Scalable Parallel Out-of-core Terrain Rendering

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University of Zurich
Department of Informatics

Organization of Talk

- Introduction
- Related Work
- Preview to Terrain Renderer
- Parallelizing Terrain Renderer
- Results
- Conclusion

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Introduction

- Interactive visualization of huge terrain data
- Advancement of hardware (CPU/GPU)
- Increasing precision of data acquisition
- Level-of-detail (LOD) based solutions
  - GPU-oriented
- Parallel rendering solutions
- Parallel + LOD rendering?

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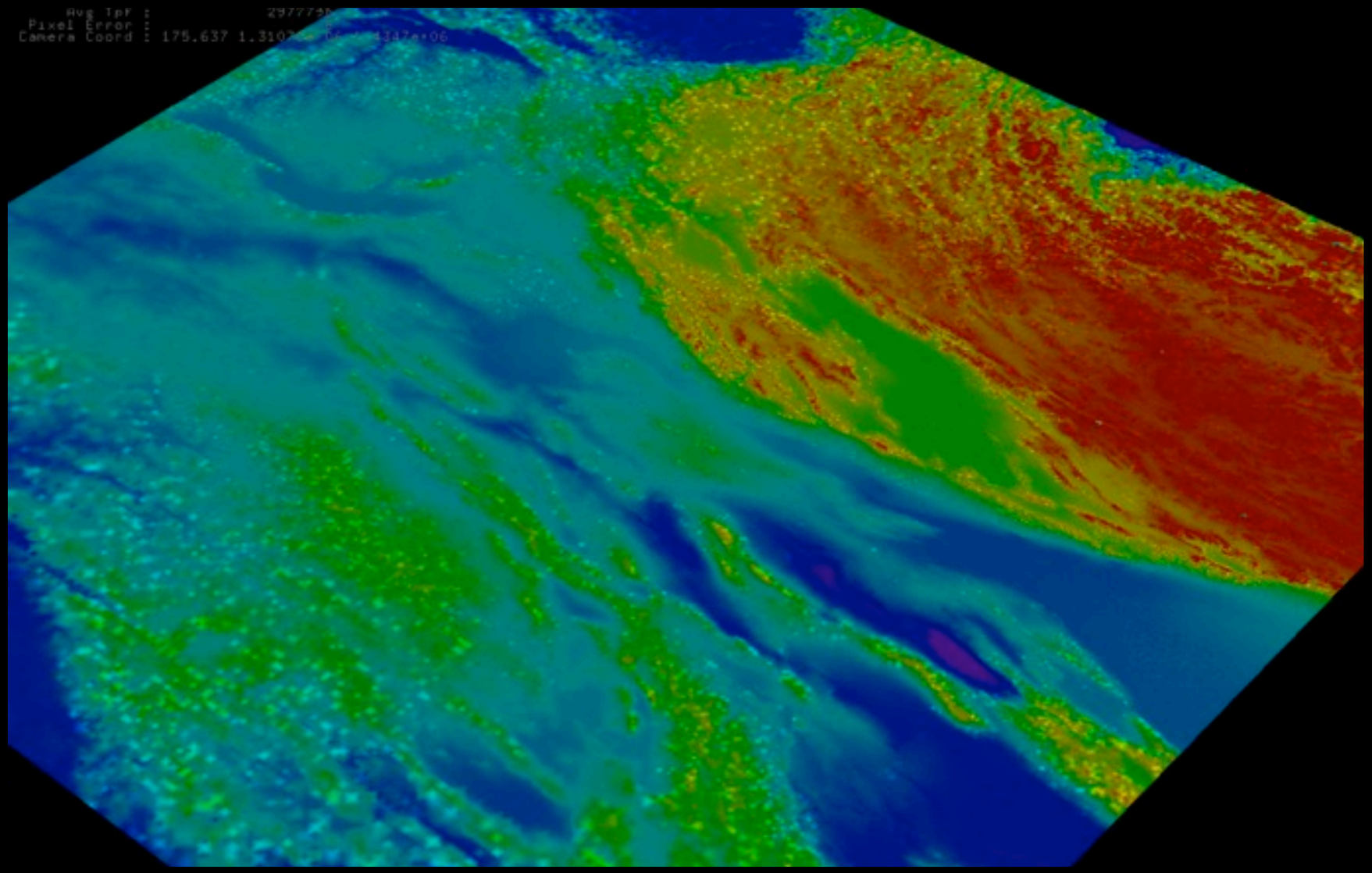
LOD - Single Machine

Data Size : 32 k X 32 k

Pixel Error : 6



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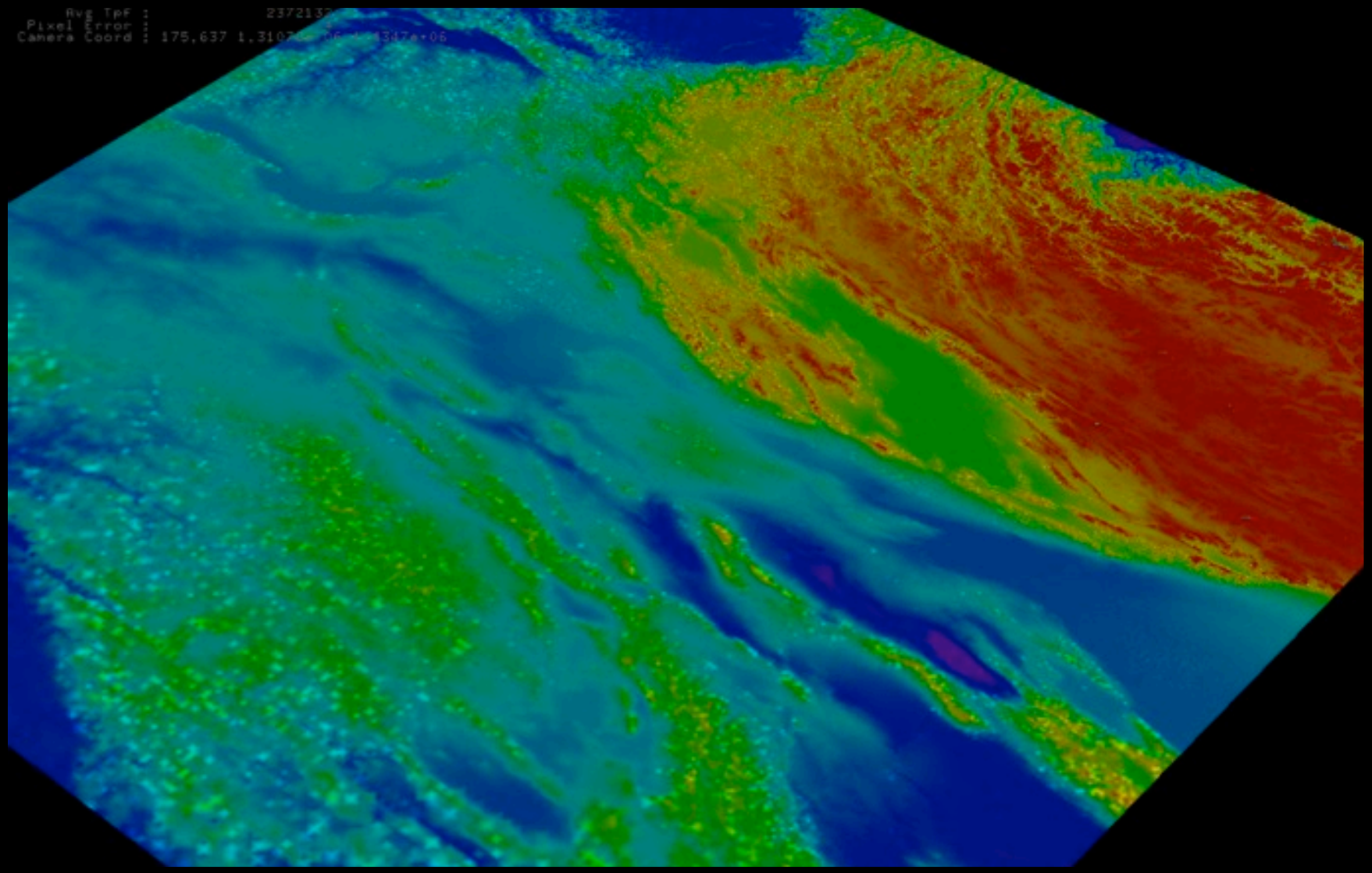
LOD - Single Machine

