Terrain Rendering using
GPU-Based Geometry Clipmaps

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Terrain Rendering Challenges

- Regular grid (image) of height values
  - Concise storage → No paging hiccups
  - Real-Time frame rates → 60 fps
  - Visual continuity → No temporal pops
A Change of Focus

- Hoppe 1998 - Highly irregular Connectivity

- Lindstrom 1996 - Semi-regular Connectivity

- Losasso & Hoppe 2004 - Totally regular Connectivity
Geometry Clipmaps

- Terrain as mipmap pyramid
- LOD using nested grids
Terrain Compression

- Store coarsest level + inter-level residuals

\[ R_l = T_l - U(T_{l-1}) \]

\[ \tilde{R}_l = \text{compress}(R_l) \]

- Reconstruction

\[ T_l = U(T_{l-1}) + \text{decompress}(\tilde{R}) \]
Why GPU?

- Much less CPU utilization
- Very little AGP/PCIe bus utilization
- Small system memory requirement
- Small video memory requirement
- Significant rendering speedup
GPU Implementation Overview

- DirectX 9.0c - support for Shader Model 3.0
- HLSL code available on book’s CD

- Store data as textures (in video memory)
  - Elevation data – 32-bit 1-channel texture
  - Residual data – 32-bit 1-channel texture
  - Normal data – 8-bit 4-channel texture

- Update parts of texture that change
System Design

Update

- Upsample coarser level elevation texture
- Add residuals
- Update normal map texture

Vertex Shader
- Use (x, y) to lookup z value in elevation texture
- Compute $\alpha$
- Blend Geometry

Pixel Shader
- Blend normals
- Does the shading
- Texture lookup

Vertex Textures
Supported in DirectX 9.0c & Shader Model 3.0 on NVIDIA GeForce 6800
Clipmap Update

- Shift clipmap levels as user moves
Upsample
Add residuals

System Memory
Compressed residuals (350MB for US)

ROI decompression (CPU)

GPU

Residual Image in video memory
Incremental update

Before update

Update region

After update
**Individual Clipmap Levels**

Example: \( n=15, m=4 \)

- \( m \times m \) block
- \( m \times 3 \) ring fix-up
- \( (2m+1) \times 2 \) interior trim
- Outer degenerate tri.

- See Section 2.3.2 in book
View-frustum culling

- Culling done at block level on CPU
- 2-3x speedup
## Timing Results

<table>
<thead>
<tr>
<th></th>
<th>Previous Implementation</th>
<th>Current Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upsampling</td>
<td>3 ms</td>
<td>1.3 ms</td>
</tr>
<tr>
<td>Decompression</td>
<td>8 ms</td>
<td>8 ms</td>
</tr>
<tr>
<td>Normal Map Computation</td>
<td>11 ms</td>
<td>0.6 ms</td>
</tr>
</tbody>
</table>
Performance

• Synthesized terrain
  – 130 frames/second (render-bound)
  – 120 frames/second during user motion
  – 60 million triangles per second
  – CPU utilization: ~0
  – AGP bus utilization: ~0

• Decompressed terrain
  – 87 frames/second during viewer motion
  – Decompression on CPU bottleneck
Summary

• Lots of Real-World Applications
  – Games
  – Flight/driving Simulators
  – Virtual Environments
  – Networked Viewer

• Advantages of current framework
  – High compression ratios
  – Terrain synthesis
  – Collision detection within GPU
Demo
Questions?

- See GPU Gems 2, Chapter 2
  The Source for GPU Programming
- [arul@cs.utah.edu](mailto:arul@cs.utah.edu)
- Slides available online
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