Interactive Walkthroughs using Multiple GPUs

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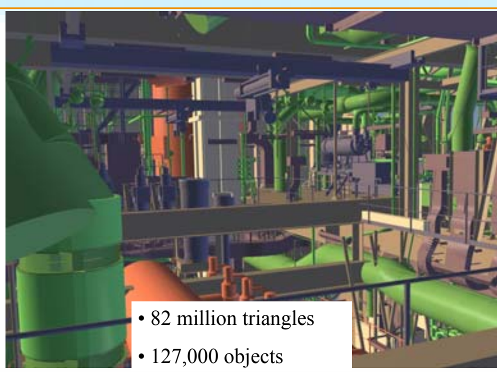
SIGGRAPH COURSE #11, 2003

Goal

- Interactive Walkthrough of *complex 3D* environments at *high fidelity*
  - Models from CAD, VR
  - High primitive count
  - Heterogeneous geometry
  - Irregular distribution

DoubleEagle Tanker Model



- 82 million triangles
- 127,000 objects

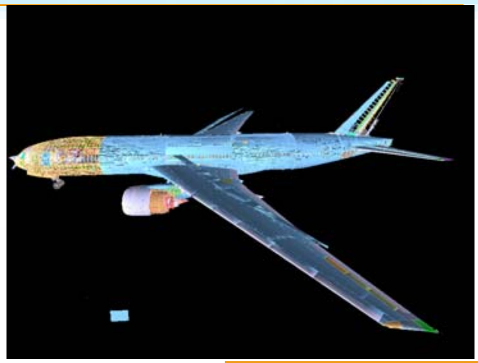
Boeing 777

470 million triangles

Boeing 777

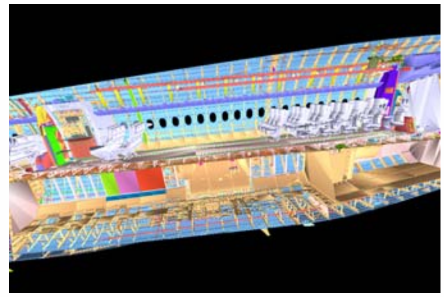
470 million

triangles

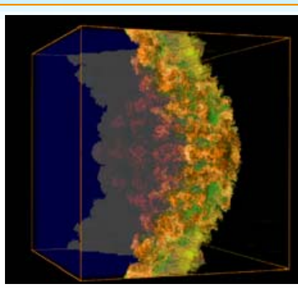


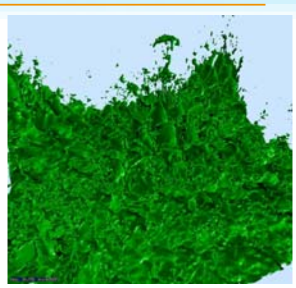
Boeing 777

470 million
triangles:
Zoomed in
View



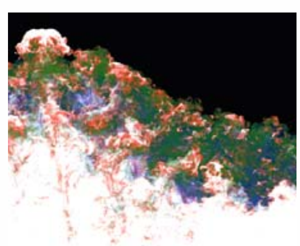
Simulation of Richtmyer-Meshkov instability

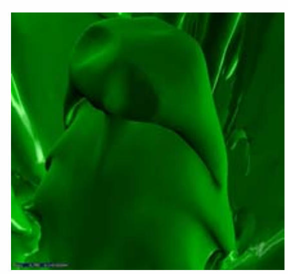




2048 * 2048 * 1920 grid and 27,000 time steps
(5832 processors, IBM SST System):
Over 3 TB of multivariate data generated.
Each time step, ~500 Million triangles for each iso-surface

Simulation of Richtmyer-Meshkov instability





Close view of a small detail
Data: Lawrence Livermore Labs

Commodity Hardware Performance

- Current GPUs have capabilities to render millions of polygons per second
- Require vertex arrays, triangle stripping to achieve these rates
- **Issues**
  - Large polygon count
  - Memory limitations

Commodity Hardware Performance

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  - Memory limitations
- **Solution** – Reduce polygon count

Acceleration Techniques

- Geometric simplification
- Occlusion culling
- Hybrid approaches

Geometric Simplification

- Static [Clark 1976; Hoppe 96; Erikson et al. 01; Garland et al. 97]
- View-Dependent [Hoppe 97; Luebke et al. 97]
- Surveyed in LOD book [Luebke et al. 02]

Occlusion Culling

- Cells and portals [Airey et al. 90; Teller 92; Luebke et al. 95]
- Urban datasets composed of large occluders [Coorg et al. 97; Hudson et al. 97; Schaufler et al. 00; Wonka et al. 01]
- Recent survey in [Cohen-Or et al. 02]
- Further classified as
  - Conservative [Greene et al. 93, Zhang et al. 97]
  - Approximate [Bartz et al. 99; Klosowski and Silva 00]

Hybrid Approaches

- Combine LOD and Occlusion Culling techniques
  - UC Berkeley Walkthrough [Funkhouser et al. 96]
  - Synthetic convex occluders [Andujar et al. 00]
  - Approximate visibility using prioritized layer projections with view dependent rendering [ElSana et al. 01]
  - UNC MMR system [Aliaga et al. 99]
  - GigaWalk [Baxter et al. 02]

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Motivation

- An algorithm that works on generic models
- Image-based culling algorithms
- Current approaches involve frame buffer readbacks [Greene et al. 93, Zhang et al. 97, Baxter et al. 02]

