GPU-Based Volume Rendering of Unstructured Grids

João L. D. Comba  
Cláudio T. Silva  
Steven P. Callahan  
Fábio F. Bernardon

UFRGS  
University of Utah  
UFRGS

SIBGRAPI 2005  
Natal - RN - Brazil

XVIII Brazilian Symposium on Computer Graphics and Image Processing
GPU-Based Volume Rendering of Unstructured Grids

Module 1:
Graphics Hardware

João L. D. Comba
UFRGS
Pre-GPU Graphics Acceleration

- Integrated Graphics Architecture
- Silicon Graphics
- Evans & Sutherland
GPU-Based Volume Rendering of Unstructured Grids

SIBGRAPI 2005

3D Application or Game

3D API commands

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB

3D Application or Game

3D API commands

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB

glBegin(GL_TRIANGLES);
glVertex3f(0.0, 0.0, 0.0);
glVertex3f(1.0, 0.0, 0.0);
glVertex3f(0.5, 1.0, 0.0);
...
glEnd();
GPU-Based Volume Rendering of Unstructured Grids

SIBGRAPI 2005

3D Application or Game

3D API commands

Verteces

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB

3D API: OpenGL or Direct 3D

3D Application or Game

3D API commands

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB
3D Application or Game

3D API: OpenGL or Direct 3D

3D API commands

1. Vertices
2. Transformed Vertices
3. Fragments
4. Colored Fragments
5. Pixel Updates
6. FB

Vertex Transformation → Primitive Assembly and Rasterization → Fragment Texturing and Coloring → Raster Operations → FB
GPU-Based Volume Rendering of Unstructured Grids

Graphics Pipeline

3D Application or Game

3D API commands

3D API: OpenGL or Direct 3D

4 Vertices

Transformed Vertices

1 2 3

Vertex Transformation

Primitive Assembly and Rasterization

Fragments

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB

GPU-Based Volume Rendering of Unstructured Grids
Graphics Pipeline

3D Application or Game

3D API commands

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragments

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB

1' 3 4

2 3 1
Graphics Pipeline

3D Application or Game

3D API commands

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

VerteX Transformation

Primitive Assembly and Rasterization

Fragments

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB

3D Application or Game

3D API commands

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragments

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB

GPU-Based Volume Rendering of Unstructured Grids
GPU-Based Volume Rendering of Unstructured Grids

Graphics Pipeline

3D Application or Game

3D API commands

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Transformed Vertices

Fragments

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB
GPU-Based Volume Rendering of Unstructured Grids

SIBGRAPI 2005

3D Application or Game

3D API commands

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

1 3 4

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Pixel Updates

Raster Operations

FB
Graphics Pipeline

3D Application or Game

3D API commands

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragnents

Fragment Texturing and Coloring

Colored Fragments

Pixel Updates

Raster Operations

FB

1 3 4

1 2' 3'
GPU-Based Volume Rendering of Unstructured Grids
Graphics Pipeline

3D Application or Game

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Pixel Updates

Raster Operations

FB

3D API commands

3D Application or Game

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Pixel Updates

Raster Operations

FB

GPU-Based Volume Rendering of Unstructured Grids
GPU-Based Volume Rendering of Unstructured Grids
3D Application or Game

3D API: OpenGL or Direct 3D

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Raster Operations

FB

GPU-Based Volume Rendering of Unstructured Grids
Graphics Pipeline

3D Application or Game

3D API commands

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Raster Operations

Pixel Updates

FB

3D API: OpenGL or Direct 3D

3D Application or Game

GPU-Based Volume Rendering of Unstructured Grids
GPU-Based Volume Rendering of Unstructured Grids
First-Generation GPUs (up to 1998)

- NVIDIA TNT2, ATI Rage, 3dfx Voodoo3
- Relevant tasks:
  - Rasterizing pre-transformed triangles
  - Applying one or two textures
  - Implement DirectX 6 feature set
GPU-Based Volume Rendering of Unstructured Grids

- NVIDIA GeForce 256, GeForce2, ATI Radeon 7500, S3 Savage 3D
- Relevant tasks:
  - Transformation & Lighting (T&L) em Hardware
  - Implement DirectX 7 feature set
  - Cube map textures
  - More math operations for combining textures (still limited)
GPU-Based Volume Rendering of Unstructured Grids

3D Application or Game

3D API: OpenGL or Direct 3D

3D API commands

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB

GPU-Related Operations:
- Fragment Texturing and Coloring
- Raster Operations
- Pixel Updates

3D Application or Game

3D API: OpenGL or Direct 3D

3D API commands

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Raster Operations

Pixel Updates

FB
Third-Generation GPUs (2001)

- NVIDIA GeForce 3, GeForce4 Ti, Microsoft XBox, ATI Radeon 8500, Quadro 4
- Relevant tasks:
  - Vertex programmability rather than more configurability
  - More pixel-level (fragment) configurability (not truly programmable)
  - 3D Textures
  - Shadow Maps
GPU-Based Volume Rendering of Unstructured Grids

3D Application or Game

3D API: OpenGL or Direct 3D

3D API commands

Vertices

Transformed Vertices

Vertex Transformation

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Colored Fragments

Pixel Updates

Raster Operations

FB

Programmable Vertex Processor

- NVIDIA GeForce FX family, ATI 9700, ATI 9800
- Relevant tasks:
  - Vertex and Fragment programmability
  - Implement DirectX 9 feature set
  - 32 Bit IEEE Floating Point per component (128-bit textures)

Intel Pentium 4 2.4 Ghz = 55 million transistors
NVIDIA GeForce FX 5800 = 125 million transistor

2.27
GPUs

3D Application or Game

3D API: OpenGL or Direct 3D

3D API commands

Vertices

Transformed Vertices

Vertex Transformation

Programmable Vertex Processor

Primitive Assembly and Rasterization

Fragment Texturing and Coloring

Fragmented Fragments

Colored Fragments

Raster Operations

Pixel Updates

FB

GPU-Based Volume Rendering of Unstructured Grids
Fifth Generation (04-05)

- NVIDIA 6800
  - 16 pipes fragment shader
- NVIDIA 7800:
  - 24 pipes fragment shader
- ATI X1800 (released 4 days ago)
- What is has to offer:
  - Memory access for vertex programs
  - Branches in fragment program
  - Longer fragment programs
Sixth Generation (2006)

- Unified Architecture:
  - Same Instruction Set (Vertex and Fragment Processors)
  - Geometry Processor:
    - Ability to program how vertices can be combined to form new primitives
    - Ability to create vertices
- Generalized Output Buffers
- More?
What the GPU offers?

- Streaming processors
- Vector operations:
  - 4-component instructions with 32-bit IEEE floating point operations
- GPU Memory Accesses through Textures:
  - 1-, 2-, 3-D tables
  - no read-write textures
- Multiple Render Targets
- Limited branching/loops
What we will see today

- Summary of solutions for Volume Rendering problems using GPUs
- Span different architectures
- Open exciting perspectives for other interesting problems:

Dynamic or Time-Varying Problems