Virtual Landscaping

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Introduction

- One of the open problems in CG is modeling
- A wide variety of complex objects can be generated by visual simulation of Nature.

- We will show some attempts on how to visually simulate
  - terrains and
  - plants.
Terrains
Terrain Modeling

**Problem**
fractal-based techniques generate terrains that look like “just created”
Real terrains are *eroded*

**Solution**
erode terrains...
Terrain Modeling

We need erosion algorithms that are:

• realistic,
• user controlled,
• fast, and
• easy to include into existing systems
Terrain Modeling

Data Structures

a) for real-time rendering (ROAM, TINs, etc.)
b) for erosion simulation

regular height fields
voxel-based structures
layered data structures

[Benes, Forsbach, IEEE SCCG 2001]
Layered Data Structure

• Terrain is a composition of multiple layers of different materials
Layered Data Structure

- Data is represented as columns
- In fact a per column RLE compressed voxel rep.
- Various erosion algorithms can be implemented on this data
Hydraulic Erosion

• Erosion caused by water
• Realistic solutions solve Navier-Stokes equations for fluid dynamics
• Can be solved for 2D or 3D cases
  • 2D: shallow water simulation
  • 3D: Eulerian approaches
  • 3D: Lagrangian approaches
2.5 D Hydraulic Erosion

• Using shallow water equation
• Simulated using the pipe-model and the layered representation
2.5 D Hydraulic Erosion

• Three erosion models
  • thermal weathering
  • force-based erosion (caused by the running water)
  • still-water erosion (caused by material dissolution)
Thermal Weathering

• Material breaks apart because of thermal shocks
• Material slipping due to the gravity
• Talus angle defines maximum difference between heights of neighboring cells

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Thermal Weathering
Thermal Weathering
Thermal Weathering
2.5 D Hydraulic Erosion

- Three erosion models
  - thermal weathering
  - force-based erosion
    (caused by the running water)
  - still-water erosion
    (caused by material dissolution)

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Force-based erosion
Force-based erosion
Force-based erosion
Force-based erosion
2.5 D Hydraulic Erosion

• Three erosion models
  • thermal weathering
  • force-based erosion (caused by the running water)
  • still-water erosion (caused by material dissolution)
Still-Water Erosion

\[ w(x,y) \]
\[ r(x,y) \]
\[ d(x,y) \]
Still-Water Erosion
Implementation

- Fully on the GPU
- Interactive for 1024x512x8 layers
- Multi-GPU support

[Stava, Benes, Brisbin, Krivanek, Eurographics/SIGGRAPH Symposium on Computer Animation, 2008]
Video
Video
Hydraulic Erosion

• erosion caused by water
• realistic solutions use Navier-Stokes equations for fluid dynamics
• solved for 2D or 3D cases
  • 2D: shallow water simulation
  • 3D: Eulerian approaches
  • 3D: Lagrangian approaches
Full 3D Simulation

• In voxel space
• Coupled Navier-Stokes equations and erosion/deposition model from hydrology
• CPU implementation
• pretty slow

Full 3D Simulation

• Cells in CFD are
  • FULL (water)
  • EMPTY (air)
  • MAT (material)
• we have extended this approach by varying FULL and EMPTY from 0 to 1.
• and by material exchange model (special actions for cell state change MAT->FULL, FULL->MAT, etc.)
• Material exchange boundary<->water
Maze Break
Maze Break
Maze Break
Meander Break
Waterfall
Underwater
Hydraulic Erosion

• erosion caused by water
• realistic solutions use Navier-Stokes equations for fluid dynamics
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  • 3D: Lagrangian approaches
Using Smooth Particle Hydrodynamics

• Similar idea, now coupled with particles
• Three phases
  1. material erosion
  2. material exchange between particles
  3. material deposition

Erosion

boundary particles

SPH particles

erosion

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Exchange

diffusion

donor

settling downwards

gravity

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Deposition

boundary particles

SPH particle deposition

relocated boundary particles

new level
Video
Conclusions

• Erosion simulation gives an important final touch to terrain scenes, difficult to achieve manually

• Problems and future work:
  • computationally expensive
  • low user control
Plants
Interactive Plant Simulation

