



4-14-2008

Time-Critical Distributed Visualization with Fault Tolerance

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Recommended Citation

Gao, J., Liu, H., Huang, J., Beck, M., Wu, Q., Moore, T., & Kohl, J. (2008). Time-Critical Distributed Visualization with Fault Tolerance. Paper presented at Eurographics 2008 Symposium on Parallel Graphics and Visualization in Crete, Greece.
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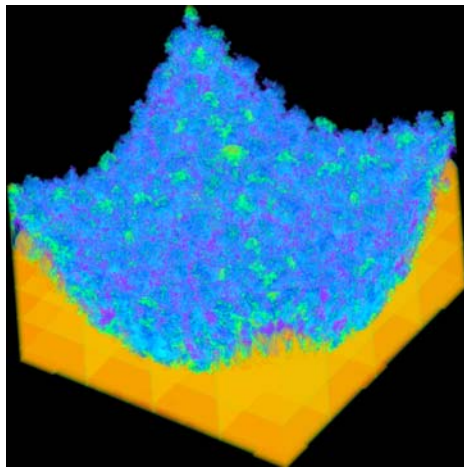
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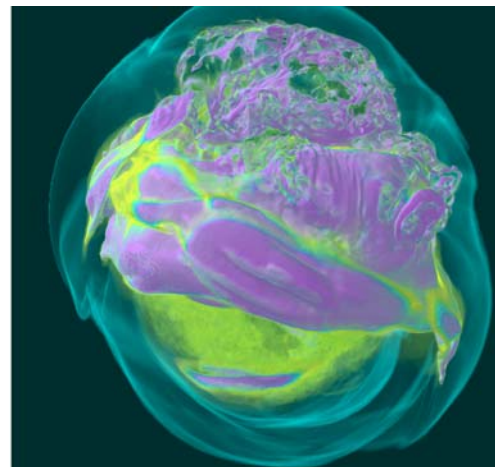
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Oak Ridge National Laboratory

Current Challenges

- Massive data must be visualized with high efficiency...



Richtmyer-Meshkov Turbulent Simulation
274 time steps, each is $2048 \times 2048 \times 1920$

