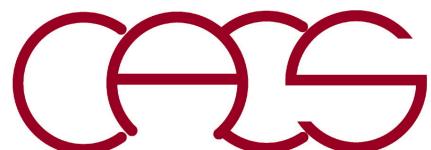


Massive Dataset Visualization

Aiichiro Nakano

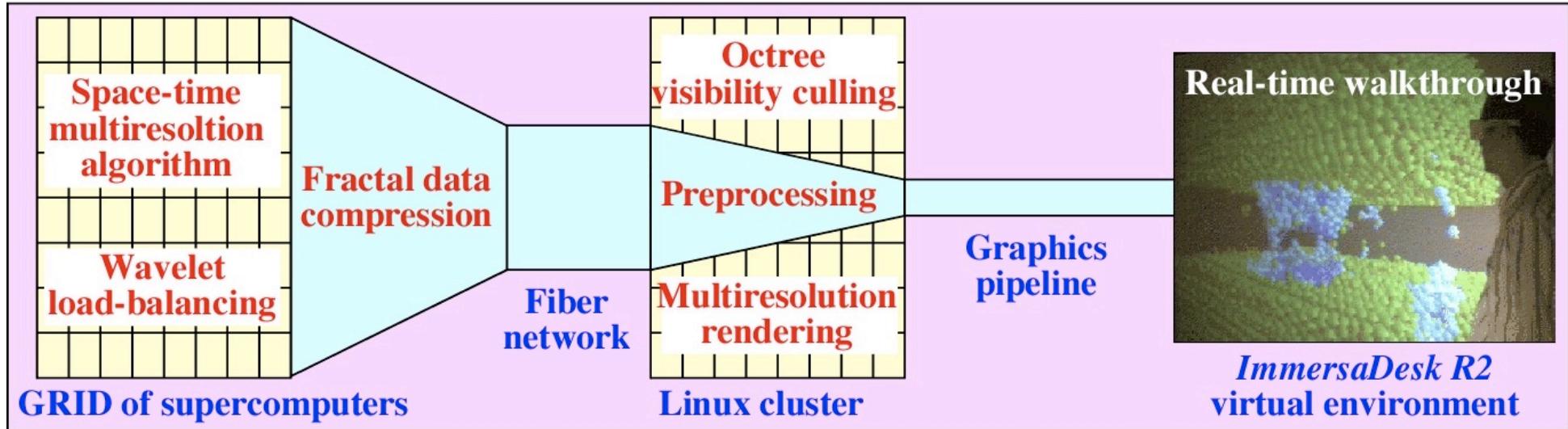
*Collaboratory for Advanced Computing & Simulations
Department of Computer Science
Department of Physics & Astronomy
Department of Quantitative & Computational Biology
University of Southern California*

Email: anakano@usc.edu

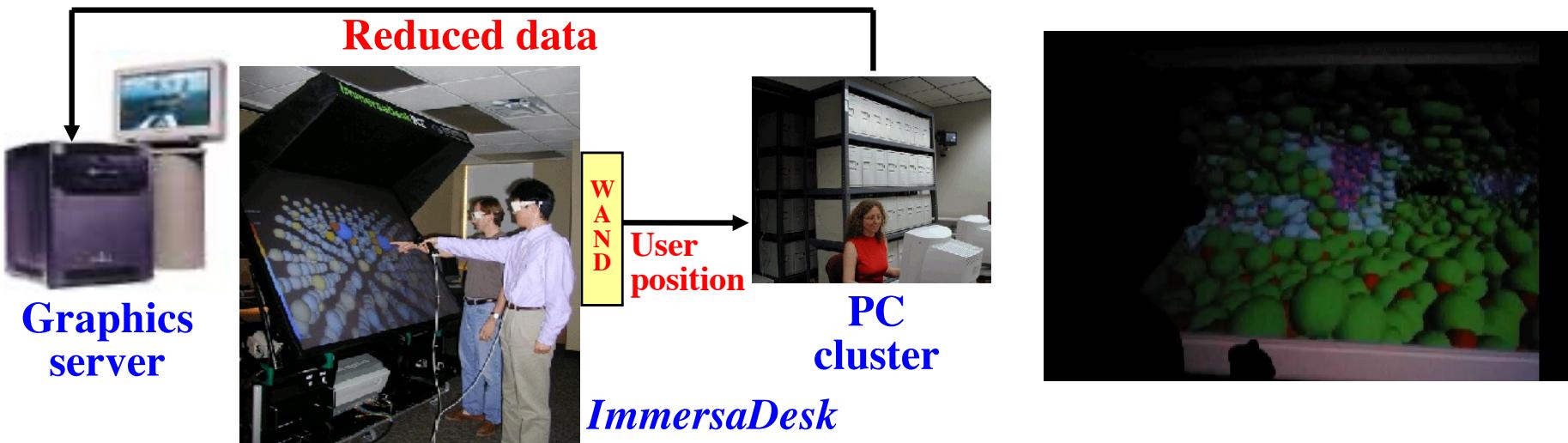


Immersive & Interactive Visualization

Challenge: billion-atom walkthrough



Solution: parallel & distributed Atomsviewer



Locality in Data Compression

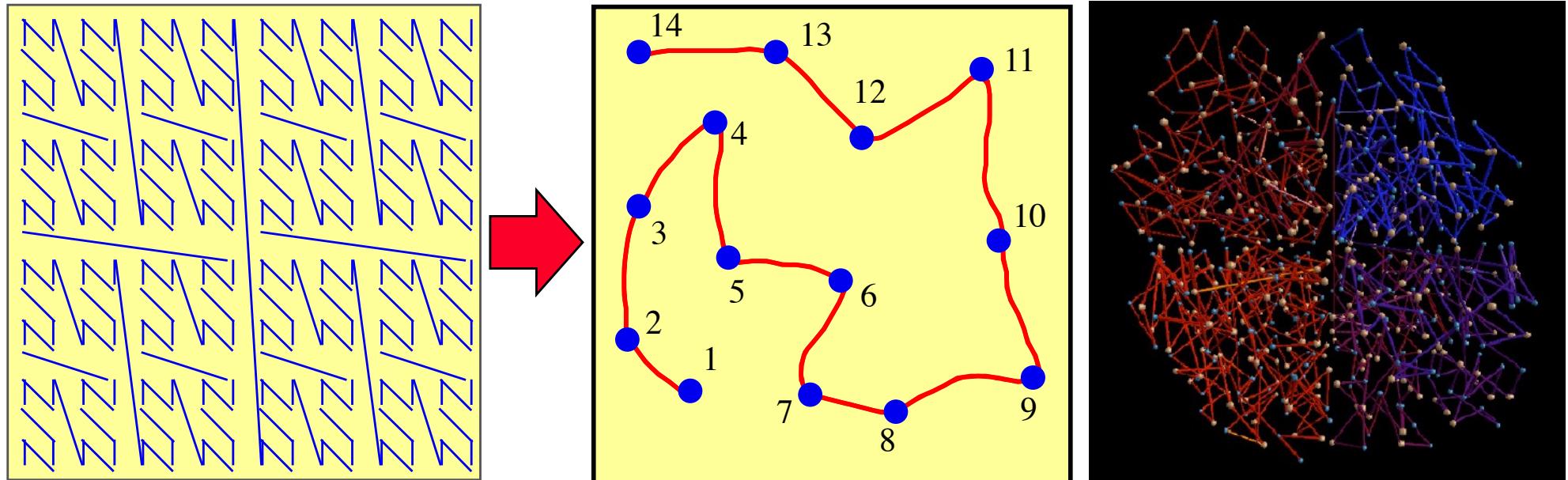
Massive data transfer via wide area network:
75 GB/step of data for 1.5 billion-atom MD!
→ Compressed software pipeline

Scalable encoding:

- Store relative positions on spacefilling curve: $O(N \log N) \rightarrow O(N)$

Result:

- Data size, 50 Bytes/atom → 6 Bytes/atom



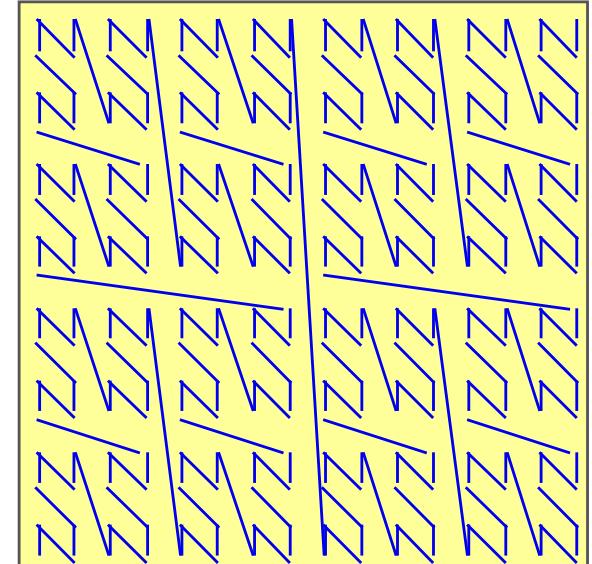
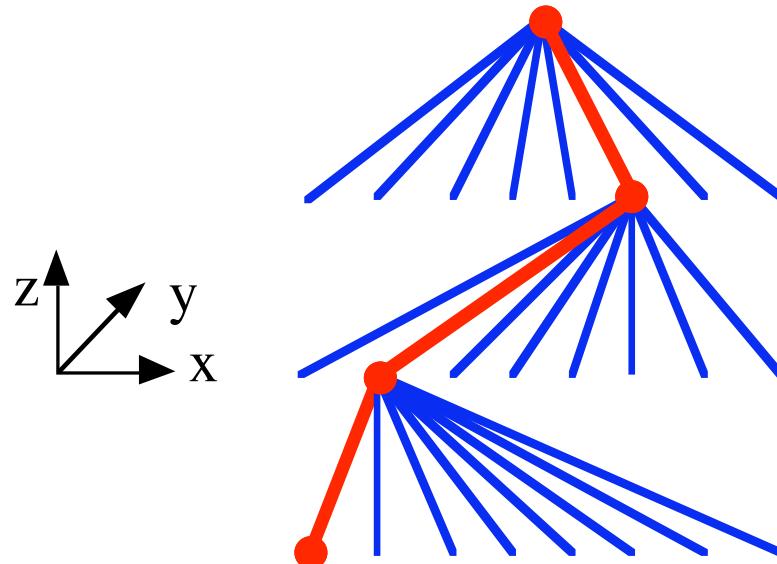
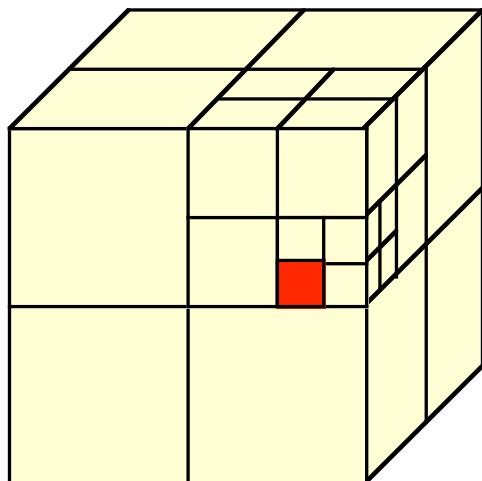
Data Compression for Scalable I/O

