Modeling

CMSC 435/634

Modeling?

Modeling

Creating a *model* of an object, usually out of a collection of simpler *primitives*

Primitive

A basic shape handled directly the rendering system

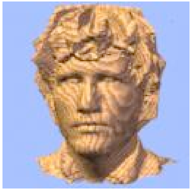
Primitives

Some common primitives

- Triangles & Polygons
  - Most common, usually the only choice for interactive
- Patches, Spheres, Cylinders, ...
  - Often converted to simpler primitives within the renderer
- Volumes
  - What's at each point in space?
  - Often with some transparent material
  - Few renderers handle both volume & surface models

Composing primitives

- Collections of large numbers of primitives
  - Sometimes called Boundary Representation (*BRep*)



Composing primitives

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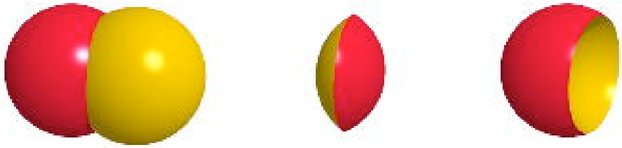
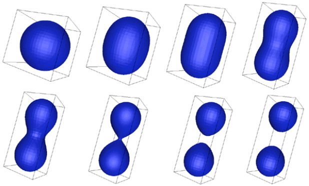
- Constructive Solid Geometry (*CSG*)
  - Set operations (union, intersection, difference)



Images: Friedrich Lohmueller

Composing primitives

- Collections of large numbers of primitives
  - Sometimes called Boundary Representation (*BRep*)
- Constructive Solid Geometry (*CSG*)
  - Set operations (union, intersection, difference)
- Implicit Models & Blobs
  - Surface where f(x,y,z)=0
  - Sum, product, etc. of simpler functions



Images: Paul Bourke

Mesh Representations

Definitions

- Vertex: all data at a point
  - Position
  - Normal
  - Texture coordinates
  - Color
  - May count as new vertex if *any* of these differ
- Edge: Line between vertices
- Face: Area between a set of vertices and edges
  - Assume planar
  - May have fixed # vertices, may not

Mesh Representations

Application-friendly

- Polygon list
- (or whatever makes sense to the application)

Hardware-friendly

- Vertex list
- Vertex + Index lists

Mesh editing-friendly

- Face-Vertex
- Winged Edge
- Half Edge

Hybrid

Application-Friendly: Polygon List

How to make it

- Define a polygon object
- Put a bunch of them in a list

Pros

- Flexible
- Fits application needs

Cons

- Hard to figure out how polygons are connected
- Duplication of vertex data
- Inefficient to render

Hardware-friendly: Vertex Array

How to make it

- Make a list of vertices
- Every 3 form a triangle

Pros

- Relatively efficient to render

Cons

- Hard to figure out how faces are connected
- Duplication of vertex data
- Fixed number of vertices per polygon

Hardware-friendly: Vertex and Index Arrays

How to make it

- Make a list of vertices
- Make a list of which vertices connect into triangles
- Every 3 indices make a triangle

Pros

- Very efficient to render
- Share vertex data
- Finding vertices in a face easy

Cons

- Finding faces that use a vertex is hard
- Finding adjacent faces is hard
- Fixed number of vertices per polygon

Mesh editing-friendly: Face-Vertex

How to make it

- Vertex: position, list of faces
- Face: list of vertices

Pros

- Finding vertices in a face easy
- Finding faces that use a vertex is easy

Cons

- Finding adjacent faces is hard

Mesh editing-friendly: Winged-edge

How to make it

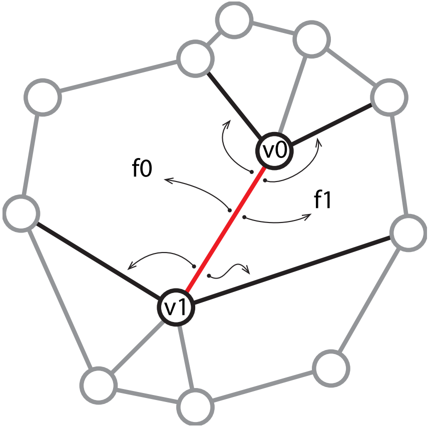
- Edge (primary structure)
  - Two vertices, two faces
  - Next and previous edges on both faces
- Vertex: position, list of edges
- Face: list of edges

Pros

- Finding vertices in a face easy
- Finding faces that use a vertex is easy
- Finding adjacent faces is easy