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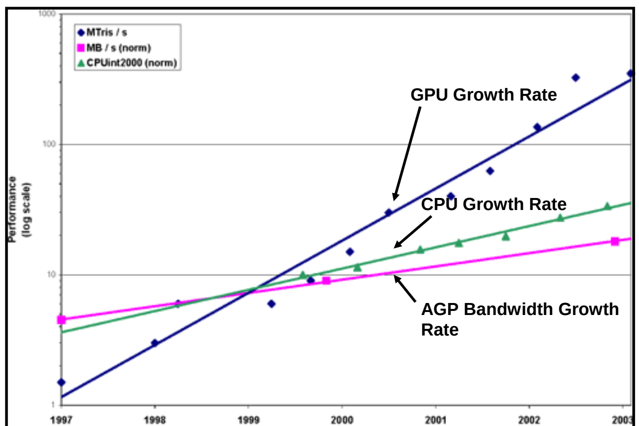

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Frame Buffer Readbacks

- GPU growth rate is higher than Moore's law
- Bandwidth growth rate lower than Moore's law
  - Result – Frame buffer readbacks are expensive
  - Also readbacks result in graphics pipeline stalls
- Require a solution that
  - Leverages high GPU power
  - Avoids frame buffer readbacks

Outline

- Parallel algorithm using mulitple GPUs
- Interactive walkthroughs
- Interactive shadow generation

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- **Parallel algorithm using mulitple GPUs**
- Interactive walkthroughs
- Interactive shadow generation

Occlusion-Switch

- Occlusion-switch has 2 GPUs
  - It takes a camera as input
  - The output is PVS and a camera

PVS: Potentially visible set

Occlusion-Switch

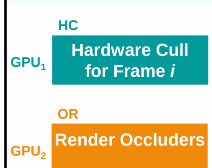
- Parallel image-based culling algorithm
- A novel switching mechanism to eliminate frame-buffer readbacks
- Exploits temporal coherence
  - ♦ Occluder selection
  - ♦ Lower bandwidth requirements
- Integrates with hierarchical LODs

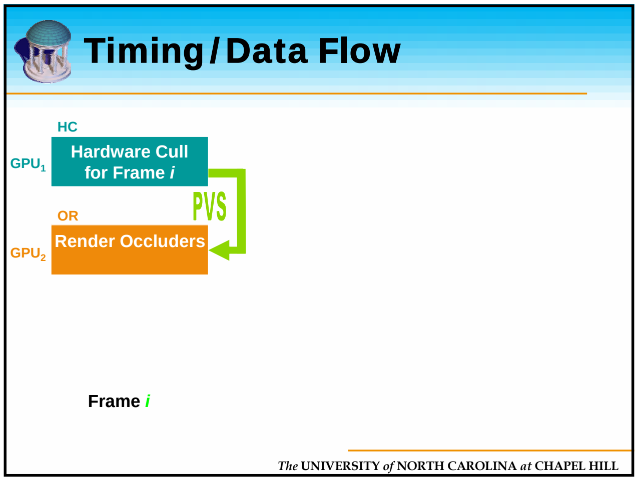
Occlusion Switch : Parallel Algorithm and Architecture

- **Three processes in parallel**
  1. **Occlusion Representation (OR)**
  2. **Hardware Culling (HC)**
  3. **Render Visible Geometry (RVG)**