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

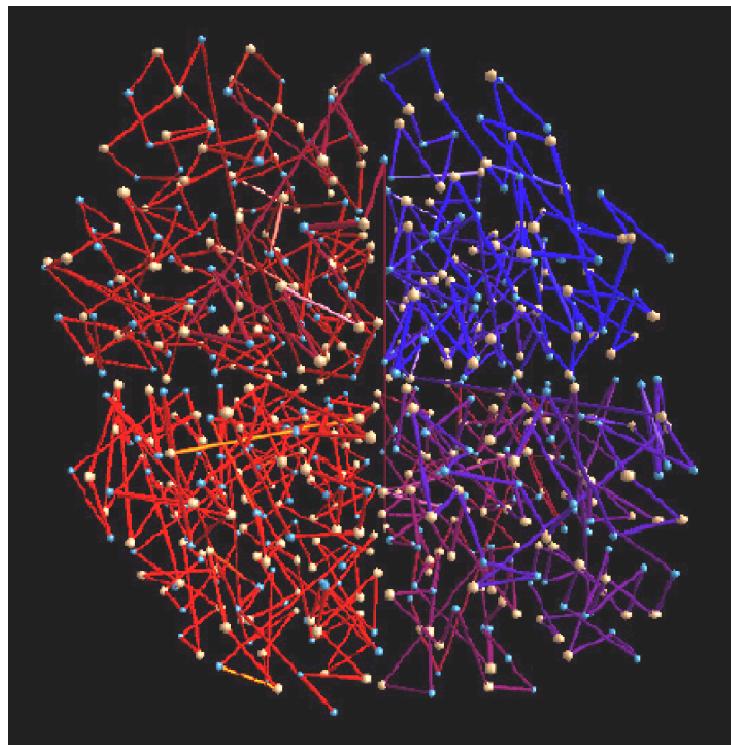


3D → list map preserves spatial proximity

Spacefilling-Curve Data Compression

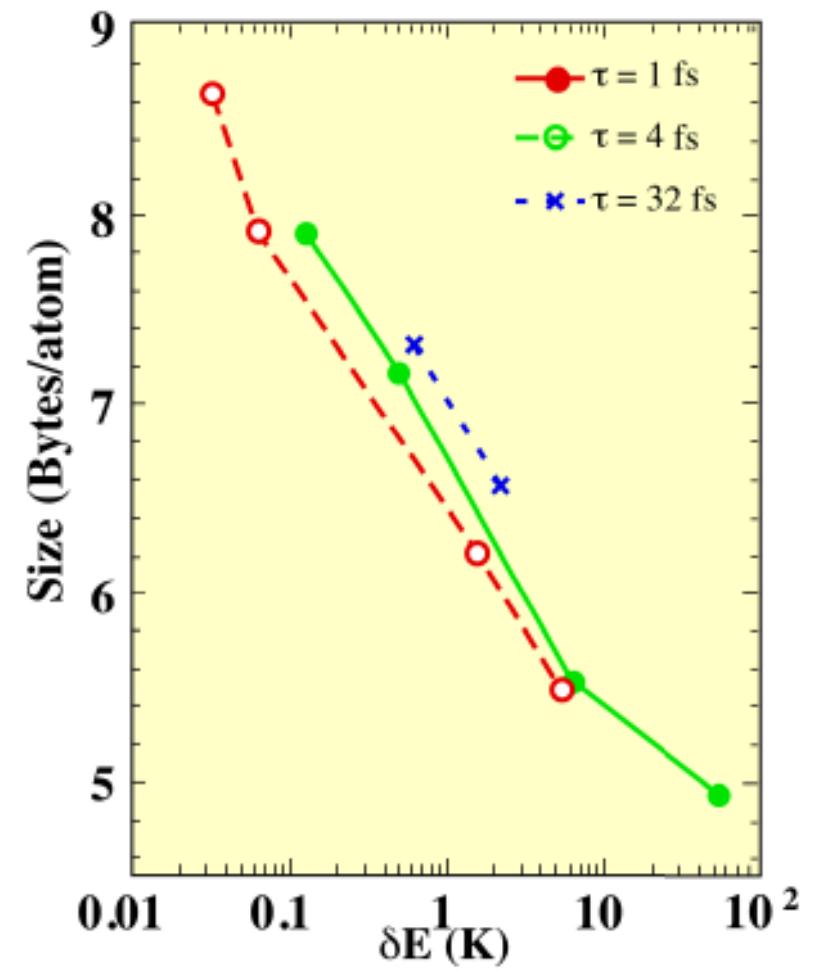
Algorithm:

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



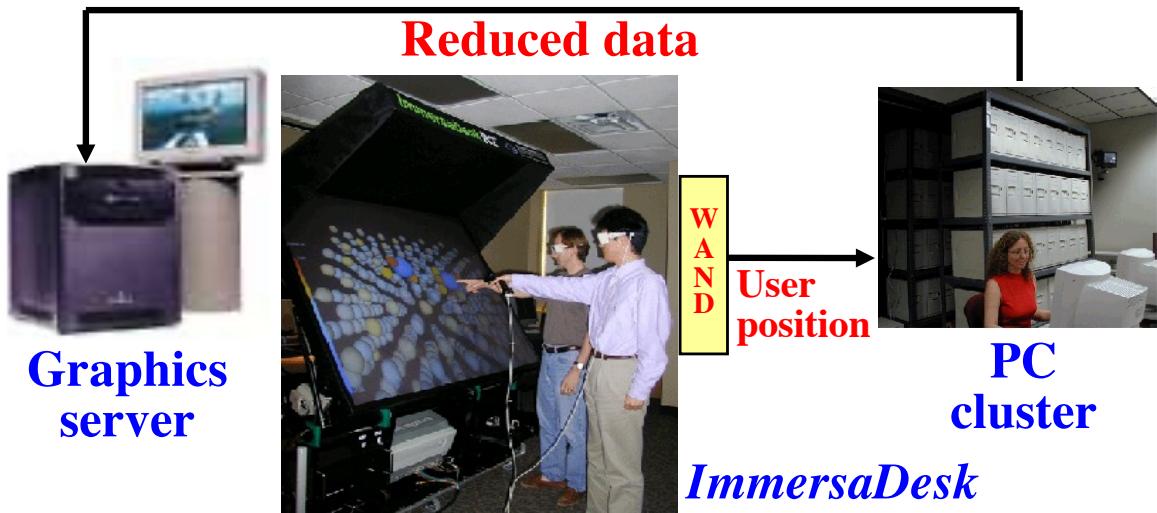
Result:

- An order-of-magnitude reduction of I/O size: $50 \rightarrow 6$ Bytes/atom

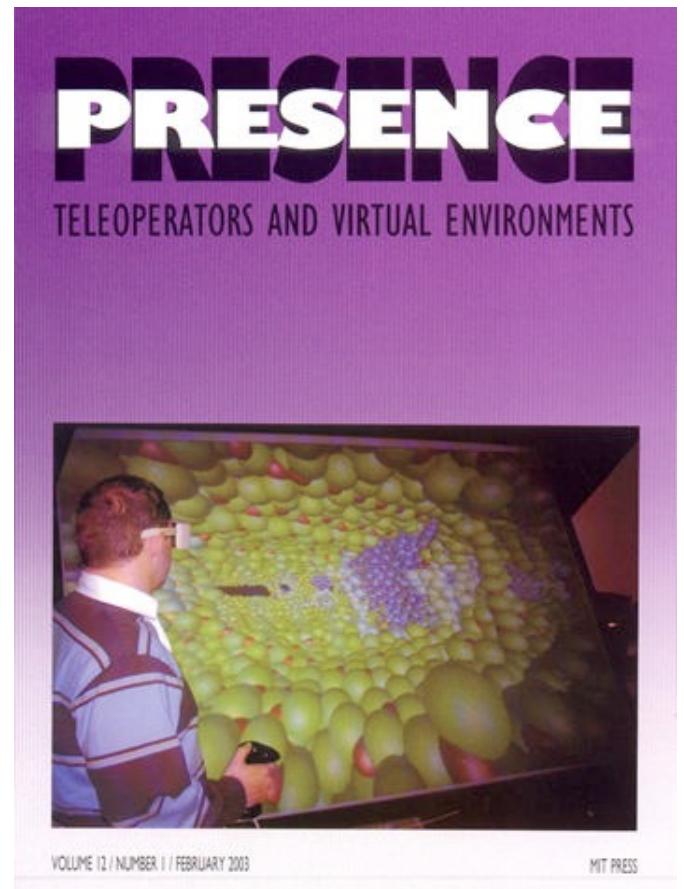
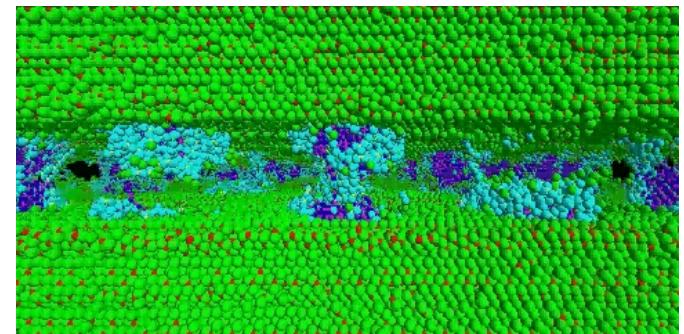