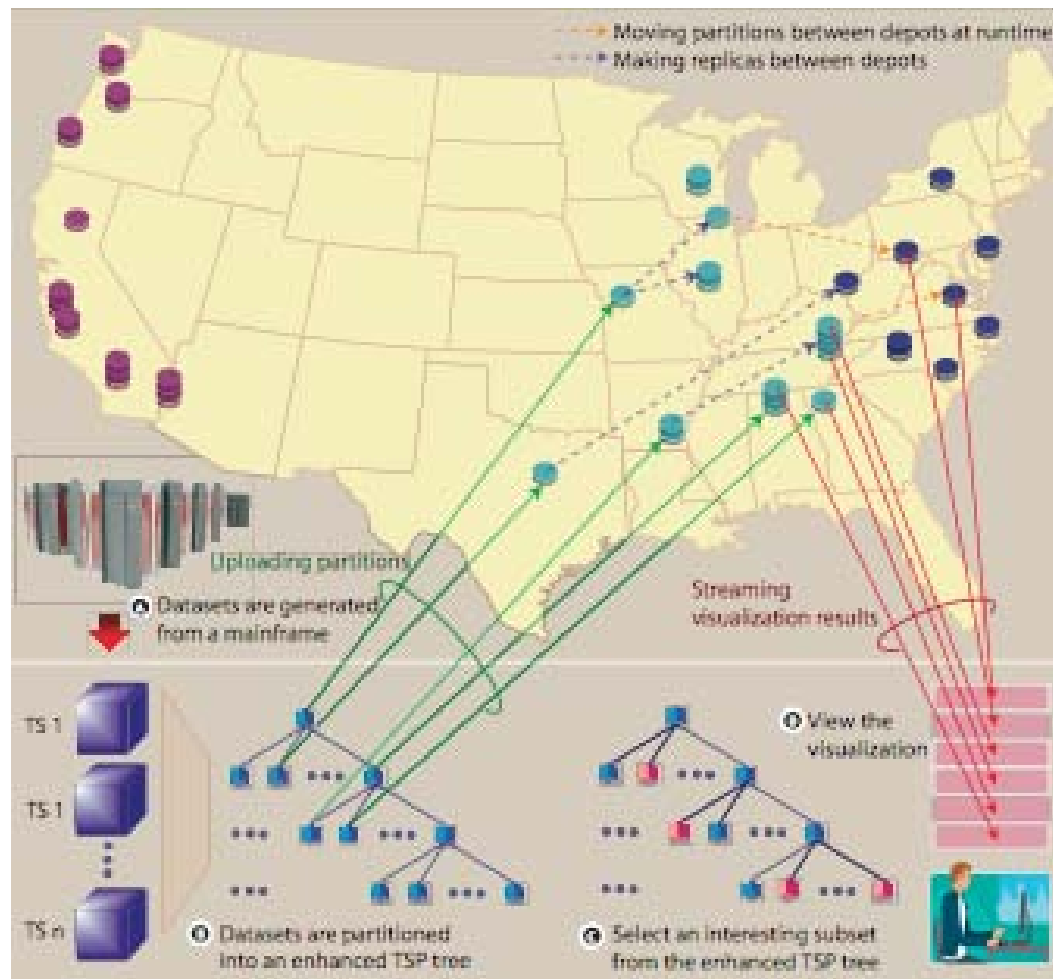


3D Core-Collapse Supernova Simulation
300 time steps, each is $864 \times 864 \times 864$
(Courtesy image of Ross Toedte, SciDAC TSI project)

Our Goal

- A fault-tolerant time-critical visualization system that tolerates
 - Heterogeneity of processors
 - Perils of wide-area distribution across the Internet

Our Goal



Our Method

- LoD data selection based on a general importance metric
- Dynamic scheduling scheme with fault-tolerance

Importance Metric

- Assign different time budget for different regions based on their importance
- The importance of a block is based on its contribution to the final image

$$I = w_{app} \times I_{app} + w_{val} \times I_{val} + w_{view} \times I_{view}$$

I_{app} : Application-dependent factor

I_{val} : Value-dependent factor

I_{view} : View-dependent factor

w : Weight coefficient

Importance – *Application-dependent*

- The importance of a block may depend on the underlying applications
- For example:
 - Time-critical applications: choose the highest possible resolution for a region

$$I_{app} = Height_{root} - Height_{node}$$

Importance – *Value-dependent*

$$I_{val} = w_{opa} \times V_{opa} + w_{var} \times V_{var} + w_{serr} \times (1 - V_{serr})$$

V_{opa} : *Opaqueness of a block*

V_{val} : *Value variance of a block*

V_{serr} : *Spatial error of a block*

w : *Weight coefficient*

Importance – *View-dependent*

- The importance of a block may depend on the eye position

$$I_{view} = 1 - ID_{traversal}/N_{block}$$

ID_{traversal}: sequential order during front-to-back traversal

N_{block}: total number of blocks

- An invisible block doesn't have an importance value

Dynamic Fault-Tolerance Load Balancing

- **Master-Worker model:**
 - *Worker* processors:
 - Distributed and heterogeneous depots
 - “*Depot*”: a processing unit with local storage and computing resources
 - Perform rendering tasks
 - *Master* processor:
 - The client’s local machine
 - Schedules entire parallel run and composites the final image

