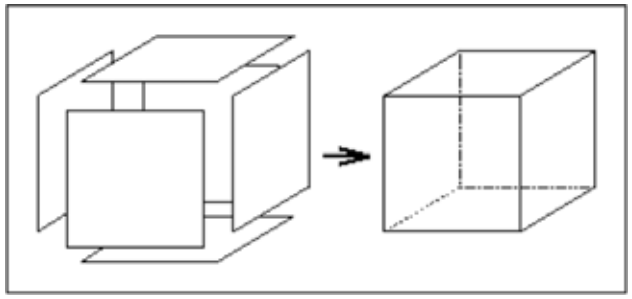
Modeling

Definitions

- Modeling
  - Creating a model of an object, usually out of a collection of simpler primitives
- Primitives
  - A basic shape handled directly the rendering system

Boundary Representation (BRep)

- Instead of representing a cube as 6 polygons, represent as 6 planes
  - Surfaces are represented as a hollow shell
  - Just the **boundary**



Common Primitives

- Triangles & Polygons
  - Most common, usually the only choice for interactive
- Patches, Spheres, Cylinders, ...
  - Found in RenderMan
  - 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)
- 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

Modeling Approaches

- Manual primitive creation
- Procedural
- Scan from physical object
- From data (visualization)
- Through image capture (IBR)

Manual Primitive Creation

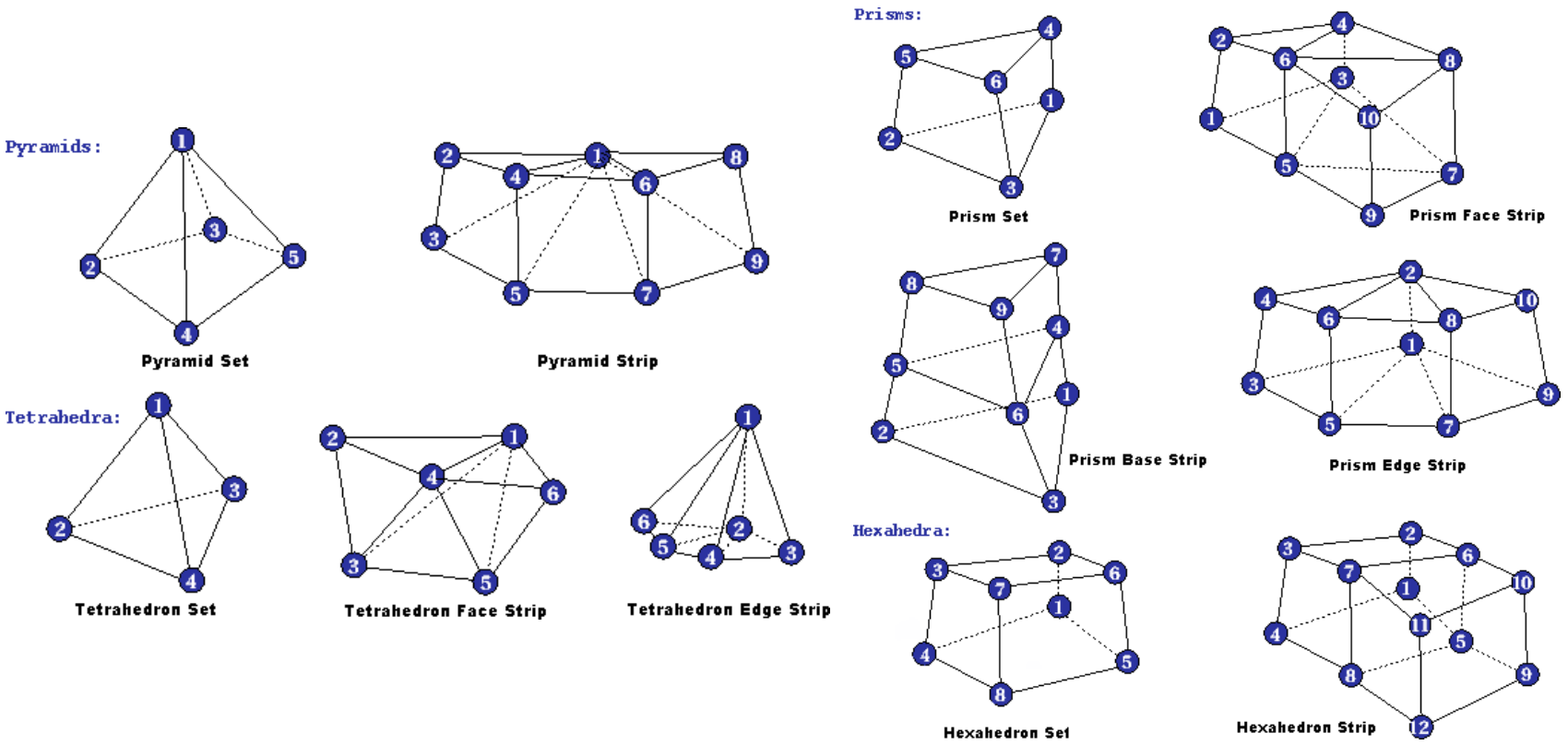
- Text Editor
- High-level primitives
- Modeling Programs

Text Editor

```
Display "cube.tif" "file" "rgba"
Format 1024 768 1
LightSource "distantlight" 1
Projection "perspective"
Translate 0 0 1.5
Rotate 40 -1 1 0
WorldBegin
Surface "matte"
AttributeBegin
Translate -0.5 -0.5 -0.5
Scale 0.02 0.02 0.02
Color [0.02 0.02 0.02]
TransformBegin
Translate 0.5 0.5 0.5
Scale 1 1 1
TransformBegin
Polygon  "P" [0.5 0.5 0.5 -0.5 0.5 0.5 -0.5 -0.5 0.5 0.5 -0.5 0.5 ]
Rotate 90 0 1 0
Polygon  "P" [0.5 0.5 0.5 -0.5 0.5 0.5 -0.5 -0.5 0.5 0.5 -0.5 0.5 ]
Rotate 90 0 1 0
Polygon  "P" [0.5 0.5 0.5 -0.5 0.5 0.5 -0.5 -0.5 0.5 0.5 -0.5 0.5 ]
Rotate 90 0 1 0
Polygon  "P" [0.5 0.5 0.5 -0.5 0.5 0.5 -0.5 -0.5 0.5 0.5 -0.5 0.5 ]
```

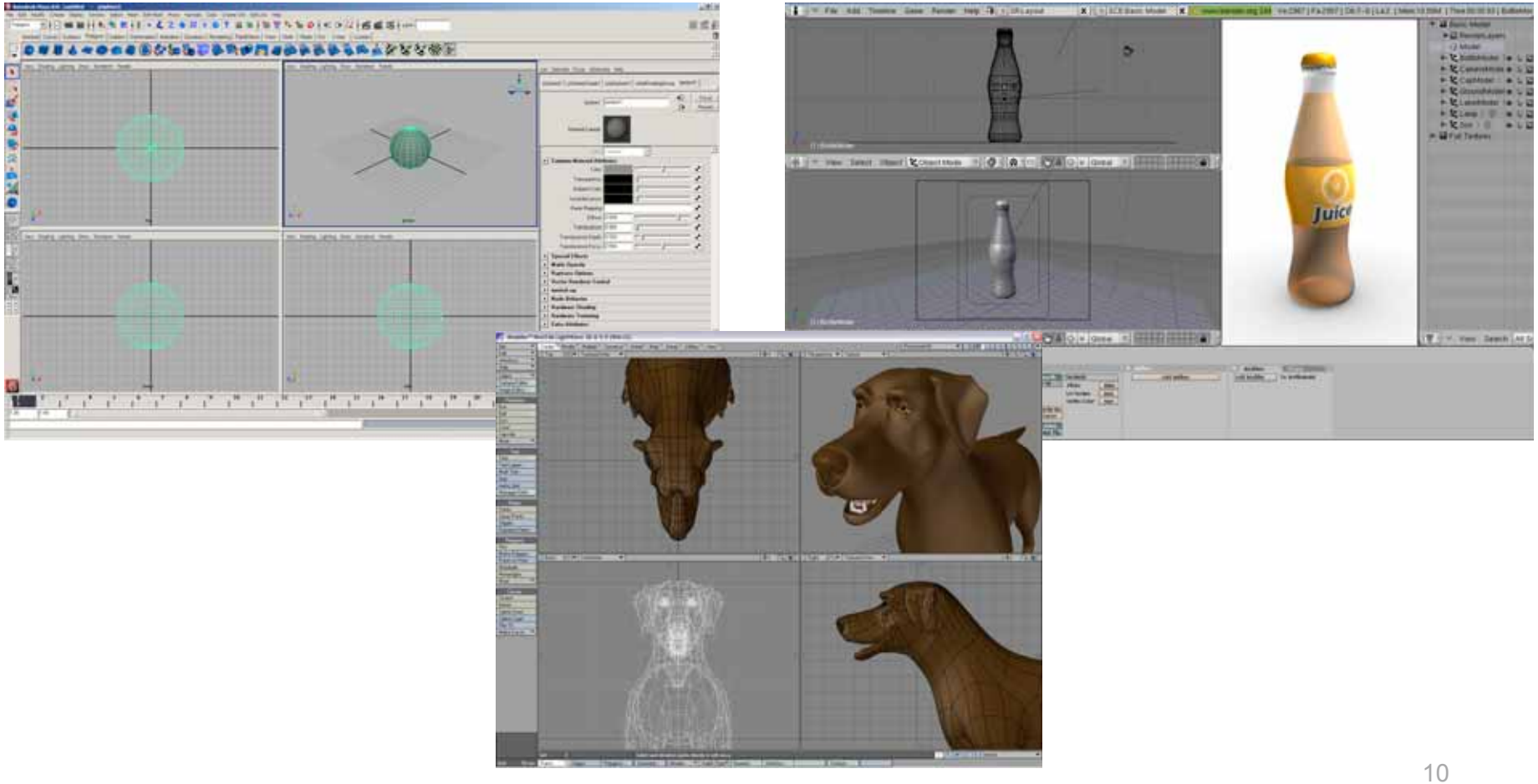
Higher Level Primitives

- Many libraries provide higher level primitives
  - (built atop lower level primitives)



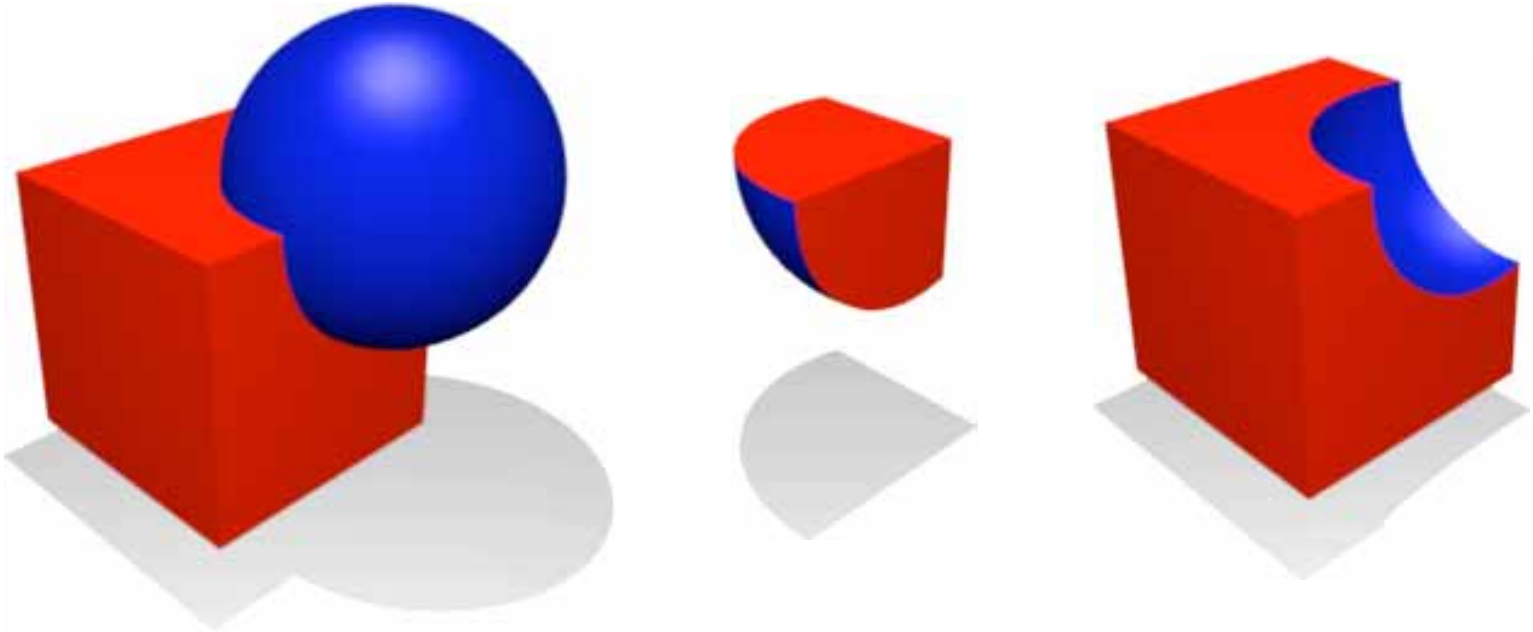
Modeling Programs

- Maya, Blender, LightWave, etc...

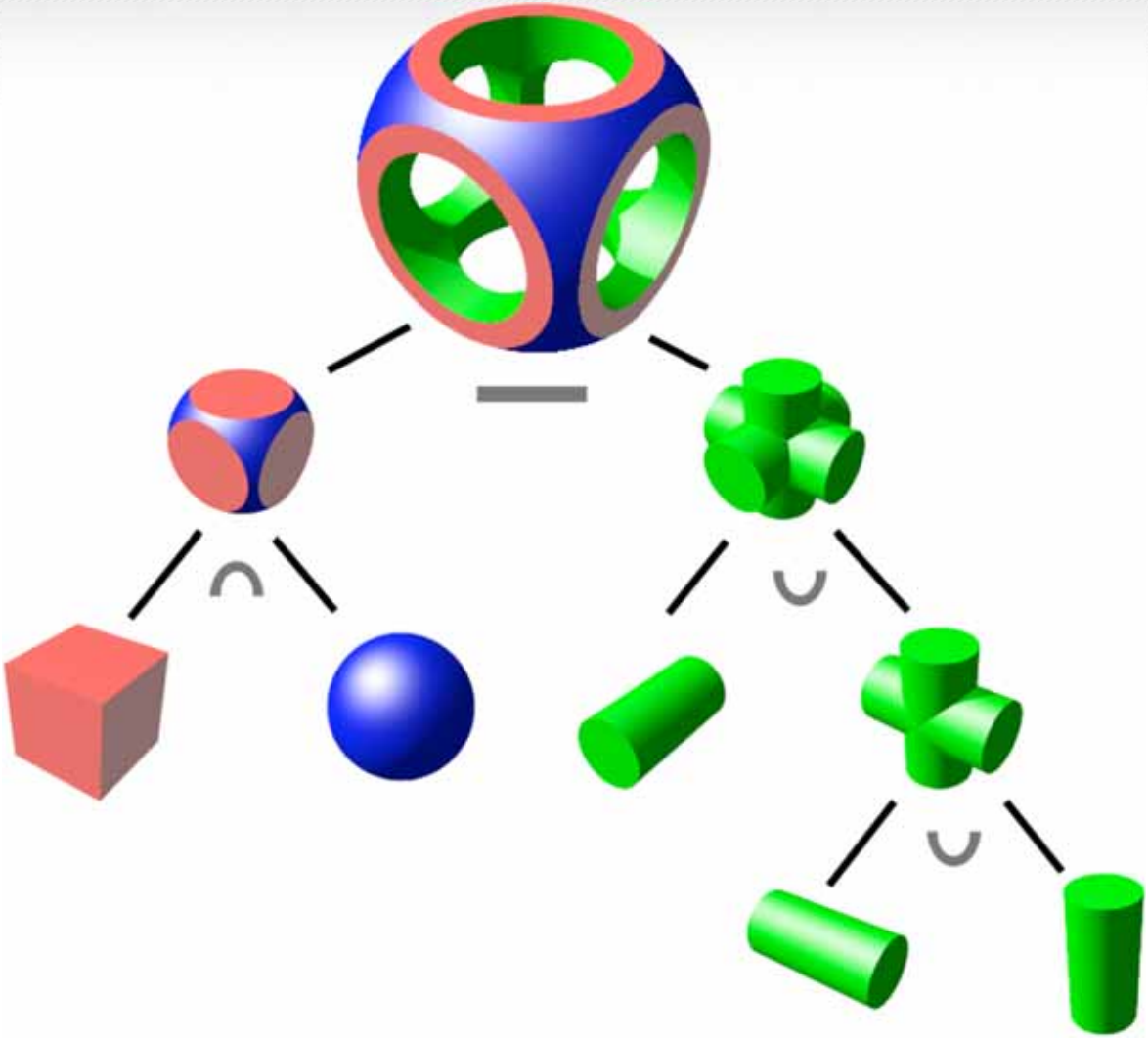


Constructive Solid Geometry (CSG)

- Objects are solids
- Boolean operations to combine objects
  - Union
  - Intersection
  - Difference



Constructive Solid Geometry (CSG)