Data Locality in Visualization

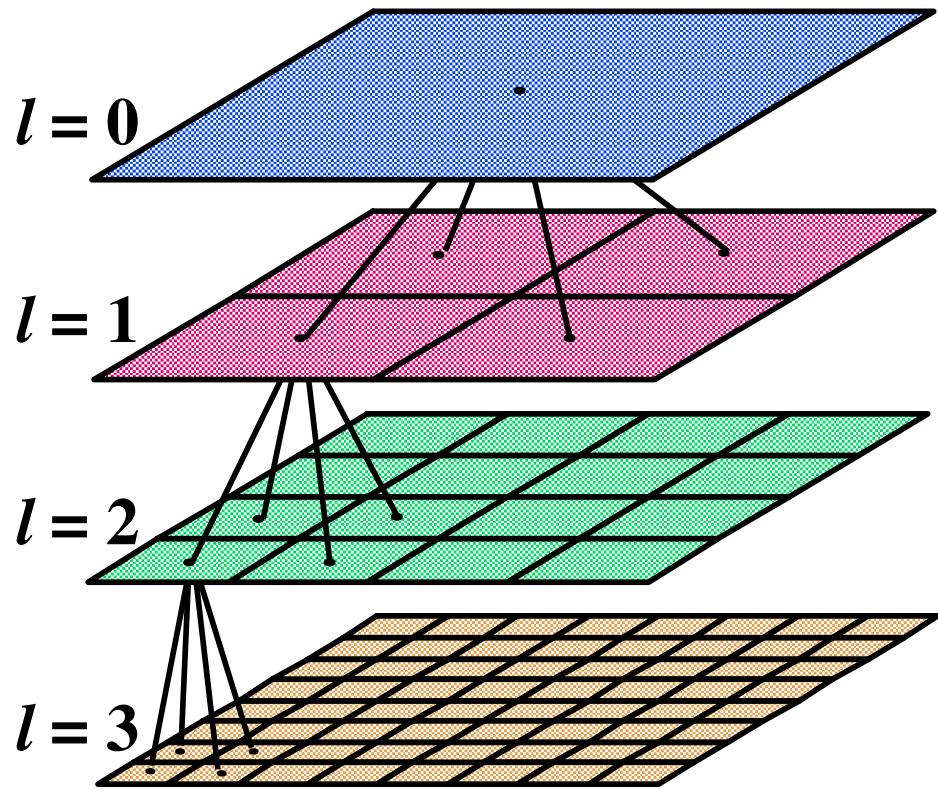
- Octree-based fast view-frustum culling
- Probabilistic occlusion culling
- Parallel/distributed processing



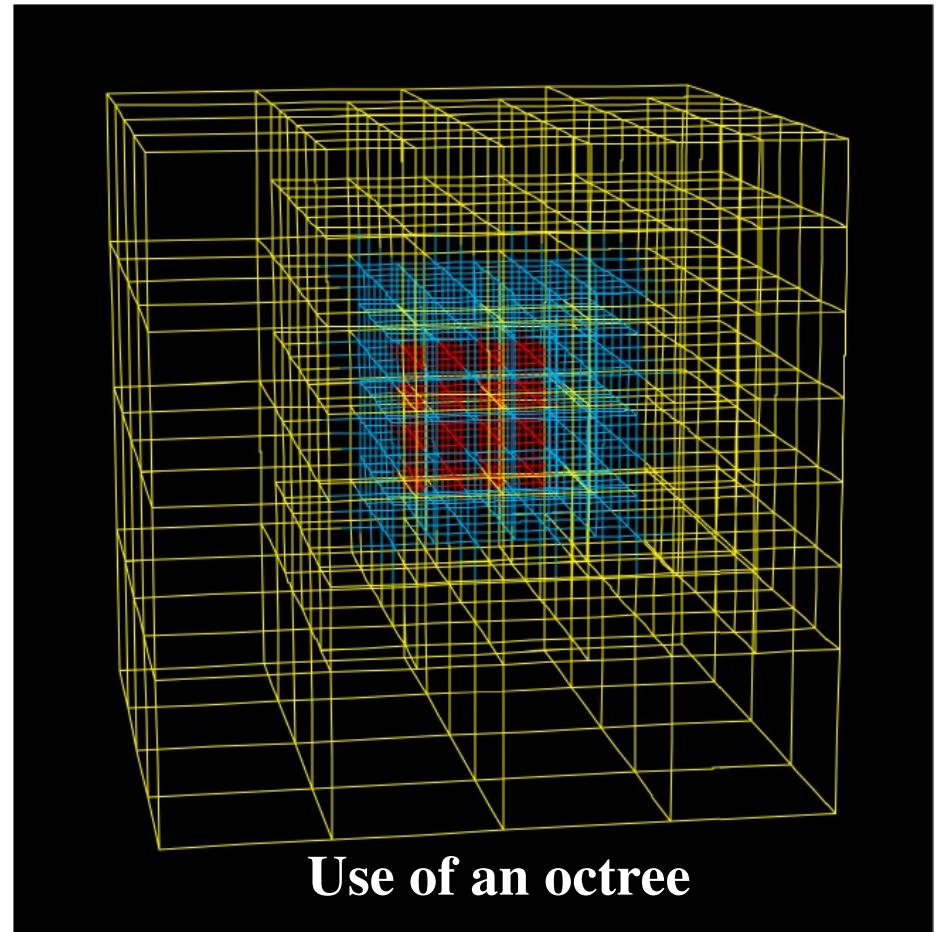
- Interactive visualization of a billion-atom dataset in immersive environment



Hierarchical Abstraction

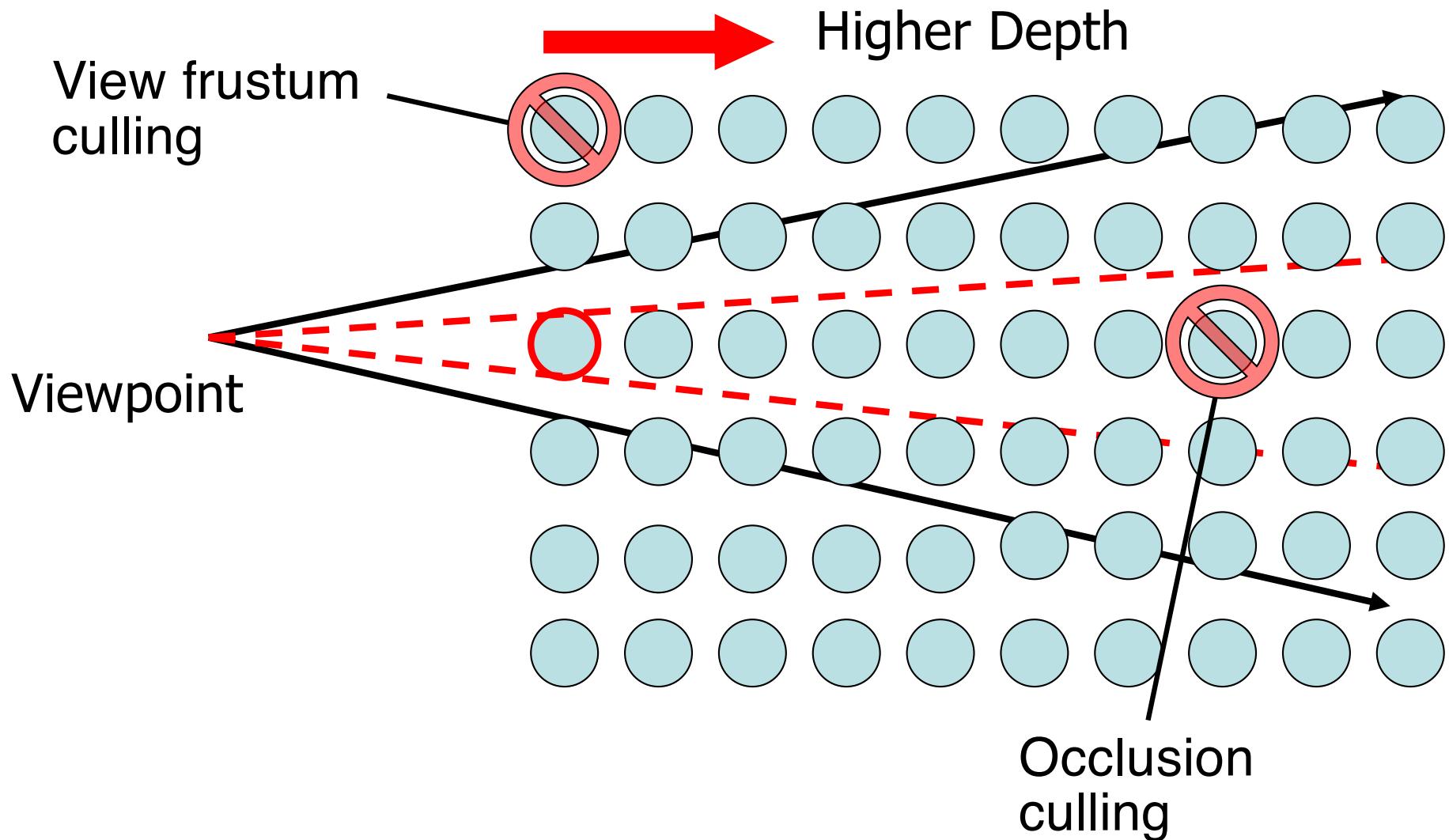


2D example

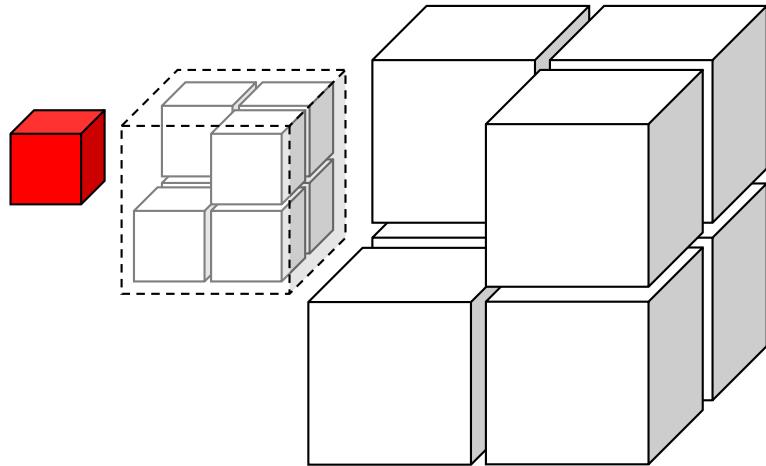


- Larger clusters for longer distances
- Recursively subdivide the 3D space to form an octree

