Massive Dataset Visualization

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Immersive & Interactive Visualization

Challenge: billion-atom walkthrough

Solution: parallel & distributed Atomviewer

- Space-time multiresolution algorithm
- Wavelet load-balancing
- Fractal data compression
- Fiber network
- Octree visibility culling
- Preprocessing
- Multiresolution rendering
- Graphics pipeline
- Real-time walkthrough

GRID of supercomputers
Linux cluster

ImmersaDesk R2 virtual environment

Reduced data

Graphics server
User position
PC cluster

ImmersaDesk
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

```
x = 1 1 0
y = 0 0 0
z = 1 0 0
R = 101 001 000
```

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

Reduced data

Graphics server

ImmersaDesk

User position

PC cluster

• 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

Viewpoint

Higher Depth

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 is more likely to be occluded than one in front of the viewer

\[
v_x = \begin{cases} 
1 & x = 0 \\
 f(D_x', \nu_x') & \text{else} \end{cases} \quad D_x = \text{density of region}
\]

- Draw fewer atoms per region as the distance of a region from the viewer increases: visibility value \( \nu(x) \) for region \( x \)
- Recurrence along the view line

\[
v'_x = f(\text{user speed}) \times \nu_x
\]

- Run time adaptation
Results of Probabilistic Occlusion Culling

68% fewer objects; 3× 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)

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

- Distributed Architecture
- Octree-based data extraction module
- Probabilistic occlusion culling module
- Rendering & visualization module
- Per-atom occluder
- Rendering system
- User position
- Near complete list of viewable atoms
- Regions of interest
- TCP/IP socket
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
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)

IEEE Virtual Reality Best Paper
Parallel Rendering


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

Cheng Zhang¹, Scott Callaghan², Thomas Jordan², Rajiv K. Kalia¹,
Aiichiro Nakano¹*, Priya Vashishta¹

- 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
Atomviewer Code

• Programming language
  > C++

• Graphics
  > OpenGL
  > CAVE Library (optional)

• Platforms
  > Windows
  > Macintosh OS X
  > SGI Irix
Atomsviewer Commands

Adjust the size of atoms
{S, s}

Set Color from Data Attribute
{1, 2, 3, 4, 5, 6, 7, 8, 9, 0}

Adjust the quality of atoms
{Q, q}

File Error
Failure

Open File
Enter

Success
Get Filename
All Keys except "Enter"

IDLE (Display)

Get Command
All Keys except "Enter"

Open File

Success

Enter

Get Filename

Failure

File Error

Enter

Parse Command

Picture/Movie

{m, M}

{B, b}

{F, f}

Recede Frame

Advance Frame
Scalable and portable visualization of large atomistic datasets

Ashish Sharma *, Rajiv K. Kalia, Aiichiro Nakano, Priya Vashishta

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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 billion atoms. The code uses a hierarchical view frustum-culling algorithm based on the octree data structure to efficiently remove atoms outside of the user’s field-of-view. Probabilistic and depth-based occlusion-culling algorithms then select atoms, which have a high probability of being visible. Finally a multiresolution 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: 2.4 GHz Pentium 4/Intel processor, professional graphics card; Apple G4 (867 MHz)/OS, professional graphics card
Operating systems under which the program has been tested: Windows 2000/XP, Mac OS 10.3/10.4, SGI IRIX 6.5
Programming languages used: C++, C and OpenGL
Memory required to execute with typical data: 1 gigabyte of RAM
High-speed storage required: 50 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.: 625K 245
Number of bits in a word: Arbitrary

* This paper and its associated computer programs are available via the Computer Physics Communications homepage on ScienceDirect (http://www.sciencedirect.com/science/journal/00018455).
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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/