Pixel Error : 4



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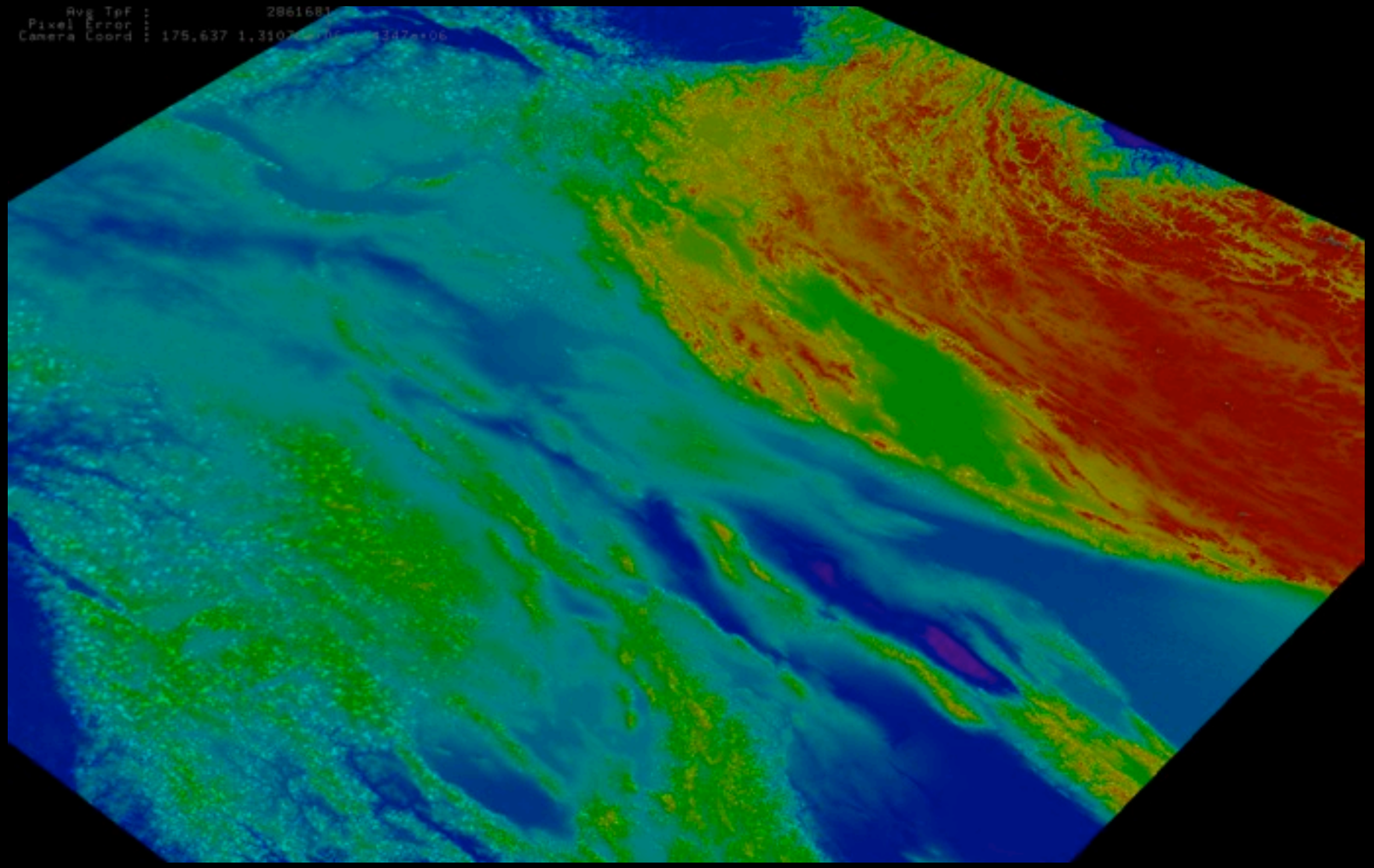
LOD - Single Machine

