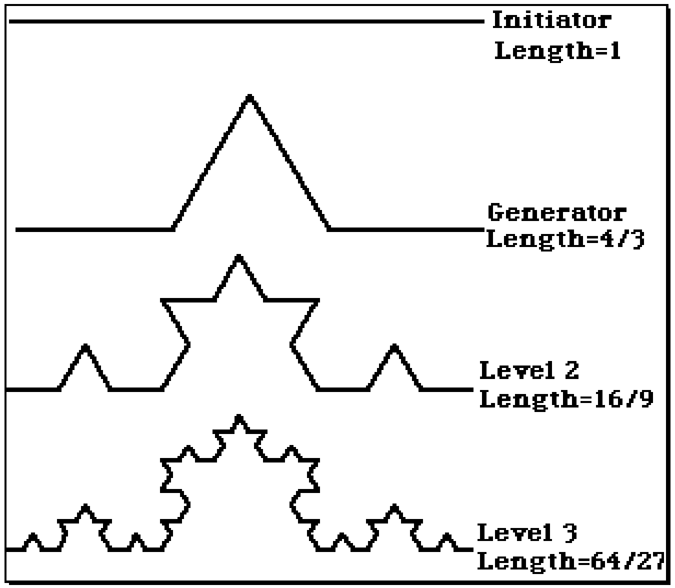
$$D = \log(N)/\log(1/S)$$

- Cantor set

$$\frac{\log 2}{\log 3} = 0.6309\ldots$$

We have an object with dimensionality less than one, between a point (dimensionality of zero) and a line (dimensionality 1)

- Koch curve



S = 1/3, N = 4

$\Rightarrow$ D = log(4)/log(3)

= 1.2619…

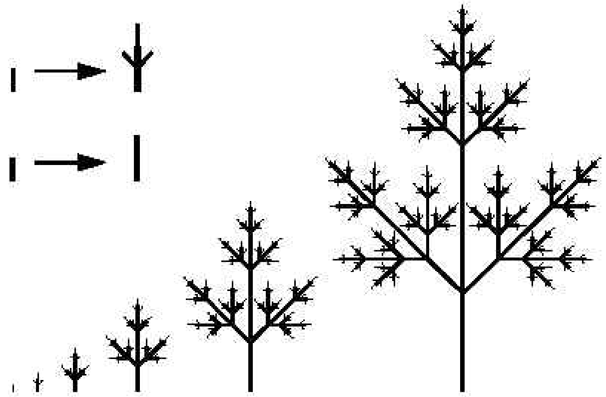
▷ Classification of Fractals

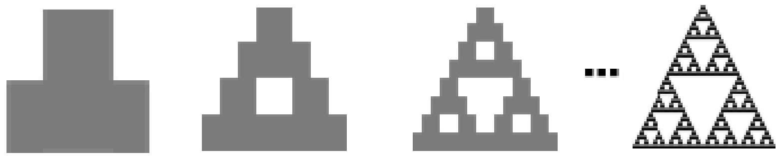
- Deterministic Fractals

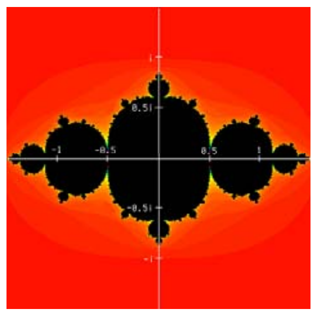
  : the algorithm produce an identical structure each time it is run.

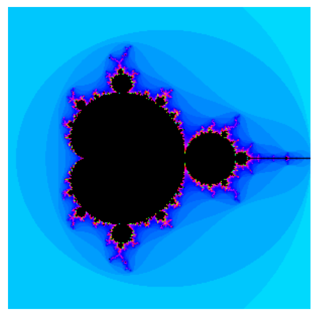
  [Algorithms]

  - Linear replacement mapping
    - statistically self-similar
    - snowflake, tree
  - Iterated function system
    - self-affine fractals
    - use contractive affine transformation
    - terrain, water, cloud
  - Complex plane mapping
    - Julia, Mandelbrot sets









Mandelbrot set

The Mandelbrot set M is defined by a family of complex quadratic polynomials given by

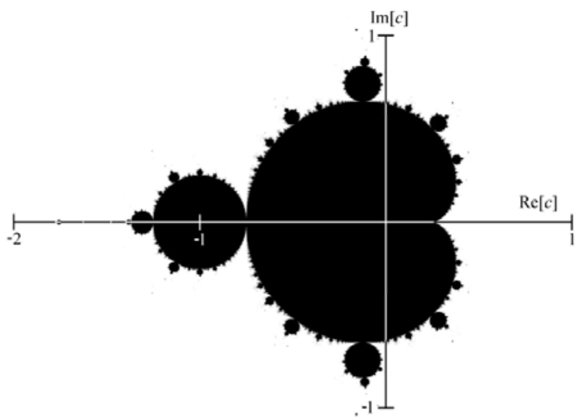
$$f_c(z) = z^2 + c$$

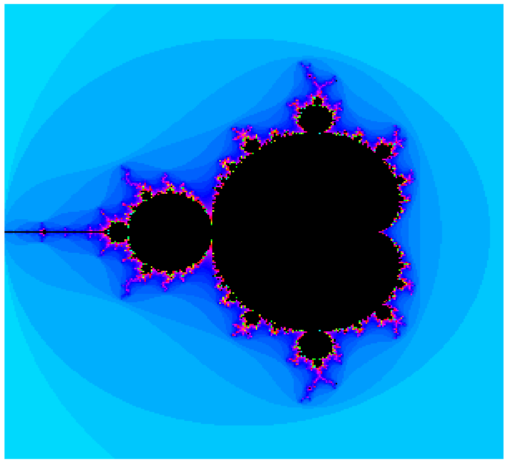
where c is a complex.

For each c, one considers the behavior of the sequence:

$$(f_c(0), f_c(f_c(0)), f_c(f_c(f_c(0))), \ldots.)$$

The Mandelbrot set is defined as the set of all points c such that the above sequence does not escape to infinity.





- Stochastic Fractals

  : the random processes play a central role in determining the structure of the fractal object

  [Algorithms]

  Stochastic processes - mountain landscapes