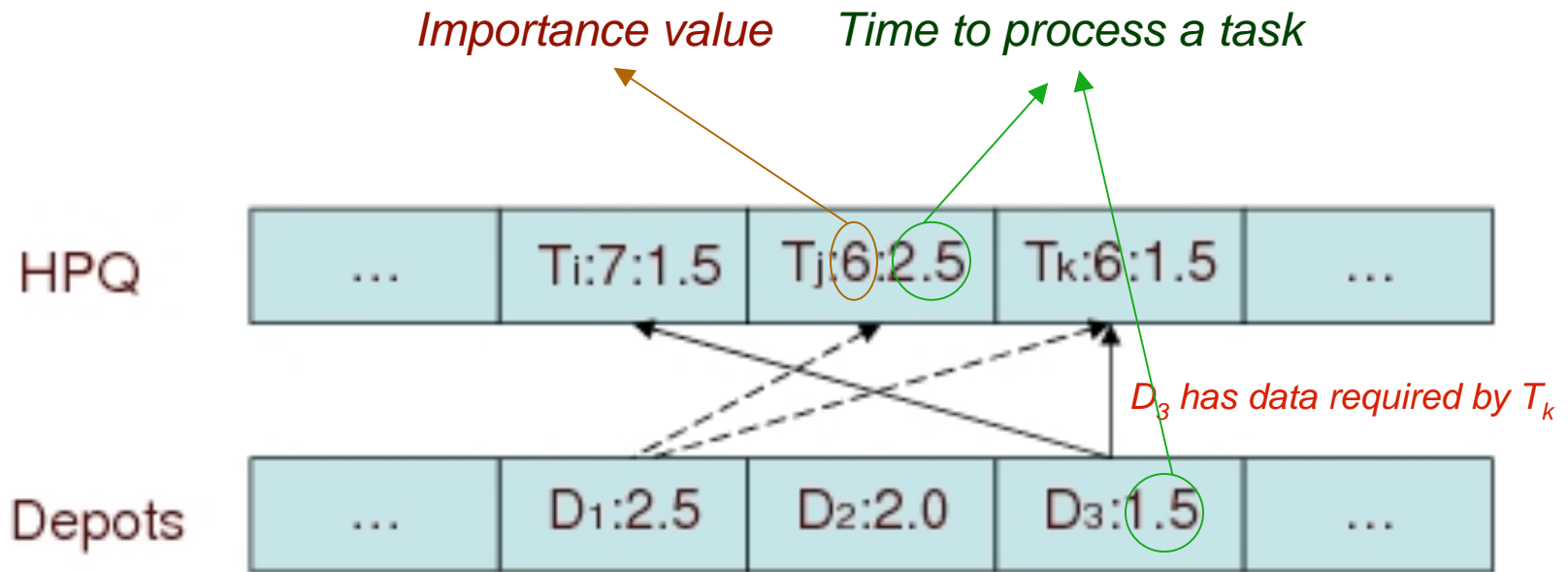
Dynamic Fault-Tolerance Load Balancing

- **Major tasks:**
 - Adaptive scheduling of rendering tasks
 - Dynamic scheduling of data movement
 - Dealing with faults
 - Quality-driven back-off

Adaptive Scheduling of Rendering Tasks

- Two generic data structures:
 - A dynamically ranked pool of depots
 - The depots are ranked in the order of their estimated rendering time for a task
 - A two-level priority queue of tasks
 - High priority queue (HPQ):
 - Tasks ready to be assigned
 - *Primary key*: importance value
 - *Secondary key*: optimal task processing time
 - Low priority queue (LPQ):
 - Tasks assigned to one or more depots but not finished
 - *Key*: estimated time left for completion
 - In HPQ and LPQ, tasks are sorted using their keys in a decreasing order

Adaptive Scheduling of Rendering Tasks



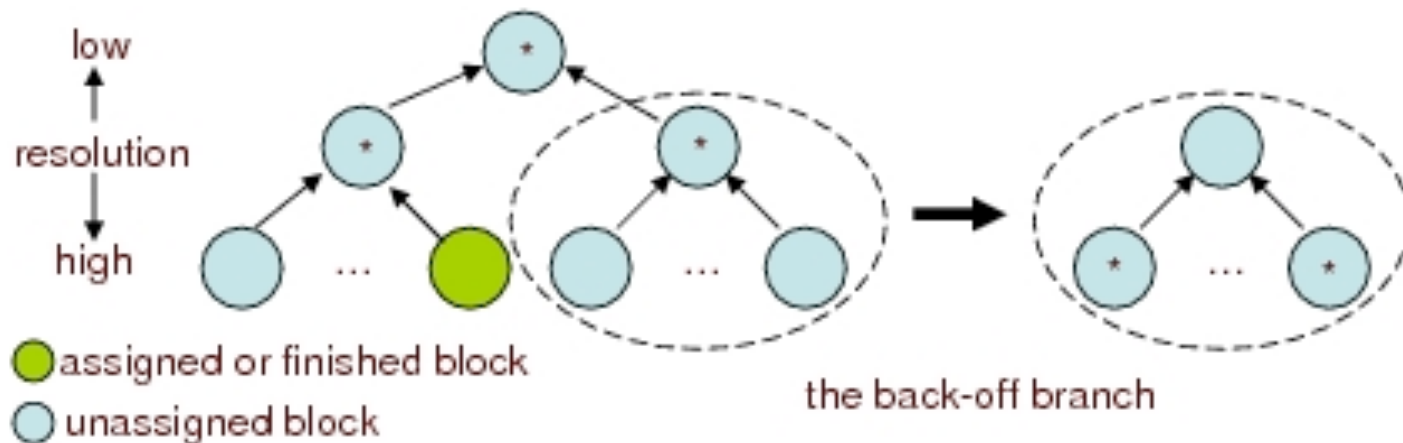
- D_1 becomes available $\rightarrow T_j$ is assigned to it
- D_2 becomes available \rightarrow It tries to help out with tasks in LPQ
- D_3 becomes available $\rightarrow T_i$ is assigned to it

Dealing with Faults

- Promote the failed task in LPQ back to HPQ
- A majority voting scheme to avoid incorrect computation result

Quality-driven Back-off

- To meet the user-specified time limit, several tasks that operate on high resolution data would be replaced with one task that operates on lower resolution data