Pixel Error : 2



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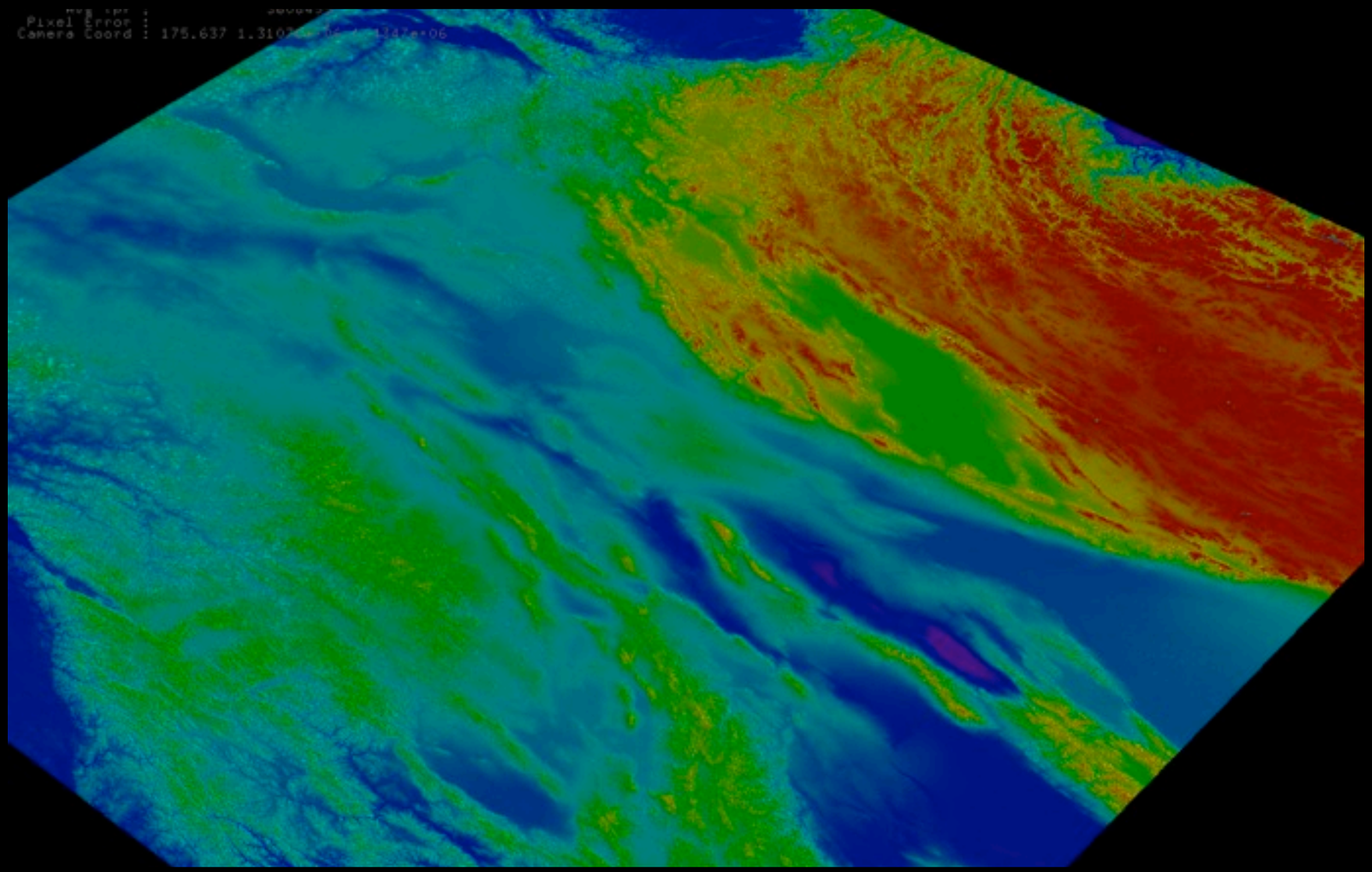
LOD - Single Machine

Pixel Error : 1



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Introduction

- Parallelizing LOD based algorithms
  - Division strategy
  - Choice of algorithm
  - Performance comparison

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Related Work

- LOD based terrain rendering
  - Pajarola[PG07]
- Realistic terrain images rendering in parallel
  - Vezina[VR91], Agranov[AG95]
  - Not interactive, cant handle large datasets
- Rendering on PC cluster
  - Yin[YJSZ06]

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Related Work

- Shared resources from community
  - Johnson[JLMVK06]
- Remote visualization parallel streaming
  - Hu[HTMS07]
- What we address ?
  - Parallel task decomposition strategies
  - Comparative analysis of performance

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RASTeR : Preview

- RASTeR uses two units[BGP09]:
  - K-Patches : Triangulation unit
  - M-Blocks : Data unit

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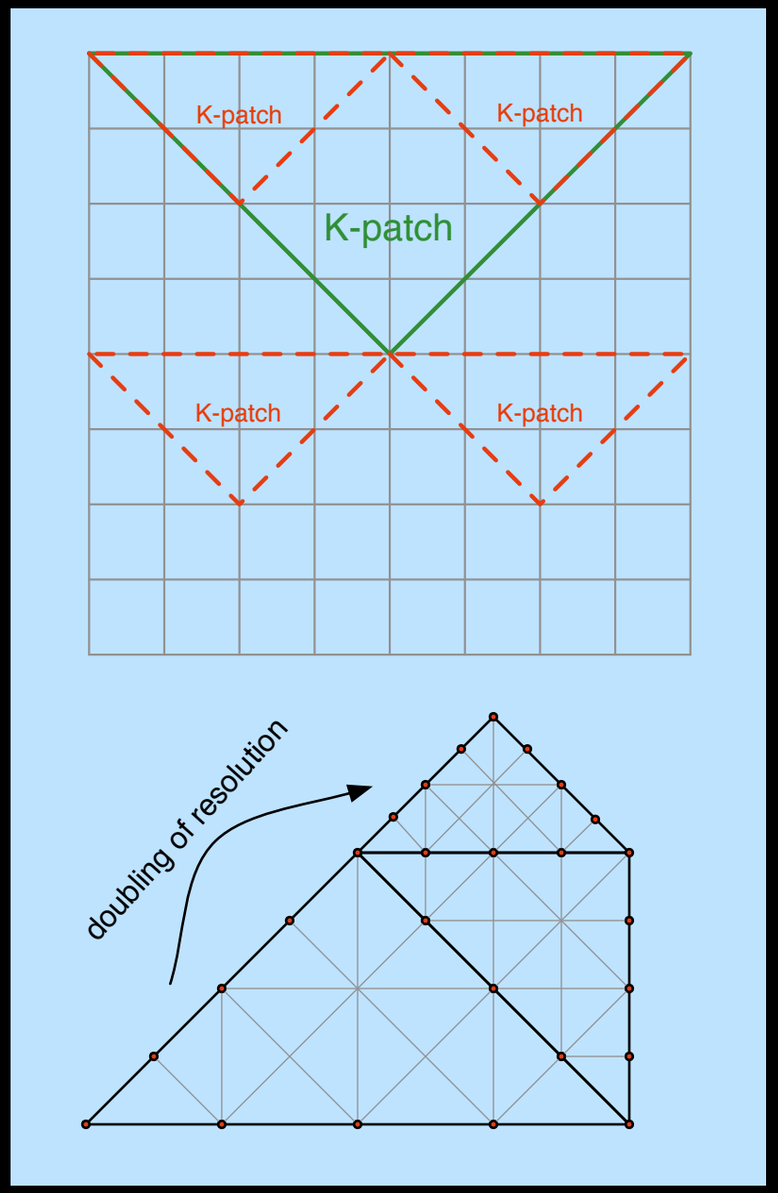
RASTeR : Preview

