Massive Dataset Visualization

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Immersive & Interactive Visualization

Billion-atom walkthrough

Parallel & distributed Atomsvviewer

Reduced data

Graphics server

PC cluster

ImmersaDesk

WAND

User position
Locality in Data Compression

Massive data transfer via wide area network:
75GB/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-3 (155 Mbps)
75 GB/frame of data for a 1.5-billion-atom MD!

Scalable encoding:
• Spacefilling curve based on octree index

3D → list map preserves spatial proximity
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

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

- 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

Original | Probabilistic | Difference

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)

Without multiresolution: .94fps - 90,000 particles

With multiresolution: 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)
Distributed Architecture

- Rendering & Visualization Module
  - Rendering System
  - Per-Atom Occluder
  - User Position
  - Near Complete List of Viewable Atoms

- Octree Based Data Extraction Module
  - Regions of Interest

- Probabilistic Occlusion Culling Module

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

- Instantaneously trained neural network (CC4 [Tang & Kak, CSSP’98]) predicts the user’s next position [Liu et al., PDPTA’02]
Parallel & Distributed Atomviewer

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 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
Atomsvviewer Code

- **Programming language**
  > C++

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

- **Platforms**
  > Windows
  > Macintosh OS X
  > SGI Irix
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 Atomsviewer has been developed to interactively visualize a large atomistic dataset consisting of up to a 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 multisampling algorithm is used to render the selected subset of visible atoms at various levels of detail. Atomsviewer is written in C++ and OpenGL, and it has been tested on a number of architectures including Windows, Macintosh, and SGI. Atomsviewer 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: Atomsviewer
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 on which it has been tested: 2.4 GHz Pentium 4Xeon processor, professional graphics card; Apple G4 (867 MHz)/G5, 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 languages used: C++, 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.: 6 258 245

Number of hours 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