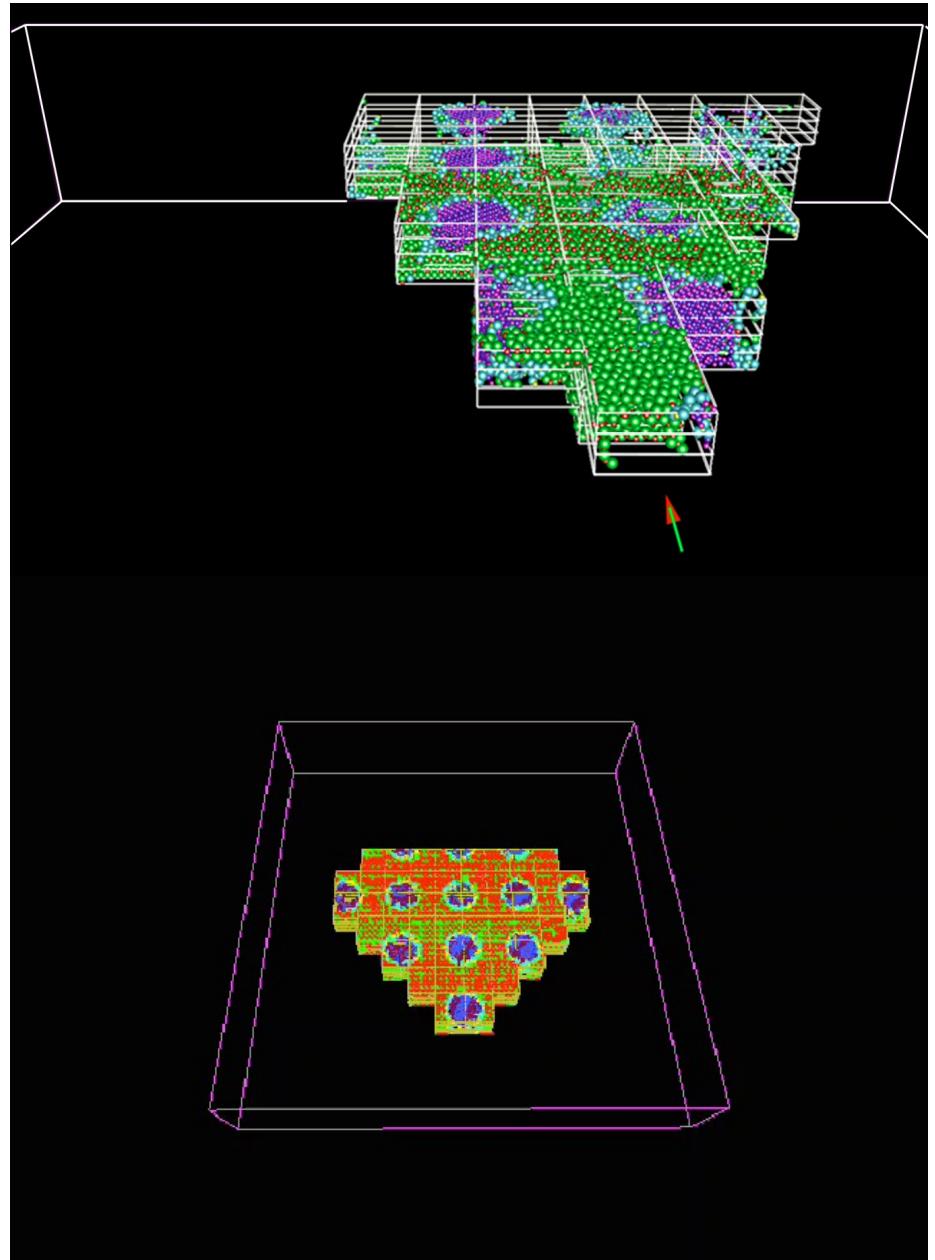
Visibility Culling



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

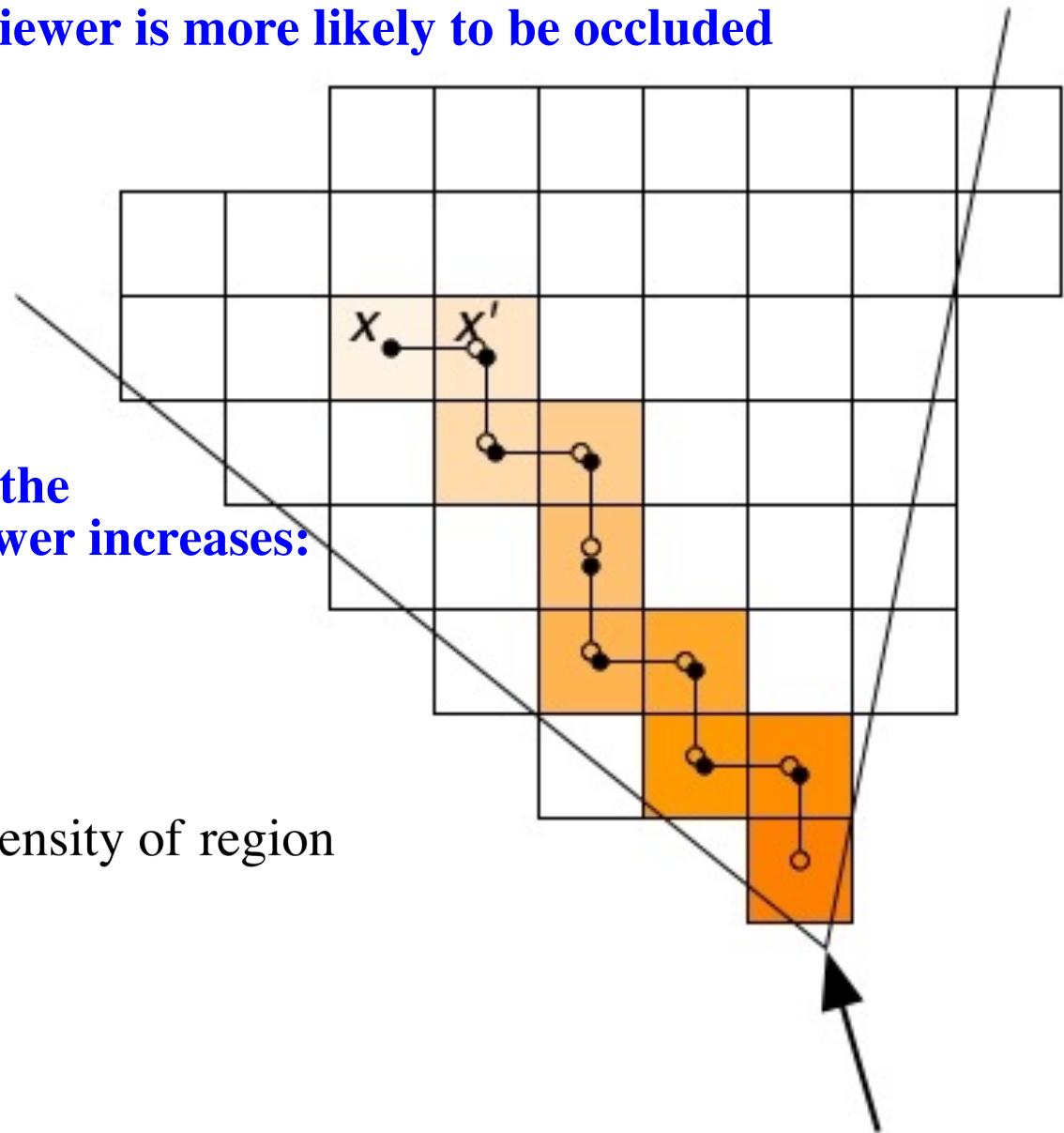
- Remove atoms that are occluded by other atoms closer to the viewer
- Regions farther away from the viewer is more likely to be occluded than one in front of the viewer