- K-Patch
  - One of 8 isosceles right triangles
  - K vertices along each edge
  - Triangles within K-Patch arranged as a triangle strip
  - Macro triangles of bintree



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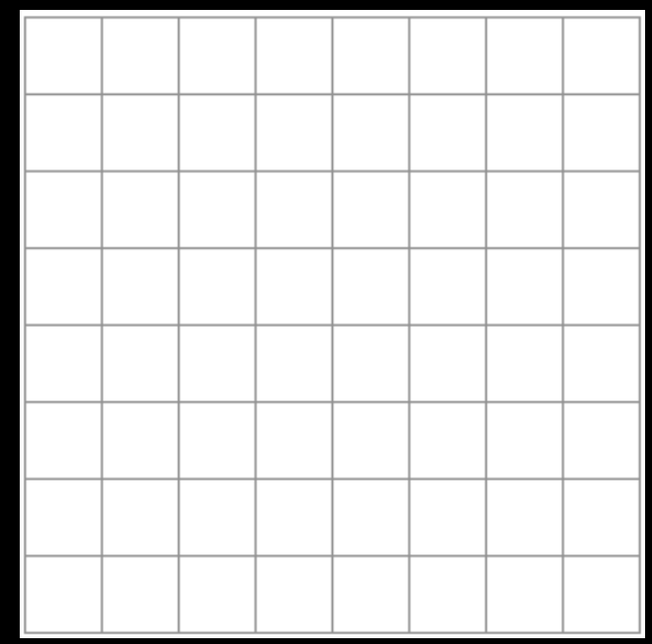
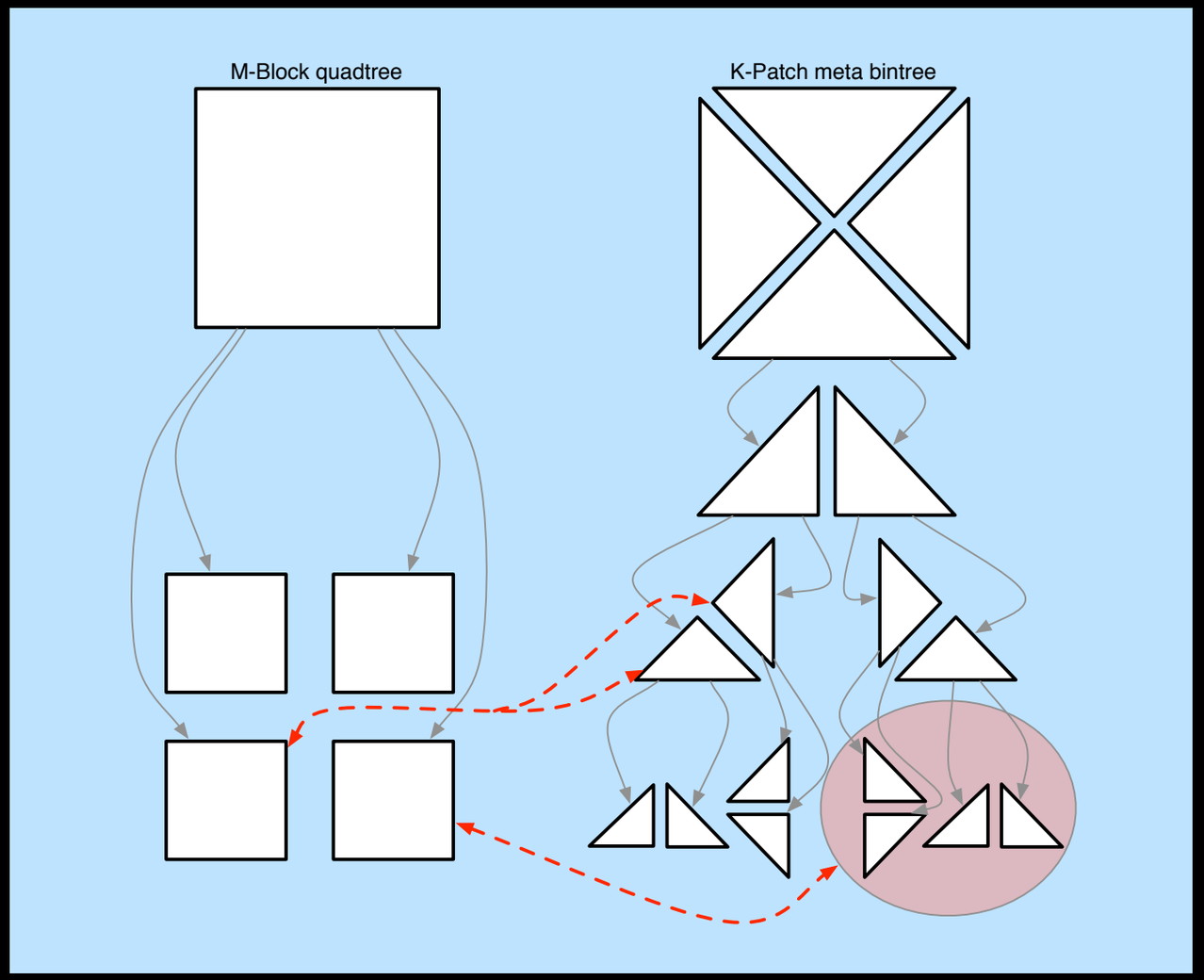
RASTeR : Preview

- M-Block
  - Square block of terrain height data
  - All M-Blocks have same size M x M
  - $M = 2^m + 1$
  - Forms quadtree hierarchy