Timing / Data Flow

Timing / Data Flow




Timing / Data Flow
HC
GPU1
Hardware Cull for Frame i
PVS
OR
GPU2
Render Occluders
Frame i
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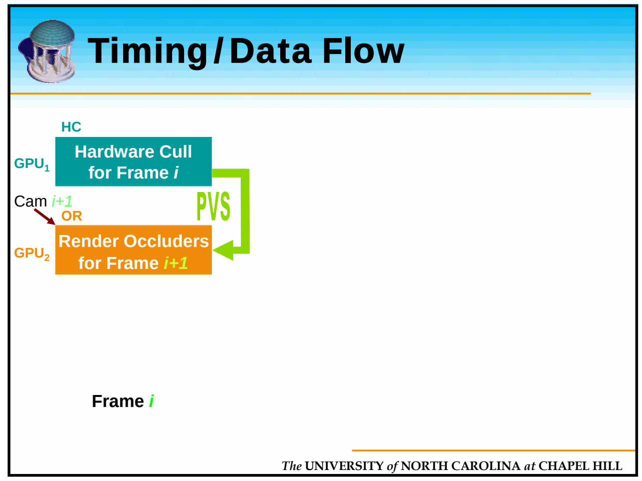
Timing / Data Flow
HC
GPU1
Hardware Cull for Frame i
Cam i+1
PVS
OR
GPU2
Render Occluders for Frame i+1
Frame i
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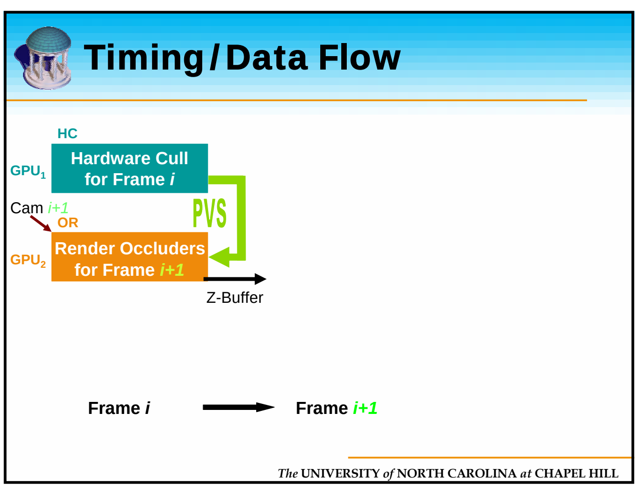
Timing / Data Flow
HC
GPU1
Hardware Cull for Frame i
Cam i+1
PVS
OR
GPU2
Render Occluders for Frame i+1
Z-Buffer
Frame i
Frame i+1
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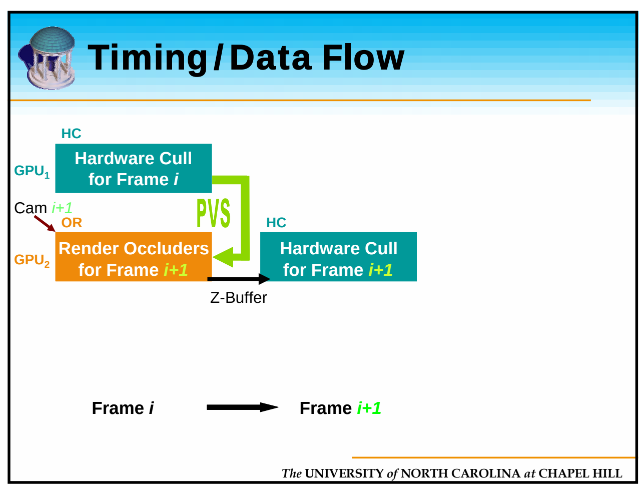
Timing / Data Flow
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GPU2
Render Occluders for Frame i+1
Hardware Cull for Frame i+1
Z-Buffer
Frame i
Frame i+1
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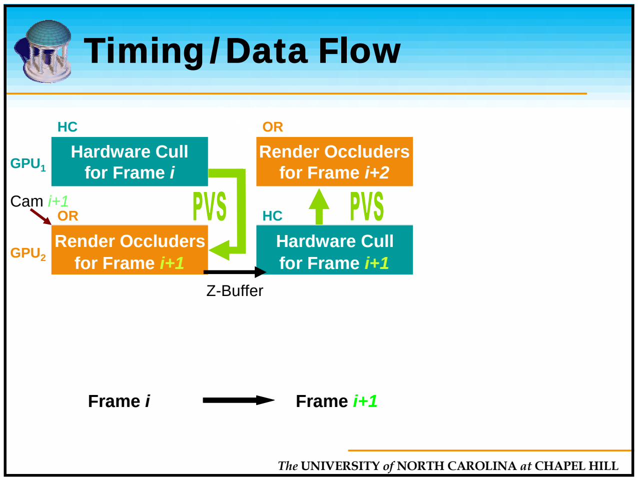
Timing / Data Flow
HC
OR
GPU1
Hardware Cull for Frame i
Render Occluders for Frame i+2
Cam i+1
OR
PVS
HC
PVS
GPU2
Render Occluders for Frame i+1
Hardware Cull for Frame i+1
Z-Buffer
Frame i
Frame i+1
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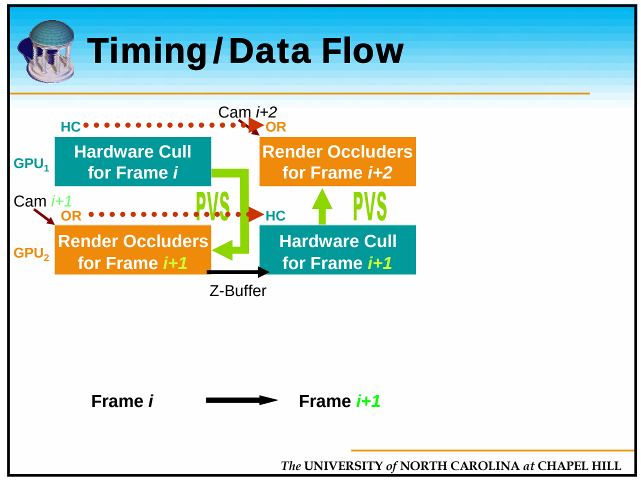
Timing / Data Flow
Cam i+2
HC
OR
GPU1
Hardware Cull for Frame i
Render Occluders for Frame i+2
Cam i+1
OR
PVS
HC
PVS
GPU2
Render Occluders for Frame i+1
Hardware Cull for Frame i+1
Z-Buffer
Frame i
Frame i+1
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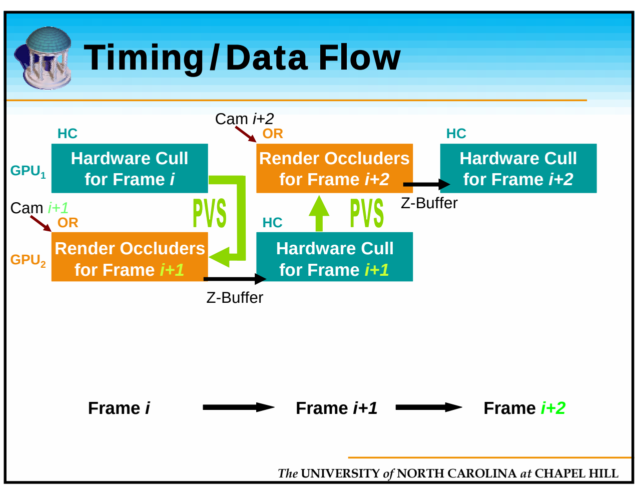
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GPU1
Hardware Cull for Frame i
Render Occluders for Frame i+2
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Z-Buffer
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HC
PVS
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Render Occluders for Frame i+1
Hardware Cull for Frame i+1
Z-Buffer
Frame i
Frame i+1
Frame i+2
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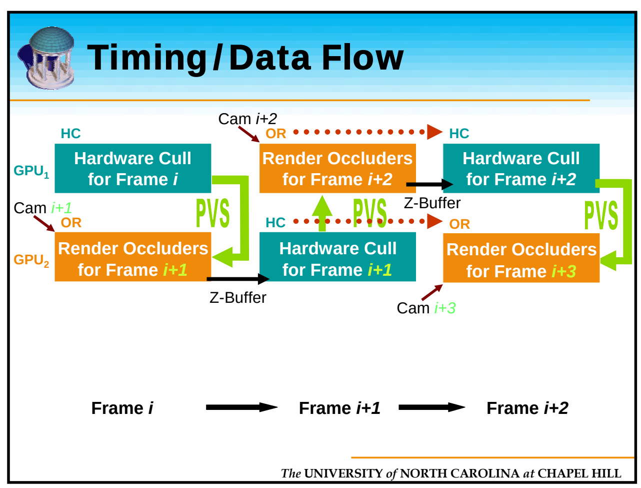
Timing / Data Flow
Cam i+2
HC
