CSE 167:
Introduction to Computer Graphics
Lecture #16: Procedural Modeling

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Announcements

- Reduced office hours today and tomorrow
- Upcoming deadline: blog, submit by sending URL to me by Sunday, December 1st
- Two more blogs due before demonstration day
- Next Tuesday:
  - Returning midterm exams
  - Presentation of midterm solutions

Lecture Overview

- Procedural Modeling
  - Concepts
  - Algorithms

3D Modeling

- Creating 3D objects/scenes and defining their appearance (texture, etc.)
- So far we created
  - Triangle meshes
  - Bezier patches
- Interactive modeling
  - Place vertices, control points manually
- For realistic scenes, need extremely complex models containing millions or billions of primitives
- Modeling everything manually is extremely tedious

Alternatives

- Data-driven modeling
  - Scan model geometry from real world examples
  - Use laser scanners or similar devices
  - Use photographs as textures
  - Archives of 3D models
    - http://www-graphics.stanford.edu/data/3Dscanrep/
    - Reader for PLY point file format: http://w3.impa.br/~diego/software/rply/
- Procedural modeling
  - Construct 3D models and/or textures algorithmically

Photograph Rendering

[Levoy et al.]

Procedural Modeling

- Wide variety of techniques for algorithmic model creation
- Used to create models too complex (or tedious) to build manually
  - Terrain, clouds
  - Plants, ecosystems
  - Buildings, cities

[Deussen et al.]

- Usually defined by a small set of data, or rules, that describes the overall properties of the model
  - Tree defined by branching properties and leaf shapes
- Model is constructed by an algorithm
  - Often includes randomness to add variety
  - E.g., a single tree pattern can be used to model an entire forest

Randomness

- Use some sort of randomness to make models more interesting, natural, less uniform
- *Pseudorandom* number generation algorithms
  - Produce a sequence of (apparently) random numbers based on some initial seed value
- Pseudorandom sequences are repeatable, as one can always reset the sequence
  - E.g., if a tree is built using pseudorandom numbers, then the entire tree can be rebuilt by resetting the seed value
  - If the seed value is changed, a different sequence of numbers will be generated, resulting in a (slightly) different tree

Recursion

- Repeatedly apply the same operation (set of operations) to an object
- Generate self-similar objects: fractals
  - Objects which look similar when viewed at different scales
- For example, the shape of a coastline may appear as a jagged line on a map
  - As we zoom in, we see that there is more and more detail at finer scales
  - We always see a jagged line no matter how close we look at the coastline

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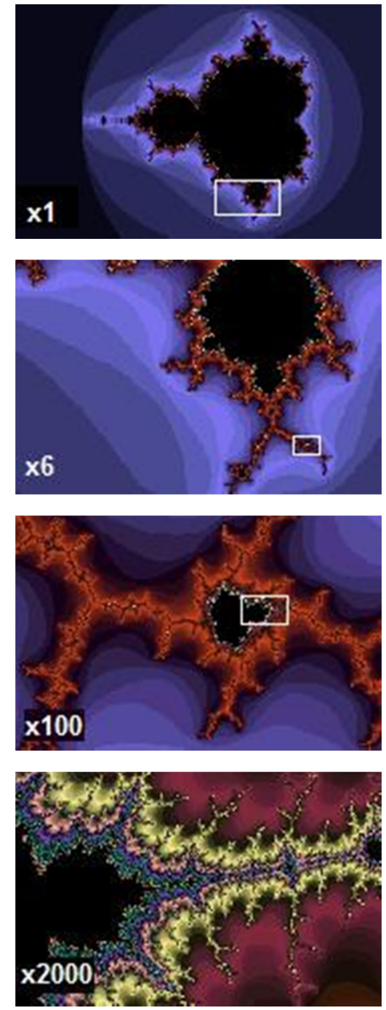
Height Fields

- Landscapes are often constructed as *height fields*
- Regular grid on the ground plane
- Store a height value at each point
- Can store large terrain in memory
  - No need to store all grid coordinates: inherent connectivity
- Shape terrain by operations that modify the height at each grid point
- Can generate height from grey scale values
  - Allows using image processing tools to create terrain height
  - → Extra credit in Homework Assignment #2

Fractals

- Fractal:
  Fragmented geometric shape which can be split into parts, each of which is (at least approximately) a smaller size copy of the whole
- Self-similarity
- Demo: Mandelbrot Set
  http://www.scale18.com/canvas2.html



From Wikipedia

Video

- 3D Mandelbrot Zoom
  - http://www.youtube.com/watch?v=0clz6WLfWaY

Fractal Landscapes

- Random midpoint displacement algorithm (one-dimensional)

```
Start with single horizontal line segment.
Repeat for sufficiently large number of times
{
  Repeat over each line segment in scene
  {
    Find midpoint of line segment.
    Displace midpoint in Y by random amount.
    Reduce range for random numbers.
  }
}
```