Cons

- Big: lots of redundant links



Half-edge

How to make it

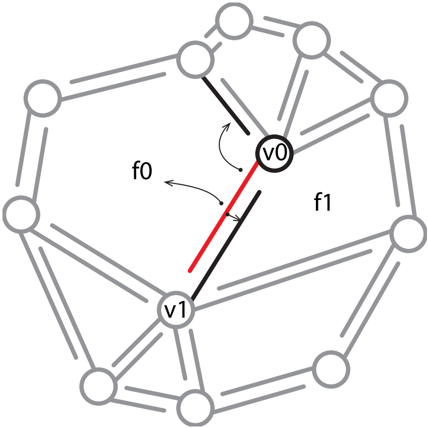
- Half-Edge (primary structure)
    - One vertex, one face
    - Pointer to pair edge
    - Next edge around face
- Face: pointer to (any) half-edge
- Vertex: pointer to (any) half-edge

Pros

- Adjacent faces
- Edges around face or vertex

Cons

- Lots of bookkeeping to update



Hybrid

Maintain multiple representations

- Separate vertex location from pointers
- Update face during edits

Delayed updates

- Do mesh updates, then rebuild index/vertex list
- Do other partial updates, then rebuild
- Traverse and build

Modeling Approaches

Manual

Procedural

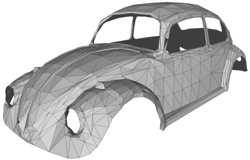
Scan

Data

Images

Manual Creation

- Text editor
  - Only very simple primitives and scenes
- High-level primitives
  - Still need to combine several somehow
- Modeling programs
  - Maya, 3D Studio, Houdini, Autocad, Blender, ...



Procedural Modeling

- Describe physical attributes through code
  - Shape
    - Output primitives
  - Density
    - Voxels
    - Couple with a conversion or rendering algorithm
  - Color, Texture
    - Enhance an existing shape

Procedural Approaches

- Fractals
- Implicit Functions
- Grammars
- Simulations

Fractals

Complex structure through self-similarity across scales

- Recursive structure
- Small features look *similar* to larger features

Iterated Equations / Mandelbrot Set

$$p' = p^2 + c$$

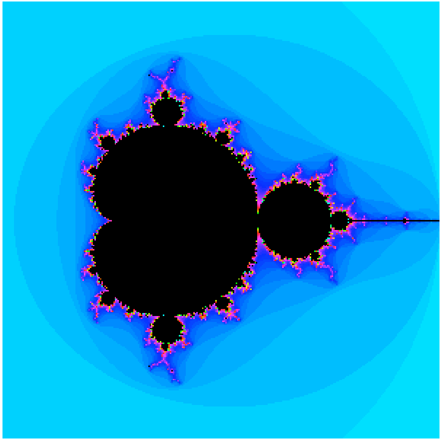
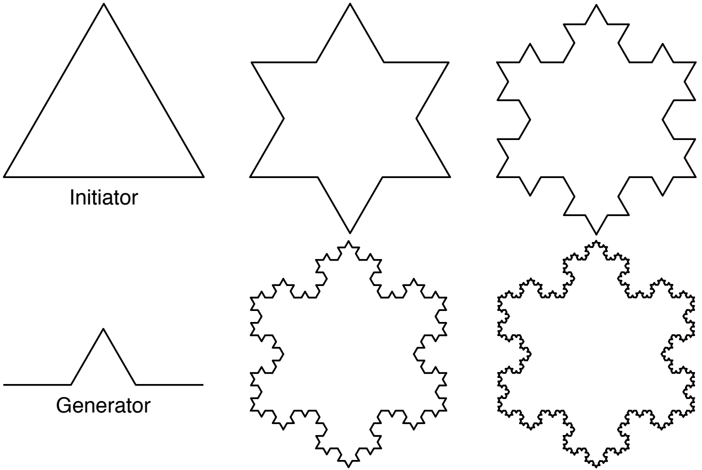