Tasks marked with a '*' will not be rendered

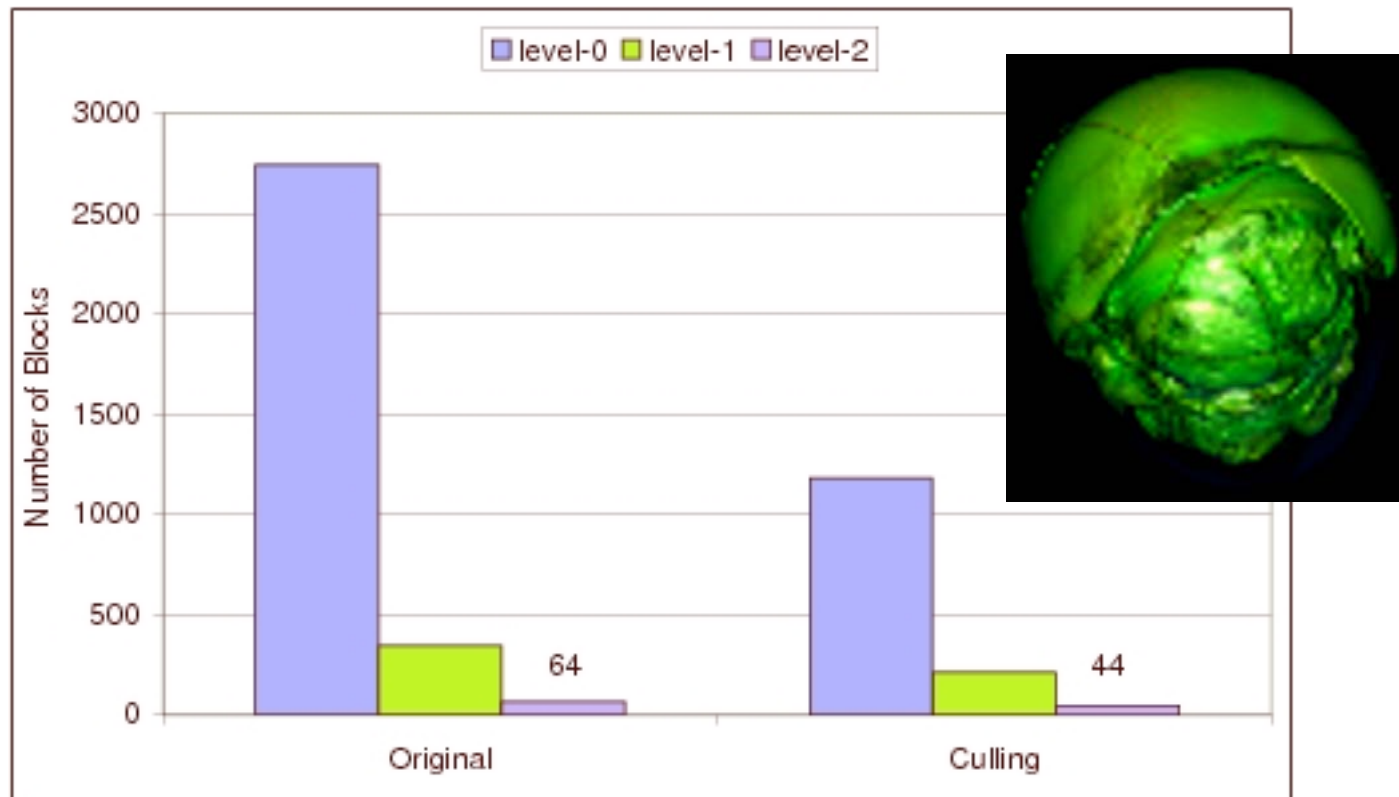
Test Environment

- 160 depots from the PlanetLab project and 10 depots from the National Logistical Networking Testbed (NLNT)
- A 128 time-step subset of the TSI data
 - Spatial resolution: $864 \times 864 \times 864$
 - After data partition, multiresolution data generation, and 3-way replication: $\sim 1\text{TB}$ of data was stored