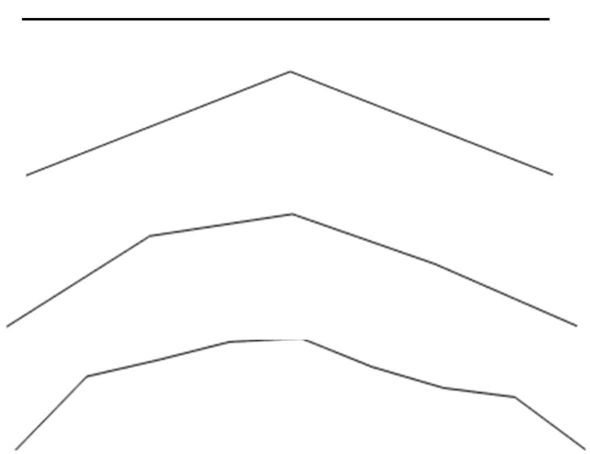
- Similar for triangles, quadrilaterals

Step 0

Step 1

Step 2

Step 3



Result: Mountain Range

Source: http://gameprogrammer.com/fractal.html#midpoint

Fractal Landscapes

- Add textures, material properties; use nice rendering algorithm
- Example: Terragen Classic (free software) http://www.planetside.co.uk/terragen/

[http://www.planetside.co.uk/gallery/f/tg09]

L-Systems

- Developed by biologist Aristid Lindenmayer in 1968 to study growth patterns of algae
- Defined by grammar

$$\mathbf{G} = \{V, S, \omega, P\}$$

  - V = alphabet, set of symbols that can be replaced (variables)
  - S = set of symbols that remain fixed (constants)
  - ω = string of symbols defining initial state
  - P = production rules
- Stochastic L-system
  - If there is more than one production rule for a symbol, randomly choose one

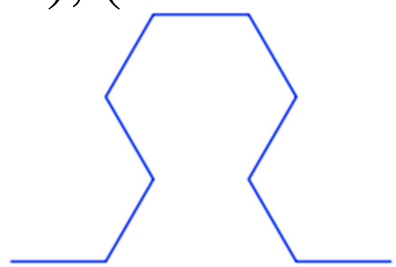
Turtle Interpretation for L-Systems

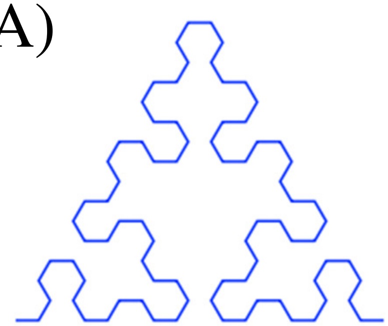
- Origin: functional programming language Logo
  - Dialect of Lisp
  - Designed for education: drove a mechanical turtle as an output device
- Turtle interpretation of strings
  - State of turtle defined by (x, y, α) *for* position and heading
  - Turtle moves by step size d and angle increment δ
- Sample Grammar
  - F: move forward a step of length d
    New turtle state: (x', y', α)
    $x' = x + d \cos \alpha$
    $y' = y + d \sin \alpha$
    A line segment between points (x, y) and (x', y') is drawn.
  - +: Turn left by angle δ. Next state of turtle is $(x, y, \alpha+\delta)$
    Positive orientation of angles is counterclockwise.
  - –: Turn right by angle δ. Next state of turtle is $(x, y, \alpha-\delta)$

Example: Sierpinski Triangle

- Variables: A, B
  - Draw forward
- Constants: + , -
  - Turn left, right by 60 degrees
- Start: A
- Rules: (A→B-A-B), (B→A+B+A)

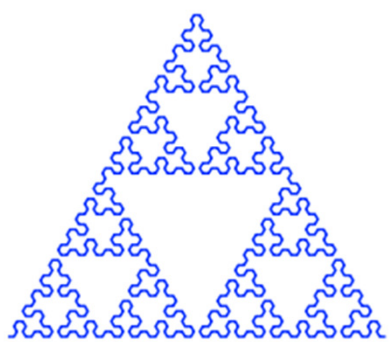
2 iterations

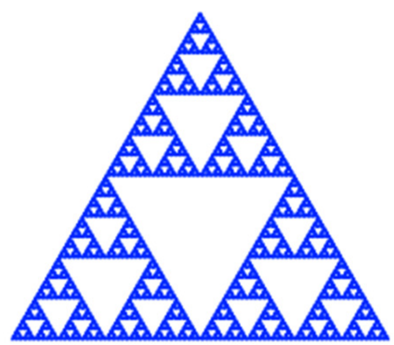




4 iterations

6 iterations





9 iterations

Example: Fern

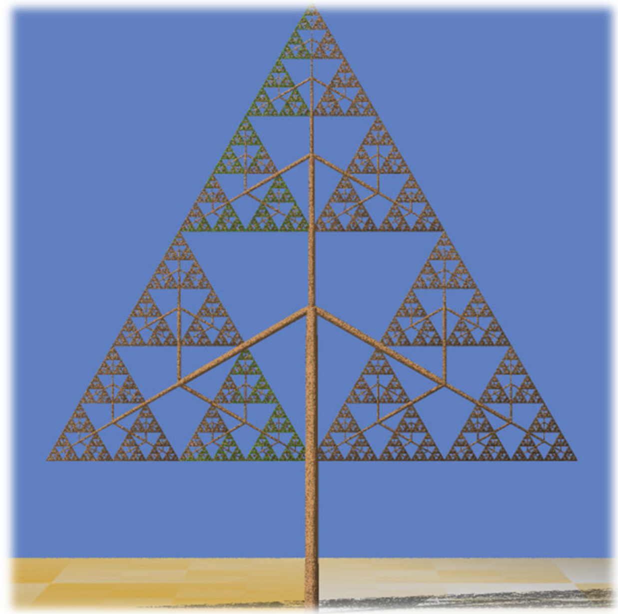
- Variables: X, F
  - X: no drawing operation
  - F: move forward
- Constants: +, –
  - Turn left, right
- Start: X
- Rules:
  (X → F-[[X]+X]+F[+FX]-X),(F → FF)