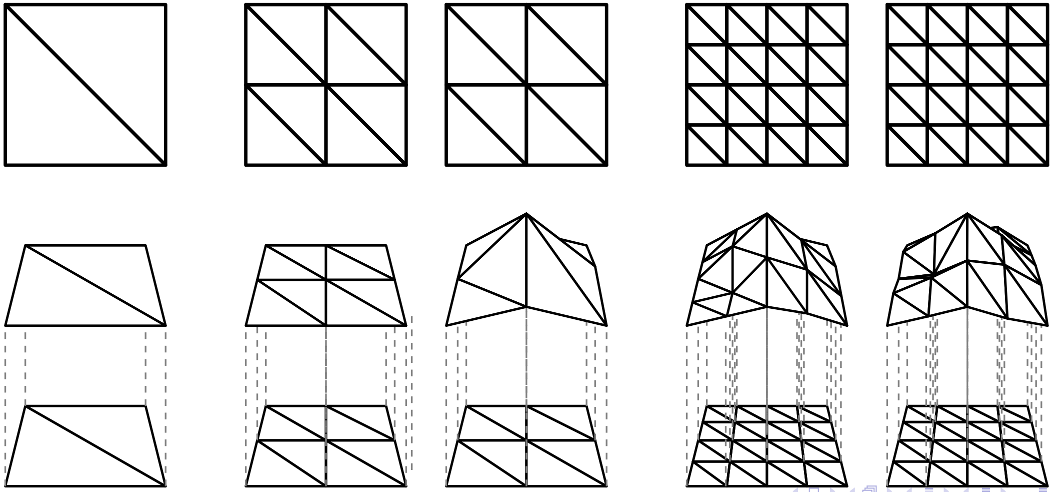
Image: David E. Joyce

Iterated Replacement / Koch Curve



Iterated Replacement / Mountains

Randomness in replacement



L-System Modeling

- Named after original developer: biologist Aristid Lindenmayer
- Use context-free grammars (CFG) to specify structural change over generations
- Often used to simulate a biological growth process
  - Plants
  - Seashells
  - ...
- Variations for other applications
  - Cities
  - Building architecture
  - Cloth weaving
  - ...

Context-Free Grammar

A CFG $G = (V, T, S, P)$ where

- V is a set of non-terminals
- T is a set of terminals
- $S \in V$ is the start symbol
- P is a set of productions (rules) of the form:
  - $A \rightarrow x$, where $A \in V, x \in (V \cup T)^*$

L-system

- L-sytem attaches geometric meaning to each symbol

L-system

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- Non-terminals
  - A, B, straight line segments
- Terminals
  - [ ], branch left 45°
  - ( ), branch right 45°

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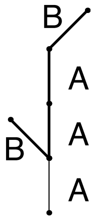

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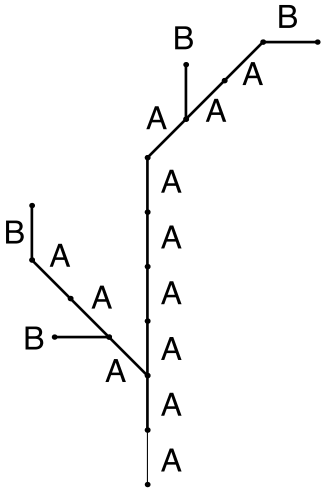
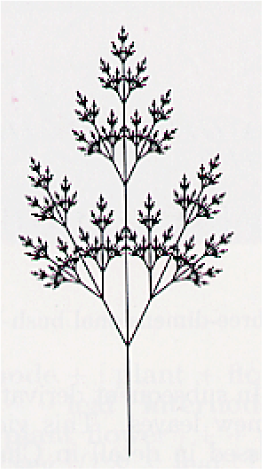


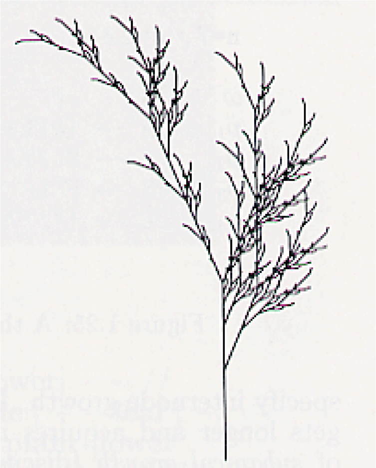
L-System Examples

- Symbols
  - [/] = push/pop
  - +/− = rotate left/right
  - $A - Z$ = straight segment
- Rules
  - 25.7°, 7 generations
  - $X \rightarrow F[+X][-X]FX$
  - $F \rightarrow FF$