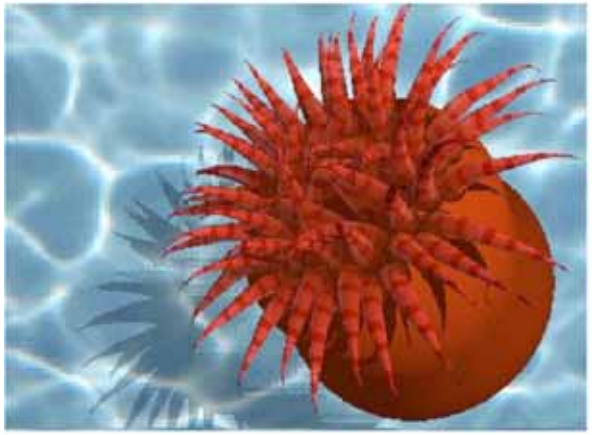


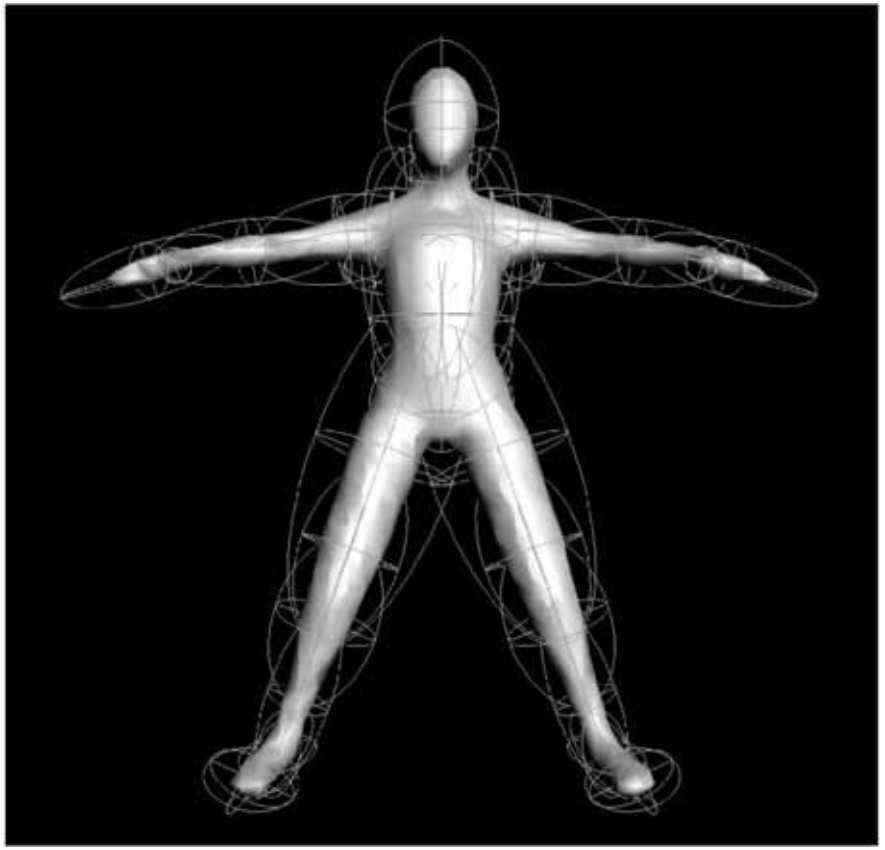
Constructive Solid Geometry (CSG)

- Supported by the RenderMan specification via
  - RiSolidBegin()
  - RiSolidEnd ()
- However, this is one of the areas where Pixie's implementation falls short of full specification compliance
  - Currently an unimplemented feature on Pixie's “wish list”

Implicit Functions

- Model as sum of implicit functions
- Surface at threshold





Liang, et al., PG'01

Hybrid Implicit & Polygonal

Procedural

- Describe physical attributes though some (spatial) function
  - Shape
  - Density
  - Color
  - Texture

Procedural Approaches

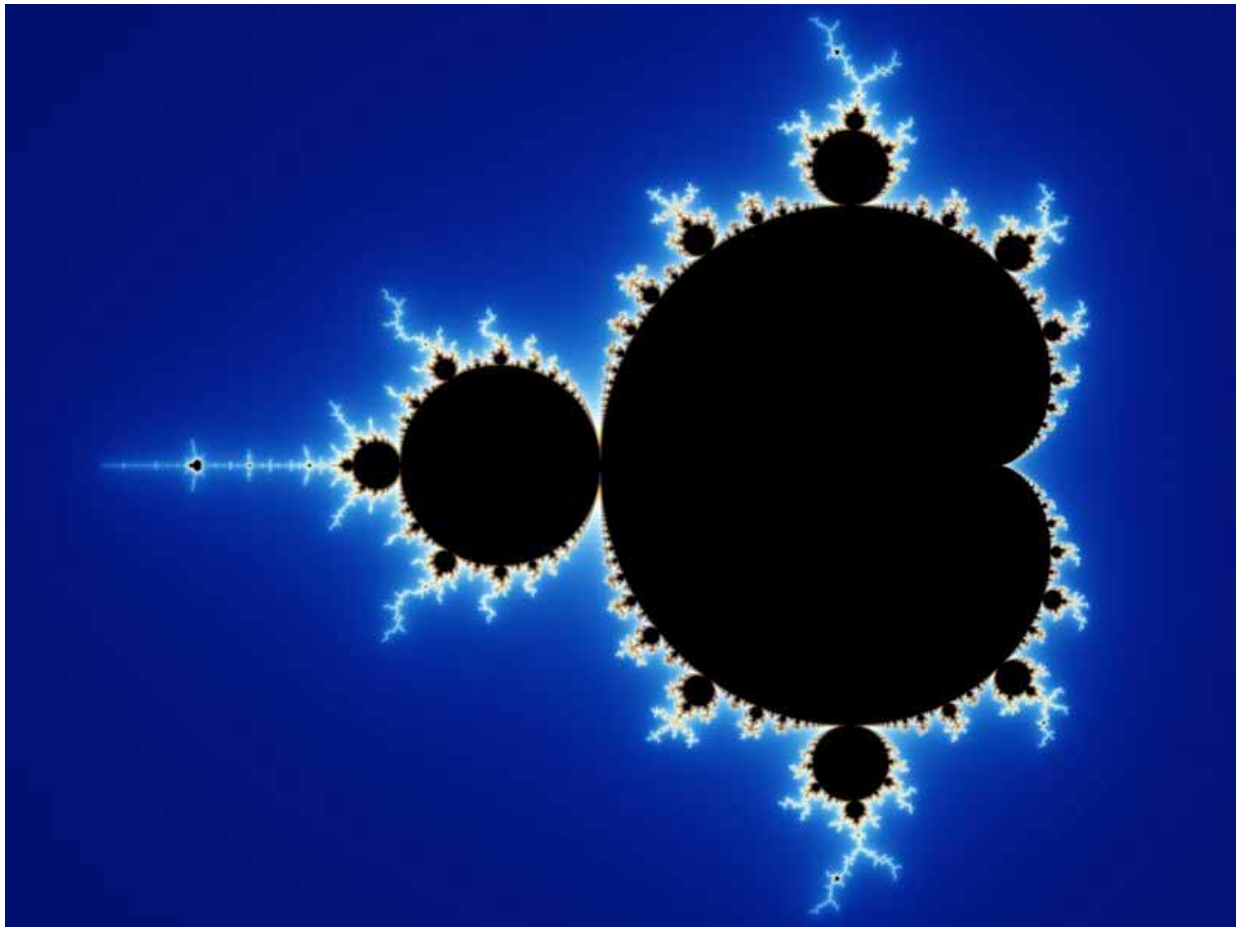
- Fractals
- Implicit Functions
- Grammars
- Simulations

Fractals

- Complex structure through self-similarity across scales
  - Iterated equations
  - Iterated replacement
  - Spectral synthesis

Fractals – Iterated Equations

- Mandelbrot Set



Fractals – Iterated Equations

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

$$f_c : \mathbb{C} \to \mathbb{C}$$

- Given by (where ***c is a complex number)***

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

- ***For each c the following behavior is considered***

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

- Obtained by iterating (staring at ***z*** = 0)

$$f_c(z)$$

Fractals – Iterated Equations

- Thus

$$f_c^n(z)$$

- Denotes the ***n***th iteration of

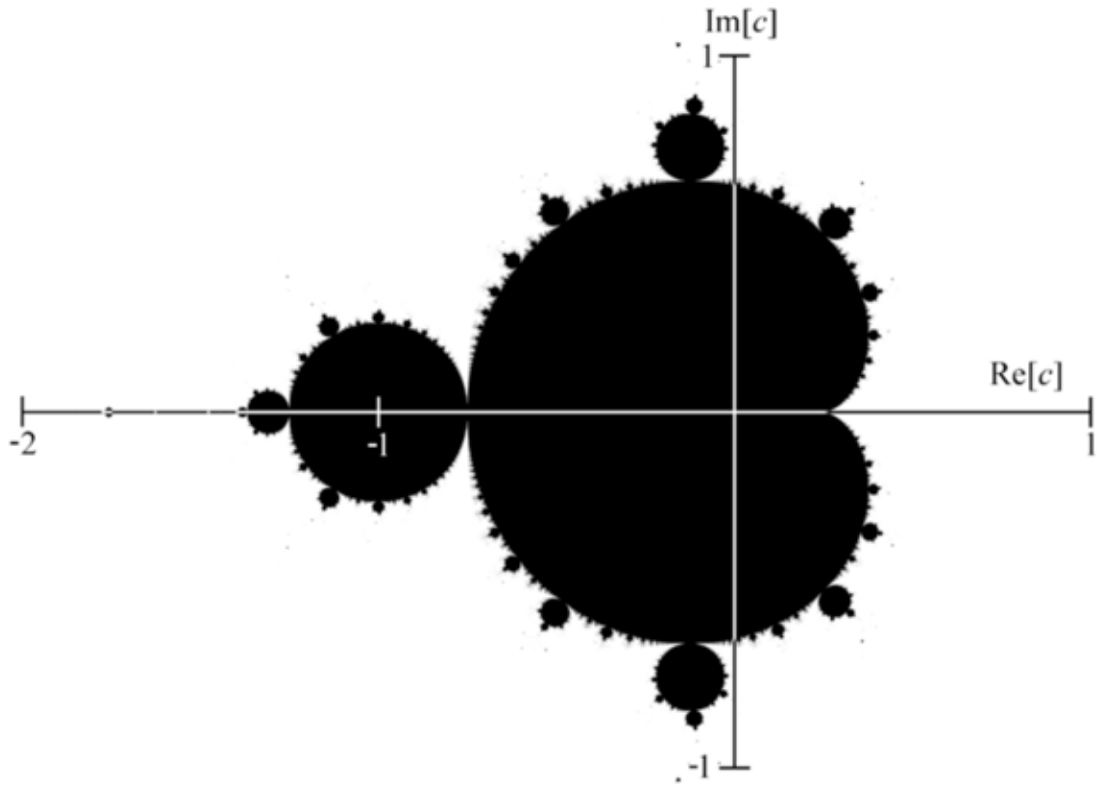
$$f_c(z)$$

- The Mandelbrot set is the subset which is constrained as

$$M = \left\{ c \in \mathbb{C} : \sup_{n \in \mathbb{N}} |f_c^n(0)| < \infty \right\}.$$

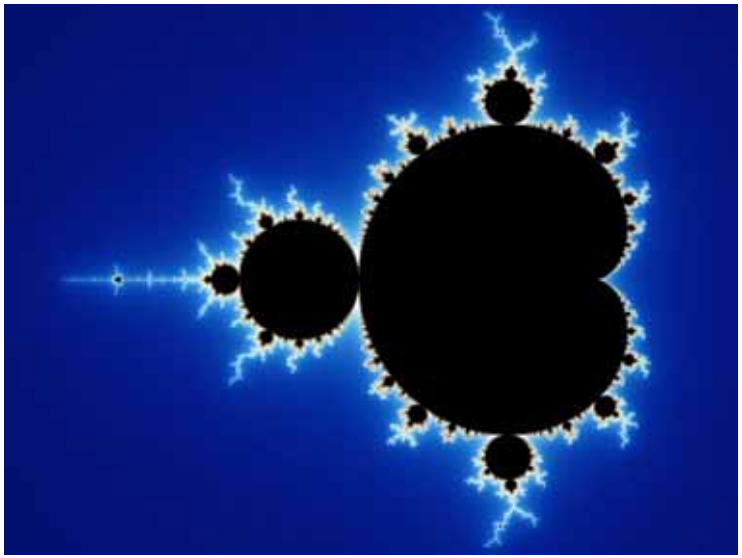
Fractals – Iterated Equations

- Mathematical depiction of the Mandelbrot set
  - Point ***c*** is black if it belongs to the set

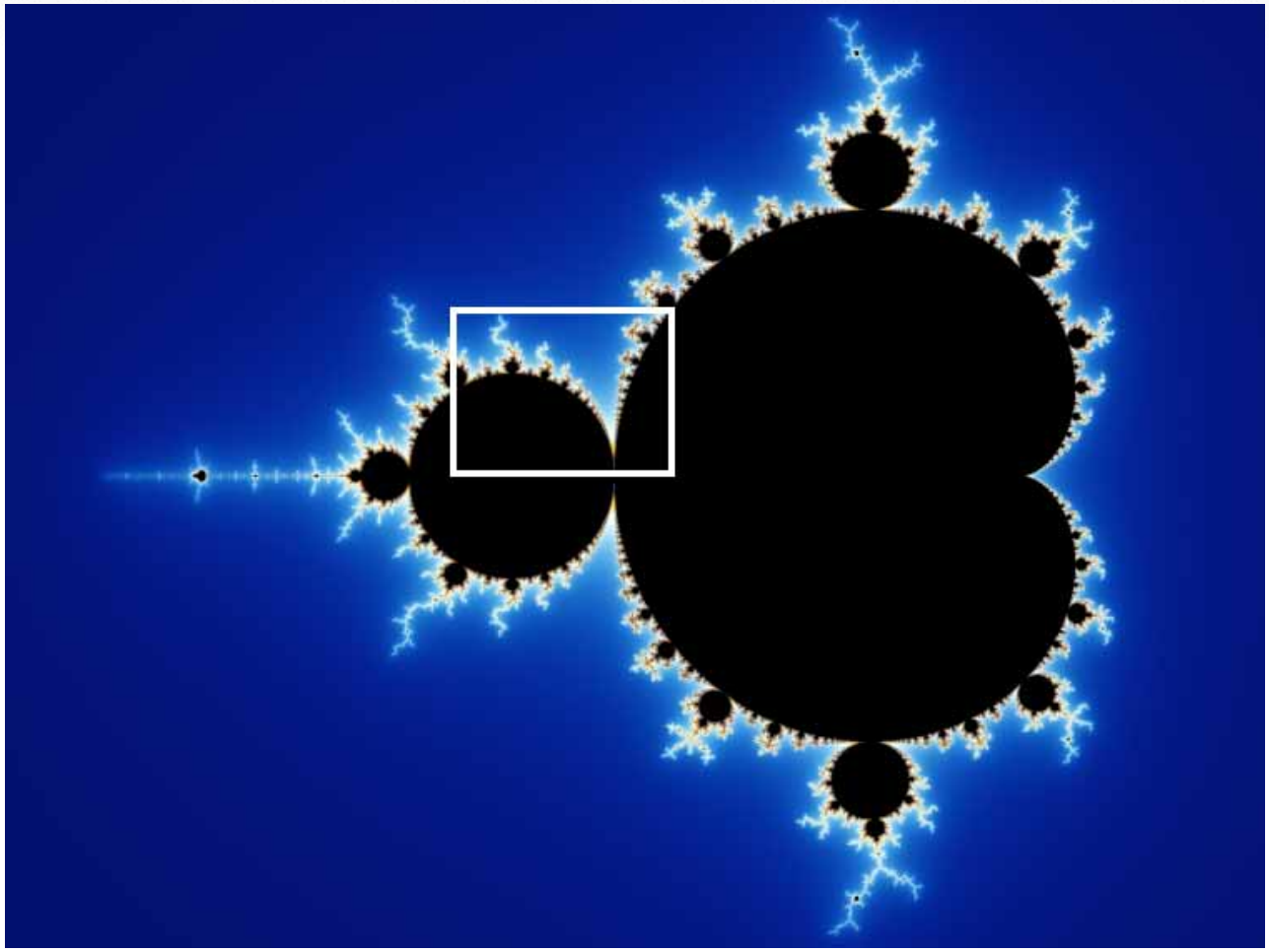


Fractals – Iterated Equations

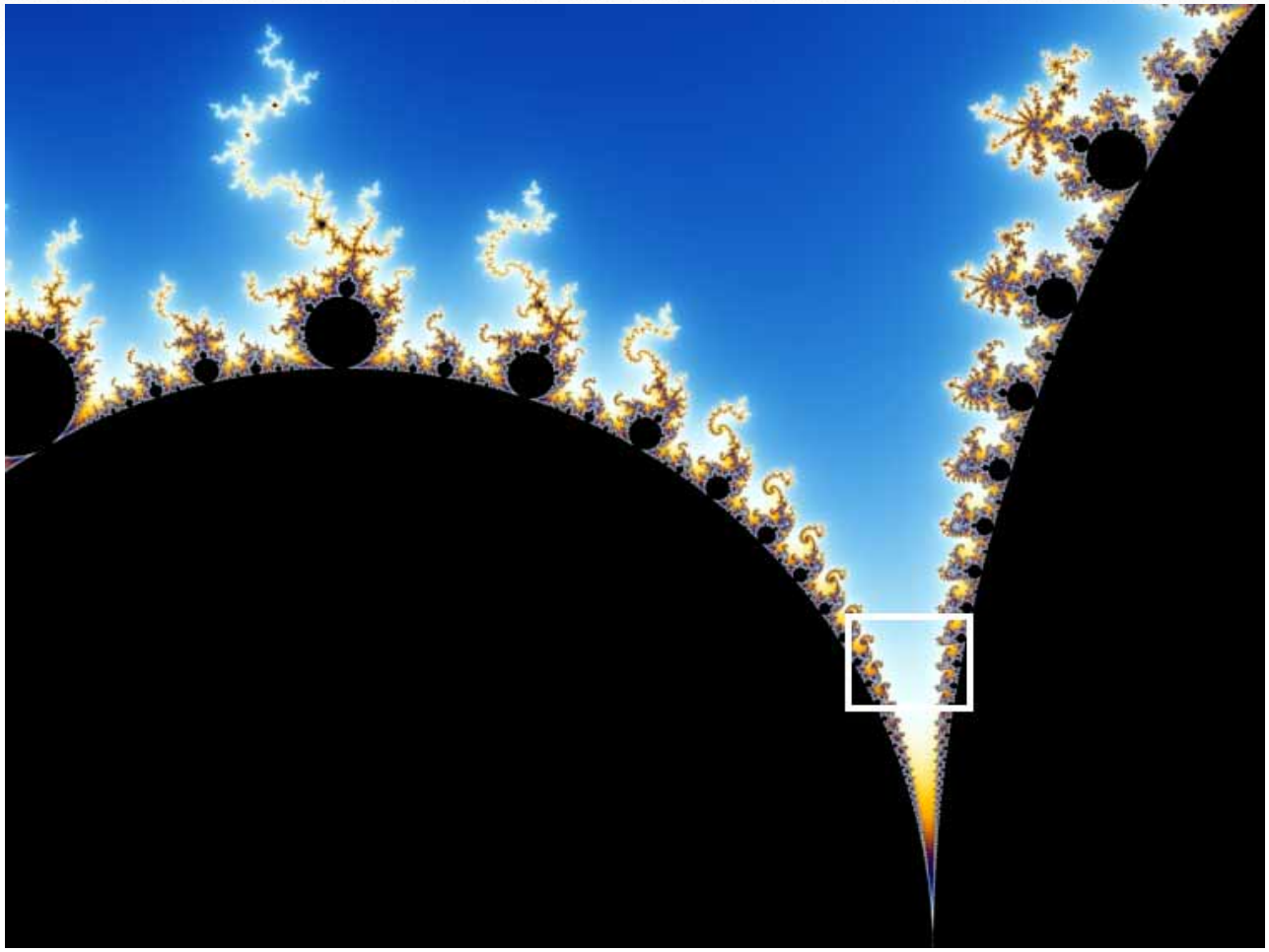
- Colored pictures are usually generated by assigning a color to each point which represents how quickly the sequence
- Diverges to infinity $\left|f_c^n(0)\right|$