[Wikipedia]

Fractal Trees

- Recursive generation of trees in 3D
  http://web.comhem.se/solgrop/3dtree.htm
- Model trunk and branches as cylinders
- Change color from brown to green at certain level of recursion

Dragon Curve Tree



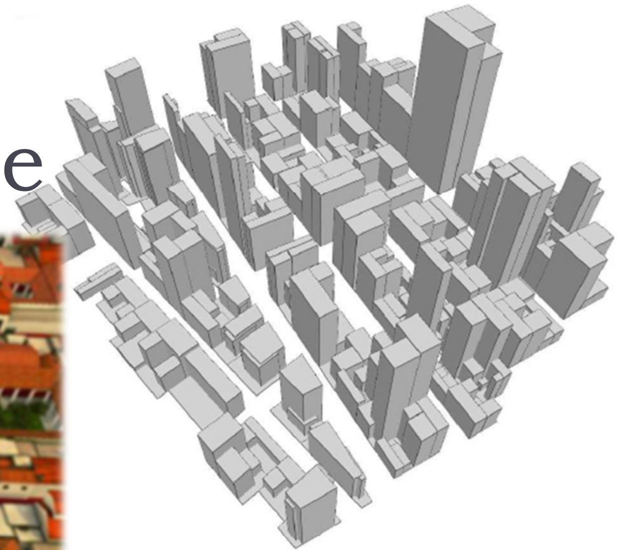
Sierpinski Tree

Algorithmic Beauty of Plants

- Book "The Algorithmic Beauty of Plants" by Przemyslaw Prusinkiewicz and Aristid Lindenmayer, 2004
- On-Line at: http://algorithmicbotany.org/papers/#abop

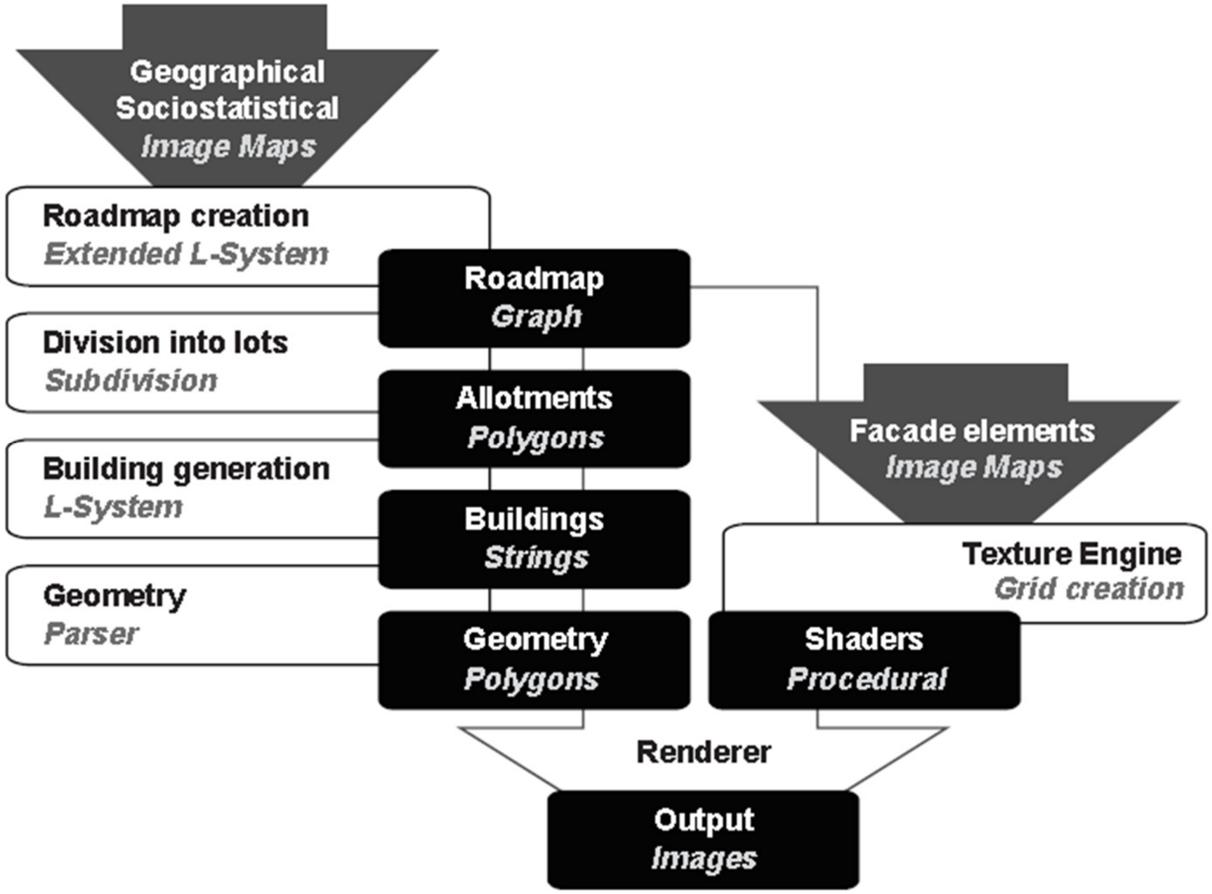
[Prusinkiewicz, http://algorithmicbotany.org/papers/positional.sig2001.pdf]