L-System Examples

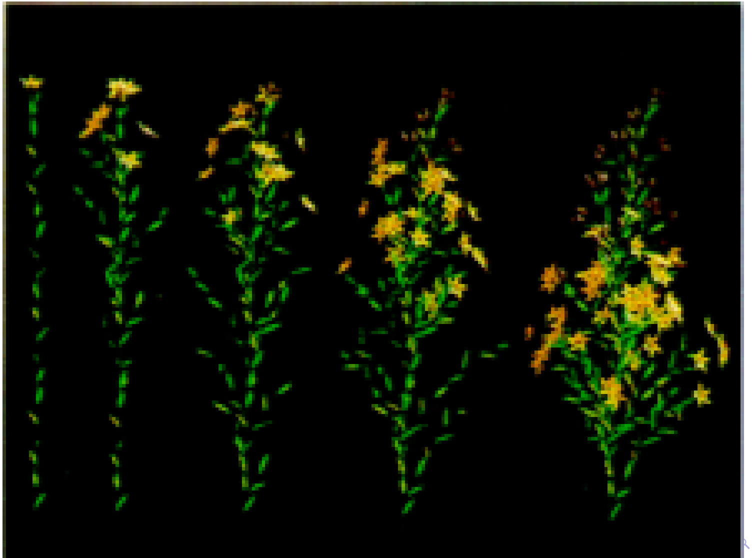
- Rules
  - 22.5°, 5 generations
  - $X \rightarrow F - [[X] + X] + F[+FX] - X$
  - $F \rightarrow FF$



L-System Examples

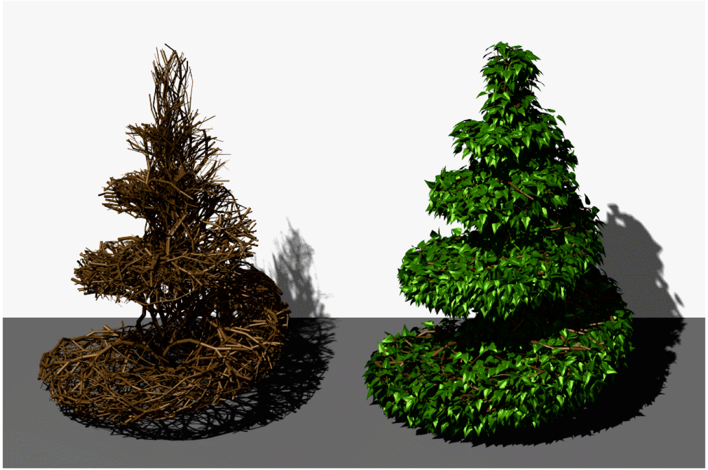
- Rules
  - 22.5°, 4 generations
  - $F \rightarrow FF-[F+F+F]+[+F-F-F]$

Additions



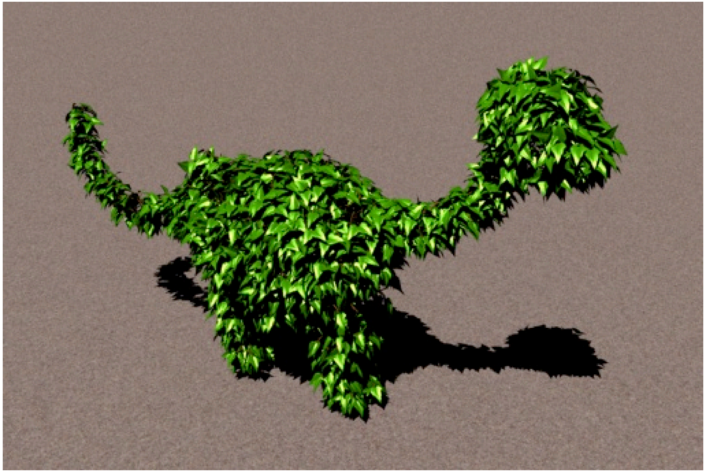
- 3D structure
- Randomness
- Leaves
- Flowers

Pruning



Prusinkiewicz, et al., SIGGRAPH 94

Pruning



Prusinkiewicz, et al., SIGGRAPH 94

Spectral Synthesis

- Alternative to explicitly defining structure
  - Define statistical properties

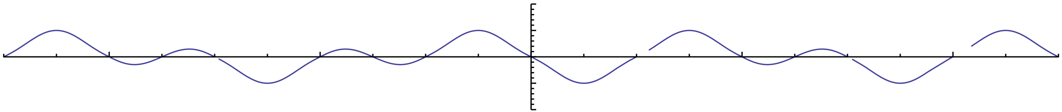
Spectral Synthesis

- Alternative to explicitly defining structure
  - Define statistical properties
- Spectral energy a function of frequency
  - Higher frequency, less energy
  - Characterizes roughness of surface
  - Natural phenomena tend to be $1/f$