OR
HC
GPU1
Hardware Cull for Frame i
Render Occluders for Frame i+2
Hardware Cull for Frame i+2
Z-Buffer
Cam i+1
OR
PVS
HC
PVS
OR
PVS
GPU2
Render Occluders for Frame i+1
Hardware Cull for Frame i+1
Render Occluders for Frame i+3
Z-Buffer
Cam i+3
Frame i
Frame i+1
Frame i+2
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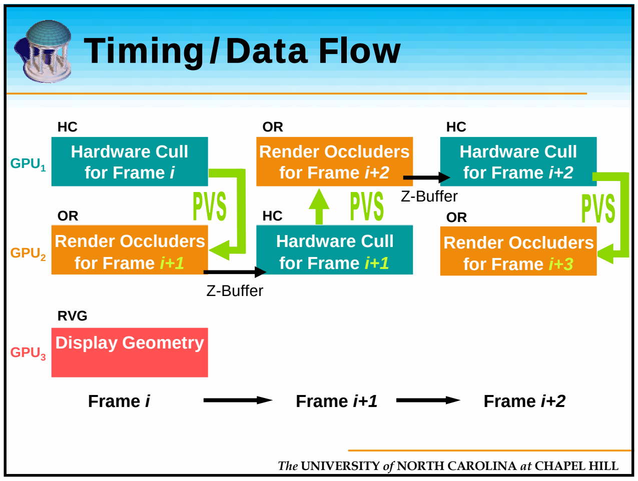
Timing / Data Flow
HC
Hardware Cull for Frame i
OR
Render Occluders for Frame i+2
HC
Hardware Cull for Frame i+2
GPU1
PVS
Z-Buffer
OR
Render Occluders for Frame i+1
HC
Hardware Cull for Frame i+1
OR
Render Occluders for Frame i+3
GPU2
Z-Buffer
RVG
Display Geometry
GPU3
Frame i
Frame i+1
Frame i+2
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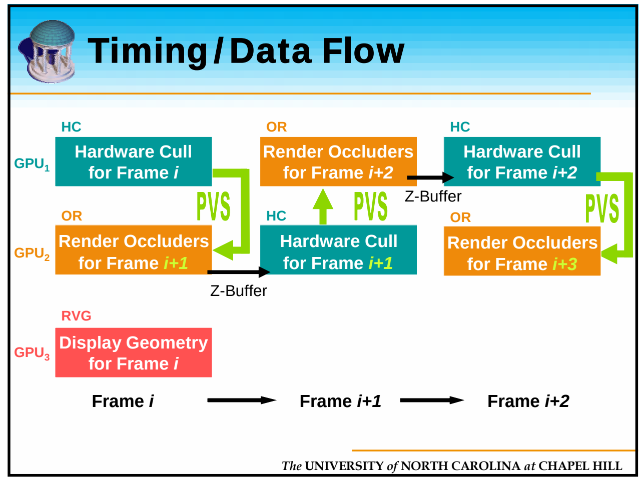
Timing / Data Flow
HC
Hardware Cull for Frame i
OR
Render Occluders for Frame i+2
HC
Hardware Cull for Frame i+2
GPU1
PVS
Z-Buffer
OR
Render Occluders for Frame i+1
HC
Hardware Cull for Frame i+1
OR
Render Occluders for Frame i+3
GPU2
Z-Buffer
RVG
Display Geometry for Frame i
GPU3
Frame i
Frame i+1
Frame i+2
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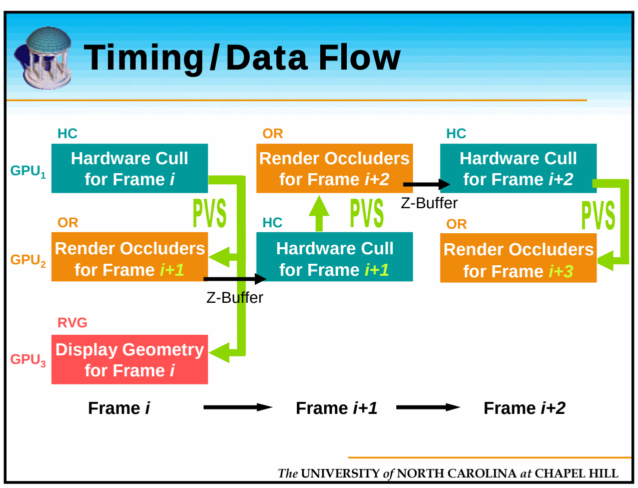
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PVS
Z-Buffer
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HC
Hardware Cull for Frame i+1
OR
Render Occluders for Frame i+3
GPU2
Z-Buffer
RVG
Display Geometry for Frame i
GPU3
Frame i
Frame i+1
Frame i+2
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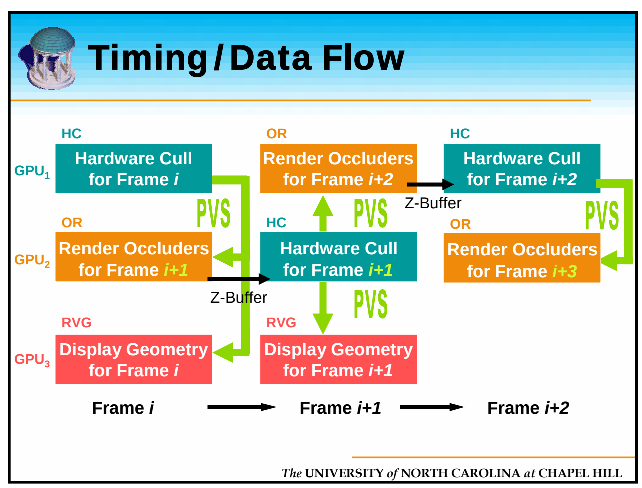
Timing / Data Flow
HC
Hardware Cull for Frame i
OR
Render Occluders for Frame i+2
HC
Hardware Cull for Frame i+2
GPU1
PVS
Z-Buffer
OR
Render Occluders for Frame i+1
HC
Hardware Cull for Frame i+1
OR
Render Occluders for Frame i+3
GPU2
Z-Buffer
RVG
Display Geometry for Frame i
RVG
Display Geometry for Frame i+1
GPU3
Frame i
Frame i+1
Frame i+2
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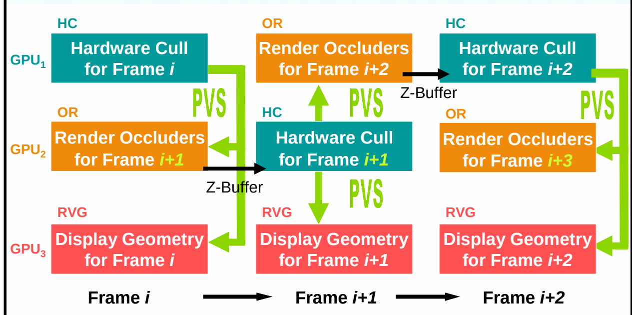
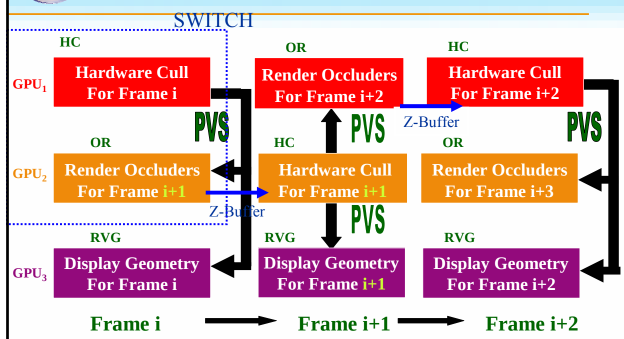
Timing / Data Flow