**Problem**

- plants libraries and plant modeling software do not allow plants to interact with the environment

**Solution**

- do it interactively - plant “sculpting”

[Benes, Andrysco, Stava, *Eurographics NAT 2009*]
Plant Description

- Branching
- Biological model (Leeuwenberg and Raugh model)
- Bud lifespan
- Plant sensitivity to external impetus
- Target plant shapes
Plant Definition

- Growth is biologically-based
- Uses plant modules to control the growth
  - Apical bud
  - Lateral buds
    - Initially dormant
    - Activated after some time
Gravity

• Gravitropism
  • Branches tend to grow against gravity
Light and Phototropism

• plant growth is driven by buds ("plant engines")
• each bud determines its illumination
• finds the brightest spot (bending)
• % of illuminated buds on a branch determines its fate
Light and Phototropism
Competition for Resources

- Branches tend to avoid each other
- Using the Honda model [Honda67]
  - A buds has a sphere of interest
  - Two spheres cannot overlap
Competition for Resources

• a small ecosystem fighting for space
Competition for Resources
Examples
Urban Ecosystems
Our Goal is to
Previous work

• A vast body of previous work on plants and ecosystems in Computer Graphics exists.

• Plant spatial distribution emerges as artificial life from *plant competition for resources.*

• Could not we just use it?
Motivation

A wild ecosystem

A wild ecosystem in a city as a stencil

Urban ecosystem

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Key Observations

• Urban ecosystems are not wild at all.

• They have certain level of organization.

• Urban and architectural rules are applied together.

• Human intervention and management are involved.
Urban Ecosystem Overview

- Urban Layout
  - Urban Simulation
  - Geometry Generation

- Plant Distribution
  - Manageability Estimation
  - Initial Plant Distribution
  - Plant Management
    - Wild Ecosystem
    - Managed Plants

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Manageability

- Manageability is a measure of how much care is taken about the plants.
- Wild areas have low manageability.
- Gardens, wealthy areas, city downtowns, etc. have high manageability.

\[0 \leq m \leq 1\]

- \(m = 0\) wild ecosystem.
- \(m = 1\) perfect garden, no wild plants allowed.
Manageability control

Few managed areas
Balanced urban ecosystem
Over-managed ecosystem

Low manageability
High manageability

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Initial Plant Distribution

- Procedural planting in managed blocks (US cities):
  - along roads,
  - between buildings,
  - along the main axis,
  - within highest value blocks, and
  - at egress sites.

- Planting in unmanaged blocks
  - random seeding.
Roads

• Along the main roads and arterials

Real road

Procedural planting
Blocks

• Main axis of a block

Real block

Procedural planting
The highest manageability blocks

• Filled with green areas

Downtown Manhattan

Procedural planting (jittering)
Plant competition
Plant competition

- Plant seeding
Clusters emerge over time

- 25 years
- 75 years
- 100 years
- 125 years

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Implementation

- Intel i7 920 CPU clocked @ 2.67 GHz
- NVidia GeForce 480 with 1.5GB of memory
- Collisions and viability implemented in CUDA
  - City - plant collision by texture lookup
  - Plant - plant collisions analytically (bins)
- Visualization Engine:
  - kd-tree subdivision of space
  - LOD selection based on distance
Results

**Fixed city layout:**
- $3 \times 3 \ km^2$ area
- $\Delta t = 1 \ month$
- 70 years
- 250,000 plants
- simulated in 2 minutes
- CUDA 50 - 70Millions collision tests per second
Results

• Fixed urban layout filled with plants
Results: Low vs. high management

low management, more wilderness

high management, more regular patterns

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Results: Low vs. high management

- low management, more wilderness
- high management, more regular patterns
Results: Urban Layout Edits
Results: Urban Layout Edits
Conclusions

• Biologically-inspired computational graphics approach to urban ecosystem design.
• Seamlessly connected to existing methods for urban design in CG.
• Interactive urban layout edits.
• Easy level of control.
• With a set of extendible procedural rules.
Meta Conclusions

• What is next?

• Modeling is an open problem in CG
• User-assisted/controlled simulations can provide CG content
• User control is a problem
• Speed of processing and size of data as well..
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