Noise-Based Synthesis

Band-limited *Perlin noise* function

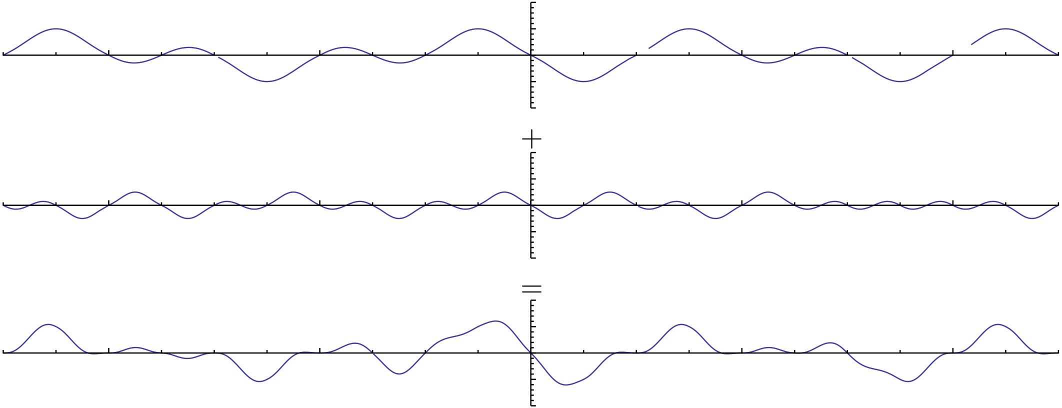
- Most energy between 1/2 and 1 cycle per unit
- Average value is 0
- Random, but repeatable
- 1D, 2D, 3D & 4D versions common



Spectral Synthesis

Sum noise *octaves*

- $n(x) + \frac{1}{2}\ n(2\ x) + \frac{1}{4}\ n(4\ x) + \ldots$
- Stop adding "..." when frequency is too high to see
- Also called *fractional Brownian motion* or *fBm*



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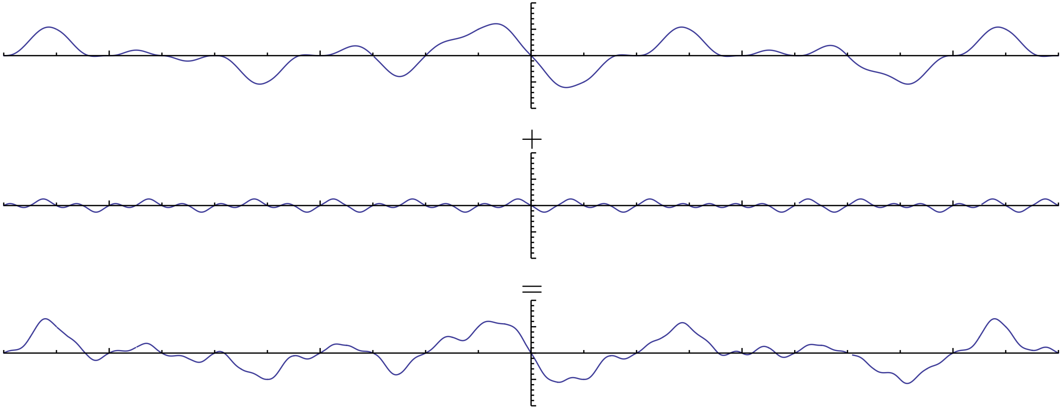

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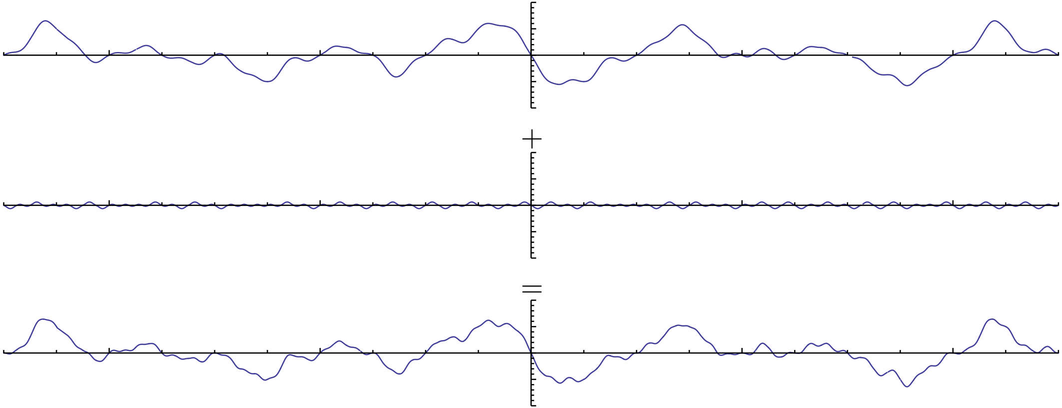