Timing / Data Flow



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Bandwidth Requirements

- Potential Visible Set (PVS) and camera parameters are transmitted over the network.
- Temporal coherence to minimize bandwidth requirements
  - Each GPU maintains current frame geometry
  - Transmit the differences in visible geometry across successive frames

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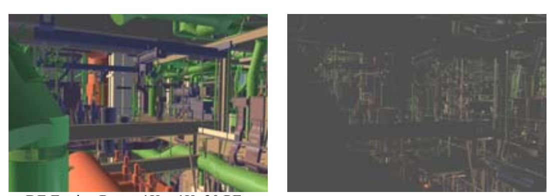
Static LOD Selection: Error Metric

- Pixel Error Metric: Max normal deviation of silhouette in image
- Traverse down scene graph till error satisfied
- Upper Bound: Highly conservative



DE Engine Room 1K x 1K, 20 PE

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Hardware Culling

- Use NV_OCCLUSION_QUERY to determine visible pixels
- Traverse scene hierarchy rendering bounding boxes of nodes

Hardware Culling Optimizations

- **Multiple Occlusion Tests**
  - Occlusion Query 'counter' for each node
  - Traverse scene graph breadth first
  - Bunch queries for all nodes at a level
  - 40% faster than testing one node with HP_OCCLUSION_TEST

LOD Selection: Visibility Metric

- **Visibility for LOD selection**
  - Visible pixels of bounding box > visible pixels of geometry
  - No. of visible pixels less than error metric $\vec{}$ provides an early termination condition
  - Provides looser bounds – reduces polygon count

Conservative Occlusion Culling

- Underlying algorithm used for occlusion culling is conservative to image precision
- Exactly same set of LODs is used for both OR and HC stages

Outline

- Parallel algorithm using mulitple GPUs
- **Interactive walkthroughs**
- Interactive shadow generation

Interactive Walkthroughs

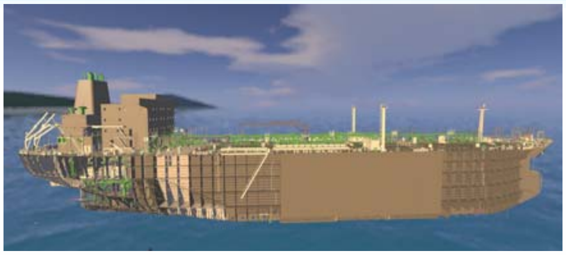
- 3 Dell Precision Workstations with dual 2 GHz Pentium IV CPUs, GeForce 4 GPU, and 2 GB main memory**: Immediate mode rendering**