- 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

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

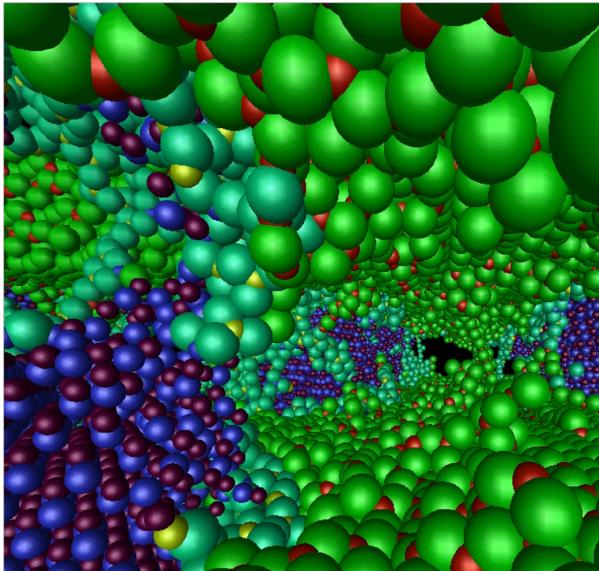
- Run-time adaptation

$$v'_x = f(\text{user speed}) \times v_x$$

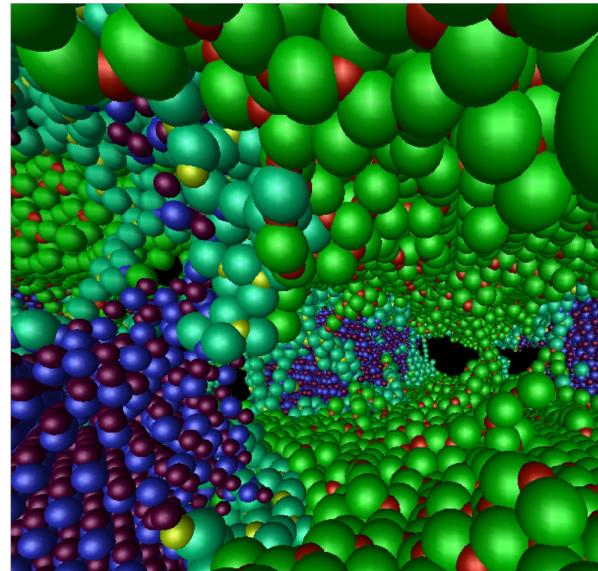


Results of Probabilistic Occlusion Culling

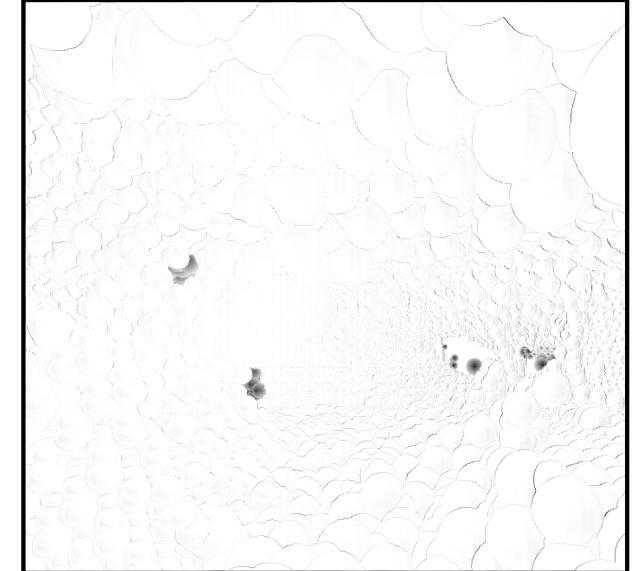
Original



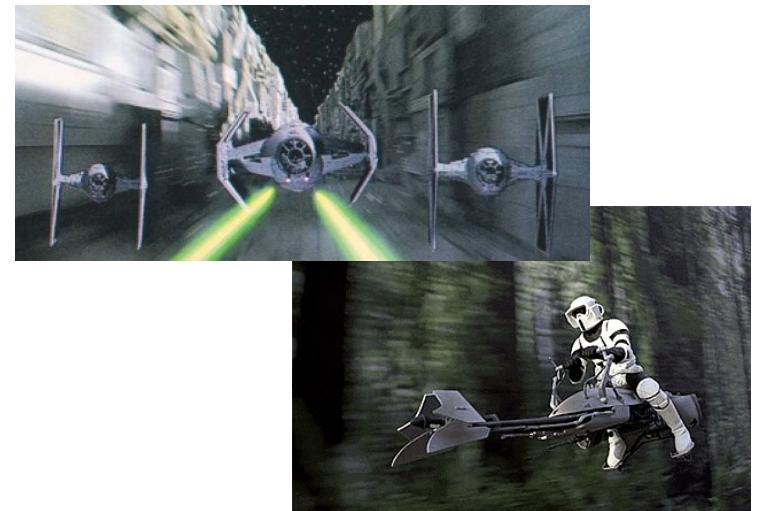
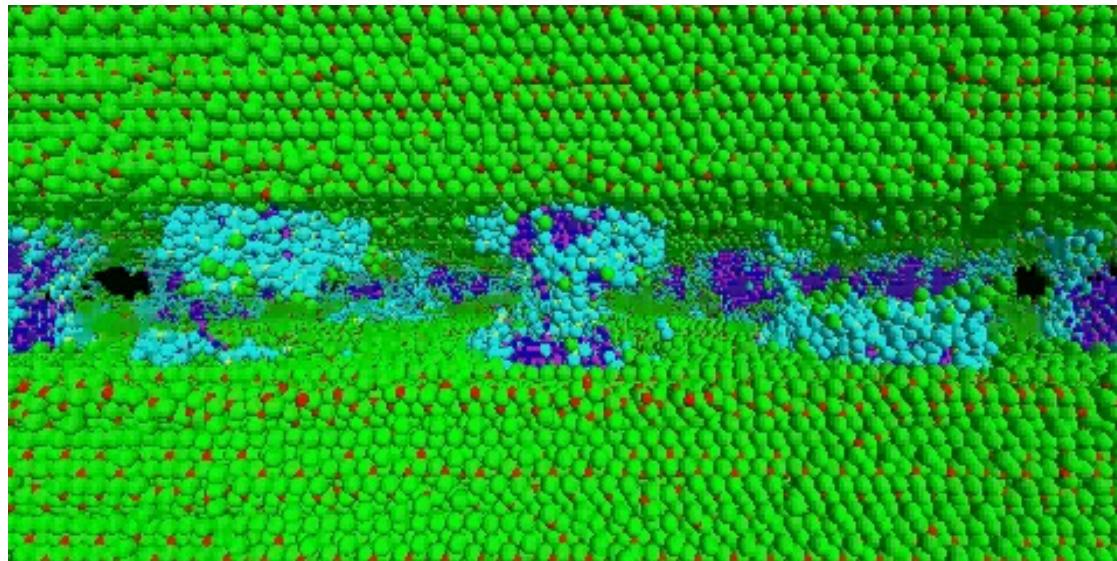
Probabilistic



Difference



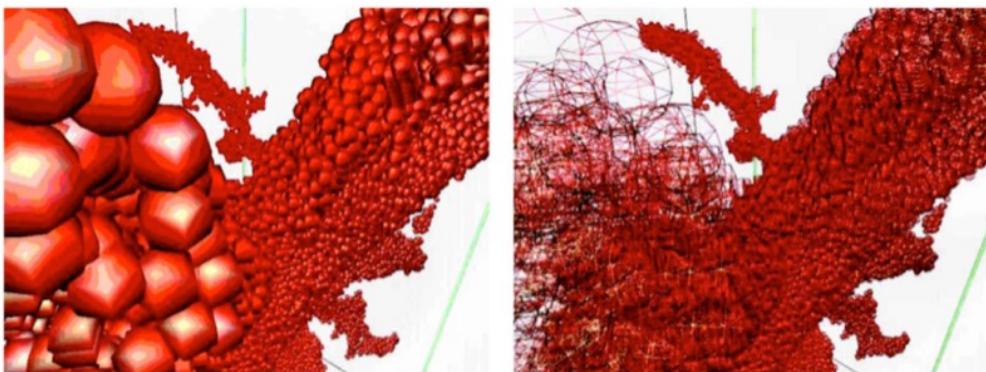
68% fewer objects; 3 \times frame rate



Multiresolution Culling & Rendering

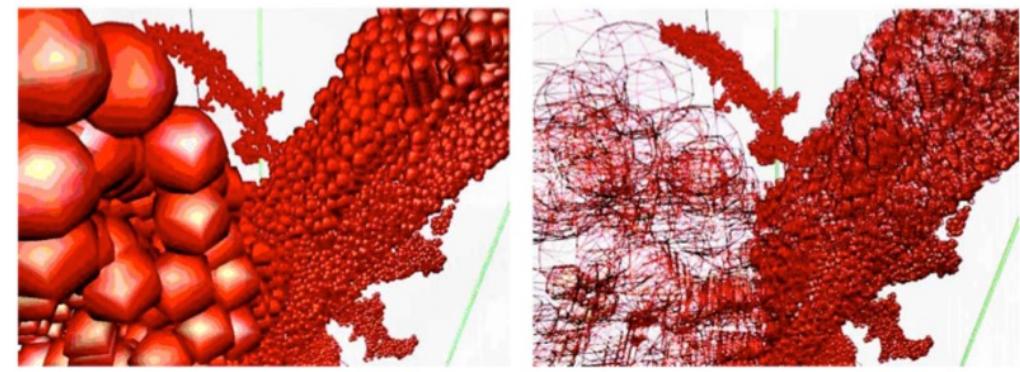
- Per-octree node operations:
 - Frustum culling
 - Probabilistic occlusion culling
- Per-atom operations
 - Multiple levels-of-detail
 - Occlusion culling (per-object, per-octree node)