Noise-based Landscape

Landscape height is a fBM function of x,y

- Plus whatever embellishments make it look good

Image: Ken Musgrave

Multifractal

- Change roughness across fractal
  - Scaling $(\frac{1}{2}, \frac{1}{4}, \ldots)$ becomes a function
- Here, scale is a function of altitude

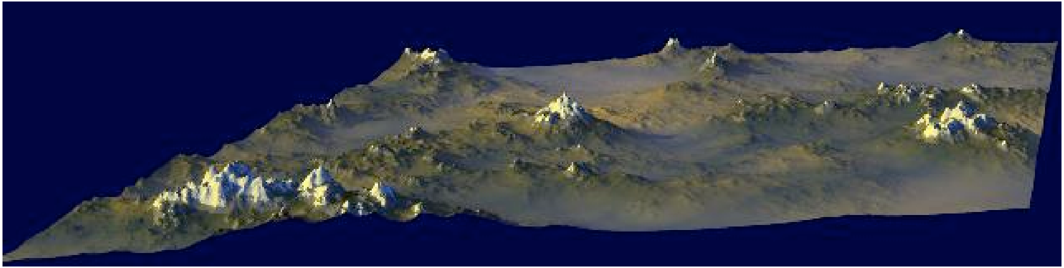
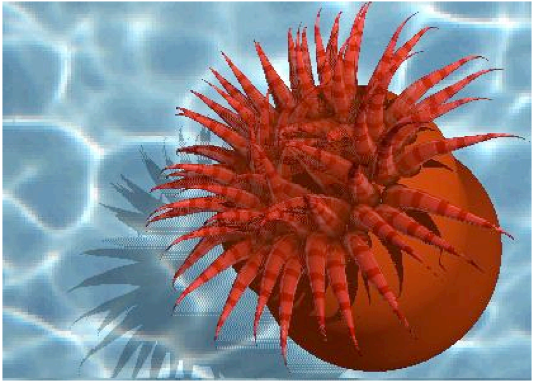