Test Model: Powerplant

Original
- 0.5 Gigabyte dataset
- 13 Million Polygons
- 1200 objects

Preprocessing
- 7 hours
- 1.2 Gigabytes
- 13 Million Polygons
- 38,000 objects

Test Model: DoubleEagle Tanker



Original
- 4 Gigabyte dataset
- 82 Million polygons
- 127,000 objects

Preprocessing
- 34 hours
- 8 Gigabytes
- 82 Million polygons
- 61,000 objects

Interactive Walkthrough: Powerplant

13M triangles: 3 Dell PCs with NVIDIA GeForce 4 cards (2002)

Interactive Walkthrough: Double Eagle Tanker

82M triangles: 3 Dell PCs with NVIDIA GeForce 4 cards (2002)

Recent Work: Use Single GPU for 3 Processes

- Use vertex arrays
- Perform OR, HC and RVG on the GPU
- Improved support for occlusion queries
- Lower performance as compared to 3 GPU-based solution
- Fewer latency problems

[July 2003]

Live Demo

Dell M50 laptop, 2.4GHz Pentium IV-M CPU, NVIDIA Quadro4 700GoGL GPU, 1GB memory running Windows XP**:** Vertex arrays

Powerplant model (13M triangles)

View-Dependent Rendering

- Use of static LODs leads to popping artifacts
- Compute a view-dependent simplification
  - ♦ Precompute a vertex and cluster hierarchy
  - ♦ Runtime: perform occlusion culling using cluster hierarchy
  - ♦ Runtime: use the vertex hierarchy to compute the view-dependent simplification

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Integrated Occlusion Culling with View-Dependent Simplification

Single Dell PC with NVIDIA GeForce FX 5800 Ultra GPU
[Yoon, Salomon and Manocha: IEEE Visualization 2003]

Occlusion-Switch : Advantages

- Generic models
  - ♦ No assumptions on model, distribution
- Conservative Occlusion Culling
- Significant Occlusion Culling
- Low Bandwidth
- Computation performed on GPUs

Outline

- Parallel algorithm using mulitple GPUs
- Interactive walkthroughs
- **Interactive shadow generation**

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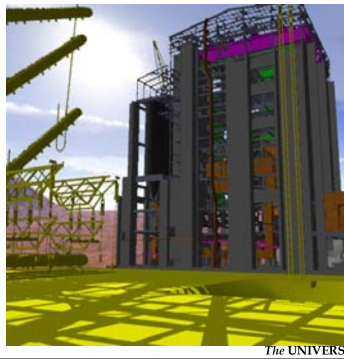
Interactive Shadows



Portions of scene that are occluded from light

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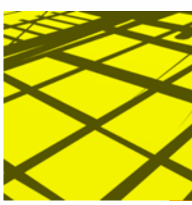
Goal

- Generate hard-edged shadows for interactive walkthroughs
  - Models with millions of polygons
  - Scenes with a moving light source



Hard-edged shadows

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Shadows: Importance

- Realism
  - Real world scenes have shadows
- Provide a sense of depth to the user
  - Better navigation
  - Enhance user experience in interactive games, VR applications

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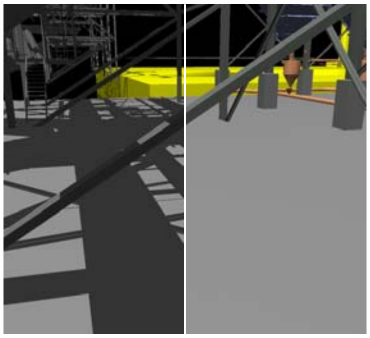
Shadows: Importance



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Interactive Shadows

N. Govindaraju et al. "Interactive Shadow Generation in Complex Environments", Proc. of ACM SIGGRAPH 2003

Talk scheduled on Tuesday at 3:40pm (Shadows section)

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Goal

- Generate high fidelity shadows
  - Requires object precision techniques
  - Compute shadow casters and shadow receivers

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Goal

- Interactive performance
  - Use visibility culling and LOD techniques
  - Reduce the number of potential shadow casters and shadow receivers

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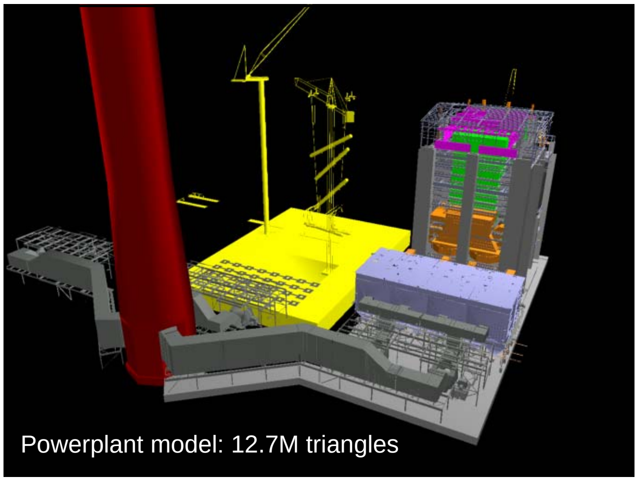
Interactive Shadows