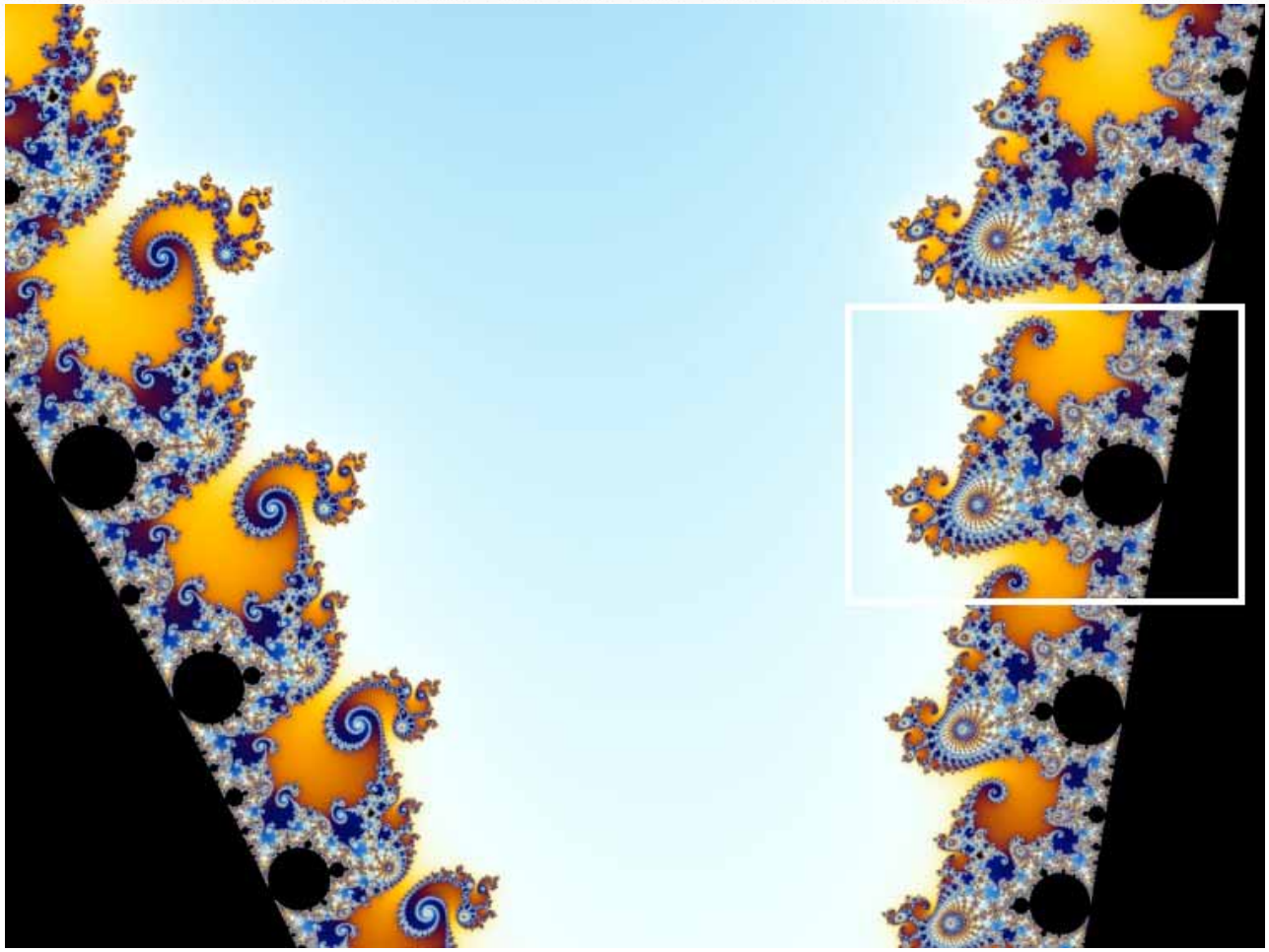
Fractals – Self Similarity



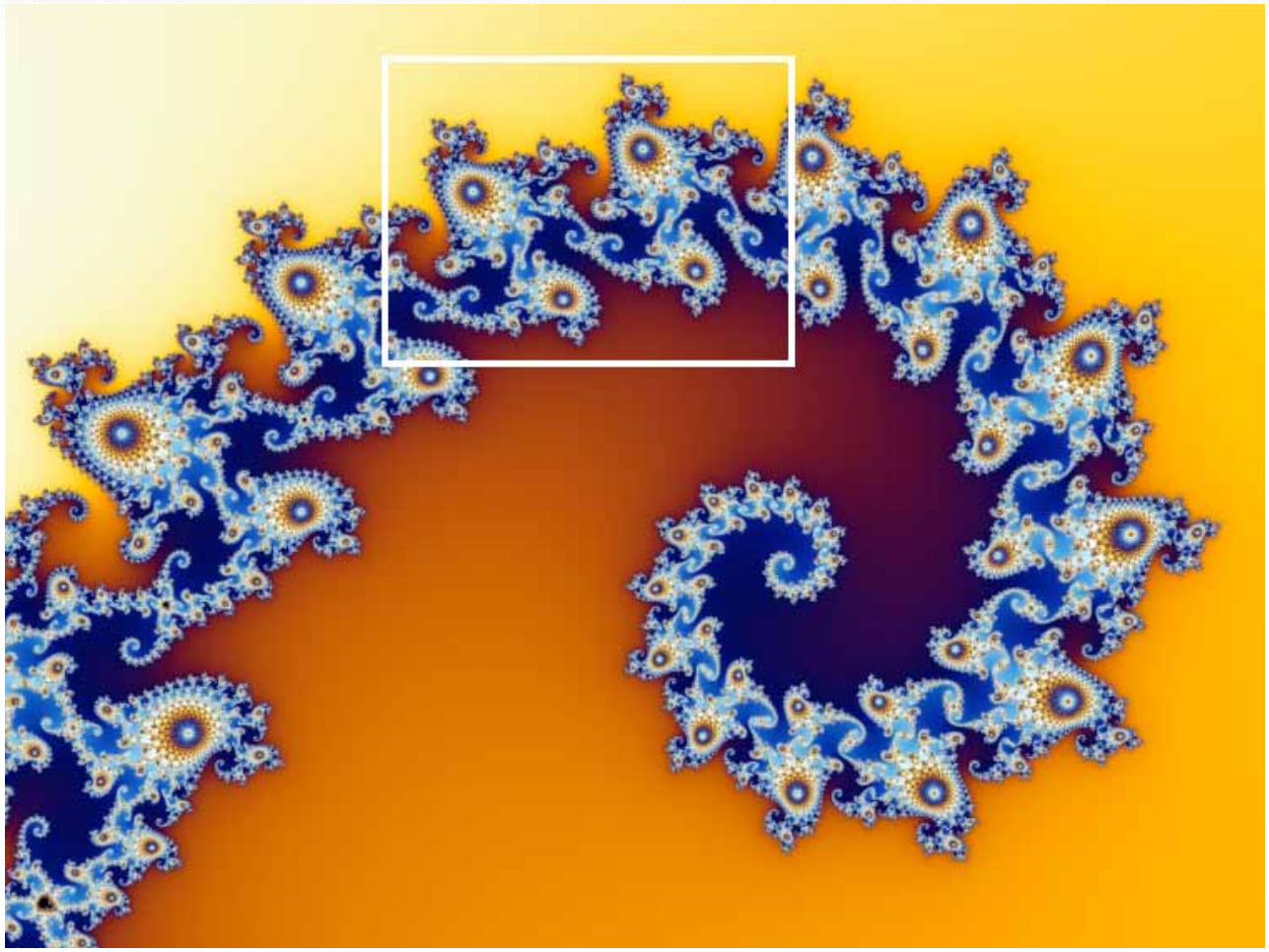
Fractals – Self Similarity



Fractals – Self Similarity

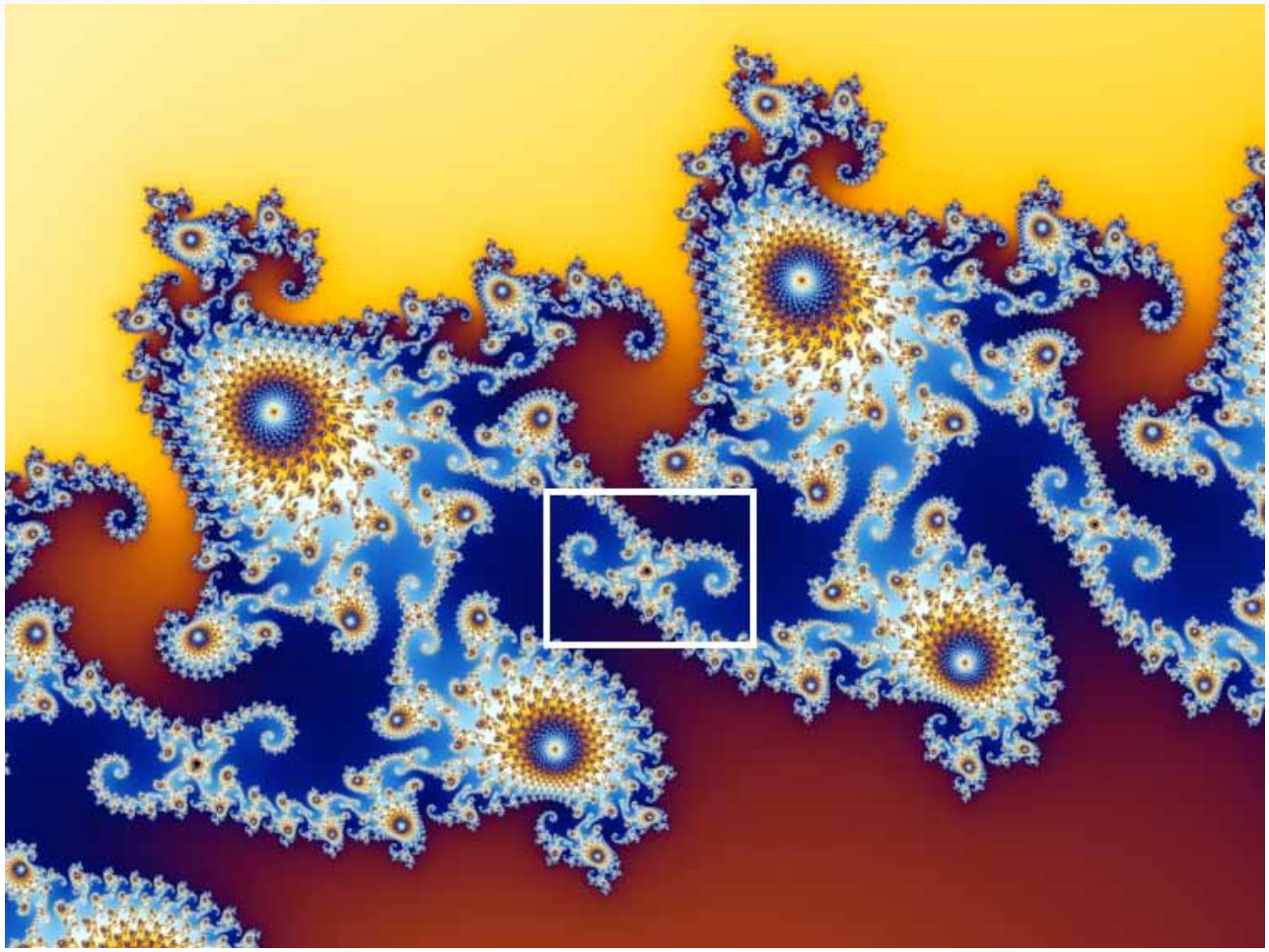


Fractals – Self Similarity

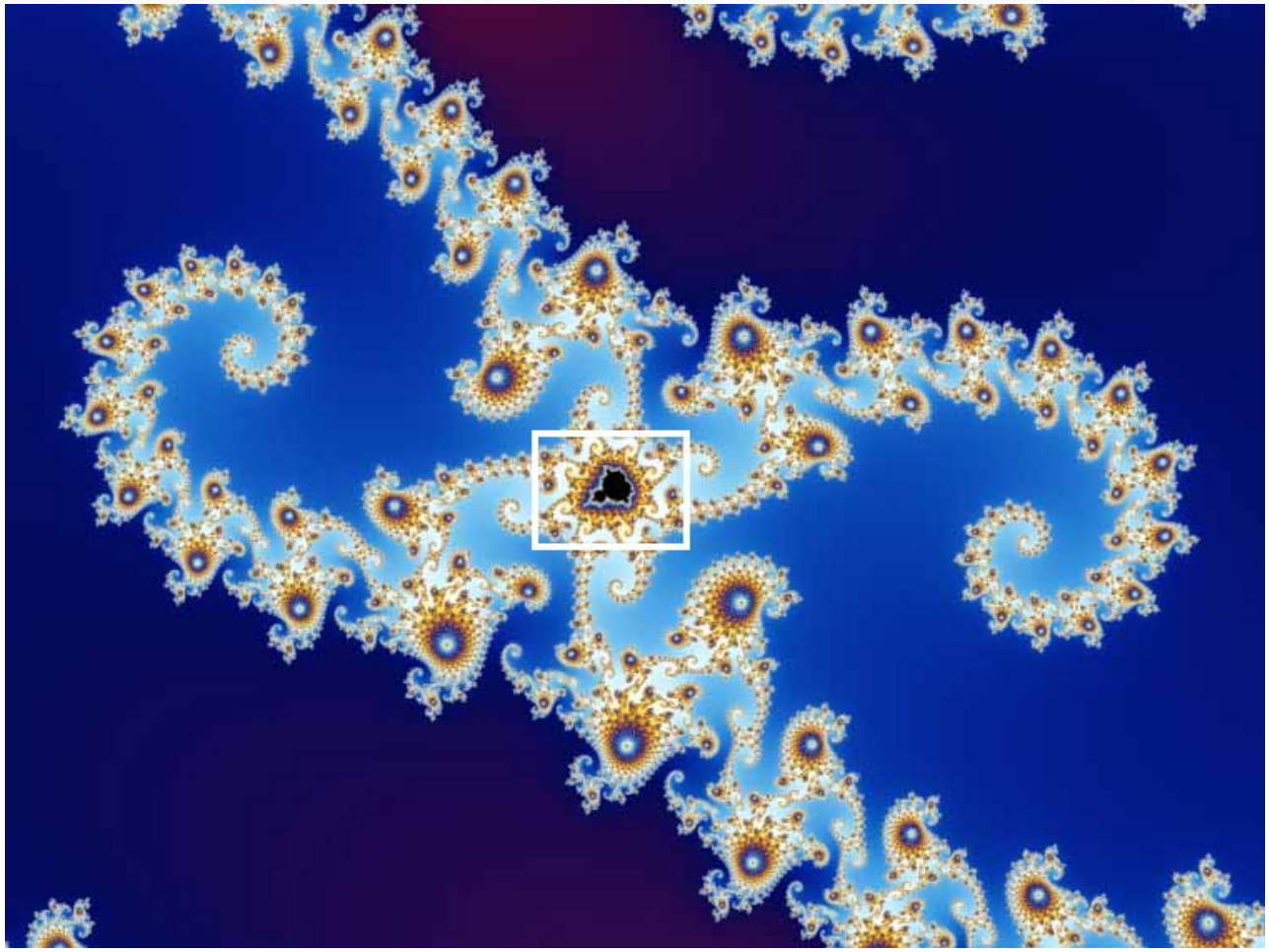


Created by Wolfgang Beyer

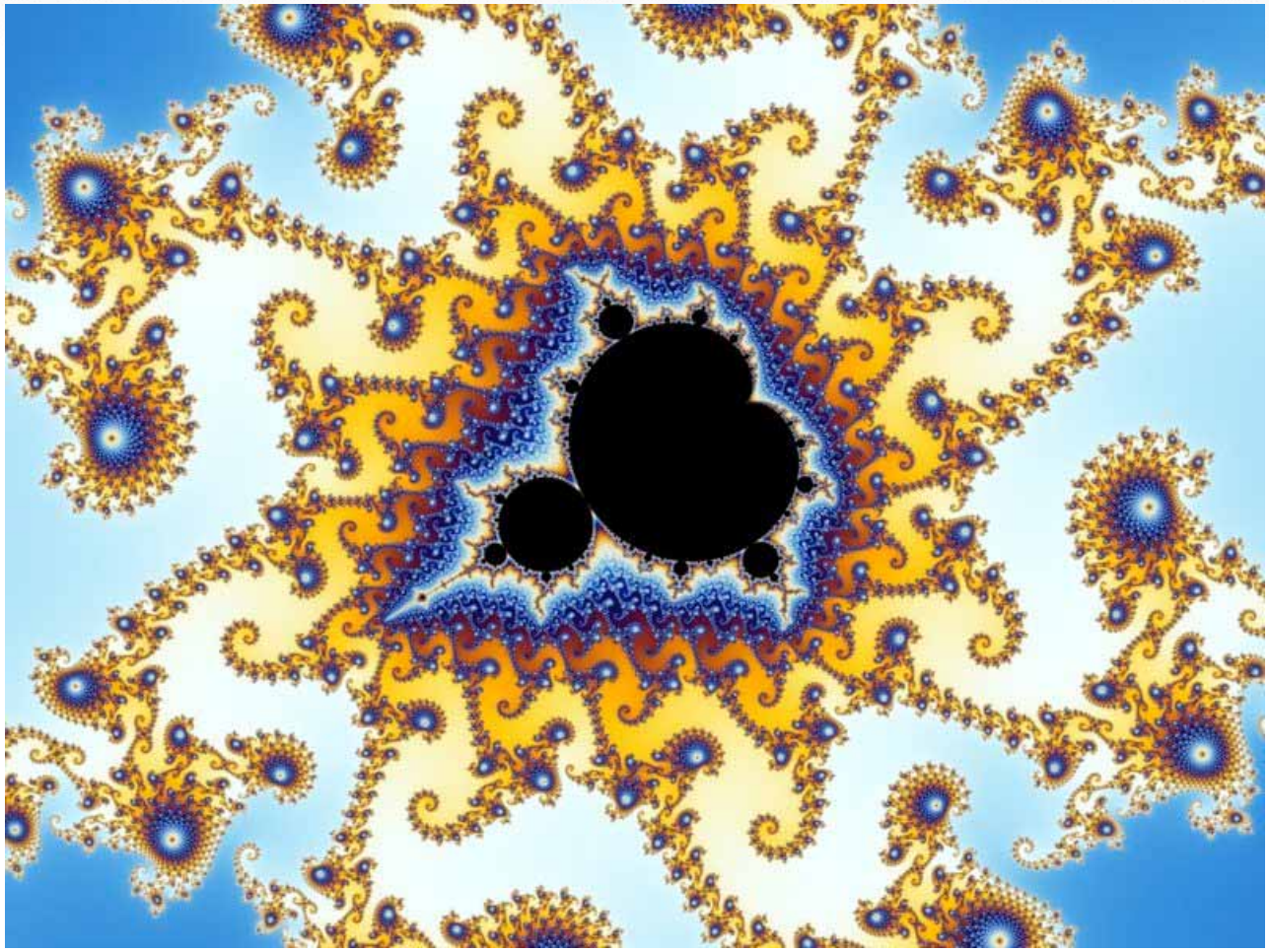
Fractals – Self Similarity



Fractals – Self Similarity



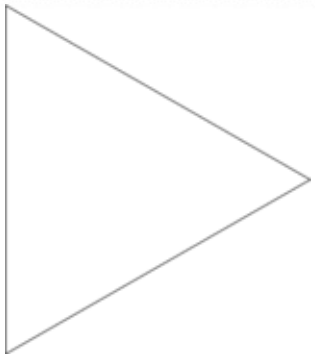
Fractals – Self Similarity



Created by Wolfgang Beyer

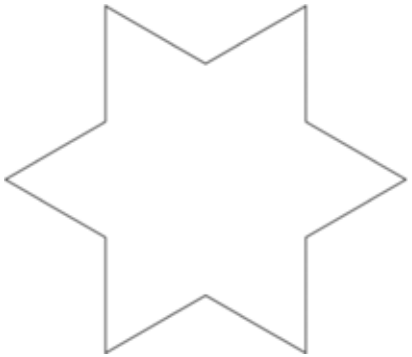
Fractals – Iterated Replacement

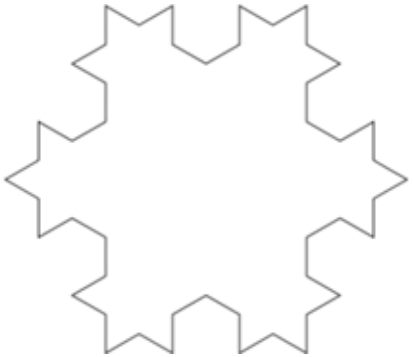
- Koch Curve

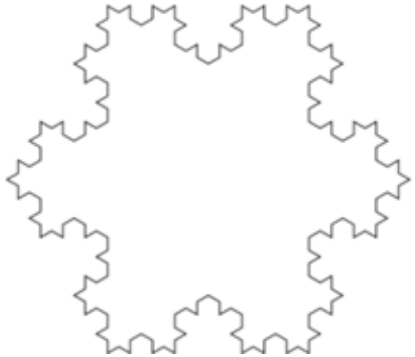


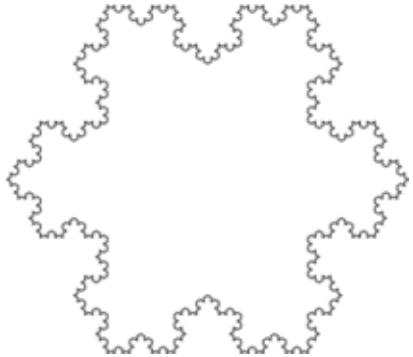
Initiator

Generator



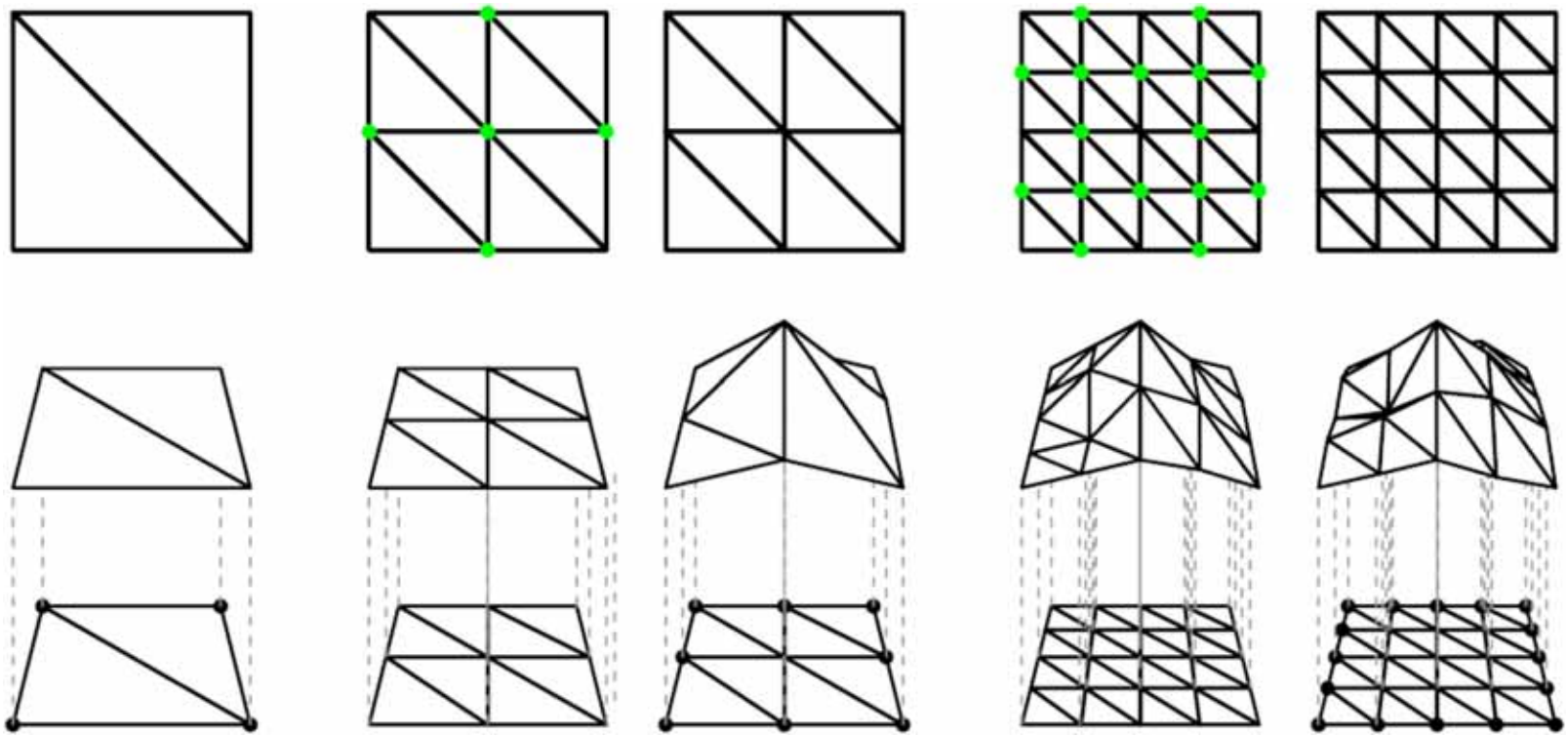






Fractals – Iterated Replacement

- Fractal Mountains



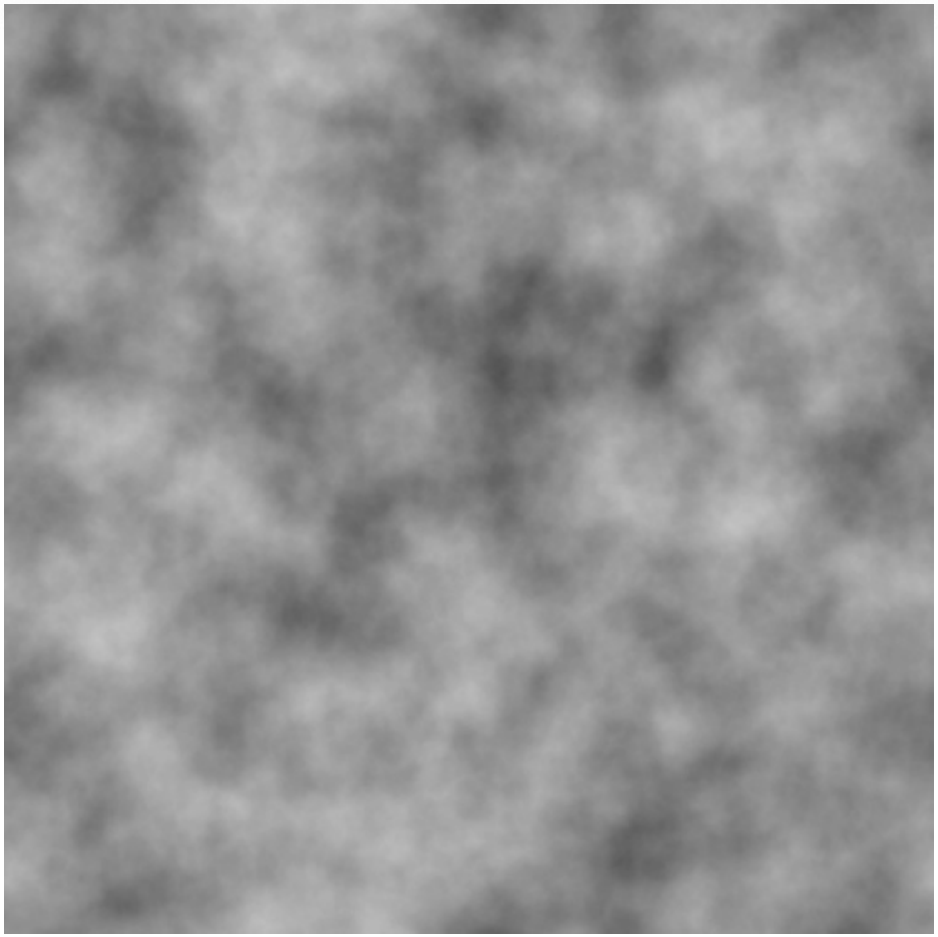
Fractals – Spectral Synthesis