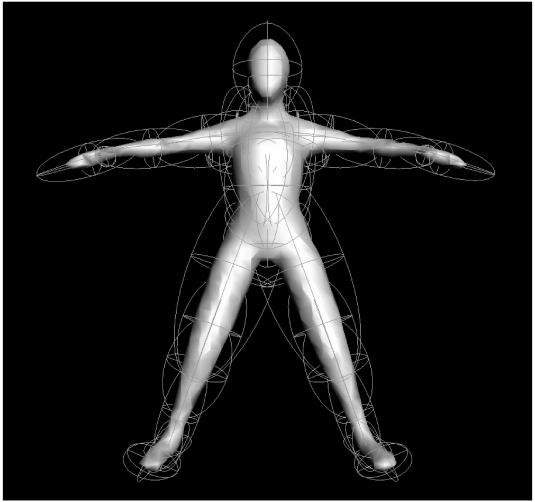
Image: Ken Musgrave

Implicit Functions or Blobby Modeling

- Model as sum of implicit functions
- Surface at threshold



Liang, et al., PG'01

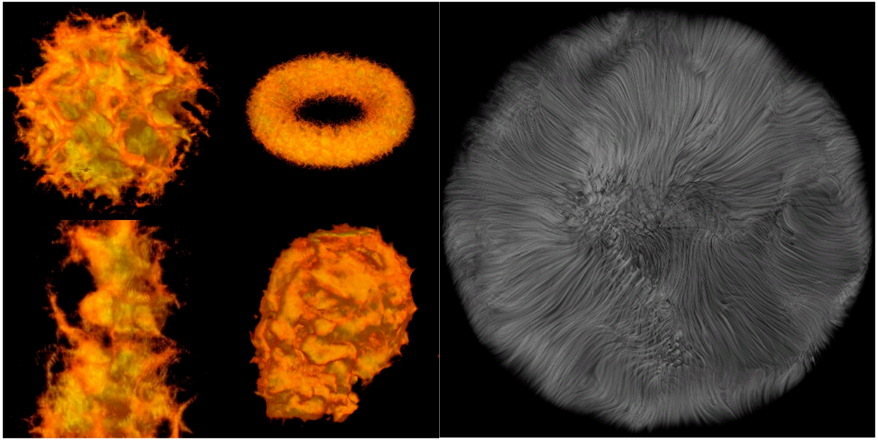


Hybrid Implicit & Polygonal

Bloomenthal, SIGGRAPH 85

Hypertexture

Add noise or turbulence to implicit functions



Perlin & Hoffert, SIGGRAPH 89

Simulations

Biological

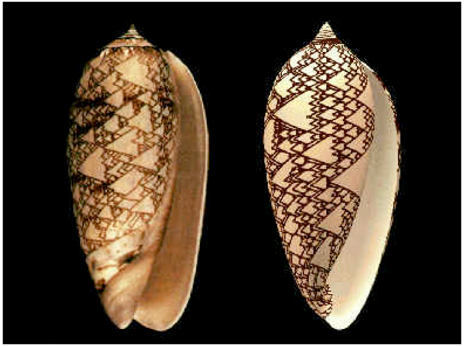
- Simulate growth, development

Physical

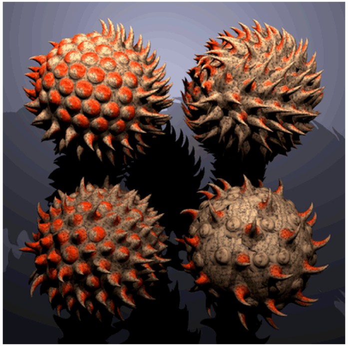
- Simulate formation or erosion

Compare to L-system or noise, where goal is just to "look right"

Biological Simulations



Fowler, et al., SIGGRAPH 92



Fleischer, et al., SIGGRAPH 95

Biological Simulations

Fowler, et al., SIGGRAPH 92

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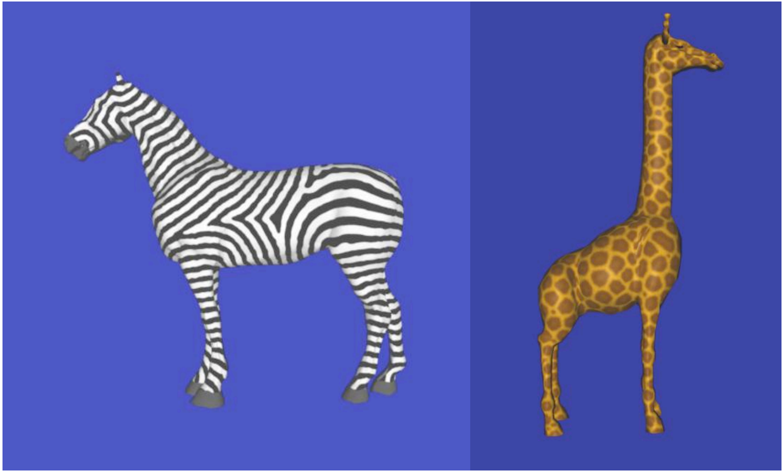


Turk, SIGGRAPH 91

Physical Simulation

Erosion, Deposition

Kenji Nagashima, Visual Computer 1997

Scan from Objects

- General concept
  - Find points on surface
  - Connect into mesh
- Mechanical
- Triangulation
  - Laser
  - Structured Light
  - Multiple Cameras
- CAT scan / MRI

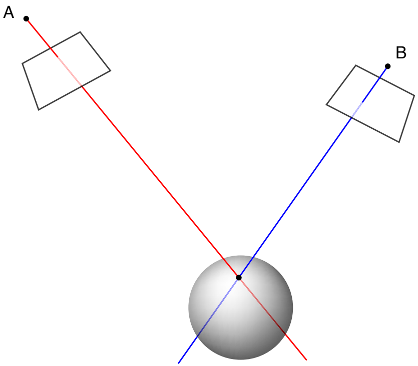
Mechanical

- Touch tip to surface
- Measure angles

Triangulation

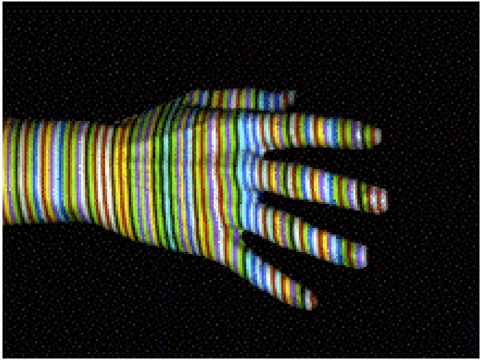
Point in space at intersection

- Ray from light A
- Ray through pixel B

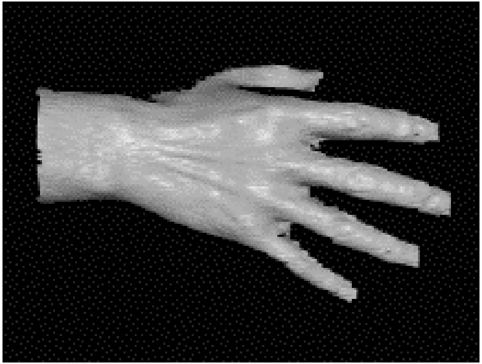


Structured Light

- Point in space at intersection of color edge from light source/projector and ray through camera pixel



