CENG 732
Computer Animation

Spring 2006-2007

Week 7

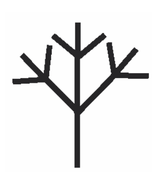
Natural Phenomena

This week

- Modeling plants
  - L-System
- Modeling clouds
  - Volumetric Procedural Methods

Modeling Plants

- Using fractals seems to appropriate to model plants, because of observed self-similarity at various levels



- But how to define the fractal? What about the stochastic behavior?

Animation

- In addition to rendering static plants we should also think about the motion to animate:
  - Motion due to environmental conditions such as wind
  - Plant growth

L-System

- Introduced and developed in 1968 by the Hungarian theoretical biologist and botanist Aristid Lindenmayer
- Formal Grammar consisting of a set of production rules
- Famously used to model the growth processes of plant development
- Can be used to generate self-similar fractals
- A procedural technique to model objects

D0L-System

- A deterministic and context-free L-System
  - Implies each non-terminal has a single grammar rule associated with it
  - And the left part of a grammar rule consists of a single non-terminal (i.e., no-context information)

D0L-System Example

S -> ABA
A -> XX
B -> TT

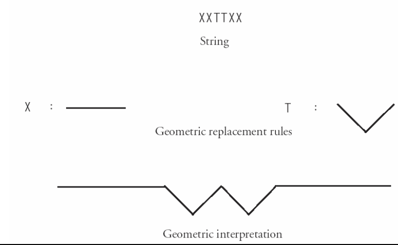
Production rules

S ← axiom
ABA
XXTTXX

String sequence

Geometric Interpretation of L-Systems

- Geometric Replacement:
  - Replace each symbol with a geometric element



Turtle Graphics

- Replace each symbol with a drawing command

Symbol	Turtle Graphic Interpretation
F	Move forward a distance *d* while drawing a line. Its state will change from (x, y, α) to $(x + d \cdot \cos\alpha, y + d \cdot \sin\alpha, \alpha)$.
f	Move forward a distance *d* without drawing a line. Its state will change as above.
+	Turn left by an angle δ. Its state will change from (x, y, α) to $(x, y, \alpha + \delta)$.
–	Turn right by an angle δ. Its state will change from (x, y, α) to $(x, y, \alpha - \delta)$.

Turtle Graphics

- Given the initial state of the cursor and the linear and rotational step sizes, a string can be used to draw a shape
- The state of the cursor at any point can be given by the current position and heading of the cursor

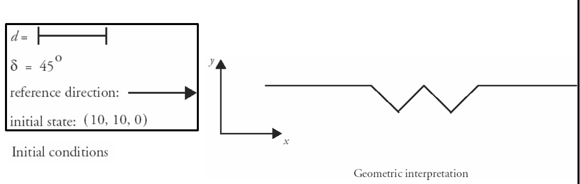
Turtle Graphics

S -> ABA
A -> FF
B -> TT
T-> -F++F-

Production rules

S ← axiom
ABA
FFTTFF
FF-F++F--F++F-FF

Sequence of strings produced from the axiom



Linearity Problem

- With only the four commands of draw/move/turn_left/turn_right one can only generate linear shapes.
- Bracketed L-systems are introduced to provide branching
- In the generation rules, a left branch indicates to push the current state on the stack and a right branch indicates a popping of the state from the stack and setting it as the current state.
- The stack structures provides unlimited branching

Bracketed L-Systems

Symbol	Turtle Graphic Interpretation
[	Push the current state of the turtle onto the stack
]	Pop the top of the state stack and make it the current state

$S \Rightarrow FAF$
$A \Rightarrow [+FBF]$
$A \Rightarrow F$
$B \Rightarrow [-FBF]$
$B \Rightarrow F$

Non-deterministic, context-free

Examples

Stochastic L-systems

- To deal with non-determinism, one can assign probabilities to production rules

$S_{1.0} \Rightarrow FAF$
$A_{0.8} \Rightarrow [+FBF]$
$A_{0.2} \Rightarrow F$
$B_{0.4} \Rightarrow [-FBF]$
$B_{0.6} \Rightarrow F$

Context Sensitive L-Systems

- You may provide a context for the left side of the grammar rule, to restrict the application of grammar rules to certain contexts

Production rules	String sequence
$S \Rightarrow FAT$	
$A > T \Rightarrow [+FBF]$	S
$A > F \Rightarrow F$	FAT
$B \Rightarrow [-FAF]$	F[+FBF]F
$T \Rightarrow F$	F[+F[–FAF]F]F

Animating Plant Growth

- Changes in topology during growth
- Elongation of existing structures
- Elongation of structures may be animated by small linear step size and using rules such as F → FF
- Changes in topology is animated by the bracketing mechanism
  - However, we should not scan and render the final generated string left to right, the rendering should be done as we proceed

Parametric L-Systems

- Symbols may have one or more parameters associated with them
  - We can specify different linear, angular step sizes

S => A(0)
A(t) => A(t+0.01)
A(t) : t>=1.0 => F

A(t0)<A(t1)>A(t2): t2>t1 & t1>t0 => A(t1+0.01)

Timed L-Systems

- A symbol has an initial age and terminal age associated with it. A global time tracks the animation time and local times associated with each symbol determines when the rules are used to generate the next symbol.

axiom: (A,0)

(A,3) => (S,0) [+ (B,0)] (S,0)
(B,2) => (S,0)

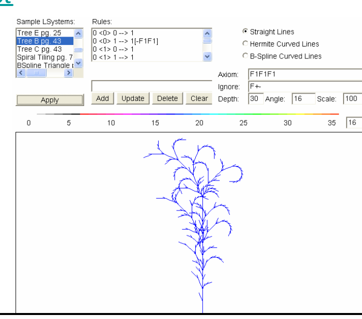
Examples

Examples

- L-System Movie 1
- L-System Movie 2

Example Applet

- Applet

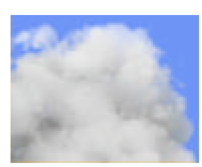


Realistic Modeling of Clouds

- Most of the teaching material used in these slides (including the material in the book) is taken from David Ebert's work on cloud generation
  - http://cobweb.ecn.purdue.edu/purpl/projects/fastclouds/frames.html

Cloud Types

- Cumulus



- Cirrus

Visual Characteristics of Clouds

- Clouds have volumetrically varying amorphous structure with detail at may different scales
- Cloud formation often results from swirling, bubbling, and turbulent processes
- Clouds have several illumination and shading characteristics

Volumetric Cloud Modeling

- Two level hierarchy
  - Implicit volumes to represent to global structure of the cloud (the cloud macrostructure)
    - Modeled by implicit functions (such as spheres)
  - Procedural methods to define turbulent, noise characteristics at a smaller scale (the cloud microstructure)
    - Modeled by turbulent volume densities

Volumetric Cloud Modeling

- The macro and micro models are combined to define a volumetric density function (*vdf*) over a 3D volumetric space
- The densities of the implicit volumes can be combined by using a cubic blending function and a weighted sum

$$F(r) = -\frac{4}{9}\cdot\frac{r^6}{R^6} + \frac{17}{9}\cdot\frac{r^4}{R^4} - \frac{22}{9}\cdot\frac{r^2}{R^2} + 1$$

$$D(p) = \sum_i w_i \cdot F(|p-q|)$$

Volumetric Cloud Modeling

- To combine the densities from implicit primitives with the turbulence-based densities a user specified blend percentage can be used (60% to 80% gives good results).

Videos

- Cumulus forming
- Flying through a cloud
- Cirrus
- Rolling cloud scene

The Swell Software

- How to build a cloud