Buildings, Cities: CityEngine



http://www.esri.com/software/cityengine/

CityEngine: Pipeline



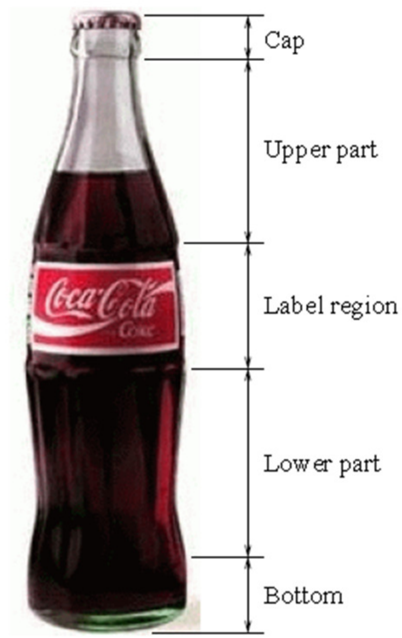
Parish, Mueller: “Procedural Modeling of Cities”, ACM Siggraph 2001

Shape Grammar

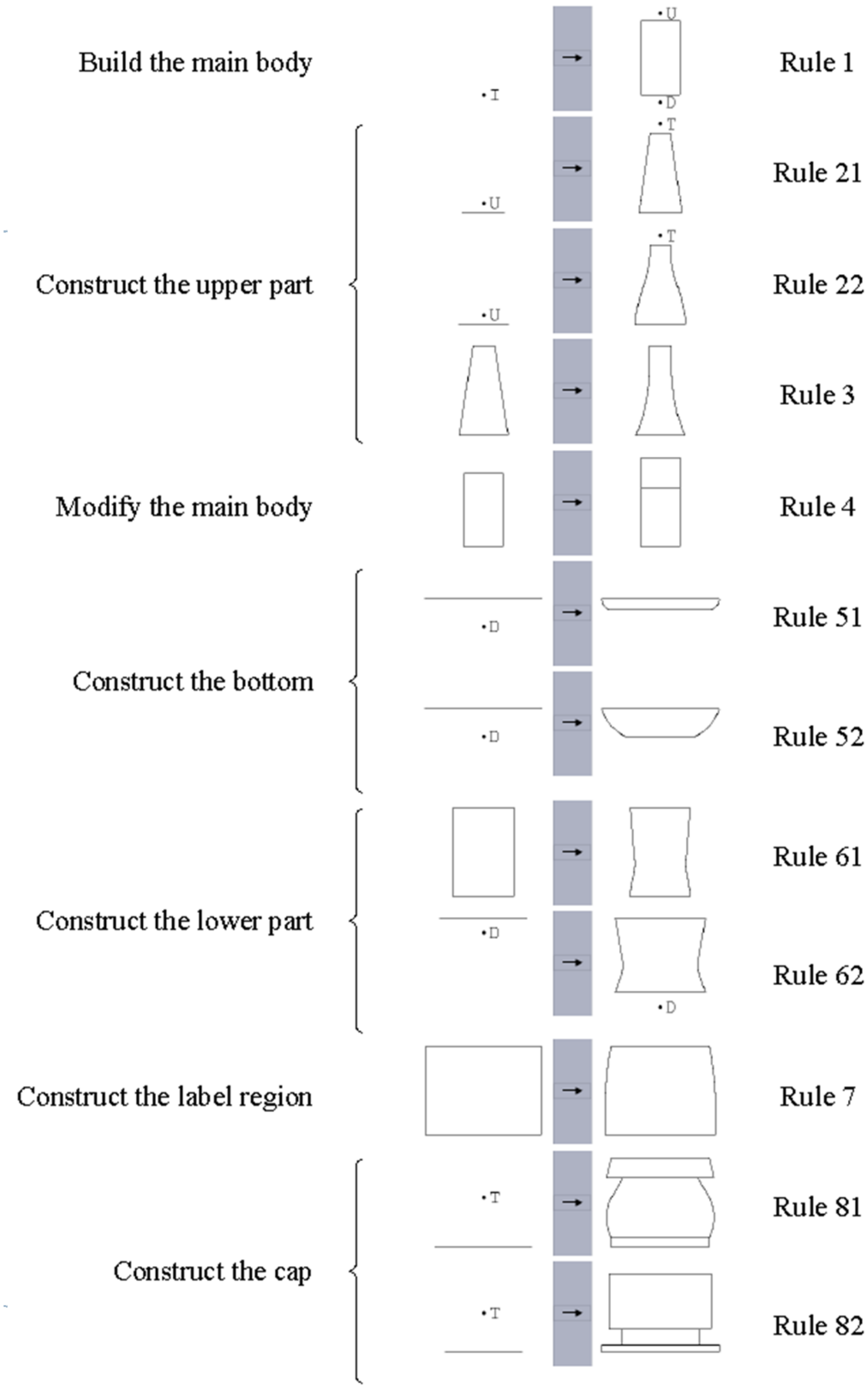
- Shape Rules
  - Defines how an existing shape can be transformed
- Generation Engine
  - Performs the transformations
- Working Area
  - Displays created geometry