projected pattern

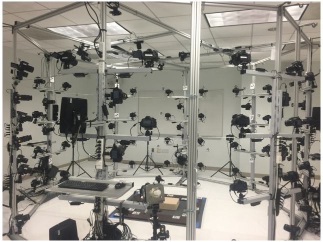


resulting model

Zhang, Curless and Seitz, 3DPVT 2002

Multiple Cameras

- Computer vision algorithm to find common features
- Triangulate to optimize cameras and points in 3D space
- Reconstruct dense mesh

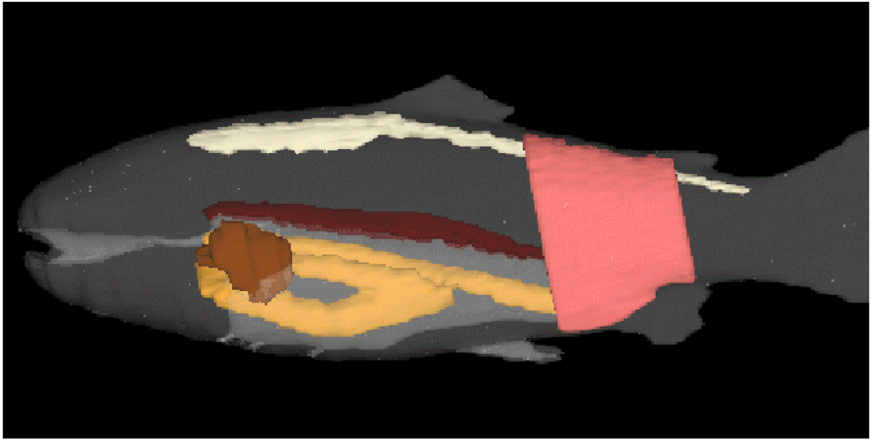


Visualization

- Data
  - measurements
  - simulation
  - information
- Present visually
  - Increase understanding
  - Recognize patterns

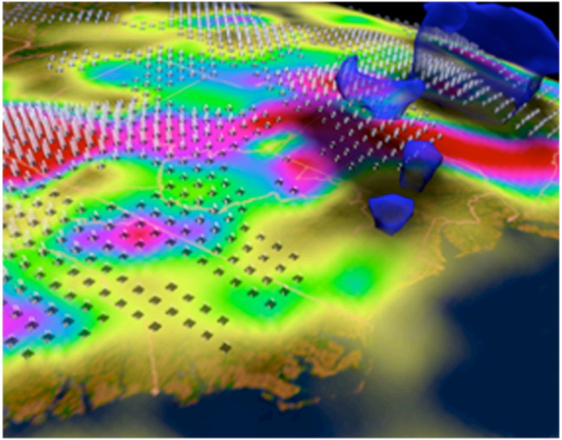
Visualization

Can be 3D Object



Visualization

Can be 3D, but showing non-visual aspects.



Visualization

Can be not traditionally geometric at all

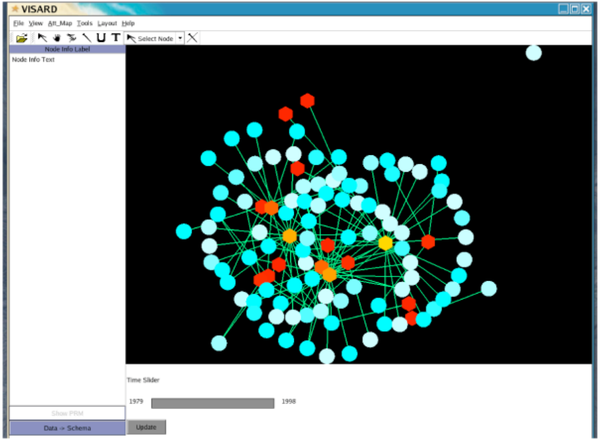


Image-based Rendering

- Construct new *novel* view using only image data
- No explicit geometric model
- Pixels in one or more cameras represent:
  - Image-Based Rendering: Color of point in space
  - Light Field Rendering: Color of light along one ray