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Time-Critical Distributed Visualization with Fault Tolerance

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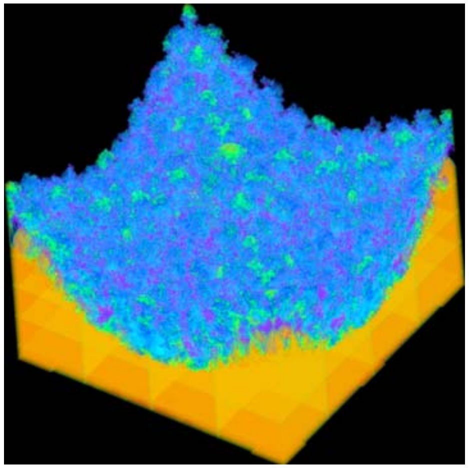
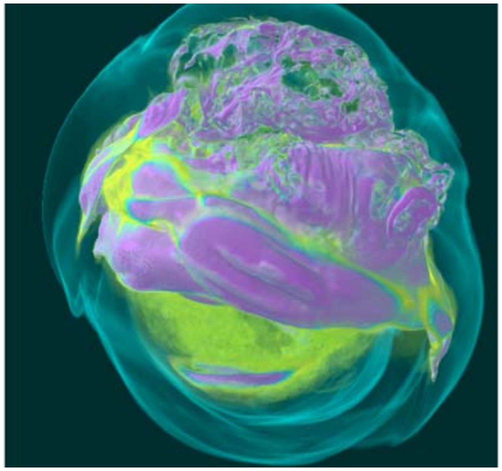
Current Challenges

- Massive data must be visualized with high efficiency…



Richtmyer-Meshkov Turbulent Simulation
274 time steps, each is 2048 × 2048 × 1920

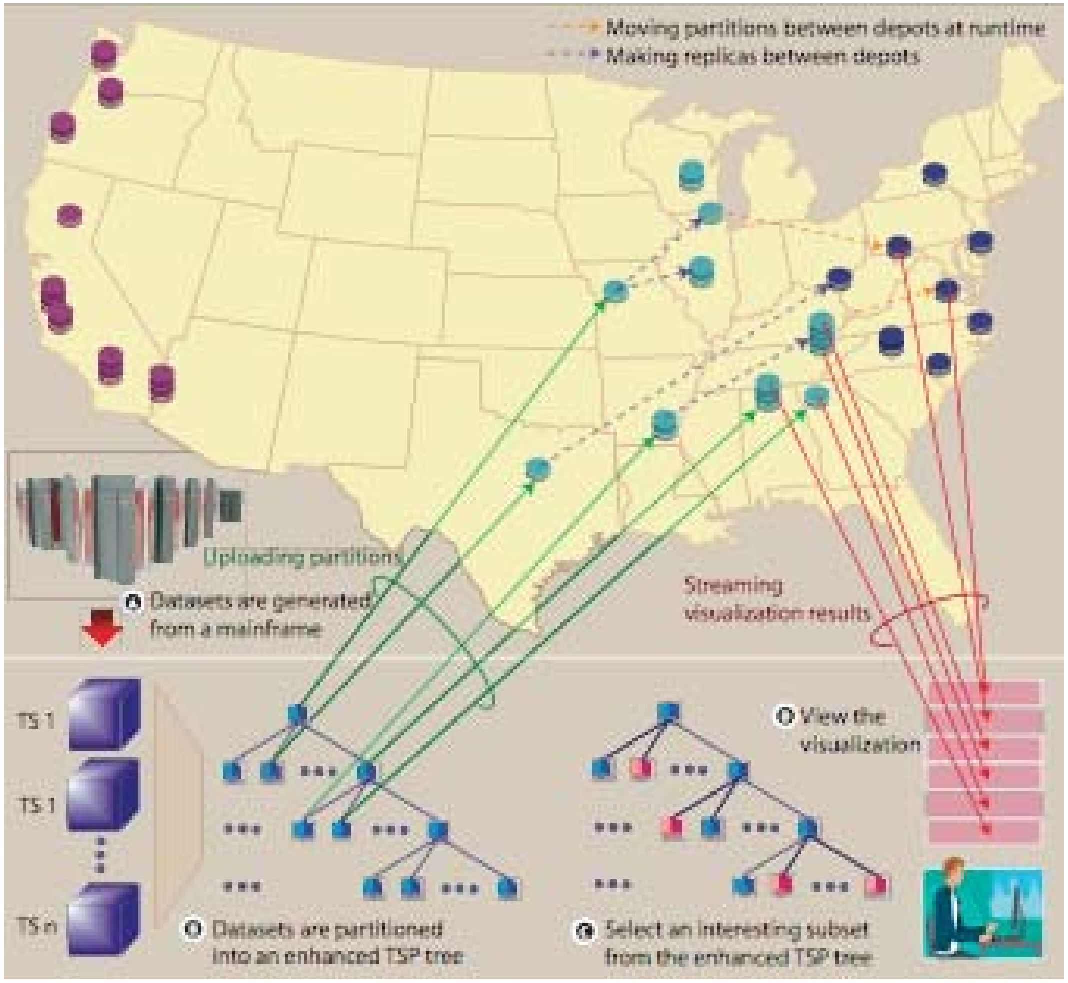


3D Core-Collapse Supernova Simulation
300 time steps, each is 864 × 864 × 864
(*Courtesy image of Ross Toedte, SciDAC TSI project*)