- Spectral energy a function of frequency
  - Higher frequency, less energy
  - Characterizes roughness of surface
  - Natural phenomena tend to be ***1/f***

Fractals – Noise-Based Synthesis

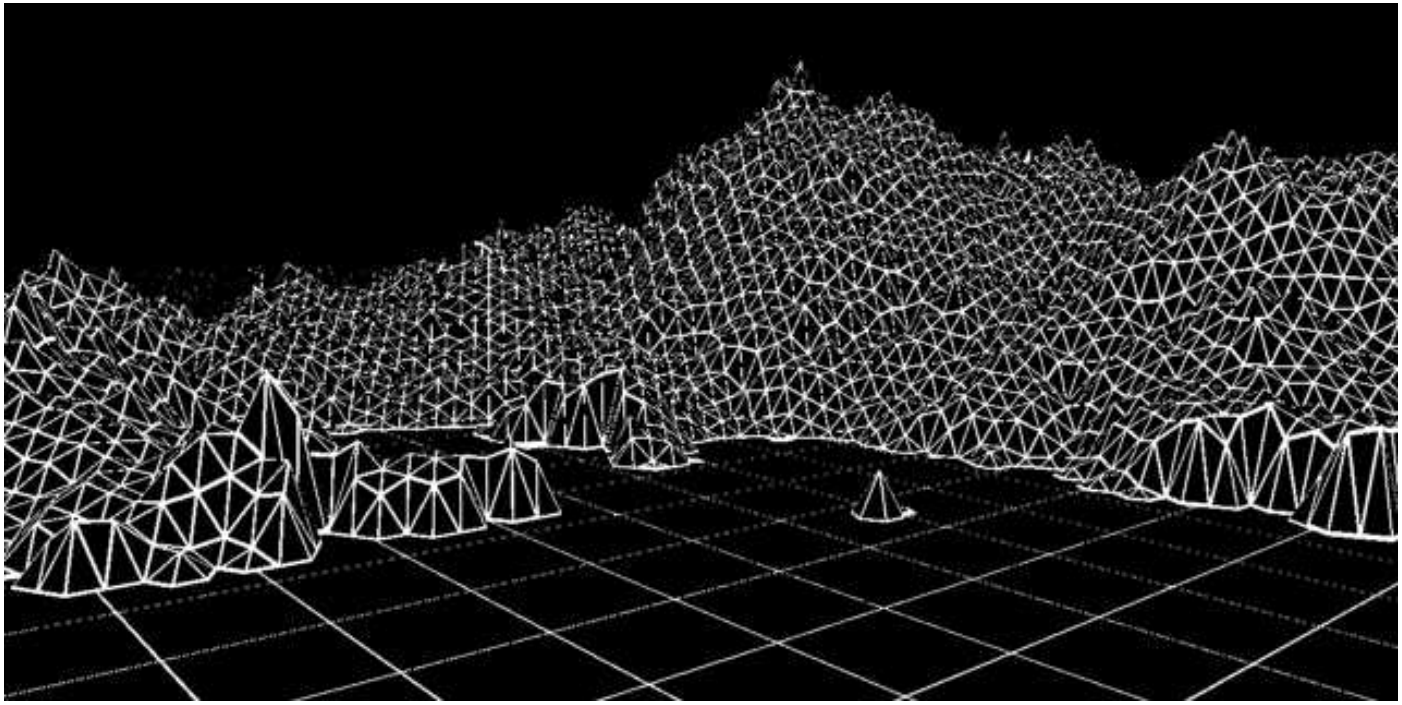
- Band-limited Perlin noise function
  - Most energy between 1/2 and 1 cycle per unit
  - Average value is 0
  - Random, but repeatable
  - 1D, 2D, 3D & 4D versions common
- Sum noise octaves
  - $\boldsymbol{n}(\boldsymbol{x}) + \frac{1}{2}\boldsymbol{n}(2\boldsymbol{x}) + \frac{1}{4}\boldsymbol{n}(4\boldsymbol{x}) + \ldots$
  - Stop add "..." when frequency is too high to see

Perlin Noise

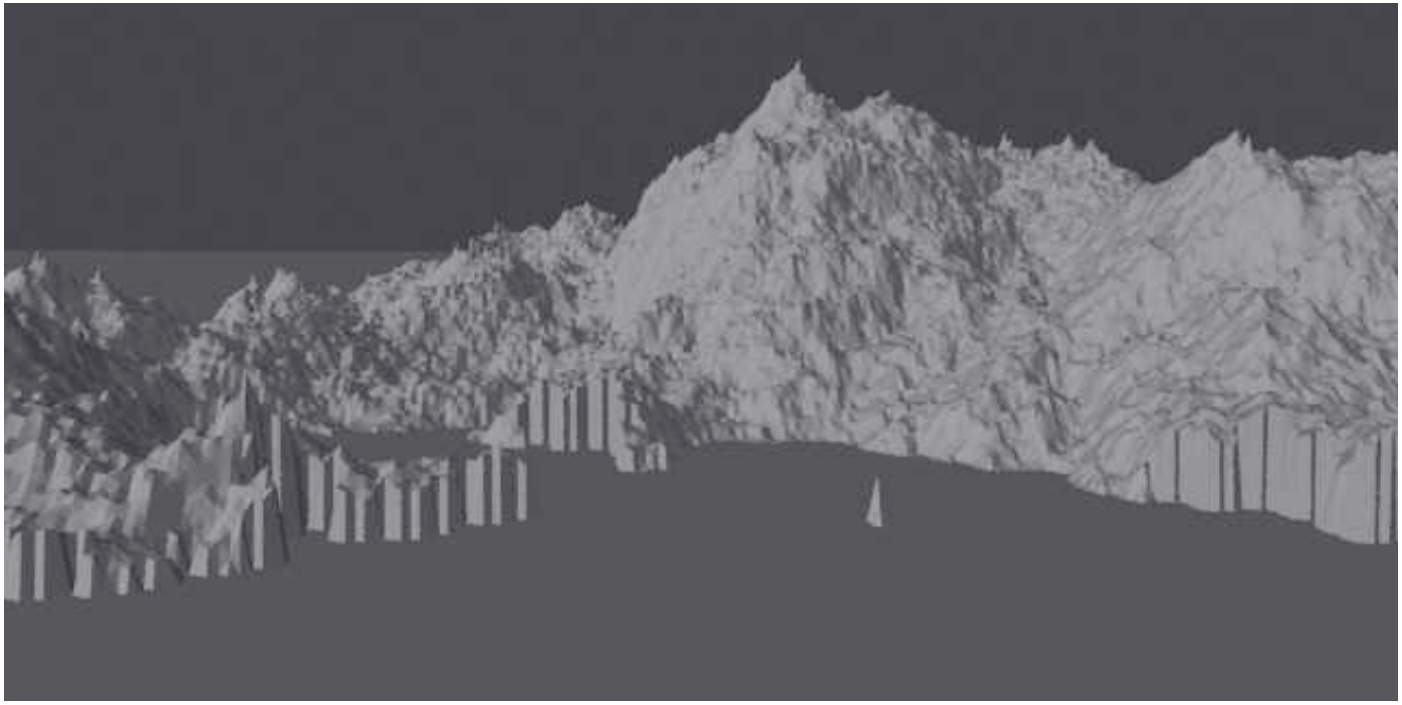


Fractals – Fractal Landscapes

- Landscape height is a fractal function of ***x, y***



Fractals – Fractal Landscapes



Fractals – Fractal Landscapes

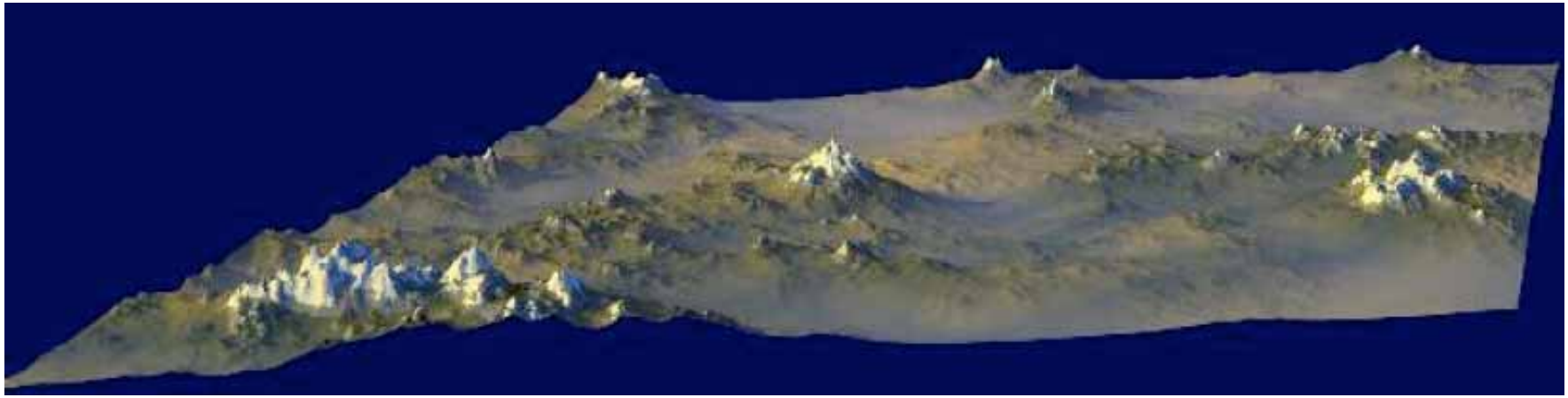
- Embellishments – textures, shadows, reflections