Example: Coca-Cola Bottle

Evolution of Coca-Cola bottles

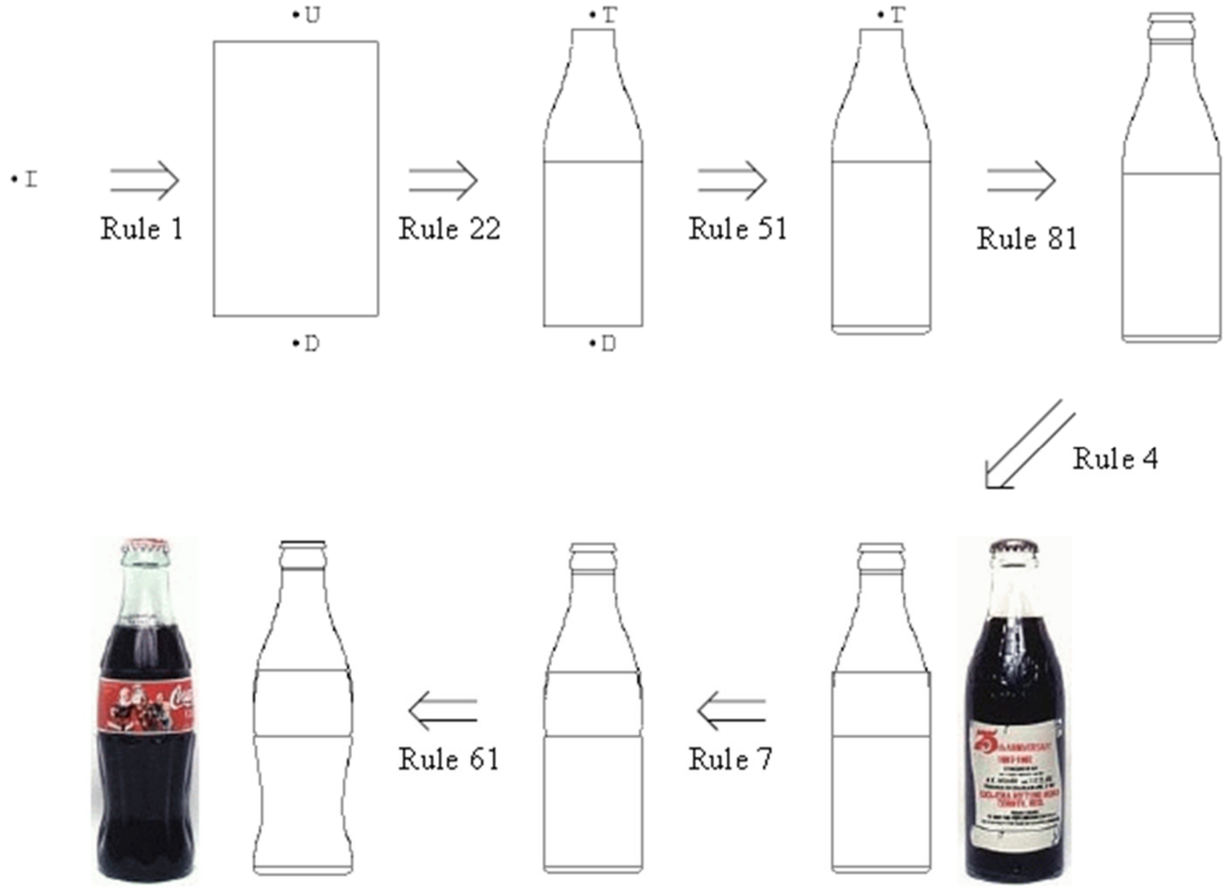


Division of a Coca-Cola bottle



Shape Computation Example

- Shape computation for two existing Coca-Cola bottles



Source: Chau et al.: “Evaluation of a 3D Shape Grammar Implementation”, *Design Computing and Cognition'04,* pp. 357-376