Our Goal

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

Our Goal



Moving partitions between depots at runtime
Making replicas between depots
Uploading partitions
Datasets are generated from a mainframe
Streaming visualization results
TS 1
TS 1
TS n
View the visualization
Datasets are partitioned into an enhanced TSP tree
Select an interesting subset from the enhanced TSP tree

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

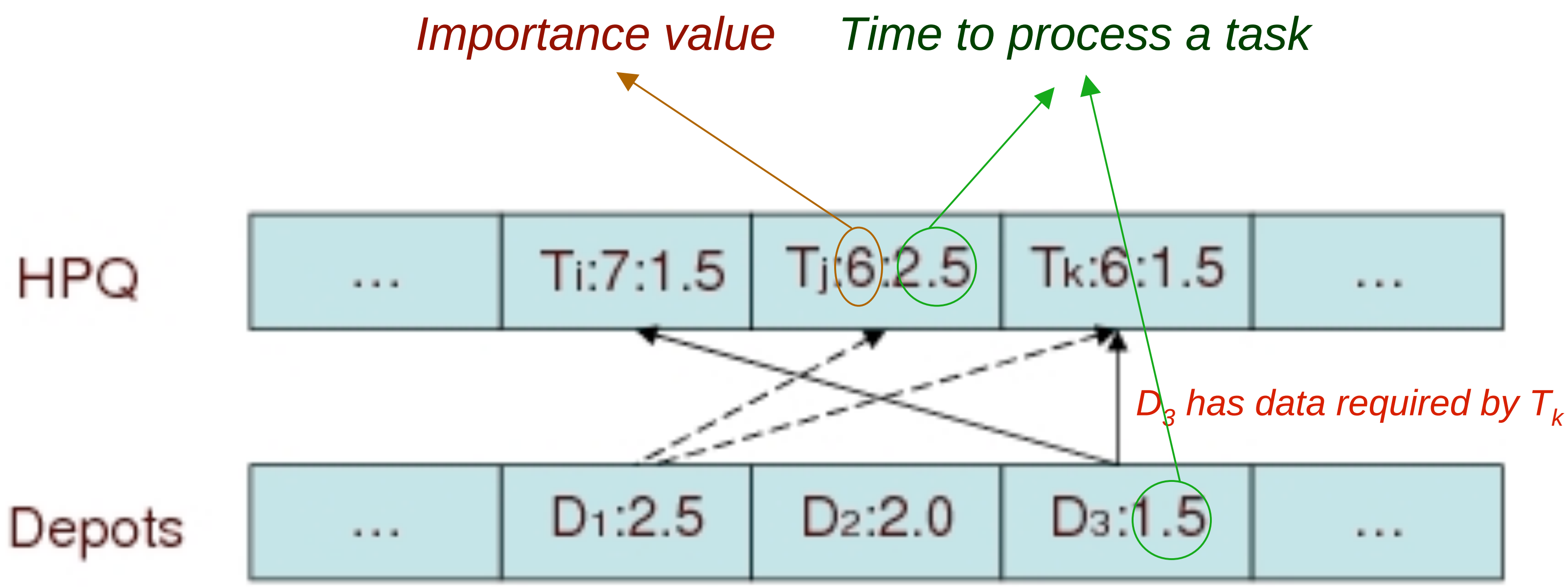
Dynamic Fault-Tolerance Load Balancing

- 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



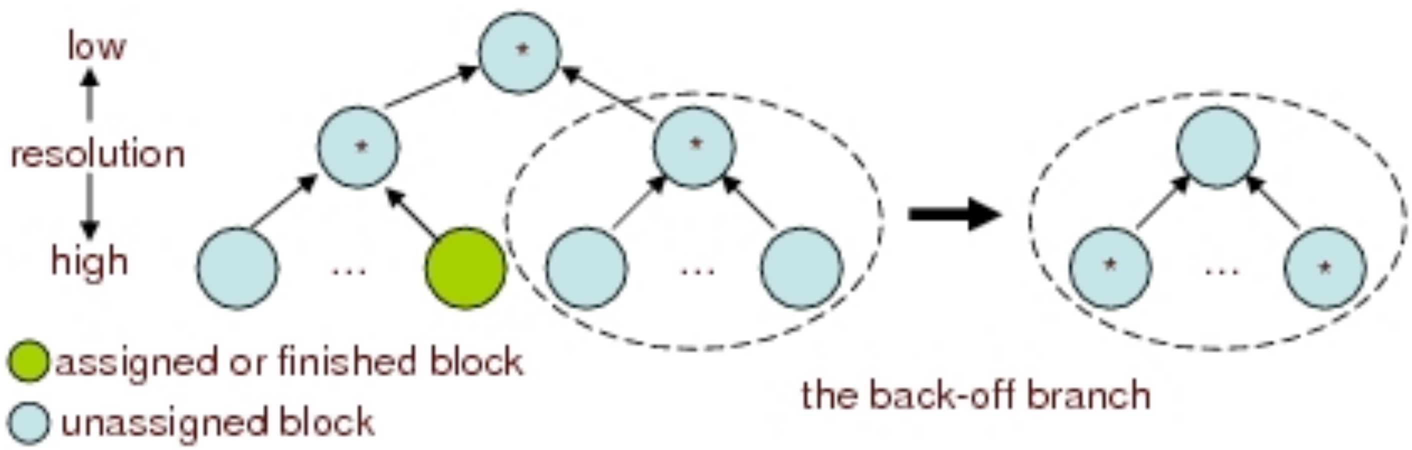
- D_1 becomes available → T_j is assigned to it
- D_2 becomes available → It tries to help out with tasks in LPQ
- D_3 becomes available → T_i is assigned to it