Fractals – Fractal Landscapes

- Further embellishments – atmospheric haze, clouds, waves, colored light source

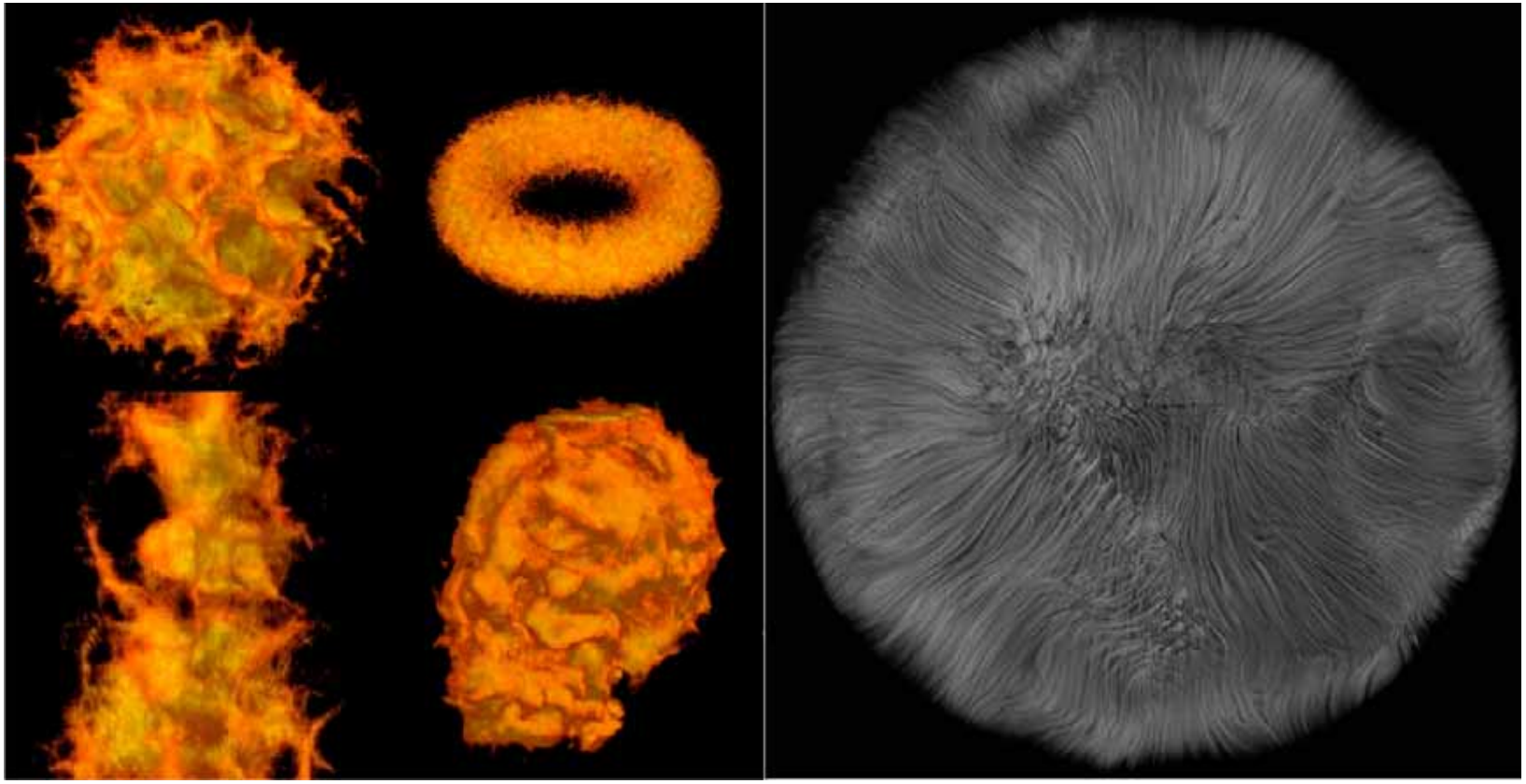
Multi-Fractal Landscapes

- Change roughness across fractal
  - Scaling (½, ¼, ...) becomes a function
- Here, scale is a function of altitude



Hypertexture

- Add noise or turbulence to functions



Grammar Based Modeling

- Use (mostly) context-free grammars (CFG) to specify structural change over generations
- Often used to simulate a biological growth process
  - Plants
  - Seashells
- L-Systems (Lindenmayer)

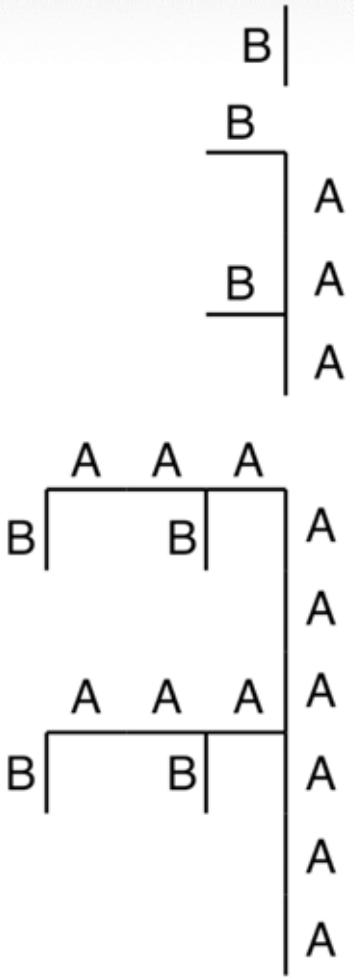
Context Free Grammars

- A CFG G = (V, T, S, P) where
  - V is a set of non-terminals
  - T is a set of terminals
  - S is the start symbol
  - P is a set of production (rules) of the form

$$A \rightarrow x, \text{ where } A \in V, x \in (V \cup T)^*$$

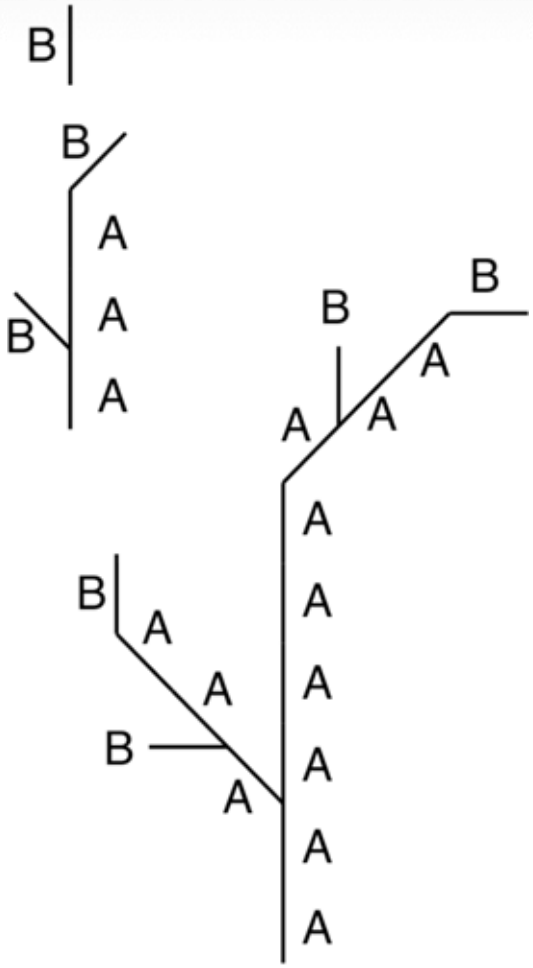
Applying Grammar Rules

- Symbols
  - A, B, straight line segments
  - [ ], branch left 90º
- Rules
  - B → A[B]AA[B]
  - A → AA
- Strings
  - B
  - A[B]AA[B]
  - AA[A[B]AA[B]]AAAA[A[B]AA[B]]



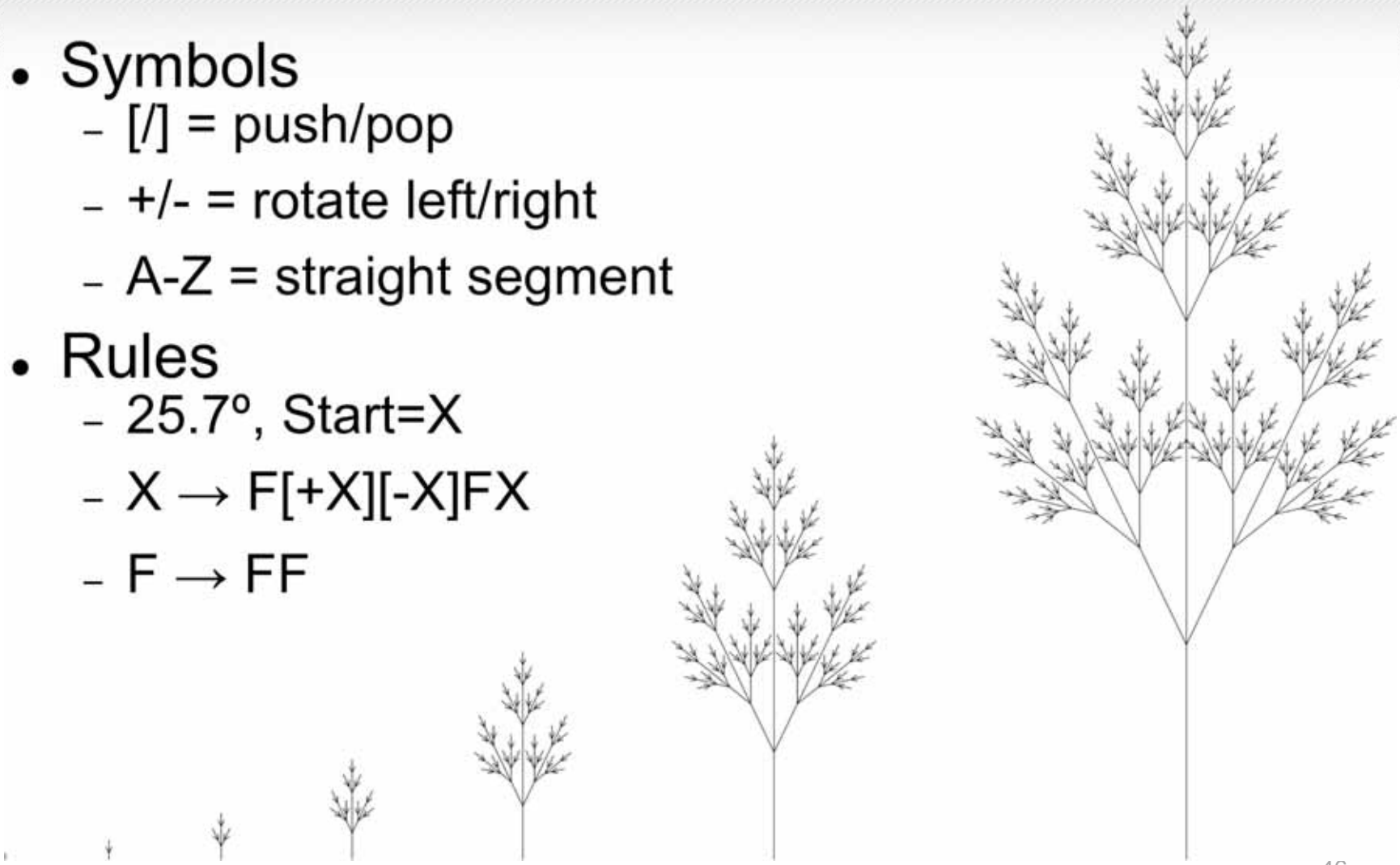
Applying Grammar Rules

- Symbols
  - A, B, straight line segments
  - [ ], branch left 45º
  - ( ), branch right 45º
- Rules
  - B → A[B]AA(B)
  - A → AA
- Strings
  - B
  - A[B]AA(B)
  - AA[A[B]AA(B)]AAAA(A[B]AA(B))



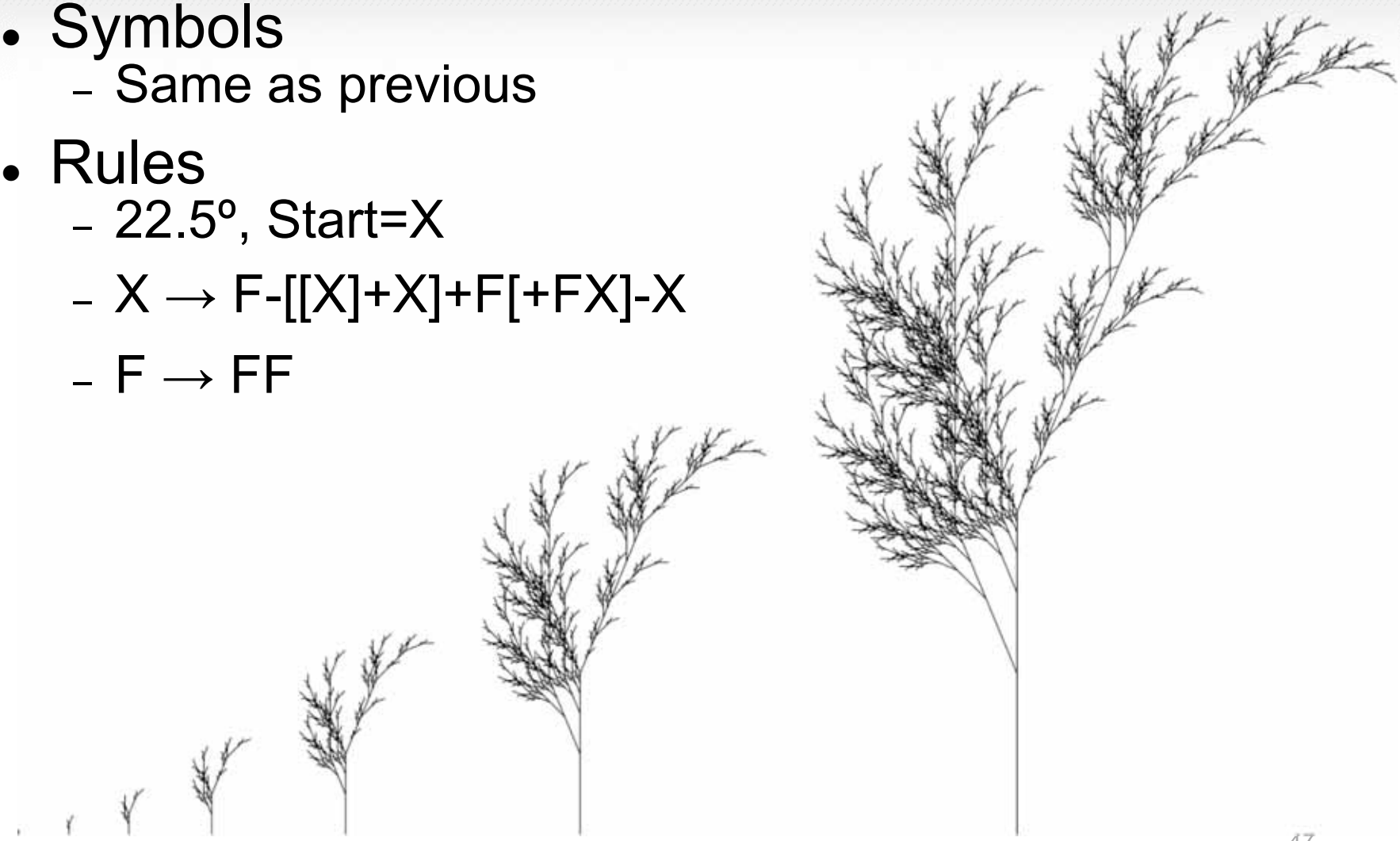
L-System Examples

- Symbols
  - [/] = push/pop
  - +/- = rotate left/right
  - A-Z = straight segment
- Rules
  - 25.7°, Start=X
  - X → F[+X][-X]FX
  - F → FF