Demonstration: Procedural Buildings

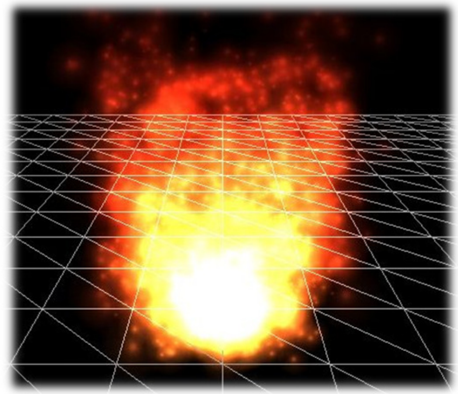
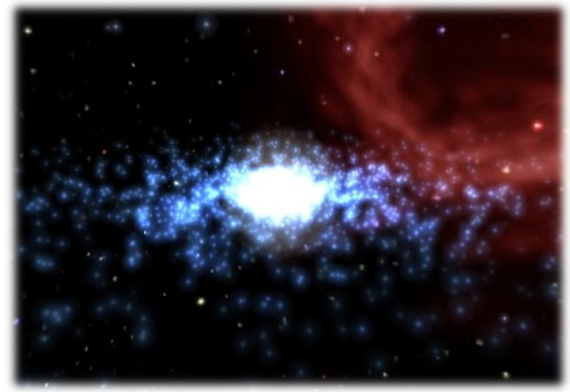
- Demo fr-041: debris by Farbrausch, 2007
- http://www.youtube.com/watch?v=wqu_IpkOYBg&hd=1
- Single, 177 KB EXE file!
- http://www.farbrausch.de/

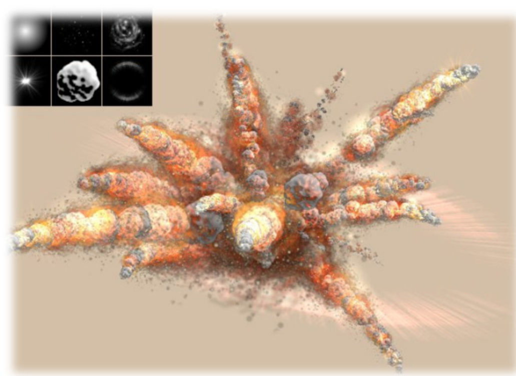
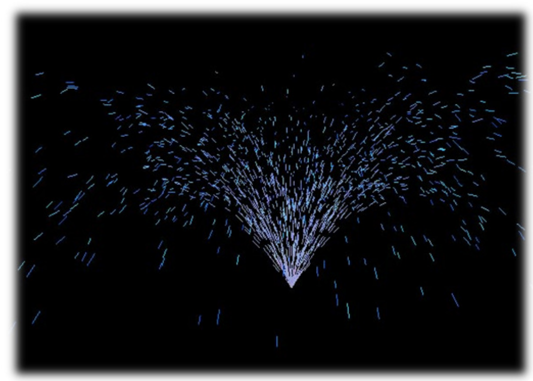
Lecture Overview

- Particle Systems
- Collision Detection

Particle Systems

- Used for:
  - Fire/sparks
  - Rain/snow
  - Water spray
  - Explosions
  - Galaxies

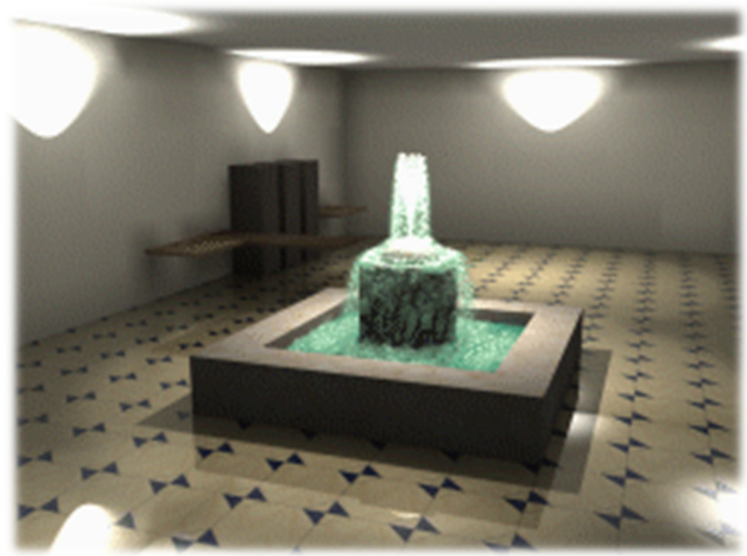



Internal Representation

- Particle system is collection of a number of individual elements (particles)
  - Controls a set of particles which act autonomously but share some common attributes
- Particle Emitter: Source of all new particles
  - 3D point
  - Polygon mesh: particles' initial velocity vector is normal to surface
- Particle attributes:
  - position (3D)
  - velocity (vector: speed and direction)
  - color + opacity
  - lifetime
  - size
  - shape
  - weight

Dynamic Updates

- Particles change position and/or attributes with time
- Initial particle attributes often created with random numbers
- Frame update:
  - Parameters: simulation of particles, can include collisions with geometry
    - Forces (gravity, wind, etc) accelerate a particle
    - Acceleration changes velocity
    - Velocity changes position
  - Rendering: display as
    - OpenGL points
    - (Textured) billboarded quads
    - Point sprites