RASTeR : Preview



K-Patch and M-Block relation

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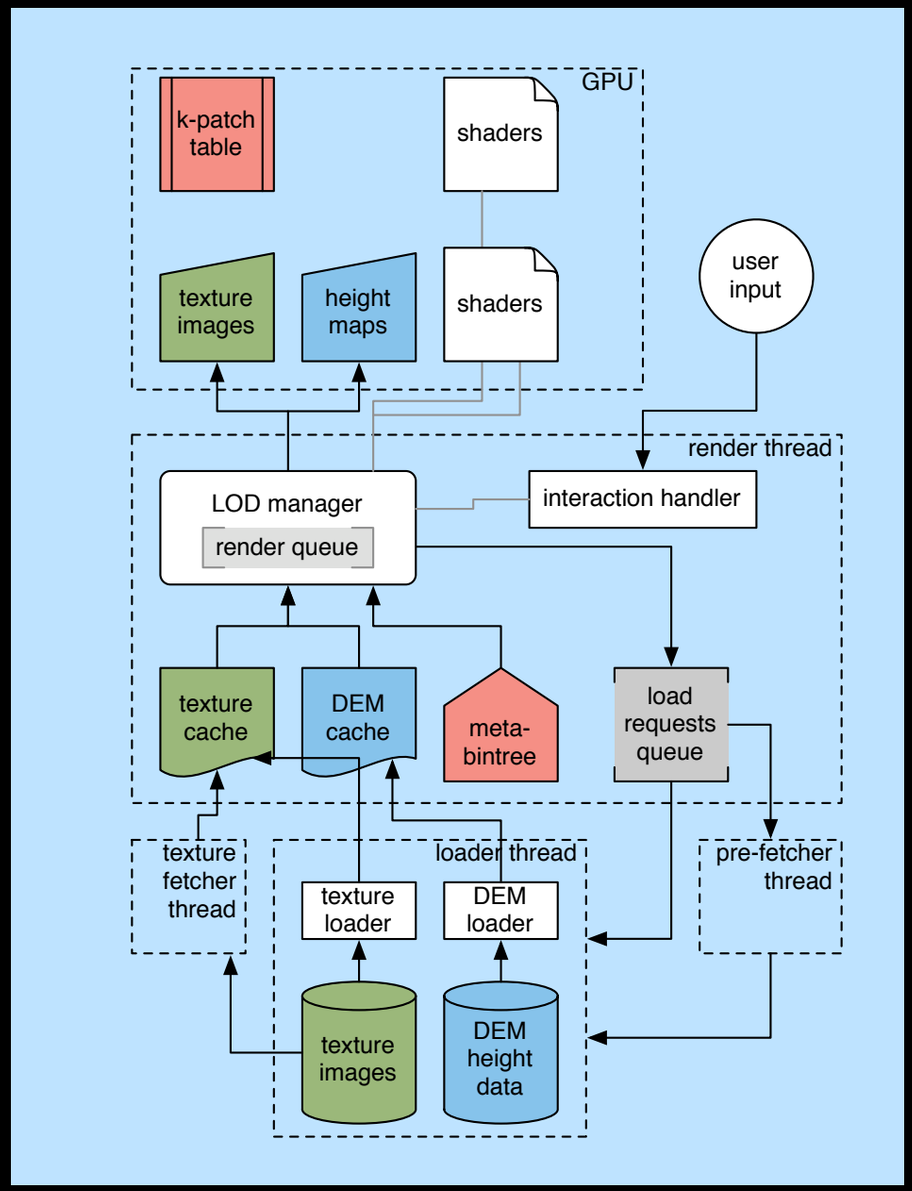
RASTeR : Preview

- View dependent saturated error metric
- Error per K-Patch
- Textures for M-Blocks
- Asynchronous fetching for M-Blocks and their textures



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Why RASTeR?

- GPU-oriented efficient rendering
- Asynchronous fetching
- Complete disentanglement of
  - Height data
  - Triangulation data
- **Easy to parallelize**

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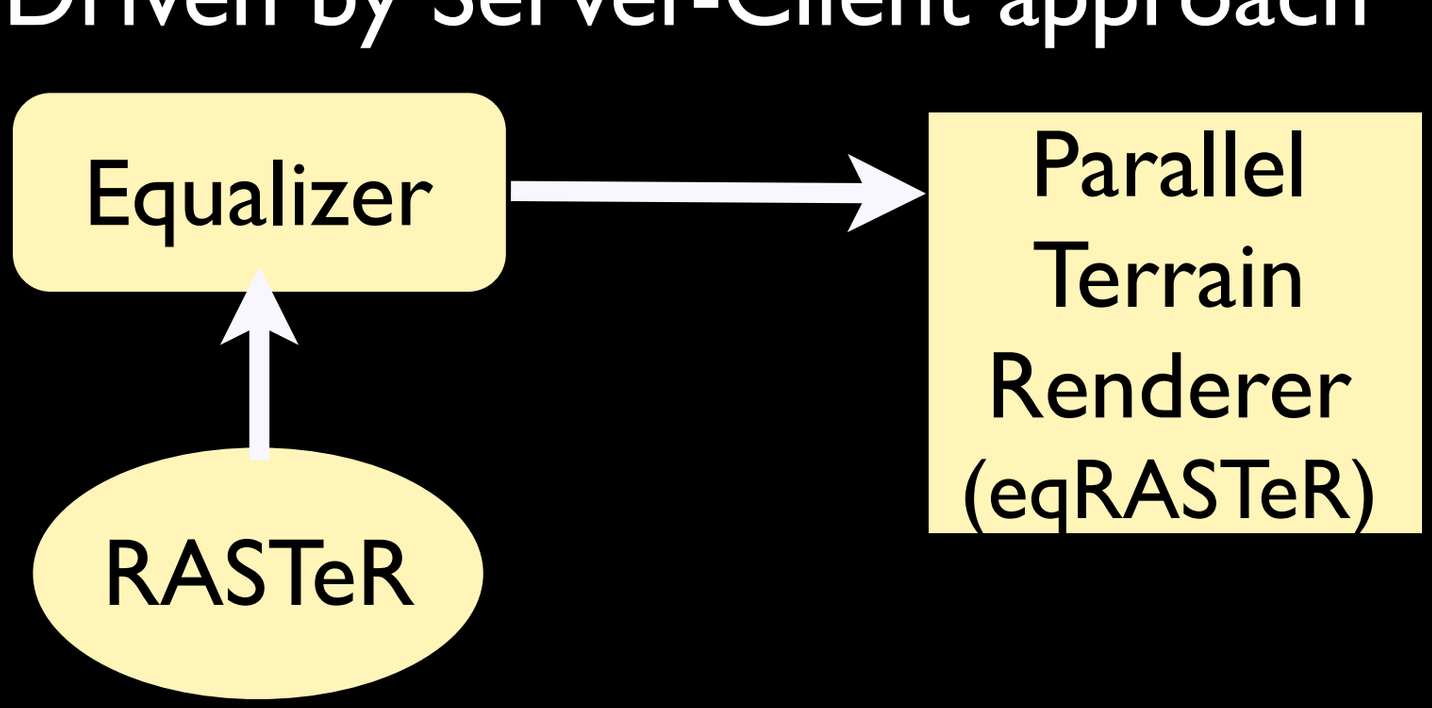
Parallel Terrain Rendering

