Overview and Introduction to Scientific Visualization

Paul Navrátil, Ph.D.
Texas Advanced Computing Center
The University of Texas at Austin

Visualization Training
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Scientific Visualization

“The purpose of computing is insight not numbers.”

-- R. W. Hamming (1961)
Visualization Allows Us to “See” the Science

Raw Data

01001101011001
11001010010101
00101010100110
11101101011011
00110010111010

Application

Geometric Primitives

Render

Pixels
Getting from Data to Insight

Data Representation → Visualization Primitives → Graphics Primitives → Display

Iteration and Refinement
“I, We, They” Development Path

Simulation Data → “I” Data Exploration → “We” Collaboration → “They” Communication

Iteration and Refinement
Visualization Process Summary

• The primary goal of visualization is **insight**

• A picture is worth not just 1000 words, but potentially tera- or peta-bytes of data

• Larger datasets demand not just visualization, but advanced visualization resources and techniques

• Visualization system technology improves with advances in GPUs and LCD technology

• Visualization software slower to adapt
Types of Input Data

• **Point / Particle**
  – N-body simulation

• **Regular grid**
  – Medical scan

• **Curvilinear grid**
  – Engineering model

• **Unstructured grid**
  – Extracted surfaces
Types of Input Data

Point – scattered values with no defined structure
Types of Input Data

Grid – regular structure, all voxels (cells) are the same size and shape
Types of Input Data

Curvilinear – regularly grided mesh shaping function applied
Types of Input Data

Unstructured grid – irregular mesh typically composed of tetrahedra, prisms, pyramids, or hexahedra.
Visualization Operations

- Surface Shading (Pseudocolor)
- Isosurfacing (Contours)
- Volume Rendering
- Clipping Planes
- Streamlines
Surface Shading (Pseudocolor)

Given a scalar value at a point on the surface and a color map, find the corresponding color (and opacity) and apply it to the surface point.

Most common operation, often combined with other ops
Isosurfaces (Contours)

- Surface that represents points of constant value with a volume
- Plot the surface for a given scalar value.
- Good for showing known values of interest
- Good for sampling through a data range
Volume Rendering

Expresses how light travels through a volume
Color and opacity controlled by transfer function
Smooter transitions than isosurfaces
Clipping / Slicing Planes

Extract a plane from the data to show features
Hide part of dataset to expose features
Particle Traces (Streamlines)

Given a vector field, extract a trace that follows that trajectory defined by the vector.

\[ P_{\text{new}} = P_{\text{current}} + V_P \Delta t \]

Streamlines – trace in space
Pathlines – trace in time
Visualization Resources

• Personal machines
  – Most accessible, least powerful

• Projection systems
  – Seamless image, high purchase and maintenance costs

• Tiled-LCD displays
  – Lowest per-pixel costs, bezels divide image

• Remote visualization
  – Access to high-performance system, latency can affect user experience
XSEDE Visualization Resources

• Longhorn (TACC)
  – 256 nodes, 2048 total cores, 512 total GPUs
  – 13.5 TB aggregate memory, QDR InfiniBand interconnect
  – Ranger file system mounted read-only across system
  – Longhorn Visualization Portal
    • [https://portal.longhorn.tacc.utexas.edu/](https://portal.longhorn.tacc.utexas.edu/)
    • Visualization job submission and monitoring
    • Remote, interactive, web-based visualization
    • Guided visualization using EnVision

• Spur (TACC)
  – 8 nodes, 128 total cores, 32 total GPUs
  – 1 TB aggregate memory, SDR InfiniBand interconnect
  – Shares interconnect and file system with Ranger

• Lonestar (TACC)
  – 8 nodes, 96 total cores, 32 total GPUs (expand to 72 nodes soon)
  – 192 GB aggregate memory, QDR InfiniBand interconnect
  – Shares interconnect and file system with Lonestar HPC nodes
TeraGrid Visualization Resources

- **Nautilus (NICS)**
  - SMP, 1024 Total Cores, 8 GPUs
    - 4 TB Global Shared Memory, SGI NUMAlink 5 interconnect

- **TeraDRE Condor Pool (Purdue)**
  - 1750 Nodes, 14000 Total Cores, 48 Nodes with GPUs
    - 28 TB Aggregate Memory, no interconnect
Visualization Challenges
Visualization Allows Us to “See” the Science

Raw Data

010011010101001
110010010010101
00101010100110
11101101011011
00110010111010

Geometric Primitives

Application

Render

Pixels
But what about large, distributed data?
Or distributed rendering?
Or distributed displays?
Or all three?
Visualization Scaling Challenges

- Moving data to the visualization machine
- Most applications built for shared memory machines, not distributed clusters
- Image resolution limits in some software cannot capture feature details
- Displays cannot show entire high-resolution images at their native resolution
Visualization scales with HPC

Large data produced by large simulations require large visualization machines and produce large visualization results.