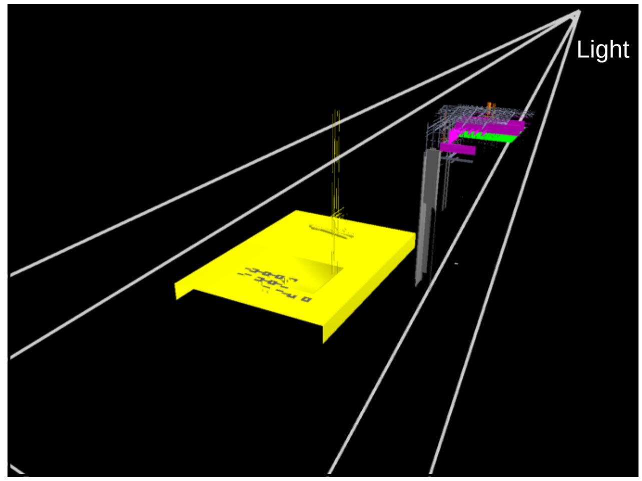
Interactive Shadows

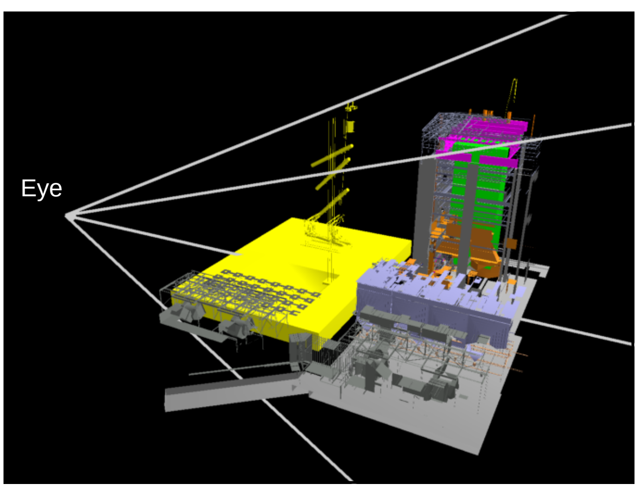
Interactive Shadows

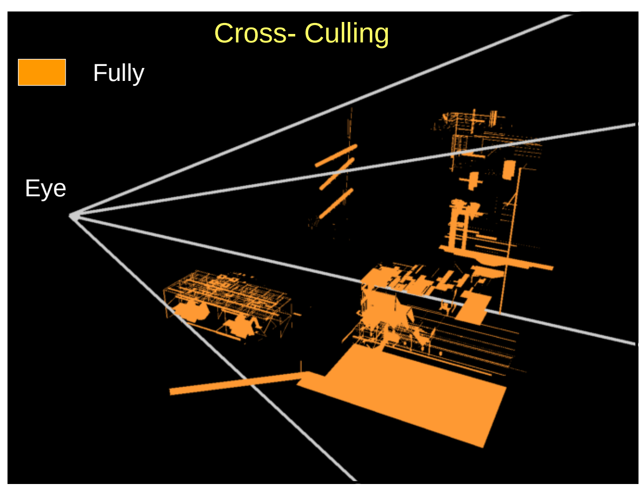
Overview

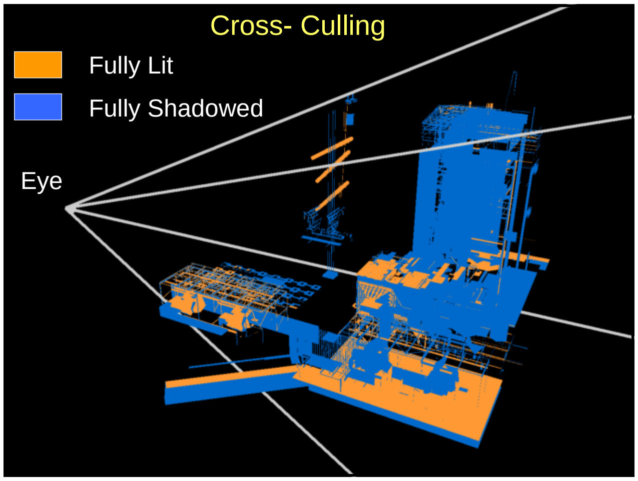
- Algorithm proceeds in three stages
- Stage I: PVS computation
  - Compute potential shadow casters and receivers
- Stage II: Cross Culling
  - Compute shadow casters and receivers that result in aliasing
- Stage III: Hybrid Shadow Generation