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

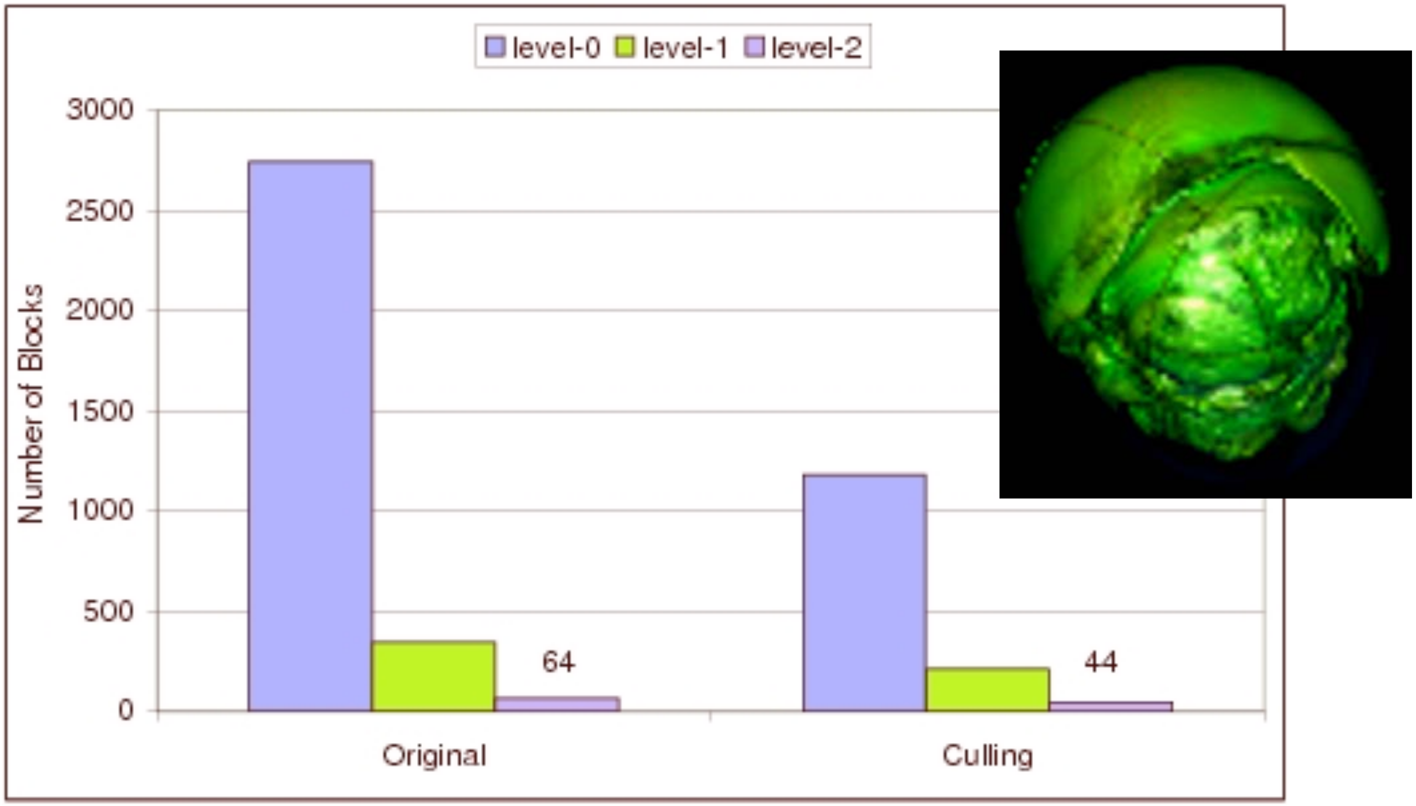
- 160 depots from the PlanetLab project and 10 depots from the National Logistical Networking Testbed (NLNT)

- A 128 time-step subset of the TSI data
  - Spatial resolution: 864×864×864
  - After data partition, multiresolution data generation, and 3-way replication: ~1TB 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

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If you have any questions …

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Thank you!