ECE 595 / CS 491 / CS 591

Real-Time Rendering & Graphics Hardware

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Announcements

- Project handout will be available online

Last time

- Real-time geometry representations

Today

- Procedural geometry for real-time applications

Introduction to procedural geometry

- Traditional ways to represent geometry has several disadvantages:
  - Large storage requirements: every polygon needs to be stored
  - Lack of scalability: not so easy to change resolution in real-time
  - Geometry is difficult to modify in the application
  - Bandwidth bottleneck between CPU and GPU

Introduction to procedural geometry

- Unlike standard geometry, procedural geometry is generated “on the fly”
- It has several advantages
  - Low storage overhead: typical tradeoff of computation for storage… store a small amount of information and reconstruct the rest
  - Scalable: The models can be generated at any target resolution
  - Reduce bandwidth bottleneck: less information to transmit from the CPU to GPU

Different kinds of “procedural” graphics

- Vertex and fragment shaders
- Procedural animation (physics based)
- Procedural geometry (plants, clouds, terrain)

Procedural animations

- Typically involve solving physics equations (mechanics) to determine the motion of objects in the environment

L-Systems

- Developed by biologist Aristid Lindenmayer to describe growth of simple multicellular organisms
- Formal grammar based on a starting axiom and a set of rules
- 3 kinds of L-systems:
  - Deterministic context-free
  - Stochastic context-free
  - Context-sensitive

Example

- Axiom: A
- Rule: A → B-A-B, B → A+B+A

A

B-A-B

A+B+A-B-A-B-A+B+A

L-Systems

- Most successful in procedural generation of plants

source: Wikipedia

Example

Pramod Sharma and Guillaume Poncin

Procedural terrain

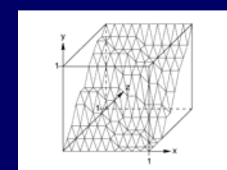
Image courtesy Jacob Olsen

Basic idea

- Terrain represented by a height field in a uniform grid
- Generate base terrain by simulating pink noise
- Erode terrain
- Render and shade

Height fields

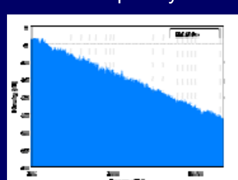
- Define height z on a uniform grid



source: povray

Pink noise

- Also known as 1/f noise
- Power spectral density is inversely proportional to the frequency



source: wikipedia

Simulating pink noise

- Two methods for simulating pink noise:
  1. Spectral synthesis
  2. Midpoint displacement

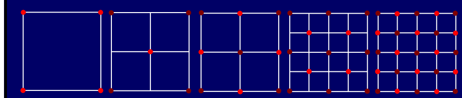
Spectral synthesis

- Add several octaves of noise together.
- With every octave, the noise frequency is doubled and the amplitude halved
- To create octaves, fill in evenly-spaced random numbers corresponding to the octave's frequency and then calculate the remaining value through interpolation

Midpoint displacement

1. Assign random values to the heights on a course grid
2. Use interpolation to compute intermediate values
3. Offset these intermediate values by a random amount stipulated by the resolution level
4. Go to 2, repeat until desired resolution is achieved

Midpoint displacement



Problems with noise terrain

- Statistical properties a little too homogeneous
- Use Voronoi diagrams to create interesting structure

Voronoi diagrams

- Randomly place "feature points" in the terrain
- Compute height according to the distance to the n closest feature points:

$$h = c_1 d_1 + c_2 d_2 + c_3 d_3 + \ldots + c_n d_n$$

- Typically, $c_1 = -1$, $c_2 = 1$, rest are 0

Voronoi cells

- Height computed from voronoi cells

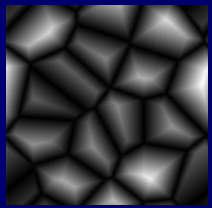


Image courtesy Jacob Olsen

Add the noise back in…

- Adding perturbation

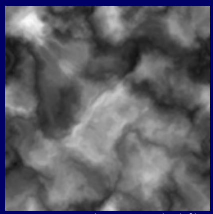


Image courtesy Jacob Olsen

Initial results

- Resulting terrain

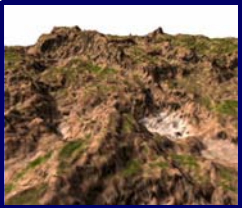


Image courtesy Jacob Olsen

Looks more like the surface of Mars than Earth! Why?

Initial results

- No erosion!

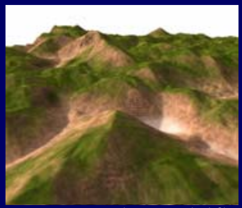


Image courtesy Jacob Olsen

Erosion algorithms

- First described by Ken Musgrave et al. 1989
- Simulate the way that soil is modified by natural phenomenon
- Two kinds:
  - Thermal erosion
  - Hydraulic erosion

Thermal erosion

- Simulates material breaking off and sliding down slopes
- Loose soil collects at the bottom
- Simulated through a series of iterations that looks at the slope of the surface to decide how much material will be displaced

Hydraulic Erosion

- Simulates erosion due to water moving through the terrain and displacing material
- Done through a series of steps:
  1. Water appears
  2. Water collects material from terrain
  3. Water flows to another part of the terrain
  4. Water evaporates and deposits sediment

Nice results!

Image courtesy Jacob Olsen

Microsoft's efforts in procedural graphics

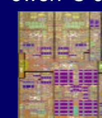
- Microsoft has been promoting procedural graphics for both DirectX and Xbox360

DirectX 10.0

- Geometry shaders add vertices on the fly
- Vertex programs had equal number of vertices going in and going out
- Geometry shaders have the capability of creating vertices where none existed!

X-box 360 Architecture

- Original Xbox had a Pentium III class processor
- Xbox360 features a Xenon processor (not Intel Xeon!)
- 3 PowerPC cores @ 3.2GHz



Xenon processor

Xenon processor architecture

source: ars technica

PowerPC Cores

- Dual issue, in-order execution for two threads
- Vector Execution Unit VMX128
- Specialized load/unload instructions to pack/unpack data in DirectX vertex format

Xenon caches

- L1 (32KB) 2-way set associative
- L2 (1MB) 8-way set associative (shared)

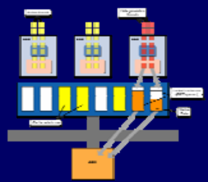
Procedural geometry on the Xbox 360

- The Xenon CPU acts like a "decompressor" and generates the procedural geometry based on a small amount of input from memory

source: ars technica

Programming approach

- One thread handles high-level graphics functions
- Another thread generates content



source: ars technica

Procedural environments

Microsoft, 2006