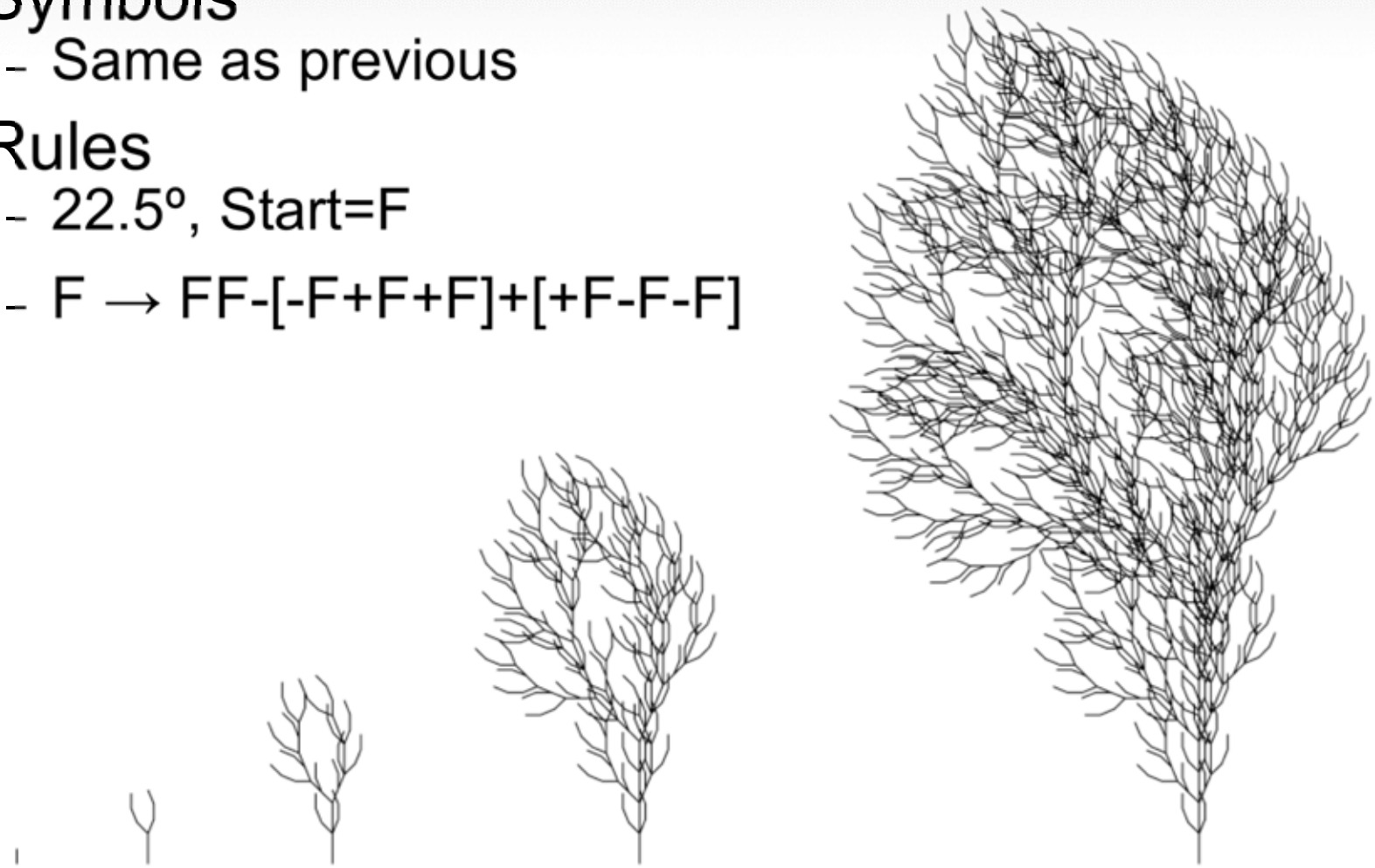
L-Systems Example

- Symbols
  - Same as previous
- Rules
  - 22.5º, Start=X
  - X → F-[[X]+X]+F[+FX]-X
  - F → FF



L-Systems Example

- Symbols
  - Same as previous
- Rules
  - 22.5º, Start=F
  - F → FF-[-F+F+F]+[+F-F-F]

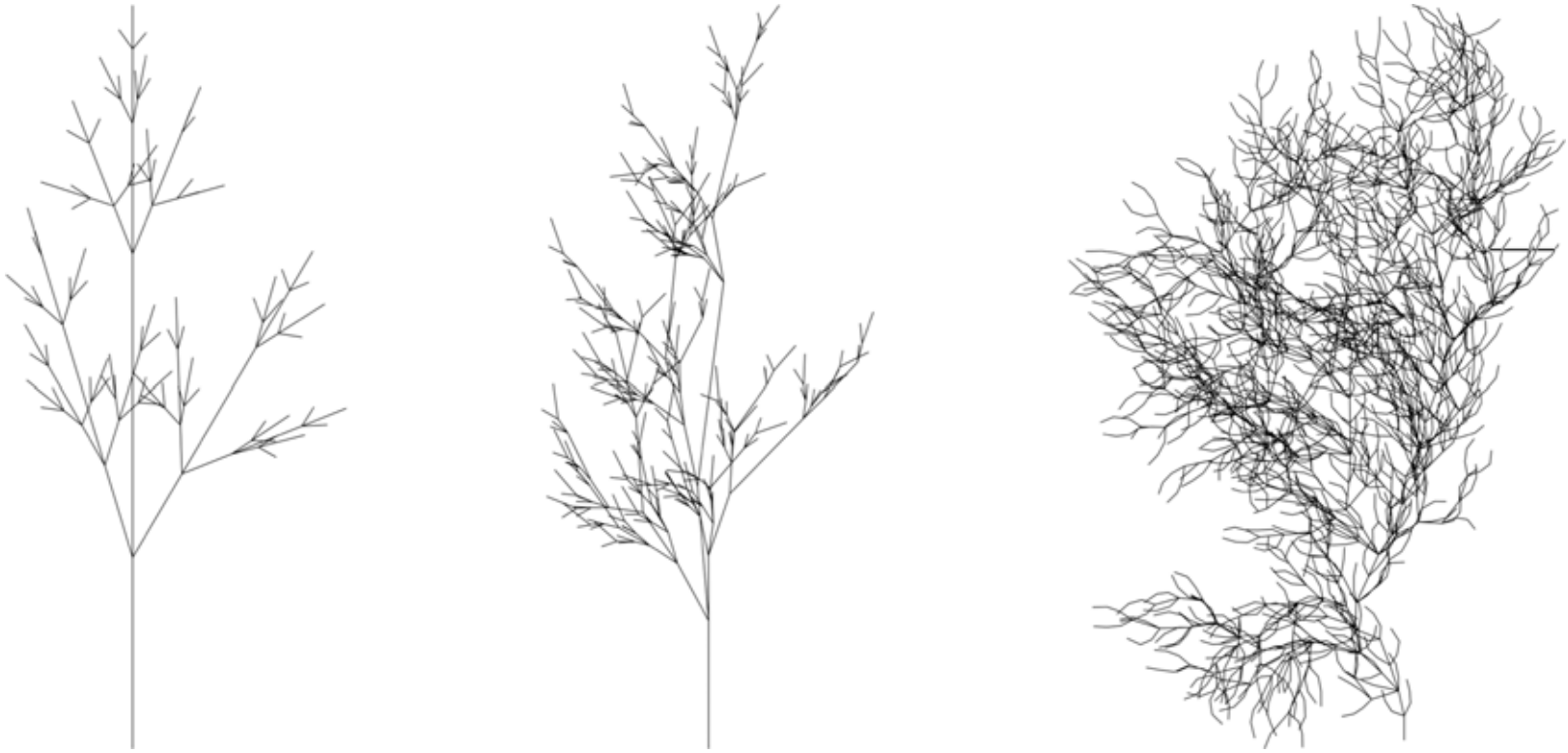


L-Systems Additions

- Add any/all of the following
  - 3D Structure
  - Randomness
  - Leaves
  - Flowers
  - Color

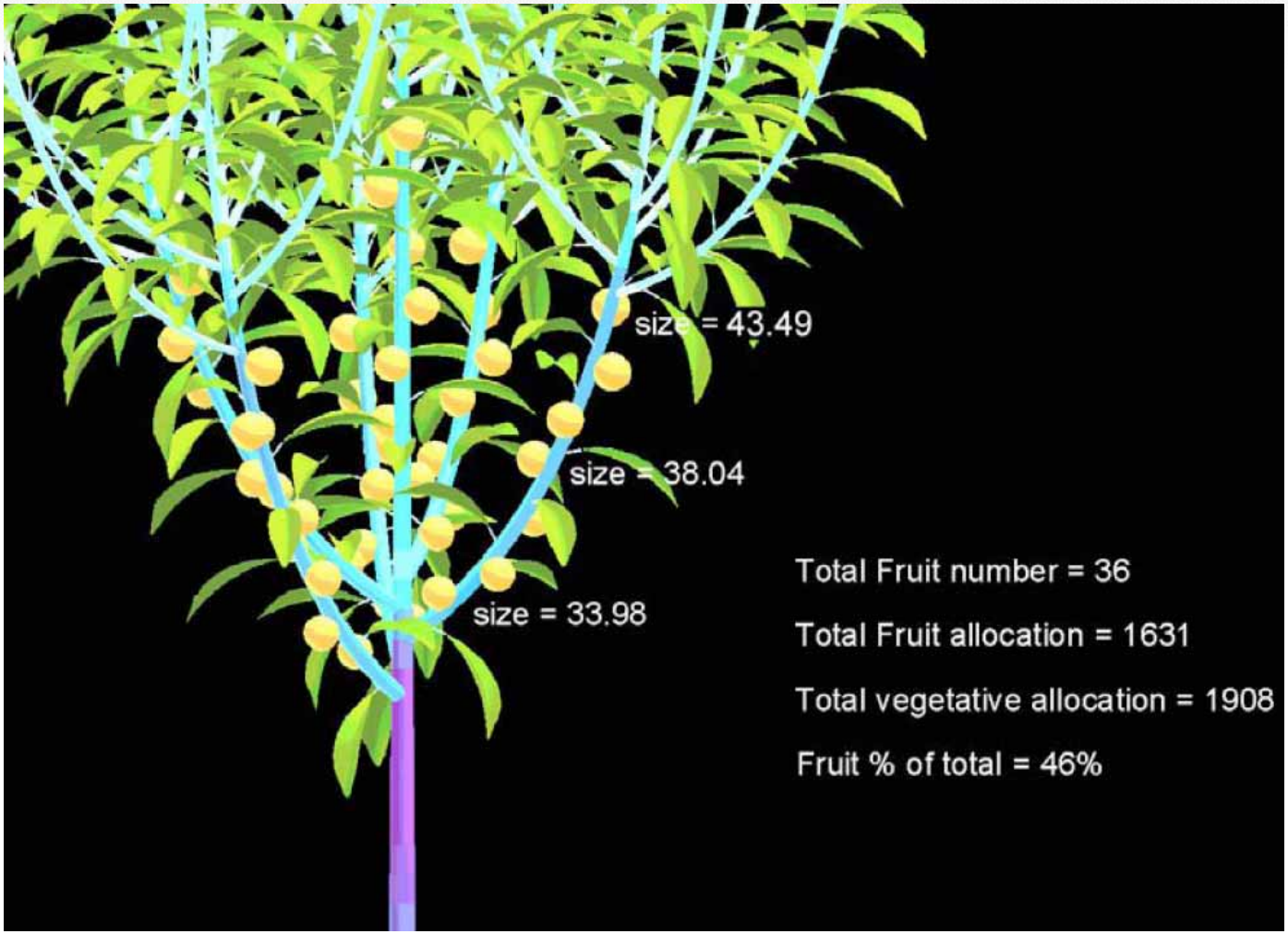
L-Systems

- Randomness of 50% introduced in both line segment length and degree of rotation