Source: http://www.particlesystems.org/

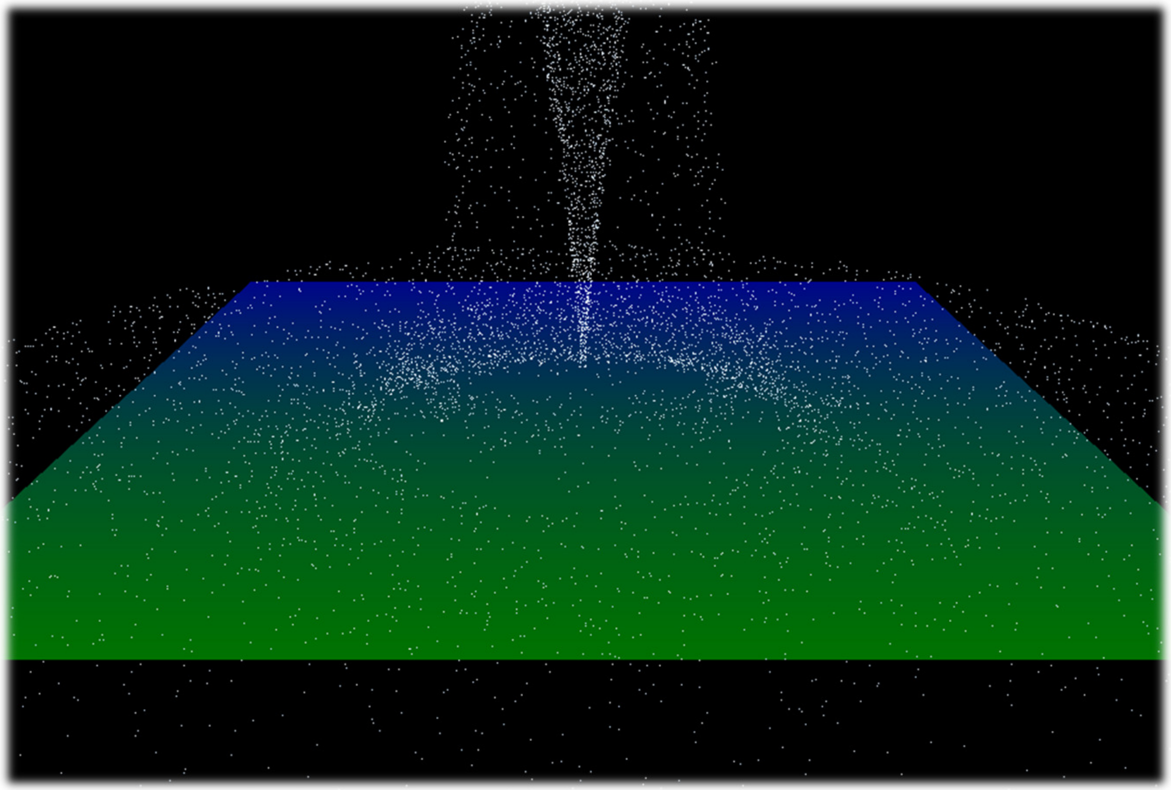
Point Sprite

- **Screen-aligned element of variable size**
- **Defined by single point**
- **Sample code:**

```
glTexEnvf(GL_POINT_SPRITE, GL_COORD_REPLACE, GL_TRUE);
glEnable(GL_POINT_SPRITE);
glBegin(GL_POINTS);
   glVertex3f(position.x, position.y, position.z);
glEnd();
glDisable(GL_POINT_SPRITE);
```

Demo

- Source:
http://www.particlesystems.org/Distrib/Particle221Demos.zip



References

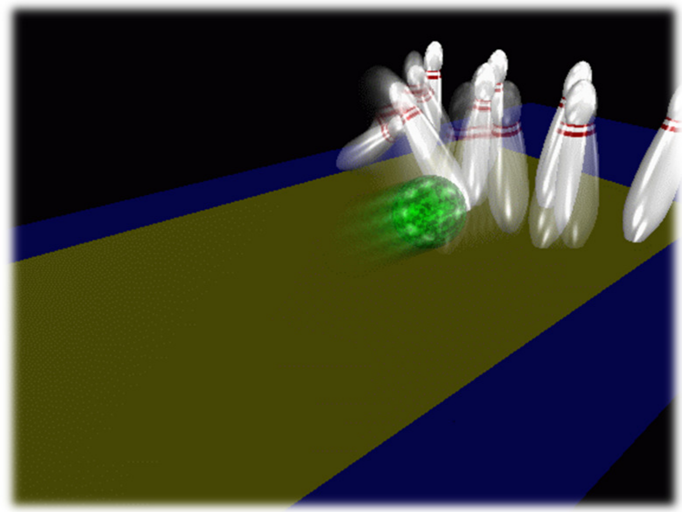
- Free particle systems API (not for final project):
  - http://particlesystems.org/
- On-line tutorial:
  - http://www.naturewizard.com/tutorial08.html
- Initial scientific paper:
  - Reeves: "Particle Systems - A Technique for Modeling a Class of Fuzzy Objects", ACM Transactions on Graphics (TOG) Volume 2 Issue 2, April 1983
- Article with source code:
  - Jeff Lander: "The Ocean Spray in Your Face", Game Developer, July 1998, http://www.darwin3d.com/gamedev/articles/col0798.pdf
- John Van Der Burg: "Building an Advanced Particle System", Gamasutra, June 2000
  - http://www.gamasutra.com/view/feature/3157/building_an_advanced_particle_.php