- Parallelized using **Equalizer**[EMP09]
  - Framework for parallel rendering
  - Driven by Server-Client approach



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RASTeR on Equalizer

- Each machine runs an independent application
- RASTeR modified to obtain from Equalizer
  - Task division parameters
    - Frustum
    - Database range
  - Mouse, keyboard controls, pixel error
    - Same across all nodes

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RASTeR on Equalizer

- RASTeR is multithreaded
  - OpenGL context handling via Equalizer
- Task division managed by Equalizer server

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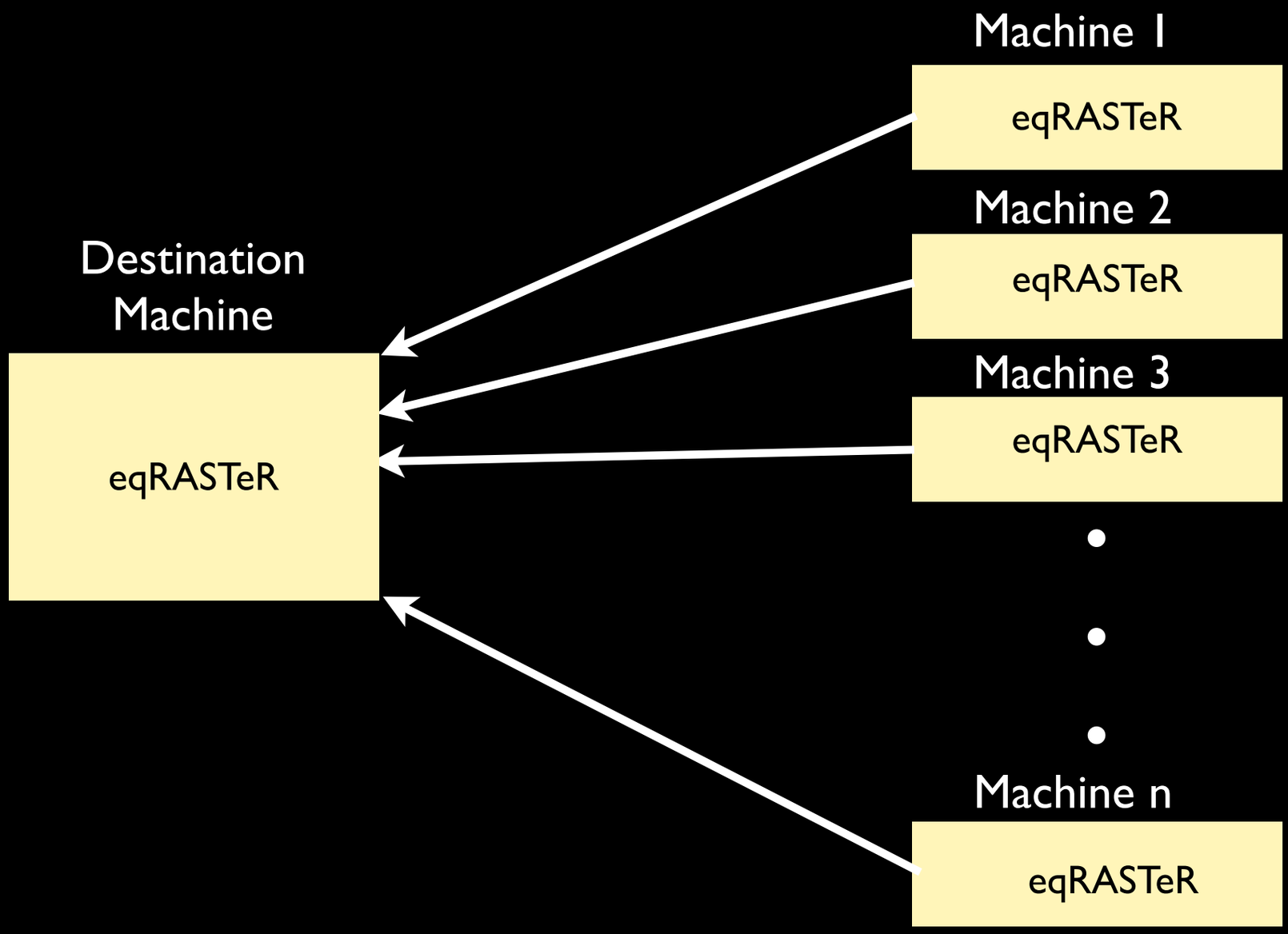
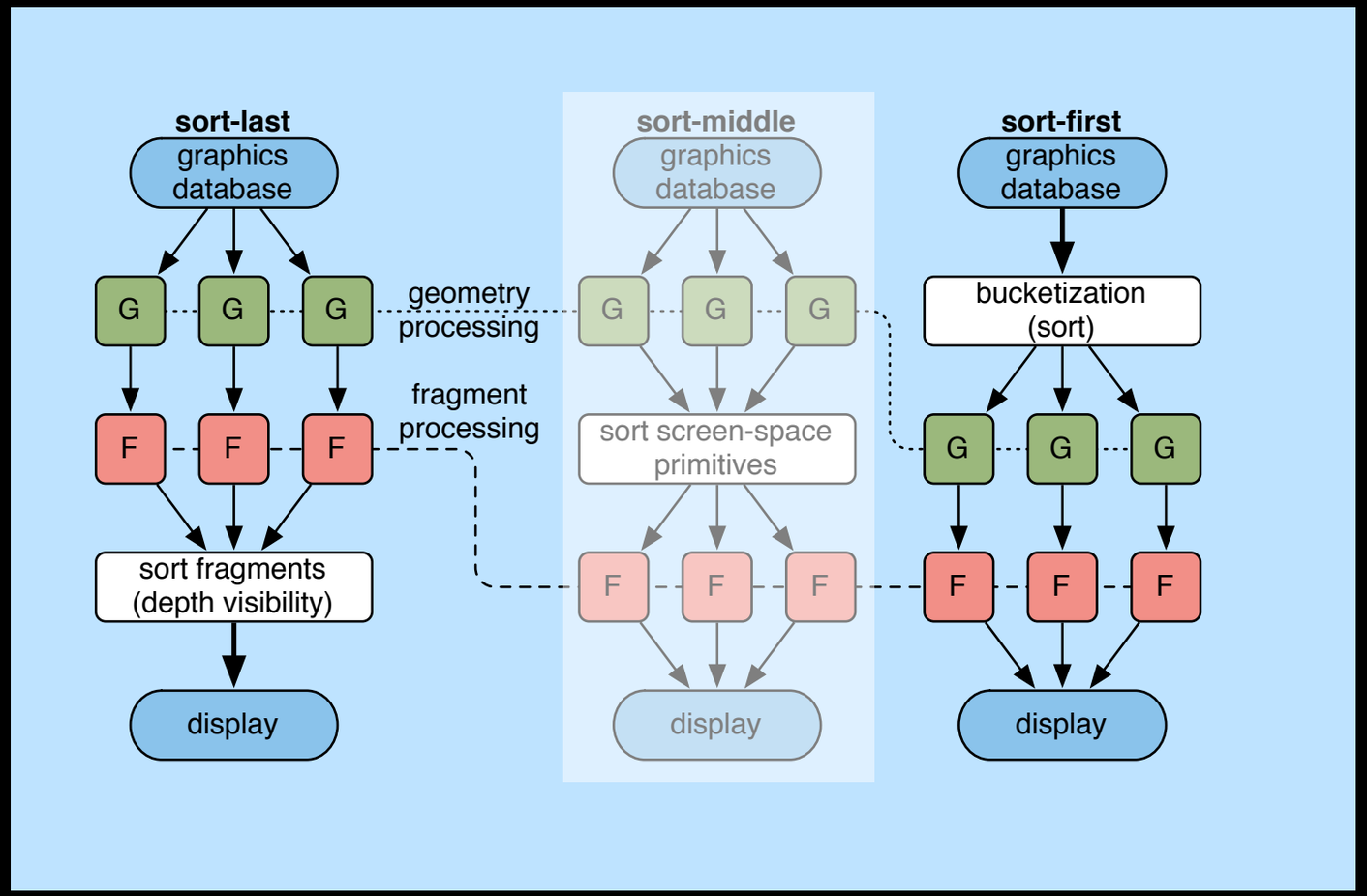