L-Systems Weeds

L-Systems Plants



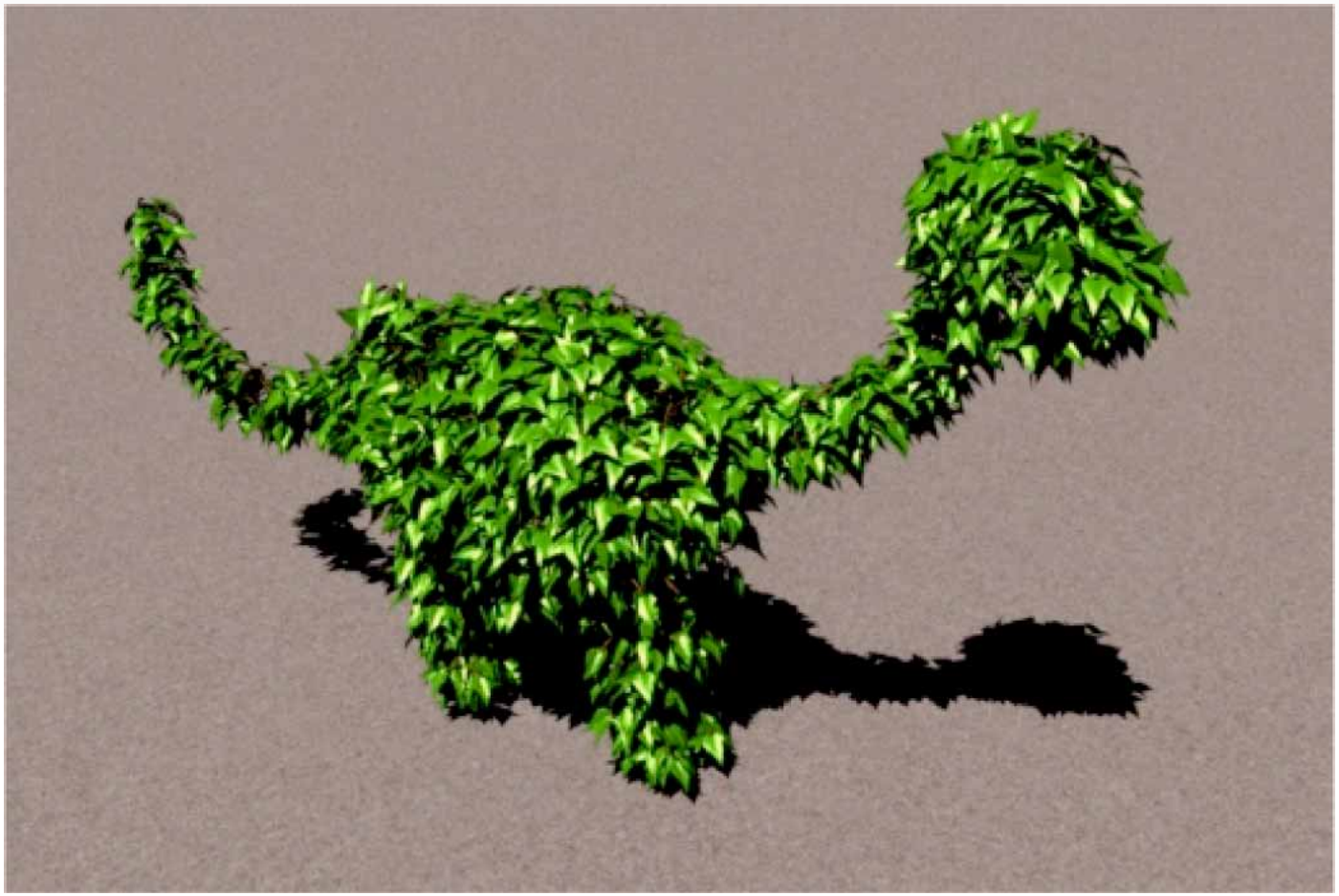
L-Systems Plants

L-Systems Flowers

Pruning

Prusinkiewicz, et al., SIGGRAPH 94

Pruning

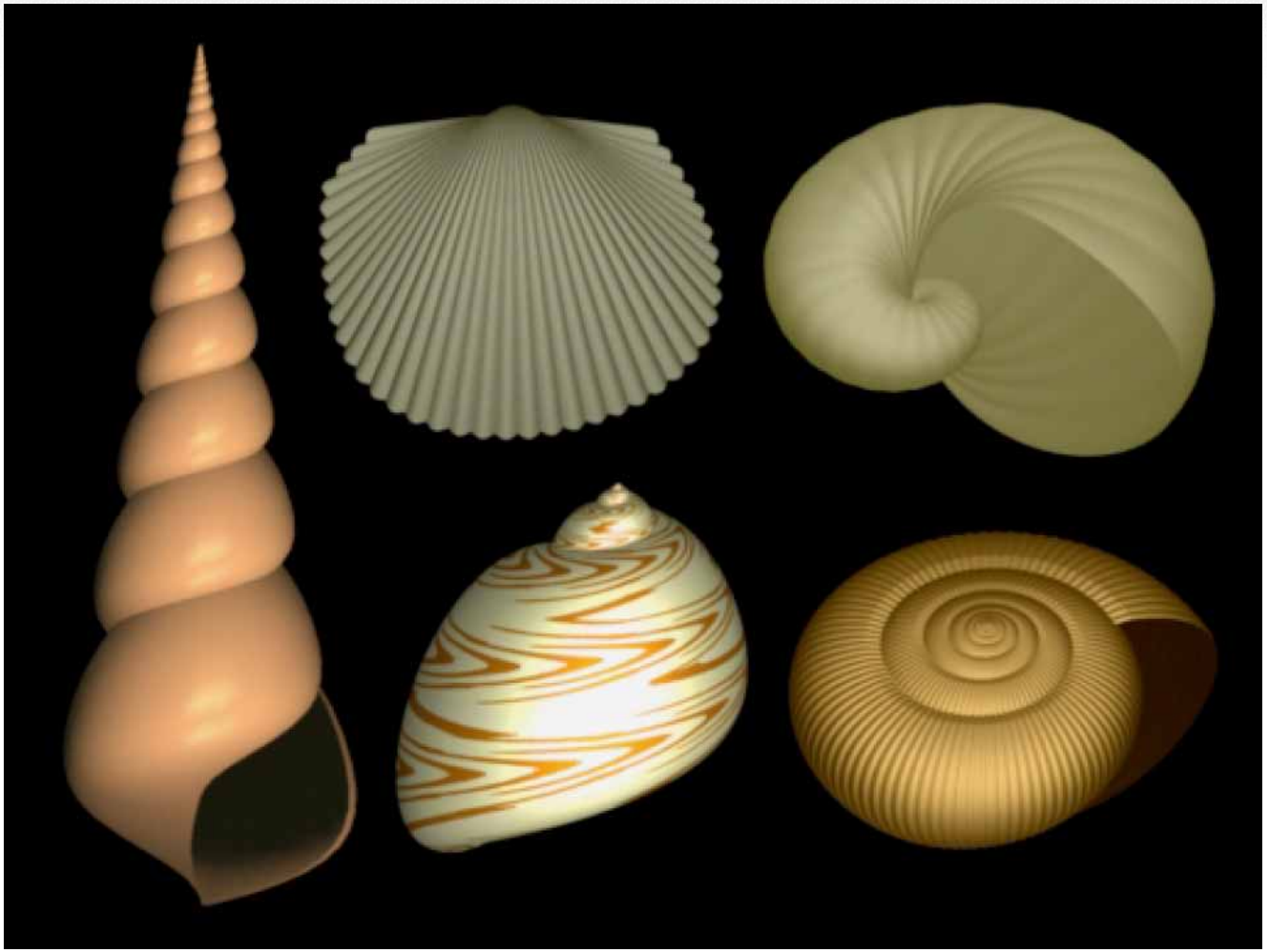


Prusinkiewicz, et al., SIGGRAPH 94

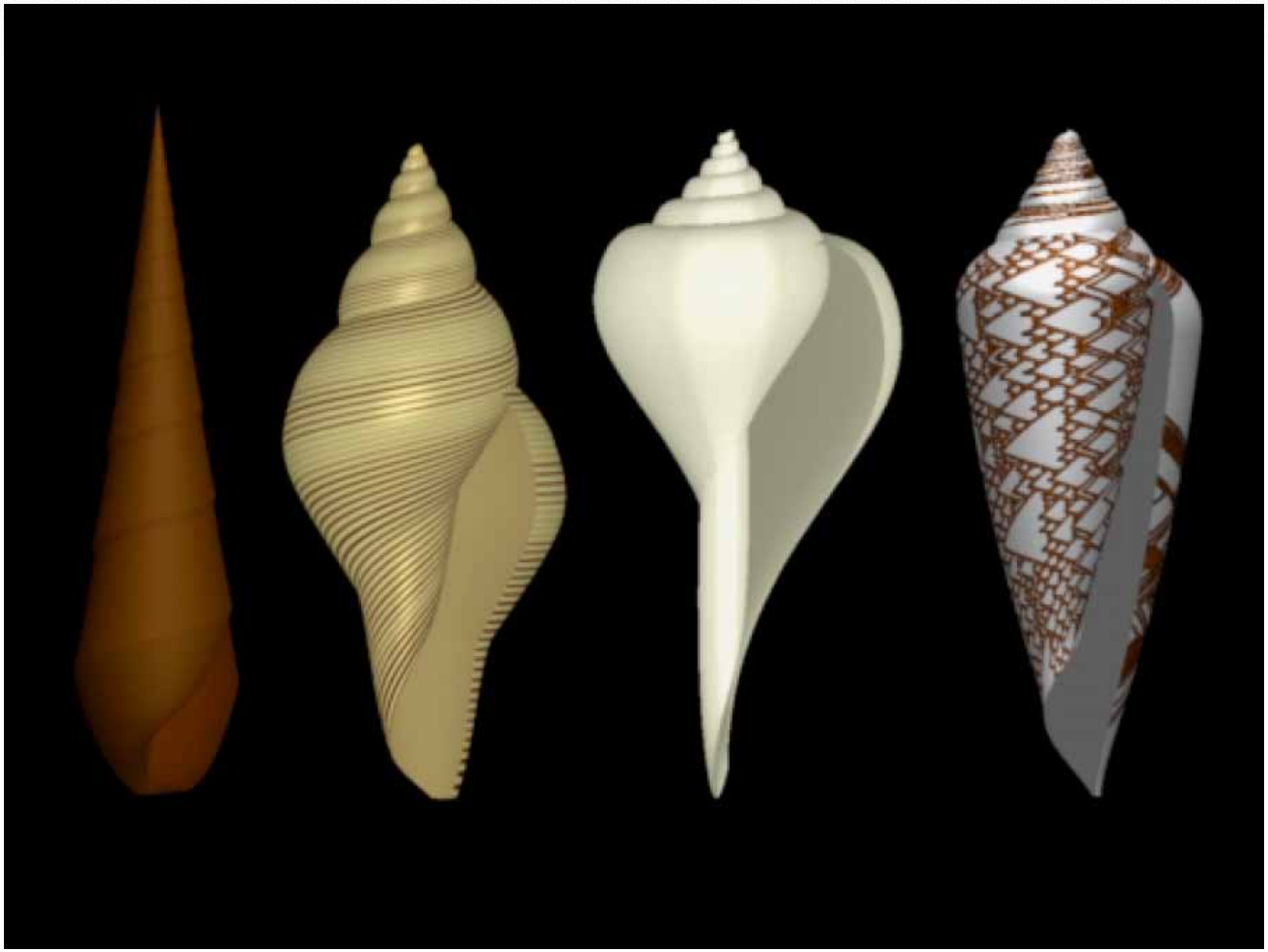
Simulations

- Biological
  - Simulate growth, development
- Physical
  - Simulate formation or erosion

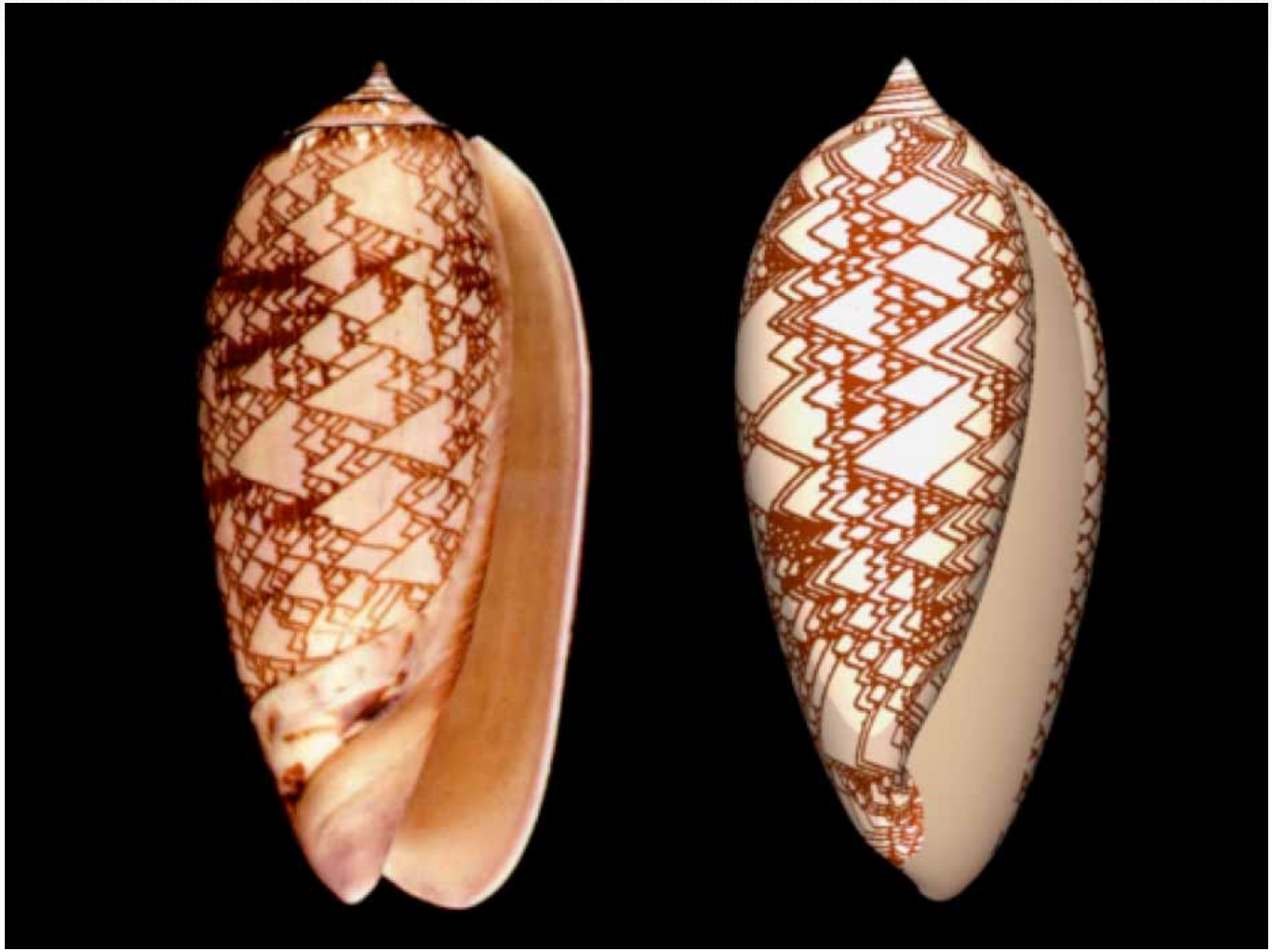
Biological Simulations



Biological Simulations

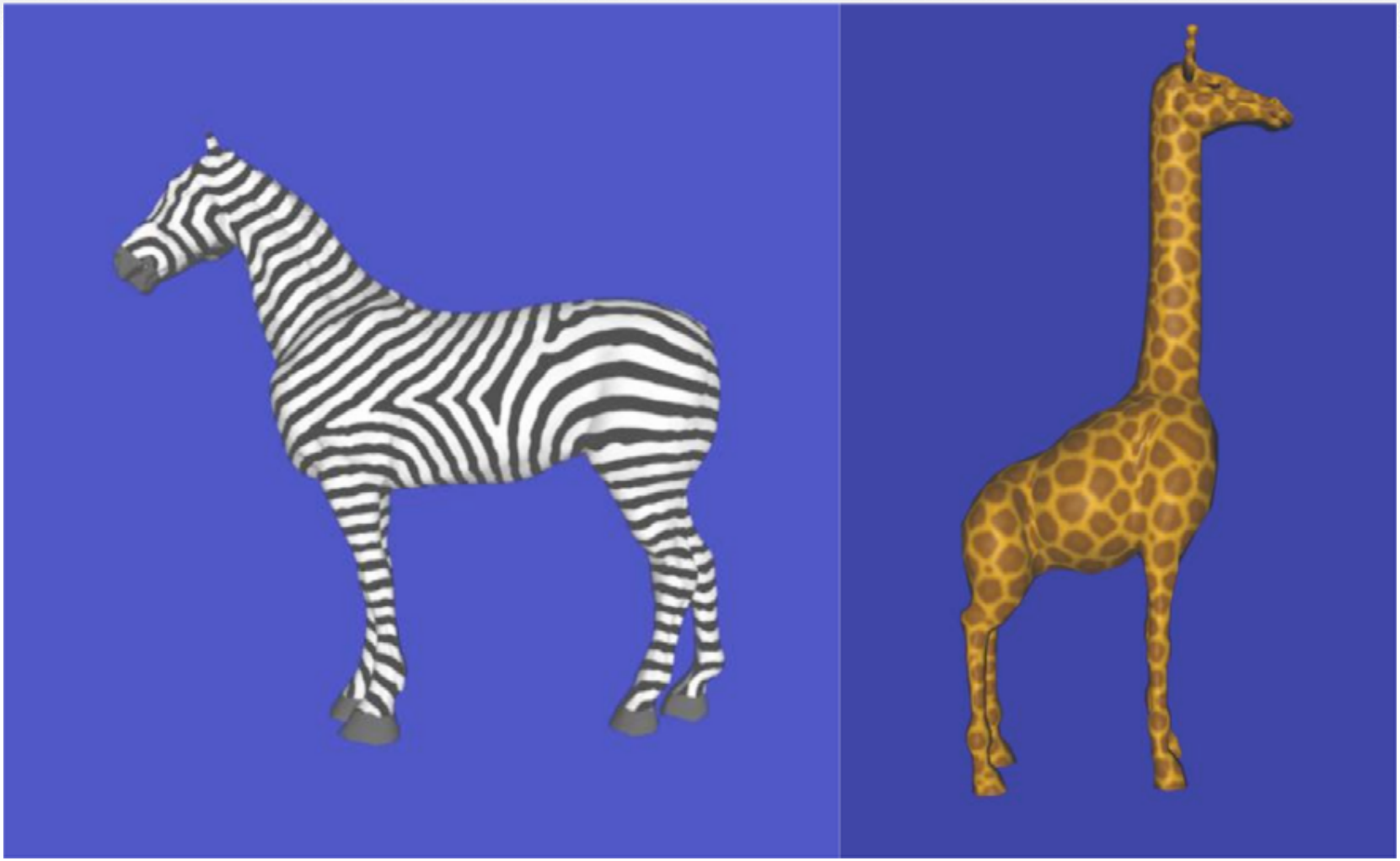


Biological Simulations



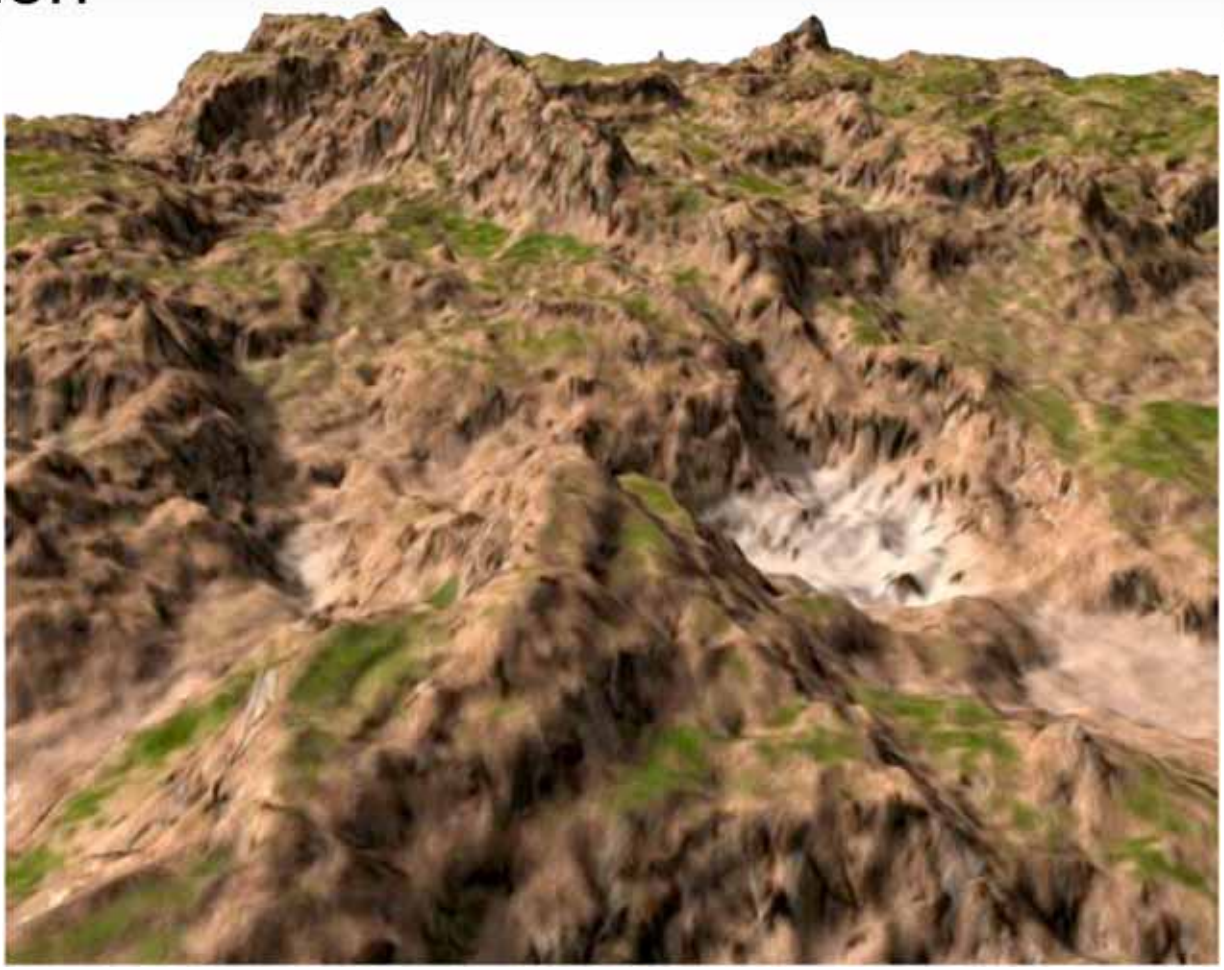
Biological Simulations

Biological Simulations



Physical Simulations

- Erosion



Scan From Objects

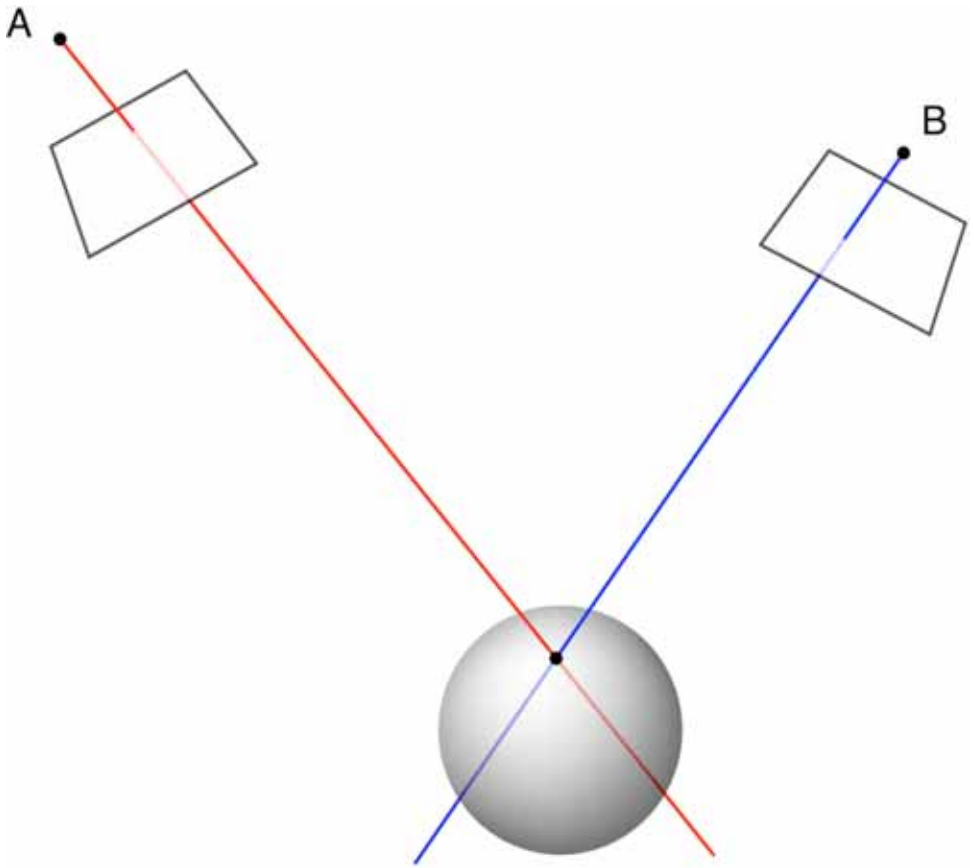
- General concept
  - Find points on surface
  - Connect with mesh
- Mechanical
- Triangulation
  - Laser
  - Structured Light
  - Multiple Cameras
- CAT/MRI scan