- Terabytes of Data
- AT LEAST Terabytes of Vis
- Gigapixel Images
  - Resampling, Application, ...
  - Resolution to Capture Feature Detail
Moving Data

- How long can you wait?

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<th>54 Mbps</th>
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<td>1 sec</td>
<td>2.5 min</td>
</tr>
<tr>
<td>1 TB</td>
<td>~17 min</td>
<td>~43 hours</td>
</tr>
<tr>
<td>1 PB</td>
<td>~12 days</td>
<td>~5 years</td>
</tr>
</tbody>
</table>
Analyzing Data

• Visualization programs only beginning to efficiently handle ultrascale data
  – 650 GB dataset -> 3 TB memory footprint
  – Allocate HPC nodes for RAM not cores
  – N-1 idle processors per node!

• Stability across many distributed nodes
  – Rendering clusters typically number N <= 64
  – Data must be dividable onto N cores

*Remember this when resampling!*
Imaging Data

**Hypothetical fly-around movie**

- 4096 x 2160 PNG  ~ 10 MB
- x 360 degrees  ~ 3.6 GB
- x 30 days  ~ 108 GB
- x 12 months  ~ 1.3 TB

@ 10 fps  3.6 hours
@ 60 fps  36 min

Image: NASA Blue Marble Project
Displaying Data

Dell 30” flat-panel LCD

4 Megapixel display

2560 x 1600 resolution
Displaying Data

Stallion – currently world’s highest-resolution tiled display

307 Megapixels
38400 x 8000 pixel resolution

Dell 30” LCD
Displaying Data

- Dell 30” LCD – 4 Mpixel (2560 x 1600)
- Stallion – 307 Mpixel (38400 x 8000)
- NASA Blue Marble
  - 0.5 km² per pixel
  - 3732 Mpixel
    - (86400 x 43200)
What’s the solution?
Solution by Partial Sums

- Moving data — integrate vis machine into simulation machine. **Move the machine to data!**
  - Ranger + Spur: shared file system and interconnect

- Analyzing data — create larger vis machines and develop more efficient vis apps
  - Smaller memory footprint
  - More stable across many distributed nodes

Until then, **the simulation machine is the vis machine!**
Solution by Partial Sums

- Imaging data – focus vis effort on interesting features, parallelize image creation
  - Feature detection to determine visualization targets, but can miss “unknown unknowns”
  - Distribute image rendering across cluster

- Displaying data – high resolution displays, multi-resolution image navigation
  - Large displays need large spaces
  - Physical navigation of display provides better insights
Old Model
(No Remote Capability)
New Model
Remote Capability

HPC System
Data Archive

Large-Scale Visualization Resource

Remote Site
Local Site

Wide-Area Network

Display

Pixels
Mouse
Using GPUs

• More than for just rendering!
  – HPC applications and Visualization algorithms
• Parallelism – kernel should be highly SIMD/SIMT
  – Switching kernels is expensive!
  – Fermi hardware supports multiple kernel execution
• Control Flow – avoid conditionals in kernels
  – Implemented with predication, harms utilization
• Job size – high workload per thread + many threads
  – amortize thread initialization and memory transfer costs
  – GPU is a throughput machine, must keep it busy!
• Memory footprint – task must decompose well
  – local store per GPU core is low (16 KB on Longhorn)
  – card-local RAM is limited (4GB on Longhorn)
  – access to system RAM is slow (treat like disk access)
• More on this Thursday during CUDA for HPC
Summary

- Challenges at every stage of visualization when operating on large data
- Partial solutions exist, though not integrated
- Problem sizes continue to grow at every stage
- Vis software community must keep pace with hardware innovations
Thank you!

pnav@tacc.utexas.edu