Without multiresolution



.94fps - 90,000 particles

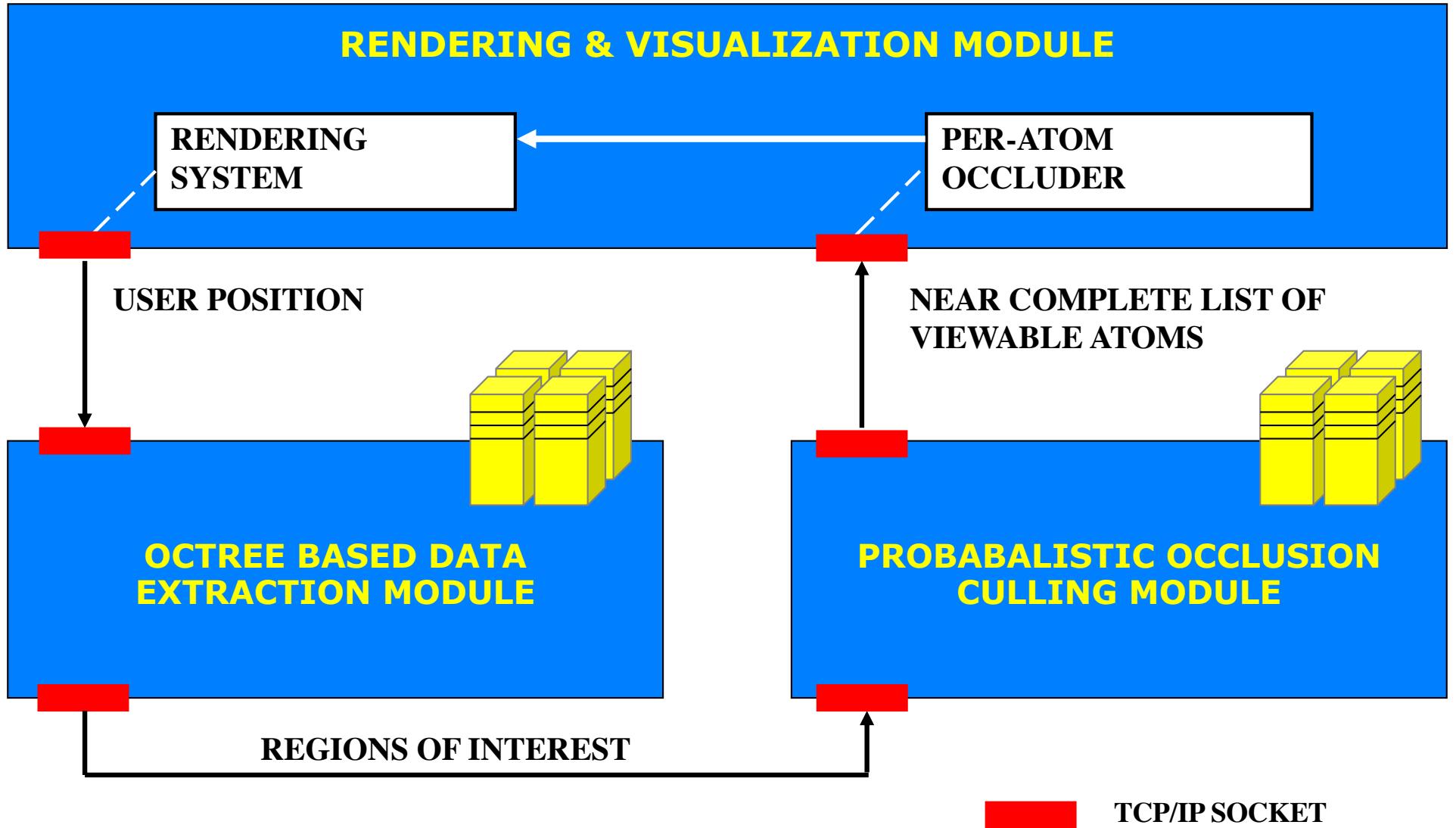
With multiresolution



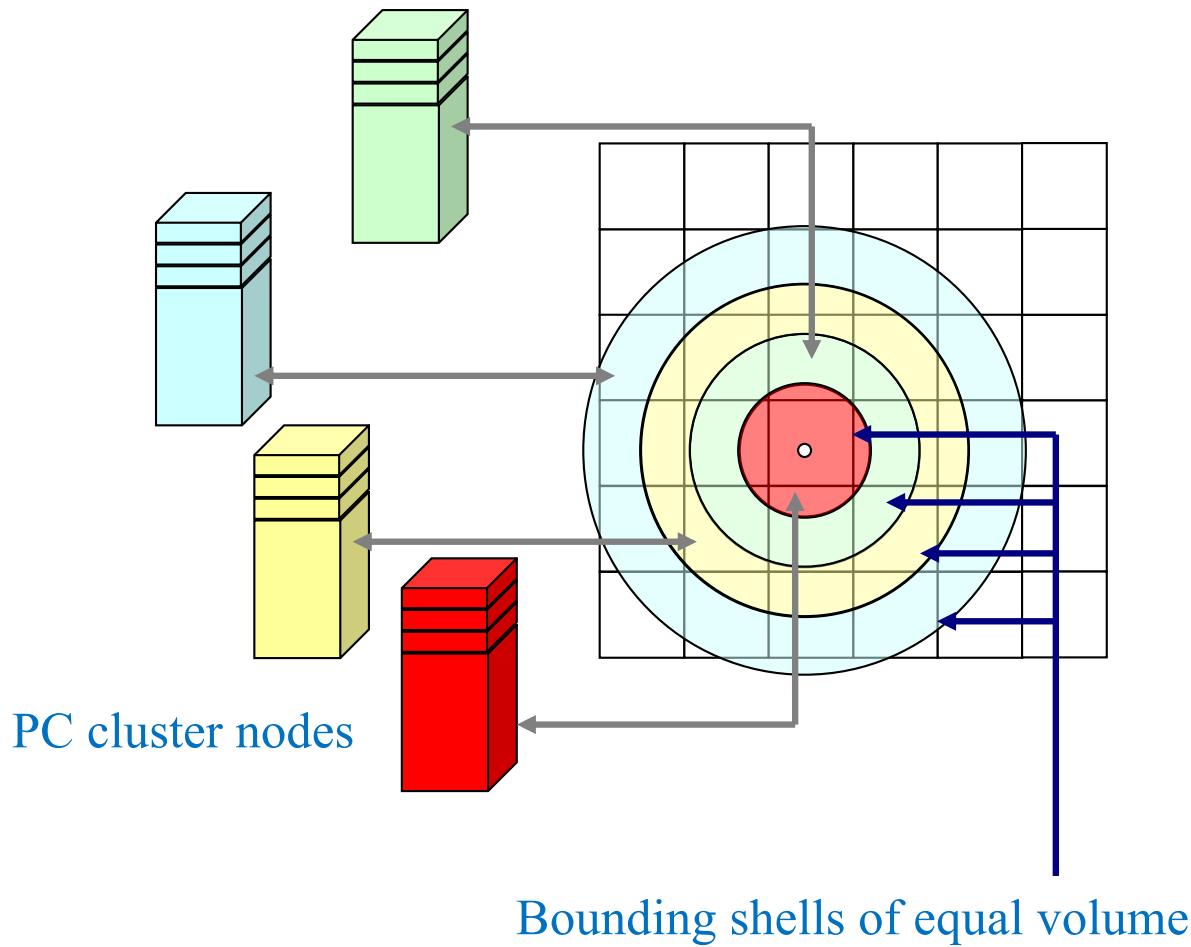
3.2fps - 4,500 particles

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

Distributed Architecture



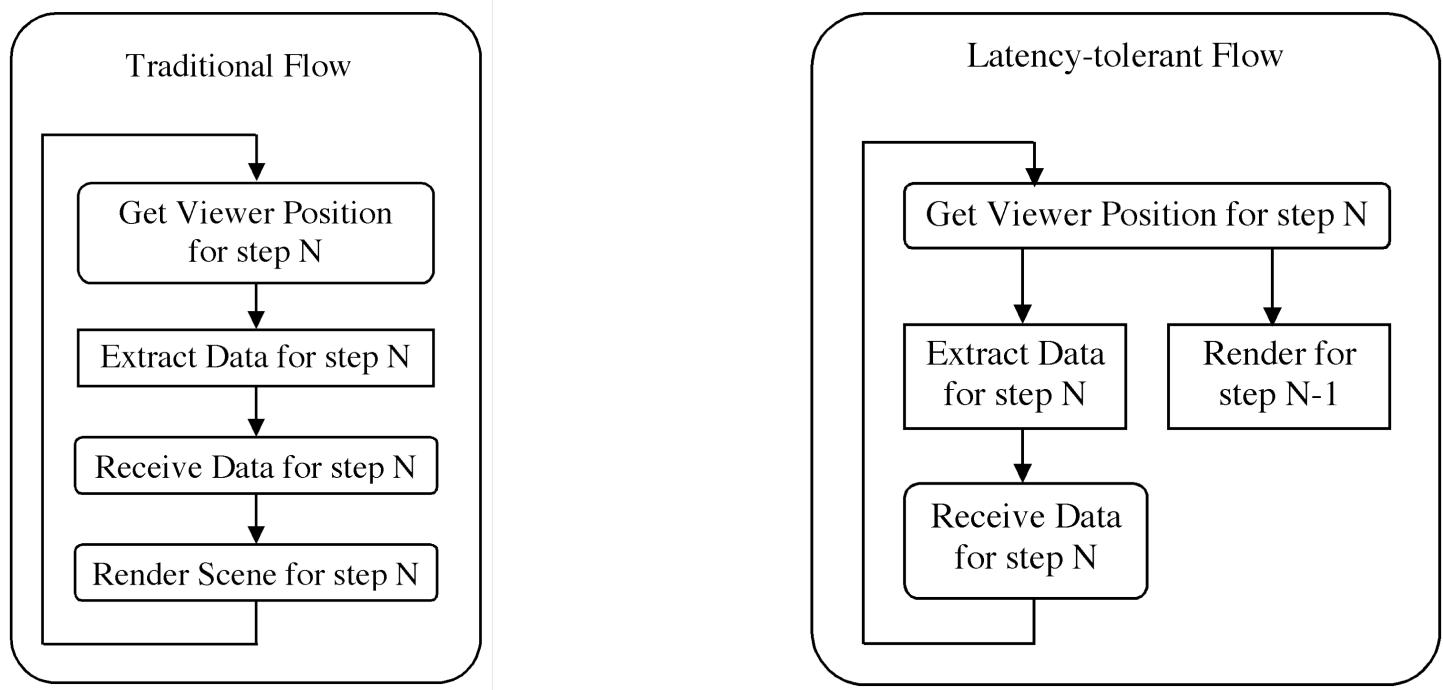
Parallel Octree Extraction



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

Latency Hiding

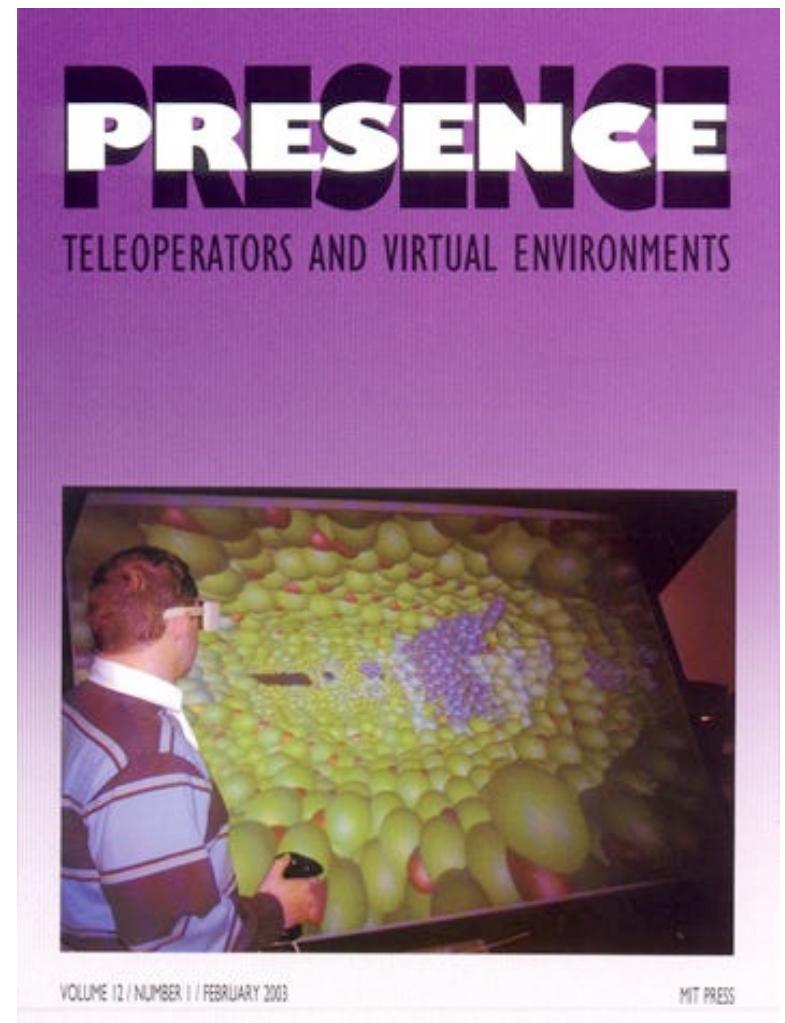
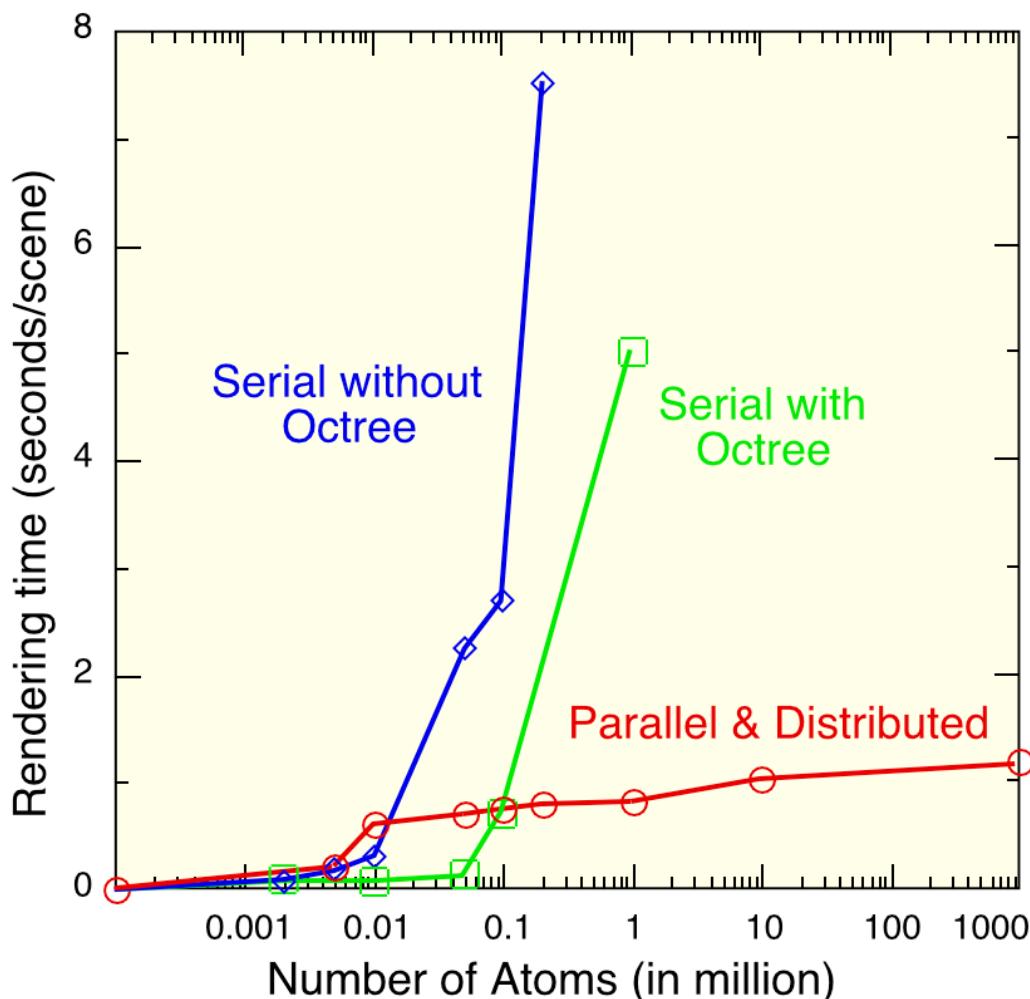
- Individual modules are multithreaded to reduce network or module latency
- Minimize latency due to inter-modular dependencies by overlapping the inter-module communication and module computation