Machine 1
eqRASTeR
Machine 2
eqRASTeR
Destination
Machine
eqRASTeR
Machine 3
eqRASTeR
Machine n
eqRASTeR

Task Division Modes

- Sort-Last / Database Decomposition
- Sort-First / Screen Decomposition

Task Division Modes



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Task Division Modes

- Sort-Last / Database Decomposition
- Sort-First / Screen Decomposition

Optimal Parallelization

- Requires
  - Task is almost equally divided among rendering machines
  - Per-frame inter communication between machines is kept minimal

Sort-Last Decomposition

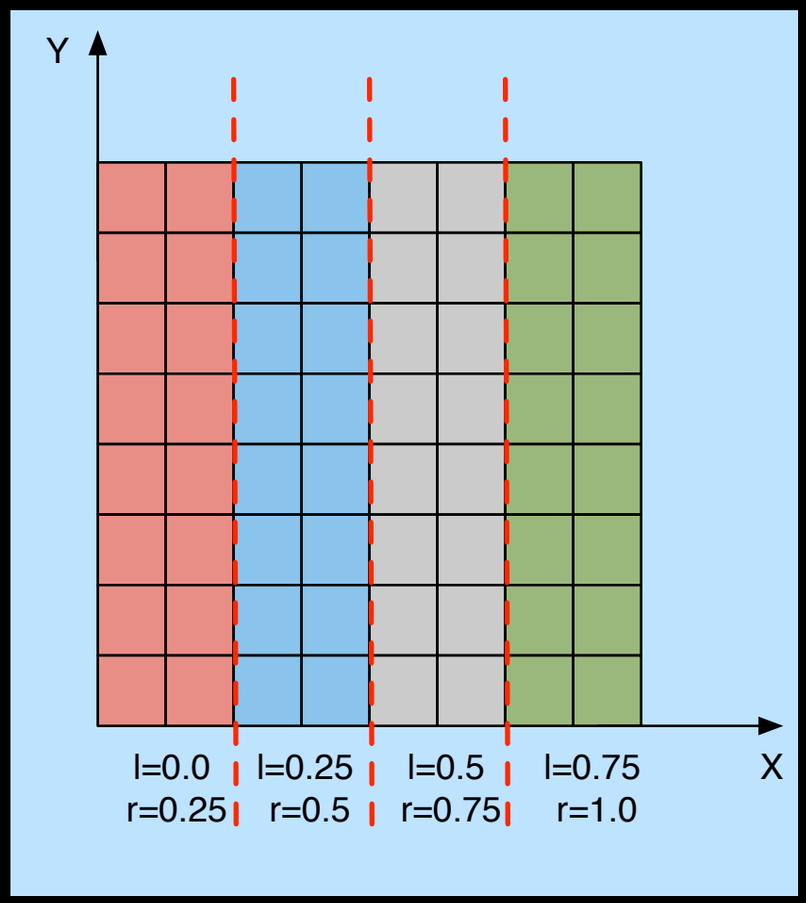
- Given
  - N machines
  - A range between $R = [0,1]$ to each of them ($R_i = [\, i/N, (i+1)/N \,]$)
- Divide the visible rendering data as equally as possible in database domain
- All machines obtain same frustum from Equalizer

Linear Enumeration

- Each machine in parallel :
  - Gets range Ri = [l, r]
  - Traverses bintree
  - Selects K-Patches with M-Blocks having origin O_M

$$l*X_{max} <= O_M(x) <= r*X_{max}$$

(X_{max} = Max X coordinate)