Lecture Overview

- Particle Systems
- Collision Detection

Collision Detection

- Goals:
  - Physically correct simulation of collision of objects
    - Not covered here
  - Determine if two objects intersect
- Slow calculation because of exponential growth $O(n^2)$:
  - # collision tests = n*(n-1)/2



Intersection Testing

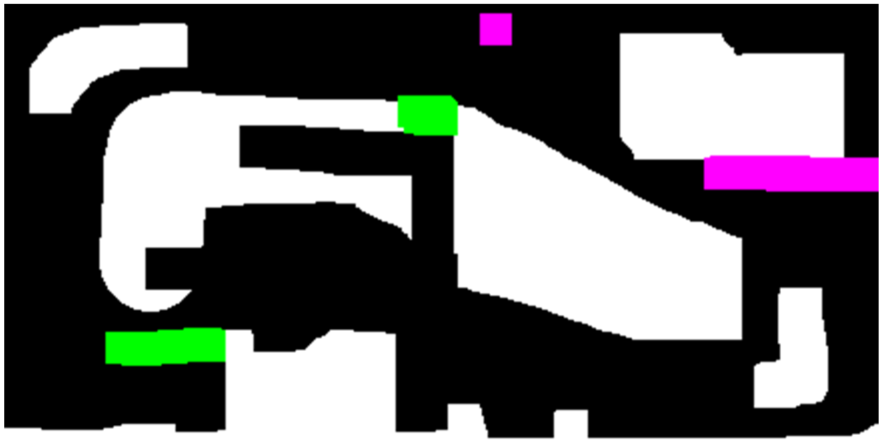
- Purpose:
  - Keep moving objects on the ground
  - Keep moving objects from going through walls, each other, etc.
- Goal:
  - Believable system, does not have to be physically correct
- Priority:
  - Computationally inexpensive
- Typical approach:
  - Spatial partitioning
  - Object simplified for collision detection by one or a few
    - Points
    - Spheres
    - Axis aligned bounding box (AABB)
  - Pairwise checks between points/spheres/AABBs and static geometry

Sweep and Prune Algorithm

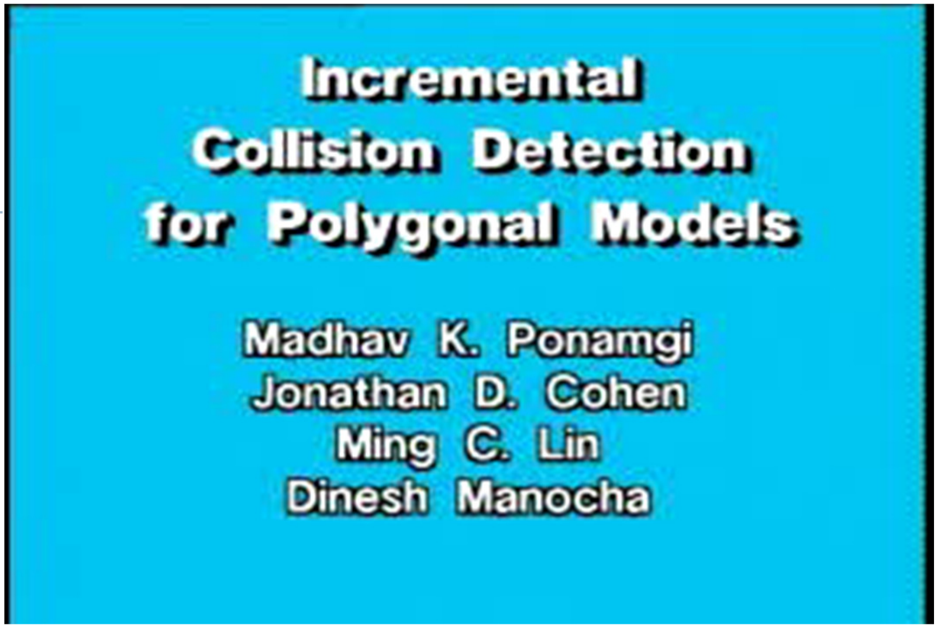
- Sorts bounding boxes
- Not intuitively obvious how to sort bounding boxes in 3-space
- Dimension reduction approach:
  - Project each 3-dimensional bounding box onto the x,y and z axes
  - Find overlaps in 1D: a pair of bounding boxes can overlap if and only if their intervals overlap in all three dimensions
    - Construct 3 lists, one for each dimension
    - Each list contains start/end point of intervals corresponding to that dimension
    - By sorting these lists, we can determine which intervals overlap
    - Reduce sorting time by keeping sorted lists from previous frame, changing only the interval endpoints
- Alternative: project bounding boxes onto coordinate axis planes and look for overlaps in 2D

Collision Map (CM)

- 2D map with information about where objects can go and what happens when they go there
- Colors indicate different types of locations
- Map can be computed from 3D model, or hand drawn with paint program
- Granularity: defines how much area (in object space) one CM pixel represents



References



- I-Collide:
  - Interactive and exact collision detection library for large environments composed of convex polyhedra
  - http://gamma.cs.unc.edu/I-COLLIDE/
- OZ Collide:
  - Fast, complete and free collision detection library in C++
  - Based on AABB tree
  - http://www.tsarevitch.org/ozcollide/