- Instantaneously trained neural network (**CC4** Tang & Kak, CSSP'98) predicts the user's next position *Liu et al., PDPTA'02*

Parallel & Distributed Atomsviewer

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 *In Situ* Rendering

International Journal of Computational Science

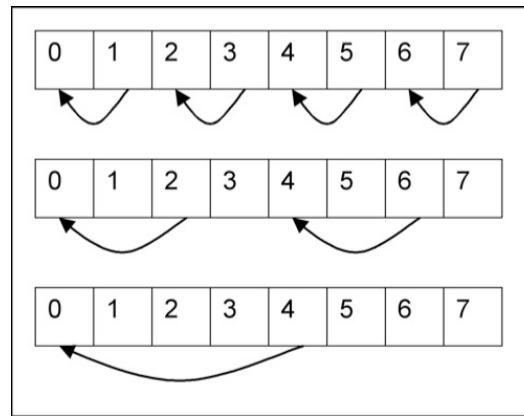
1992-6669 (Print) 1992-6677 (Online) © Global Information Publisher
2007, Vol. 1, No. 4, 407-421

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

Cheng Zhang¹, Scott Callaghan², Thomas Jordan², Rajiv K. Kalia¹,

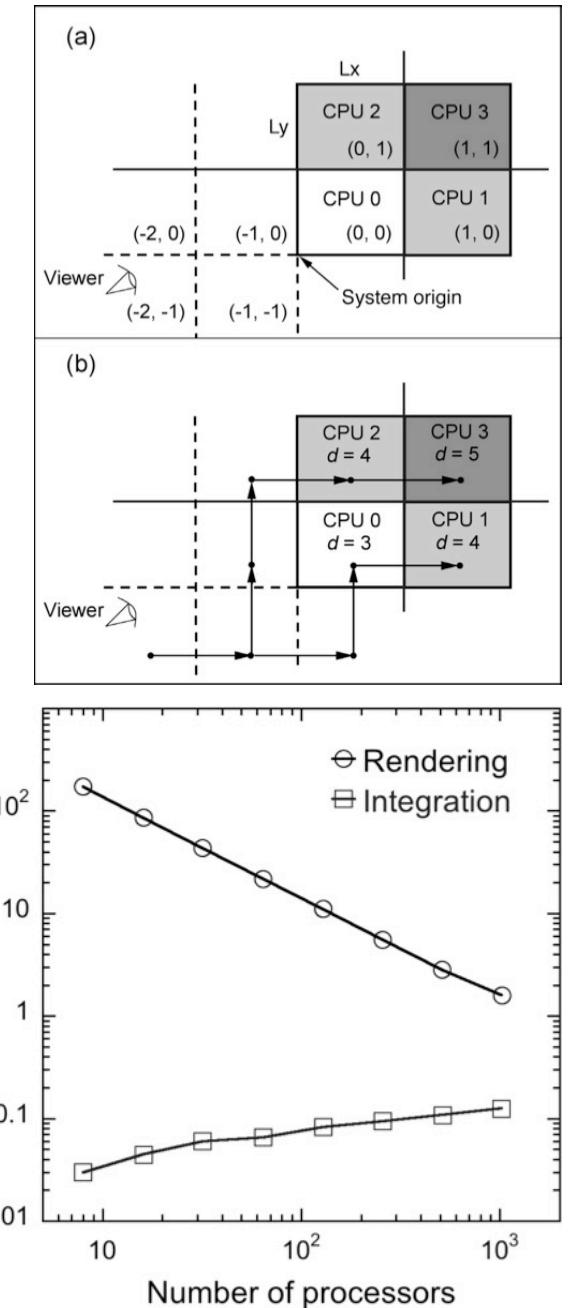
Aiichiro Nakano^{1*}, Priya Vashishta¹

- **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

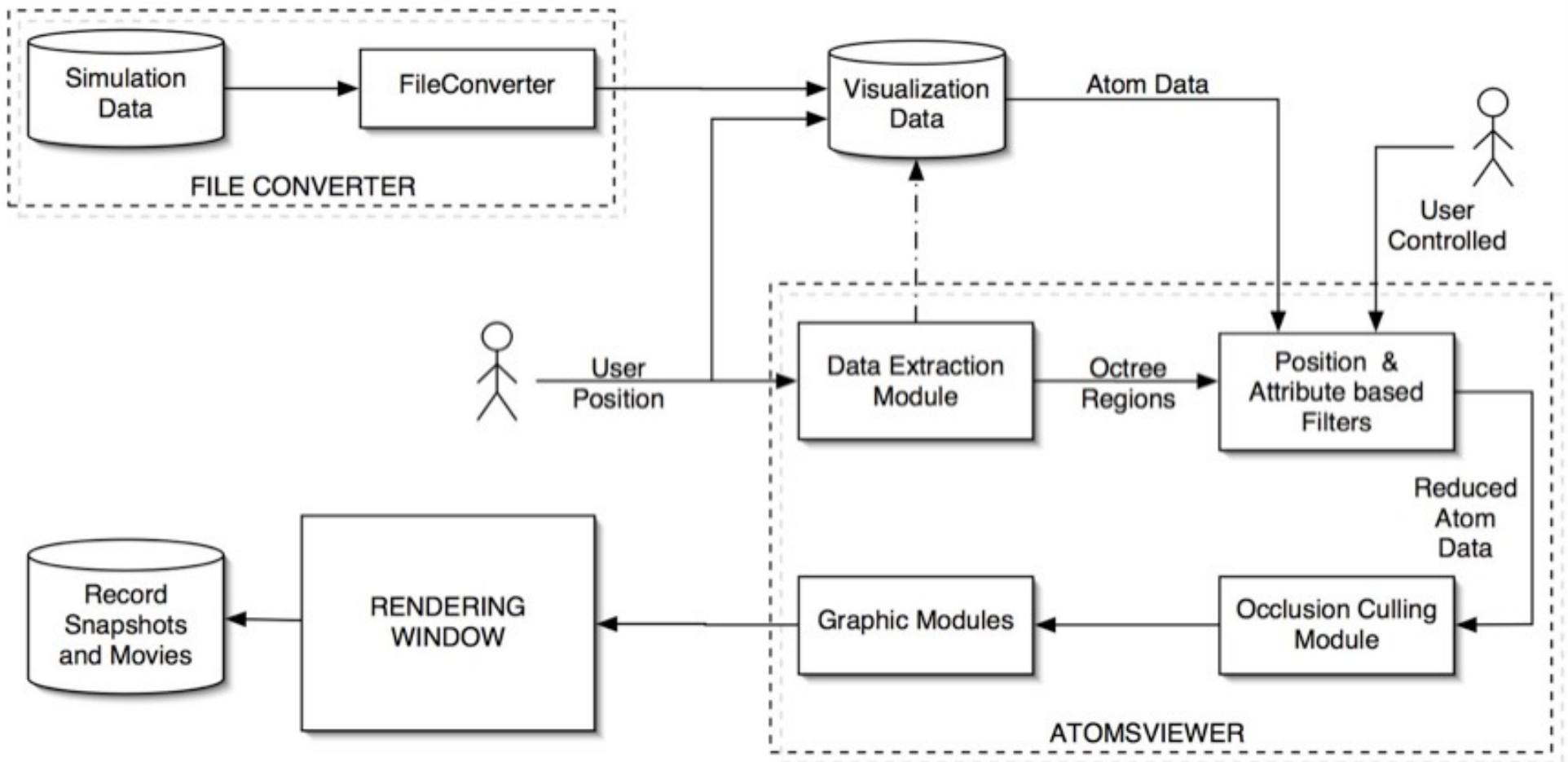
<http://www.mesa3d.org>



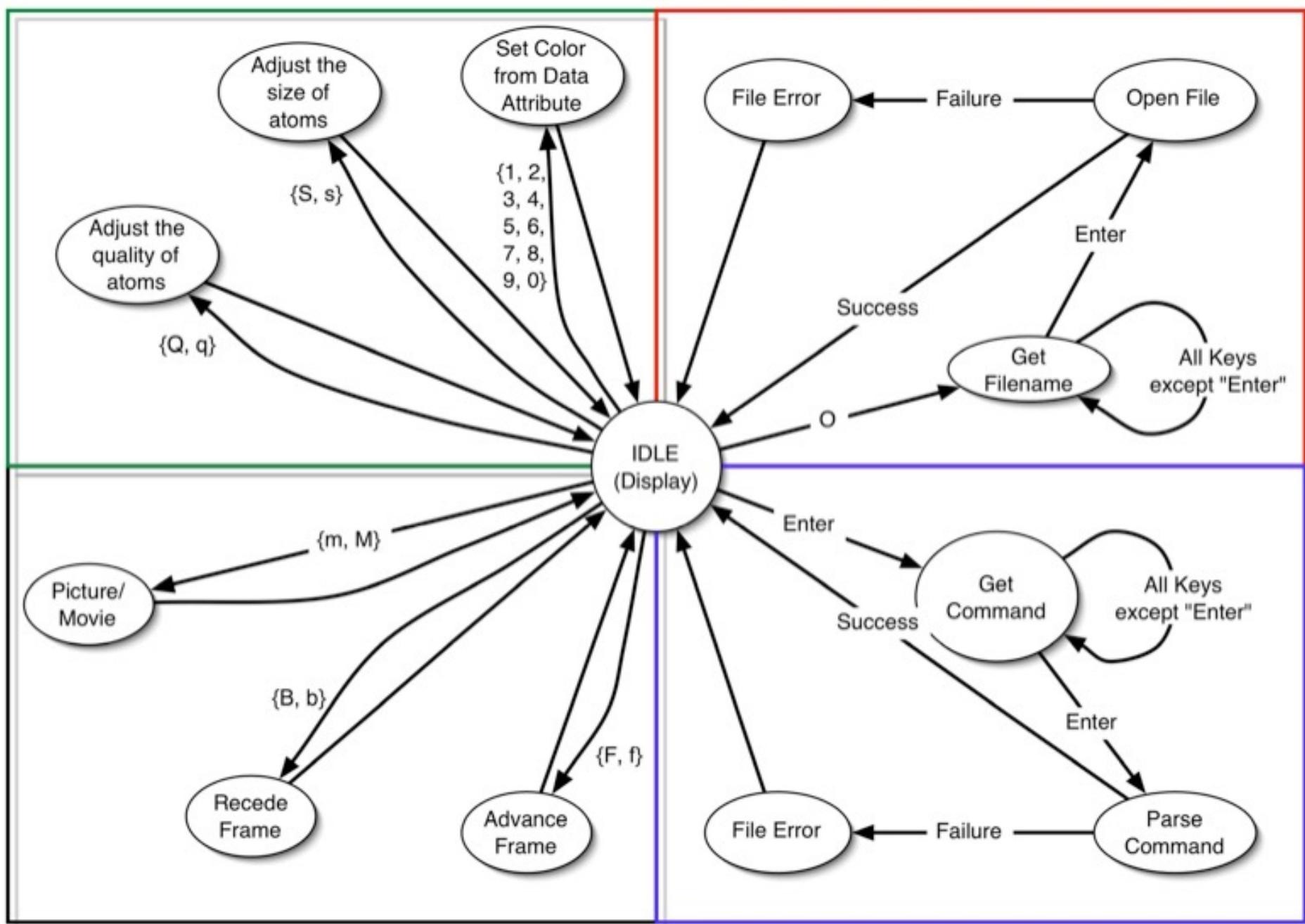
Atomsviewer Code

- **Programming language**
 > C++
- **Graphics**
 > OpenGL
 > CAVE Library (optional)
- **Platforms**
 > Windows
 > Macintosh OS X
 > SGI Irix

Atomsviewer System



Atomsviewer Commands



Atomsviewer Code Dissemination

Computer Physics Communications Program Library



Available online at www.sciencedirect.com



Computer Physics Communications 163 (2004) 53–64

Computer Physics
Communications

www.elsevier.com/locate/cpc

Scalable and portable visualization of large atomistic datasets [☆]

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

*Collaboratory for Advanced Computing and Simulations, Department of Computer Science, Department of Physics & Astronomy,
Department of Material Science & Engineering, University of Southern California, Los Angeles, CA 90089-0242, USA*

Received 15 June 2004; accepted 8 July 2004

Available online 16 September 2004

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 multiresolution algorithm is used to render the selected subset of visible atoms at varying 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 others on which it has been tested: 2.4 GHz Pentium 4/Xeon 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 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>).