Mechanical

- Touch tip to surface
- Measure angles

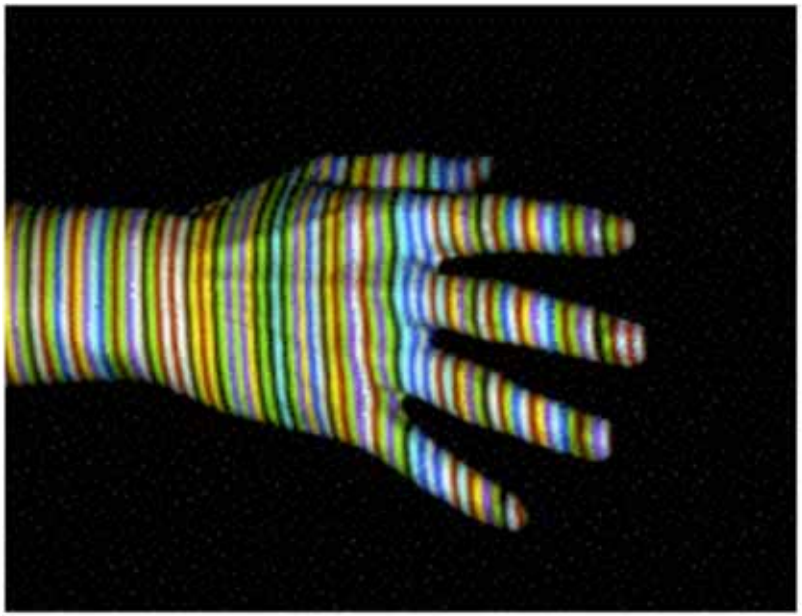
Triangulation

- Point in space at intersection of ray from ***A*** and ray from ***B***

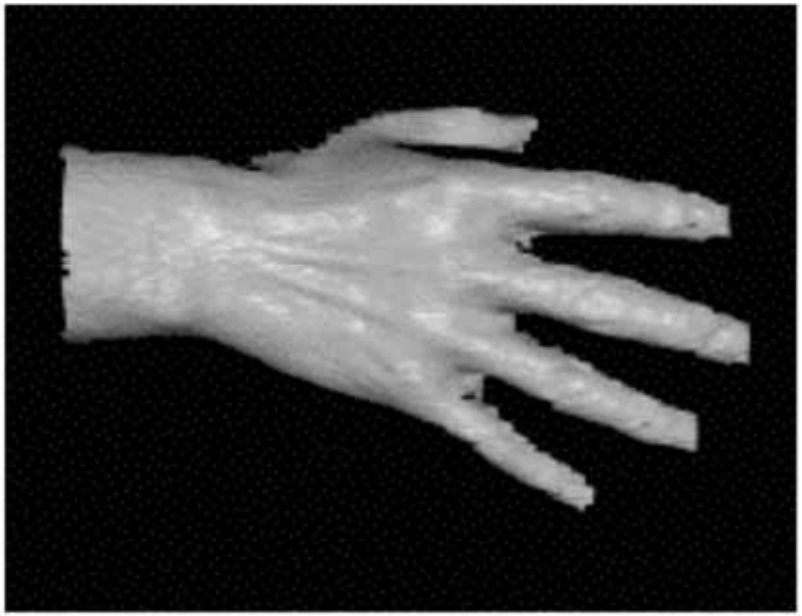


Structured Light

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



projected pattern



resulting model

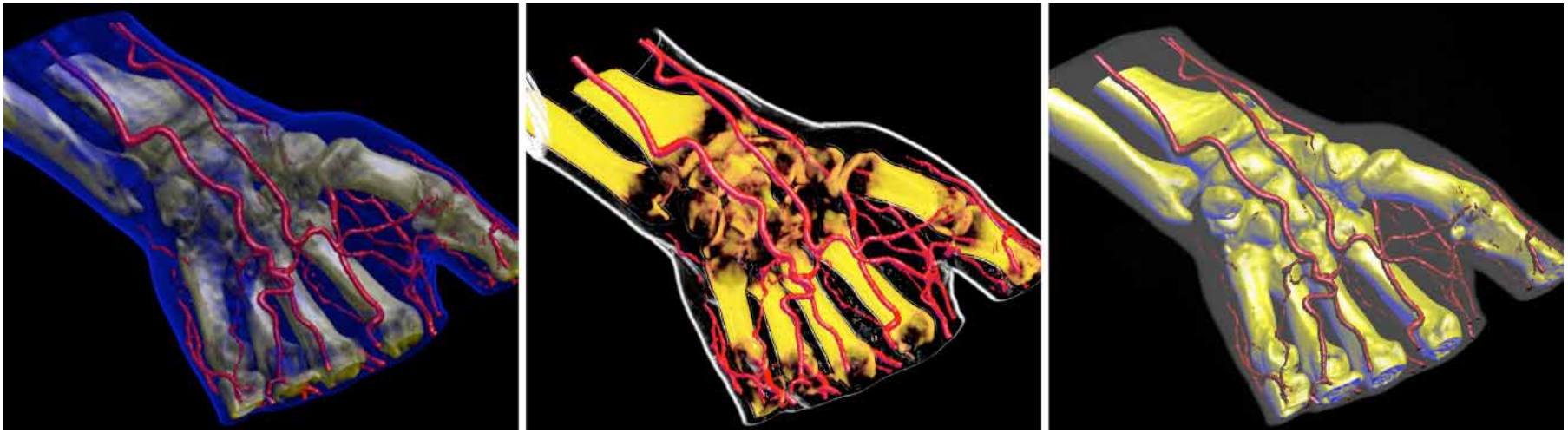
Zhang, Curless and Seitz, 3DPVT 2002

Visualization

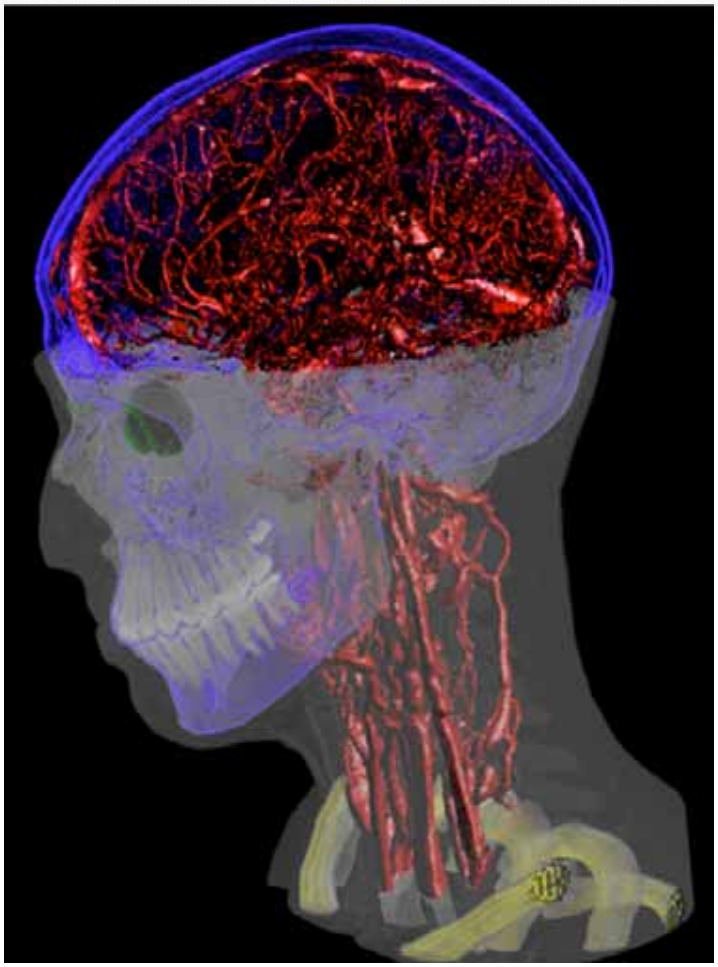
- Data
  - Measurements
  - Simulation
  - Information
- Present visually
  - Increase understanding
  - Recognize patterns

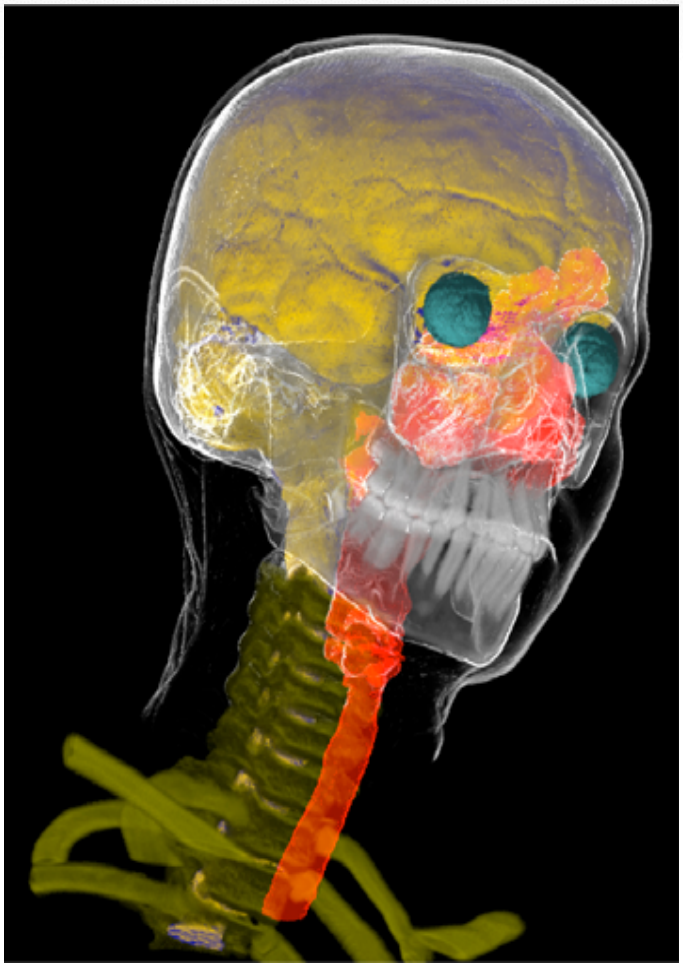
Visualization

- Can be 3D object



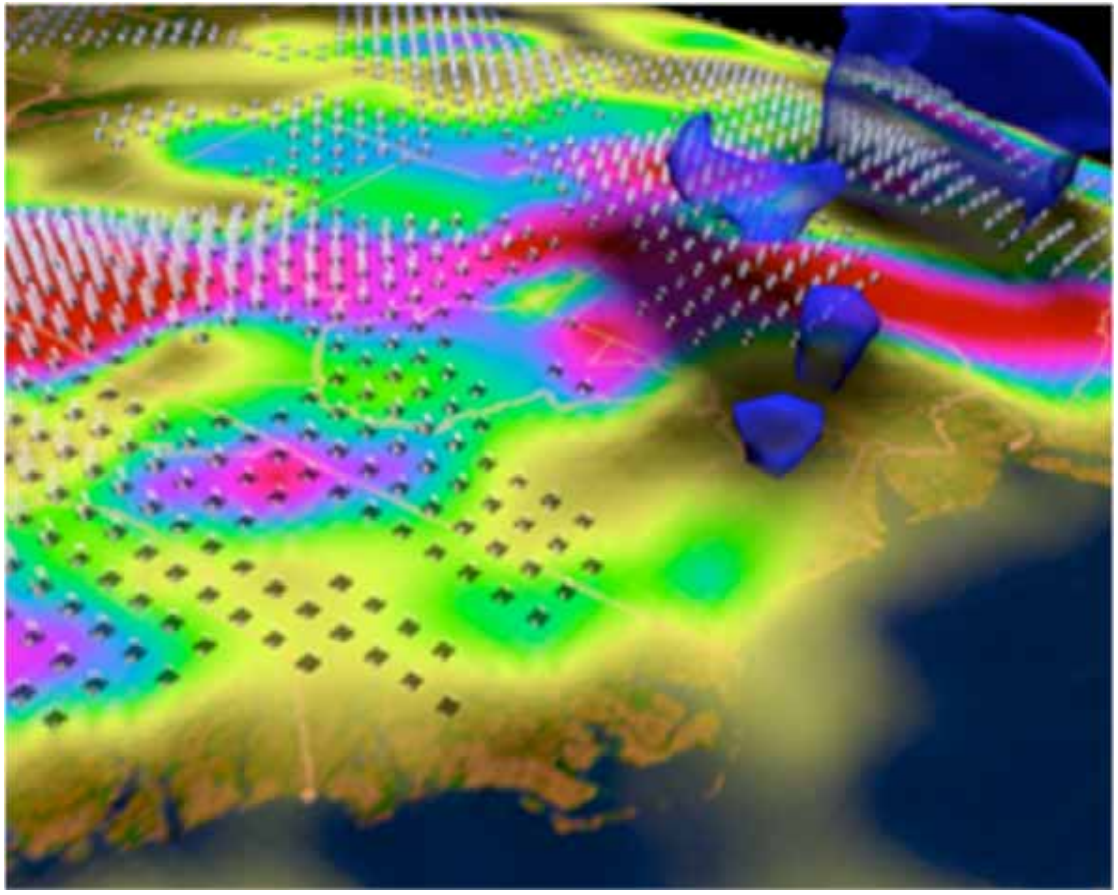
Visualization





Visualization

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



Visualization

- Can be not traditionally geometric at all

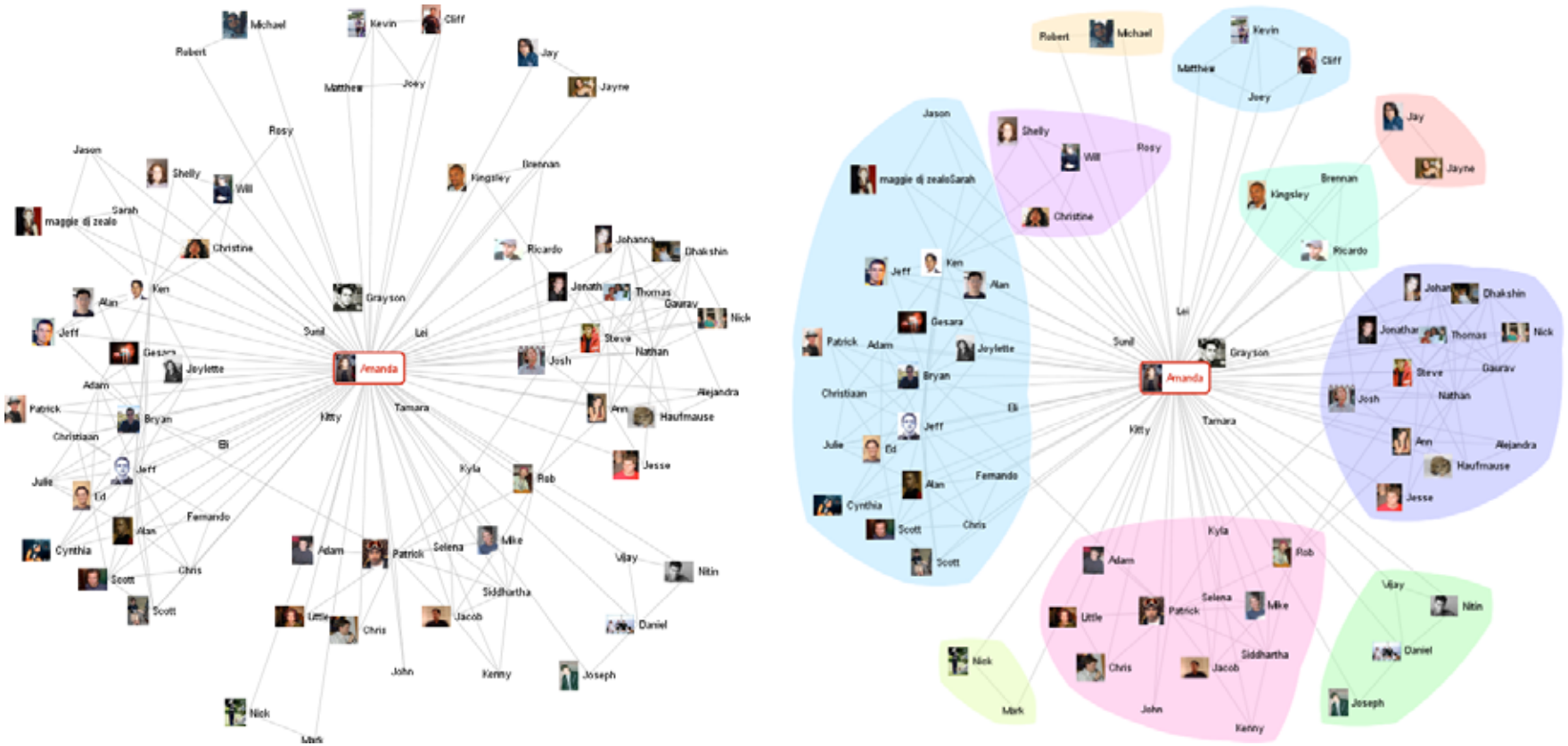


Image-Based Rendering

- Pixels in one or more cameras
  - Color of point in space
  - Color of light along one ray
- IBR
  - Construct new novel view using only image data

Image Based Rendering