Performance Evaluation

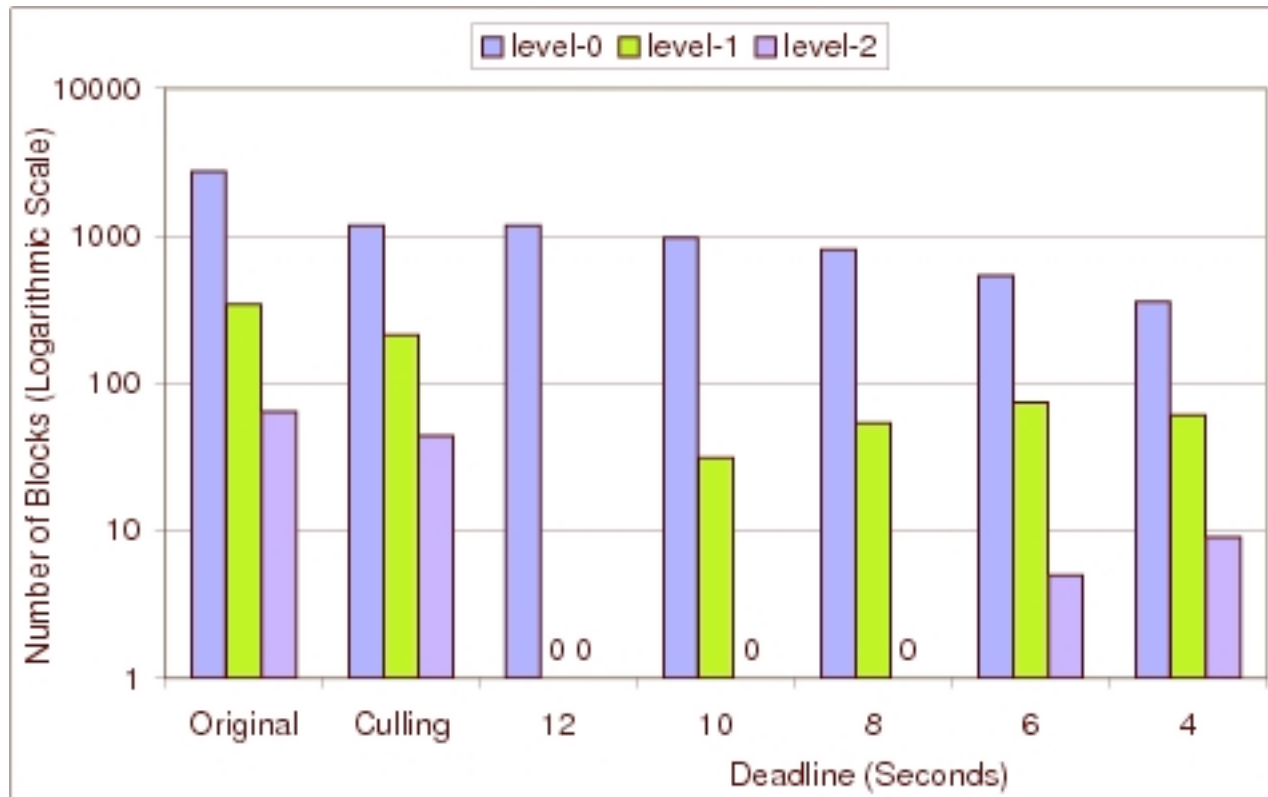
- Data preparation: 10-20 hours
- Software raycasting is used
- About 51 seconds to process four time steps and generate an 800×800 image for each time step
 - It took 62 minutes to perform the same task on a dedicated node with 2.2GHz P4 CPU, 512 KB cache and 2GB RAM

Performance Evaluation



The number of original blocks and visible blocks after culling at resolution level 0, 1, and 2 of a TSI dataset

Performance Evaluation



Logarithmic plot of the number of blocks rendered at different resolution level with different running deadline

Performance Evaluation

- Time-critical & fault tolerance
 - Initially 8 depots were used, deadline = 31 seconds
 - 1181 level-0 blocks can be rendered
 - If one depot is disabled,
 - 1025 level-0 blocks
 - 156 level-0 blocks are replaced by 32 level-1 blocks
 - If two depots are disabled
 - 876 level-0 blocks
 - 305 level-0 blocks are replaced by 52 level-1 blocks

Conclusion

- Perform time-critical visualization on hundreds of geographically distributed, free, unreserved, heterogeneous processors
- Demonstrate a great potential to use distributed heterogeneous processors as a fundamental computing platform

Acknowledgement

- Mathematics, Information and Computational Sciences Office, Office of Advanced Scientific Computing Research, U. S. Department of Energy, under contract No. DE-AC05-00OR22725 with UT-Battelle, LLC
- NSF ACI-0329323, NGS-0437508
- Dr. Mark Duchaineau (Lawrence Livermore National Lab)
- Anthony Mezzacappa (ORNL), John Blondin (NCSU), Ross Toedte (ORNL) and the DOE SciDAC TeraScale Supernova Initiative project team

If you have any questions ...

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Thank you!