^{*} Corresponding author.

E-mail address: anakano@usc.edu (A. Sharma).

Scientific Visualization Tools

- **Atomsviewer: Billion-atom visualizer**

<https://www.sciencedirect.com/science/article/pii/S0010465504004084>

- **VMD: Molecular-dynamics data**

<http://www.ks.uiuc.edu/Research/vmd>

- **OVITO: Open visualization tool**

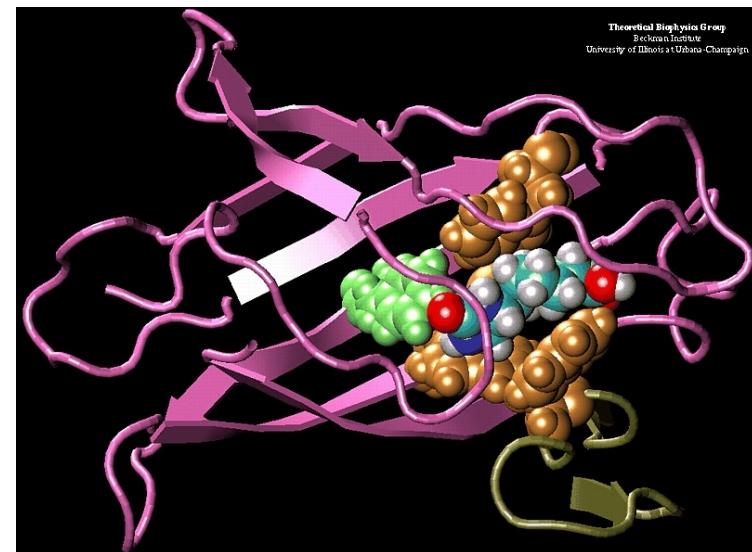
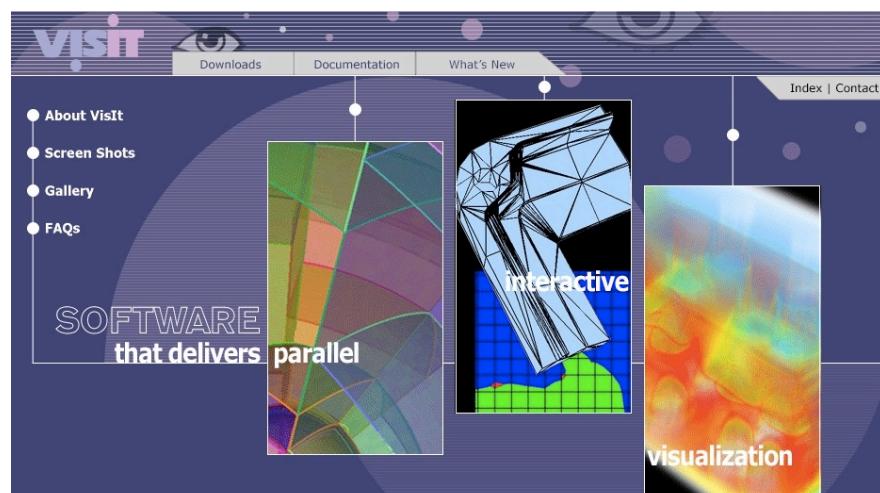
<https://ovito.org>

- **VisIT: General visualization system**

<https://visit.llnl.gov>

- **ParaView: General visualization system**

<http://www.paraview.org>



Example: Our SC25 Presentation

- Simulated laser-induced ultrafast dynamics of topological patterns in a prototypical ferroelectric topotronics material, PbTiO_3

Credit: J. Insley, V. Mateevisti, S. Rizzi, J. Knowles

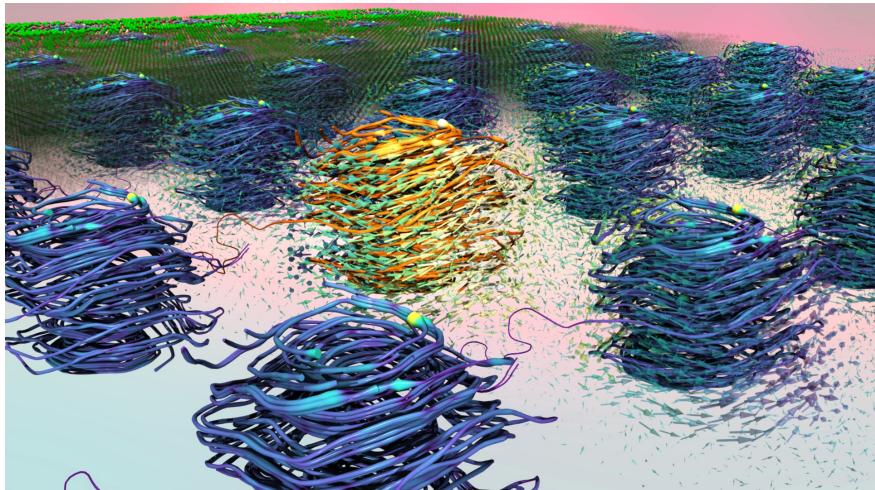


Photo-switching of skyrmion superlattice

<https://www.youtube.com/watch?v=79Rp0v9cc4E>

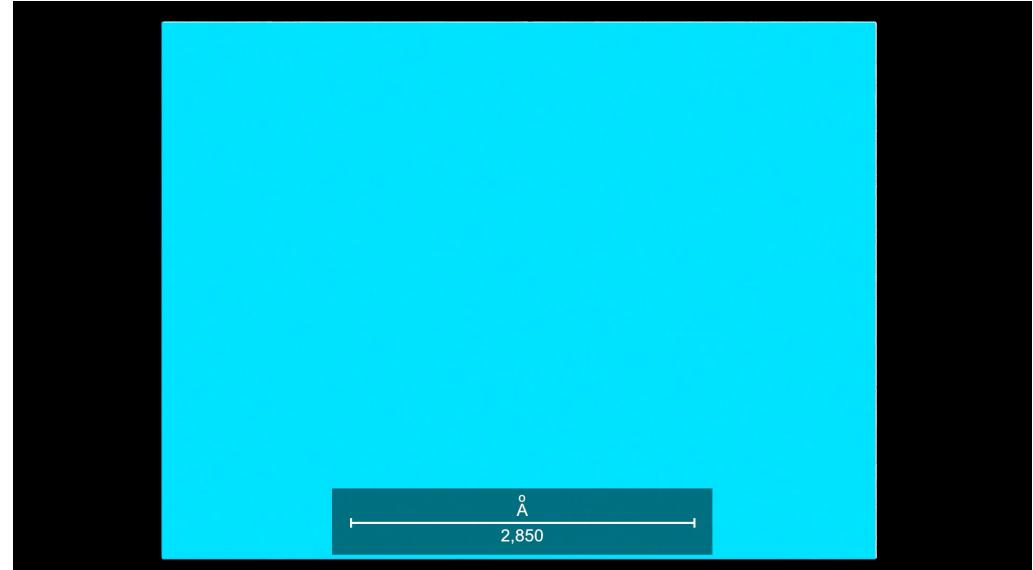


Photo-induced topological phase-transition dynamics (cf. Kibble-Zurek mechanism in cosmology)

Recent experimental breakthrough using X-ray free electron laser (XFEL)
at Linac Coherent Light Source (LCLS) Stoica et al., *Nature Mater.* 23, 1394 ('24)
cf. Our earlier NAQMD-LCLS synergy Tung et al., *Nature Photon.* 13, 425 ('19)

- Topological quantum matter holds key to sustainable society with ubiquitous & power-hungry AI, by enabling ultralow-power transistors & robust quantum computers Kosterlitz, Thouless & Haldane, 2016 Nobel physics prize

cf. AttoJoule-switching logic? Datta et al., *Science* 378, 733 ('22)

Animation for final Project?

- “Splash in a flash: sharpness-aware minimization for efficient liquid splash simulation,” V. Jetly, H. Ibayashi, & A. Nakano, *Eurographics*, 1003 ('22) DOI: [10.2312/egp.20221003](https://doi.org/10.2312/egp.20221003)
- “GPU-based inverse rendering with multi-objective particle swarm optimization,” K. Nagano, T. Collins, C.-A. Chen & A. Nakano, *SIGGRAPH Asia* ('15) DOI:[10.1145/2818517.2818523](https://doi.org/10.1145/2818517.2818523)

