Massive Dataset Visualization

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Immersive & Interactive Visualization

Challenge: billion-atom walkthrough

Solution: parallel & distributed Atomviewer
Locality in Data Compression

Massive data transfer via wide area network:
75 GB/step of data for 1.5 billion-atom MD!
→ Compressed software pipeline

Scalable encoding:
• Store relative positions on spacefilling curve: $O(N\log N) \rightarrow O(N)$

Result:
• Data size, 50Bytes/atom → 6 Bytes/atom
Data Compression for Scalable I/O

Challenge: Massive data transfer via OC-12 (622 Mbps)
75 GB/frame of data for a 1.5-billion-atom MD!

Scalable encoding:
• Spacefilling curve based on octree index

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>z</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
<td>101</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>000</td>
</tr>
</tbody>
</table>

3D → list map preserves spatial proximity
Spacefilling-Curve Data Compression

Algorithm:
1. Sort particles along the spacefilling curve
2. Store relative positions: $O(N\log N) \rightarrow O(N)$
   - Adaptive variable-length encoding to handle outliers
   - User-controlled error bound

Result:
- An order-of-magnitude reduction of I/O size: 50 $\rightarrow$ 6 Bytes/atom
Data Locality in Visualization

- Octree-based fast view-frustum culling
- Probabilistic occlusion culling
- Parallel/distributed processing

- Interactive visualization of a billion-atom dataset in immersive environment
Hierarchical Abstraction

- Larger clusters for longer distances
- Recursively subdivide the 3D space to form an octree
Visibility Culling

View frustum culling

Higher Depth

Viewpoint

Occlusion culling
Octree-based View-Frustum Culling

- Use the octree data structure to efficiently select only visible atoms

- Complexity
  Insertion into octree: $O(N)$
  Data extraction: $O(\log N)$
Probabilistic Occlusion Culling

- Remove atoms that are occluded by other atoms closer to the viewer.
- Regions farther away from the viewer are more likely to be occluded than one in front of the viewer.
- Draw fewer atoms per region as the distance of a region from the viewer increases: visibility value $v(x)$ for region $x$.
- Recurrence along the view line:
  $$v_x = \begin{cases} 
  1 & x = 0 \\
  f(D_{x'}, v_{x'}) & \text{else}
  \end{cases}$$
  $D_x$ = density of region.
- Run time adaptation:
  $$v'_x = f(\text{user speed}) \times v_x$$
Results of Probabilistic Occlusion Culling

68% fewer objects; 3\times frame rate
Multiresolution Culling & Rendering

- **Per-octree node operations:**
  - Frustum culling
  - Probabilistic occlusion culling

- **Per-atom operations**
  - Multiple levels-of-detail
  - Occlusion culling (per-object, per-octree node)

Without multiresolution

With multiresolution

.94fps - 90,000 particles

3.2fps - 4,500 particles

Outflow pathways of optic nerves from the retina of a rabbit eye
(Experimental data by C. Burgoyne & R. Beuerman, LSU Eye Center)
Parallel Octree Extraction

- Individual copies of the octree with each node
- Spherical extraction by the use of shells of equal volume
- Load balancing due to the equal use of each processor for extraction

PC Cluster Nodes

Bounding Shells of Equal Volume
Latency Hiding

- Individual modules are multithreaded to reduce network or module latency

- Minimize latency due to inter-modular dependencies by overlapping the inter-module communication and module computation
Parallel & Distributed Atomsvviewer

Real-time walkthrough for a billion atoms on an SGI Onyx2 (2 × MIPS R10K, 4GB RAM) connected to a PC cluster (4 × 800MHz P3)

![Graph showing rendering time vs. number of atoms for serial and parallel methods.]

*IEEE Virtual Reality Best Paper*
Parallel Rendering

ParaViz: A Spatially Decomposed Parallel Visualization Algorithm Using Hierarchical Visibility Ordering

Cheng Zhang\textsuperscript{1}, Scott Callaghan\textsuperscript{2}, Thomas Jordan\textsuperscript{2}, Rajiv K. Kalia\textsuperscript{1}, Aiichiro Nakano\textsuperscript{1*}, Priya Vashishta\textsuperscript{1}

- Parallel (software) rendering of spatially distributed data: hybrid sort-first/sort-last
- Scalable depth buffer by domain-level distributed visibility ordering
- On-the-fly visualization of parallel simulation without data migration
- Parallel efficiency 0.98 on 1,024 processors for 16.8 million-atom molecular-dynamics simulation

Soft rendering
http://www.mesa3d.org
• **Programming language**
  > C++

• **Graphics**
  > OpenGL
  > CAVE Library (optional)

• **Platforms**
  > Windows
  > Macintosh OS X
  > SGI Irix
Atomsviewer Commands
Scalable and portable visualization of large atomistic datasets

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Abstract
A scalable and portable code named Atomviewer has been developed to interactively visualize a large atomistic dataset consisting of up to a billion atoms. The code uses a hierarchical view fusion-calling algorithm based on the user’s data structure to efficiently remove atoms outside of the user’s field of view. Probabilistic and depth-based occlusion-calling algorithms are used to select atoms which have a high probability of being visible. Finally a multi-resolution algorithm is used to render the selected subset of visible atoms at varying levels of detail. Atomviewer is written in C++ and OpenGL, and it has been tested on a number of architectures including Windows, Macintosh, and SGI. Atomviewer has been used to visualize tens of millions of atoms on a standard desktop computer and, in its parallel version, up to a billion atoms.

Program summary
Title of program: Atomviewer
Catalogue identifier: ADUM
Program summary URL: http://cpc.cs.qub.ac.uk/summaries/ADUM
Program obtainable from: CPC Program Library, Queen’s University of Belfast, N. Ireland
Computer for which the program is designed and others on which it has been tested: 2.6 GHz Pentium 4/Xeon processor, professional graphics card: Apple G4 (867 MHz)/C5, professional graphics card
Operating systems under which the program has been tested: Windows 2000/XP, Mac OS 10.2/10.3, SGI IRIX 6.5
Programming language used: C++ and OpenGL
Memory required to execute with typical data: 1 gigabyte of RAM
High speed storage required: 60 gigabytes
No. of lines in the distributed program including test data, etc.: 550 241
No. of bytes in the distributed program including test data, etc.: 6298 245
Number of bits in a word: Arbitrary

* This paper and its associated computer program are available via the Computer Physics Communications homepage on ScienceDirect (http://www.sciencedirect.com/science/journal/00104655).
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http://www.cpc.cs.qub.ac.uk/cpc
Other Visualization Tools

• **VisIT** visualization tool at Lawrence Livermore National Laboratory
  
  http://www.llnl.gov/visit/

• **ParaView** parallel visualization application at Los Alamos National Laboratory
  
  http://www.paraview.org/New/index.html

• **VMD** visual molecular dynamics at University of Illinois at Urbana-Champaign
  
  http://www.ks.uiuc.edu/Research/vmd/