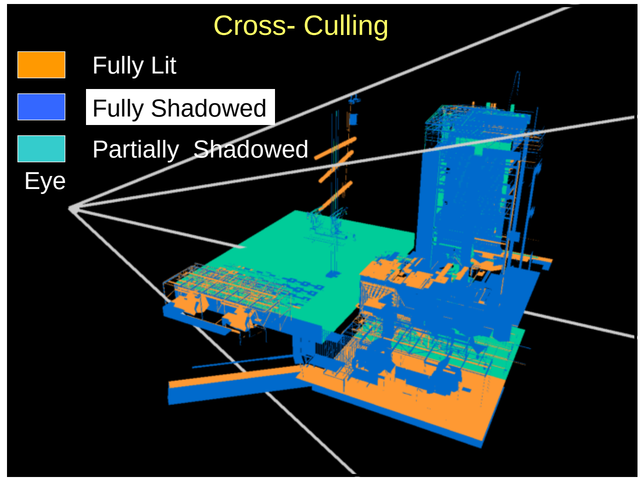

Powerplant model: 12.7M triangles

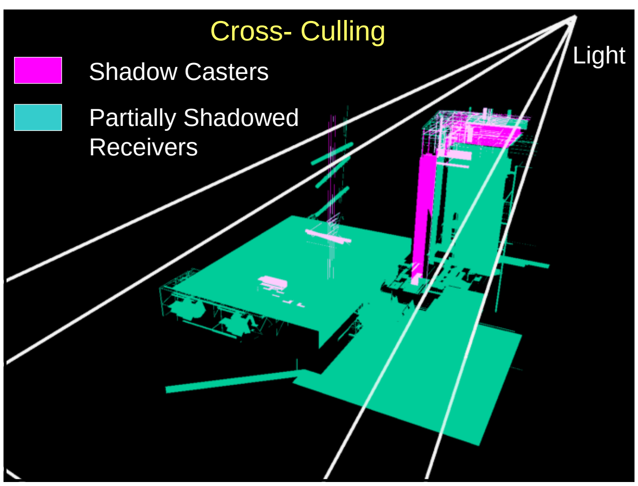

Light

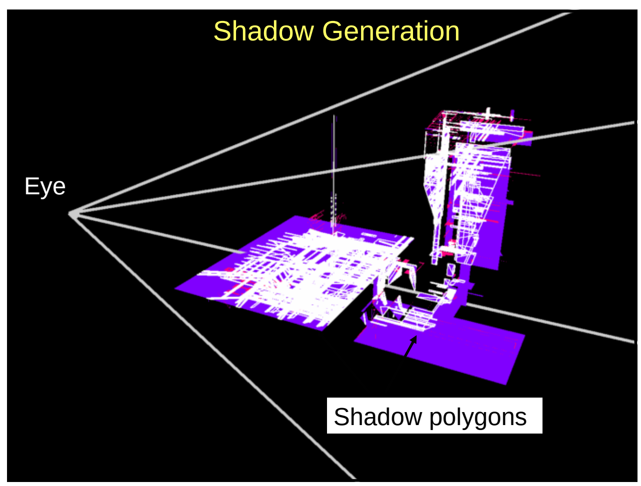

Eye

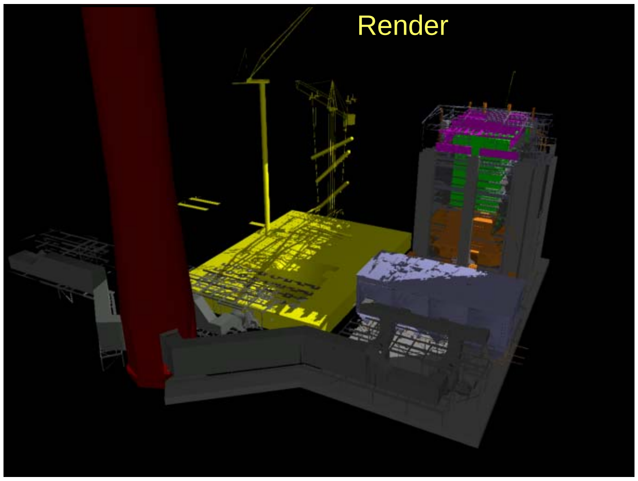

Cross- Culling
Fully
Eye


Cross- Culling
Fully Lit
Fully Shadowed
Eye


Cross- Culling
Fully Lit
Fully Shadowed
Partially Shadowed
Eye


Cross- Culling
Shadow Casters
Partially Shadowed
Receivers
Light


Shadow Generation
Eye
Shadow polygons



Process-parallel Algorithm

Utilize multiple GPUs to improve performance

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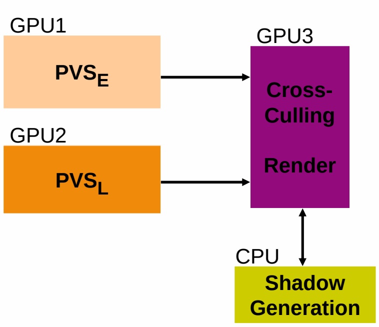
Architecture



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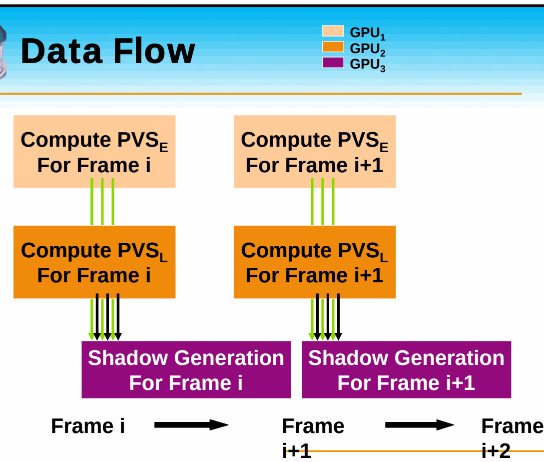
Data Flow



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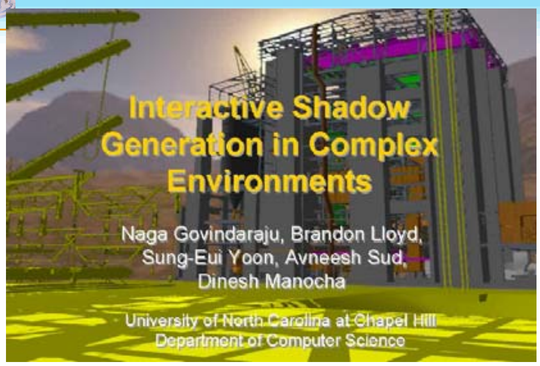
Interactive Shadows



Conclusions

- Interactive display and shadows
- Massive models
- Use multiple GPUs for visibility computations
- Application to complex models

Collaborators

- Naga Govindaraju
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- Sungeui Yoon

http://www.cs.unc.edu/~walk

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The End

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