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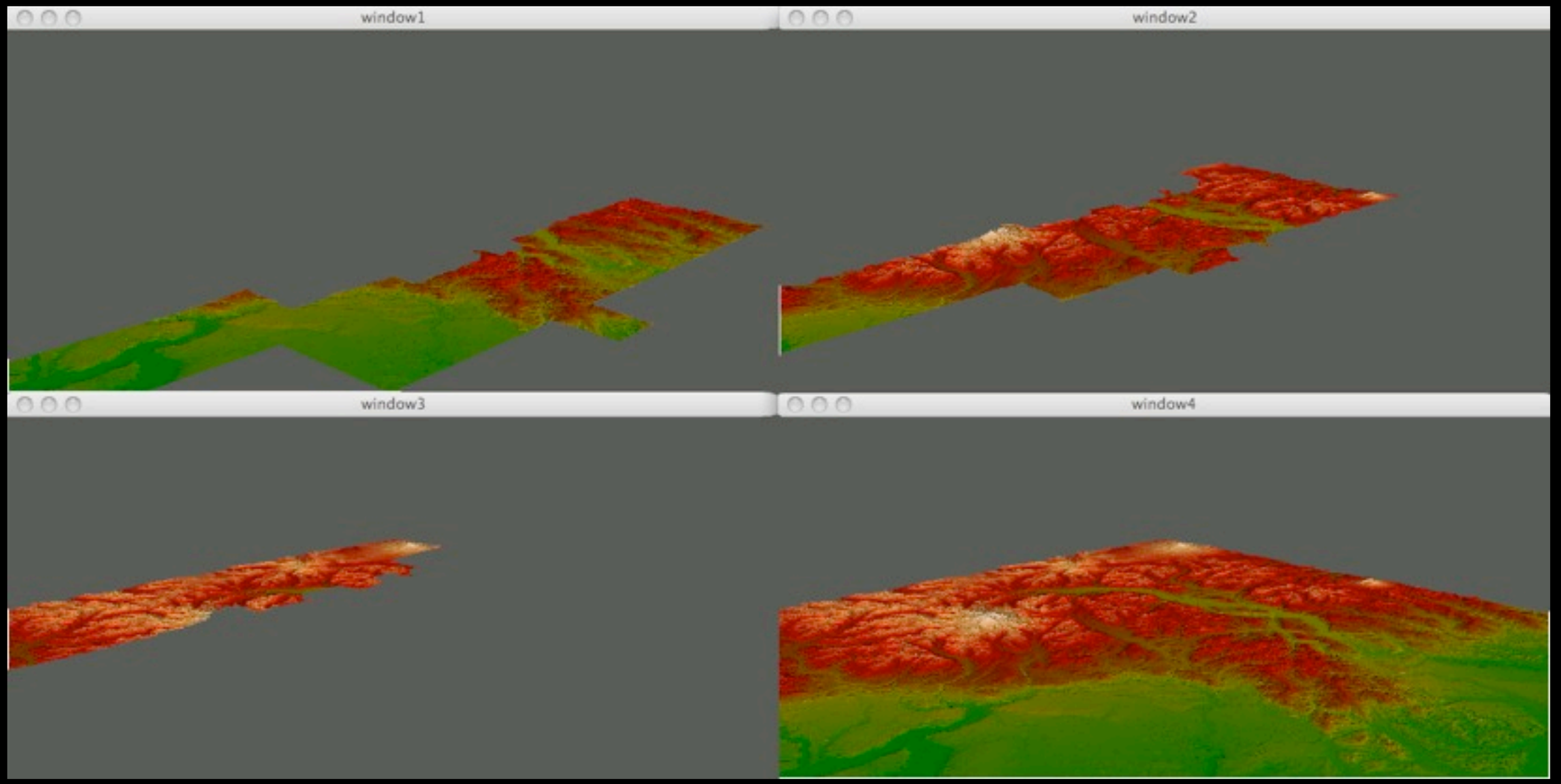
Linear Enumeration



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Linear Enumeration

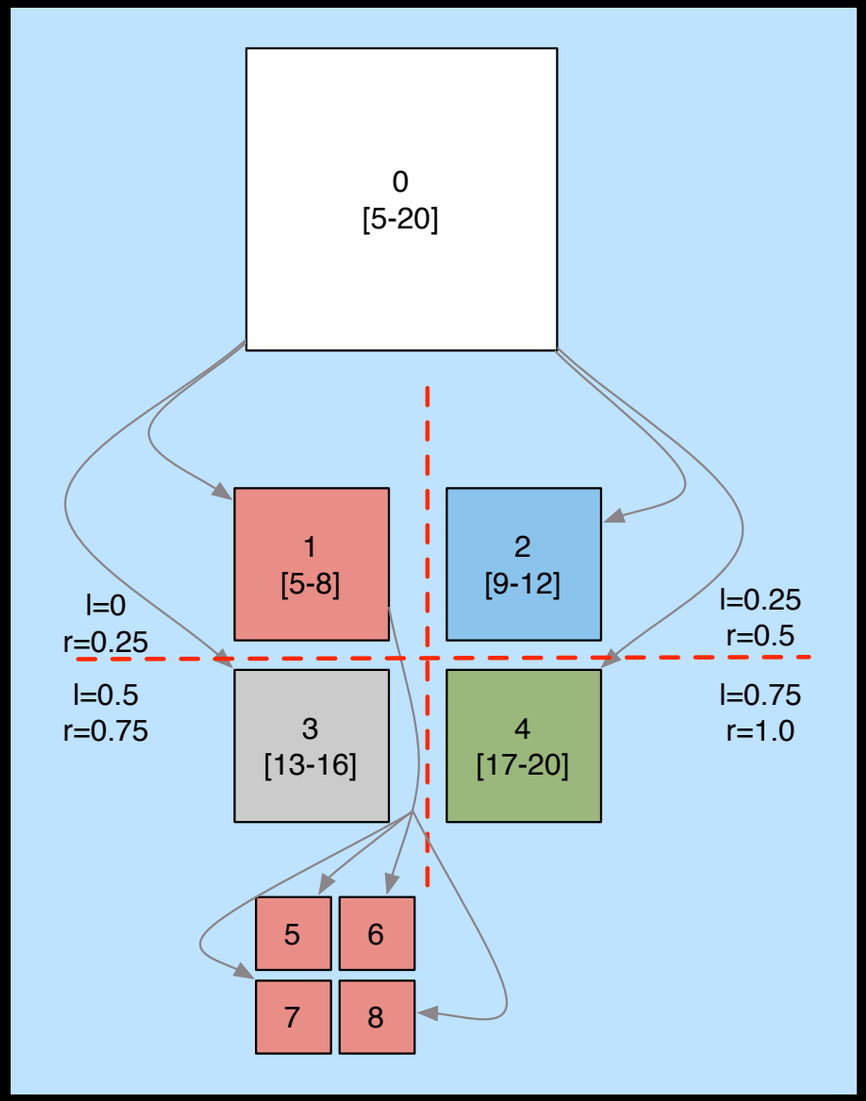
- Drawbacks
  - Traversal coherence lost
    - Division follows M-Blocks, not K-Patches
    - Susceptible to changes on translation and rotation
  - Data distribution among machines unequal

Quadtree Enumeration

- Enumerate nodes of quadtree
- Assign intervals [L,R] to each node in bottom-up fashion
  - Range of a node covers that of all its descendants
- Given range Ri = [l, r], select M-Blocks

$$l * n_{max} <= [L, R] <= r * n_{max}$$

n_{max} : maximum number of leaf nodes



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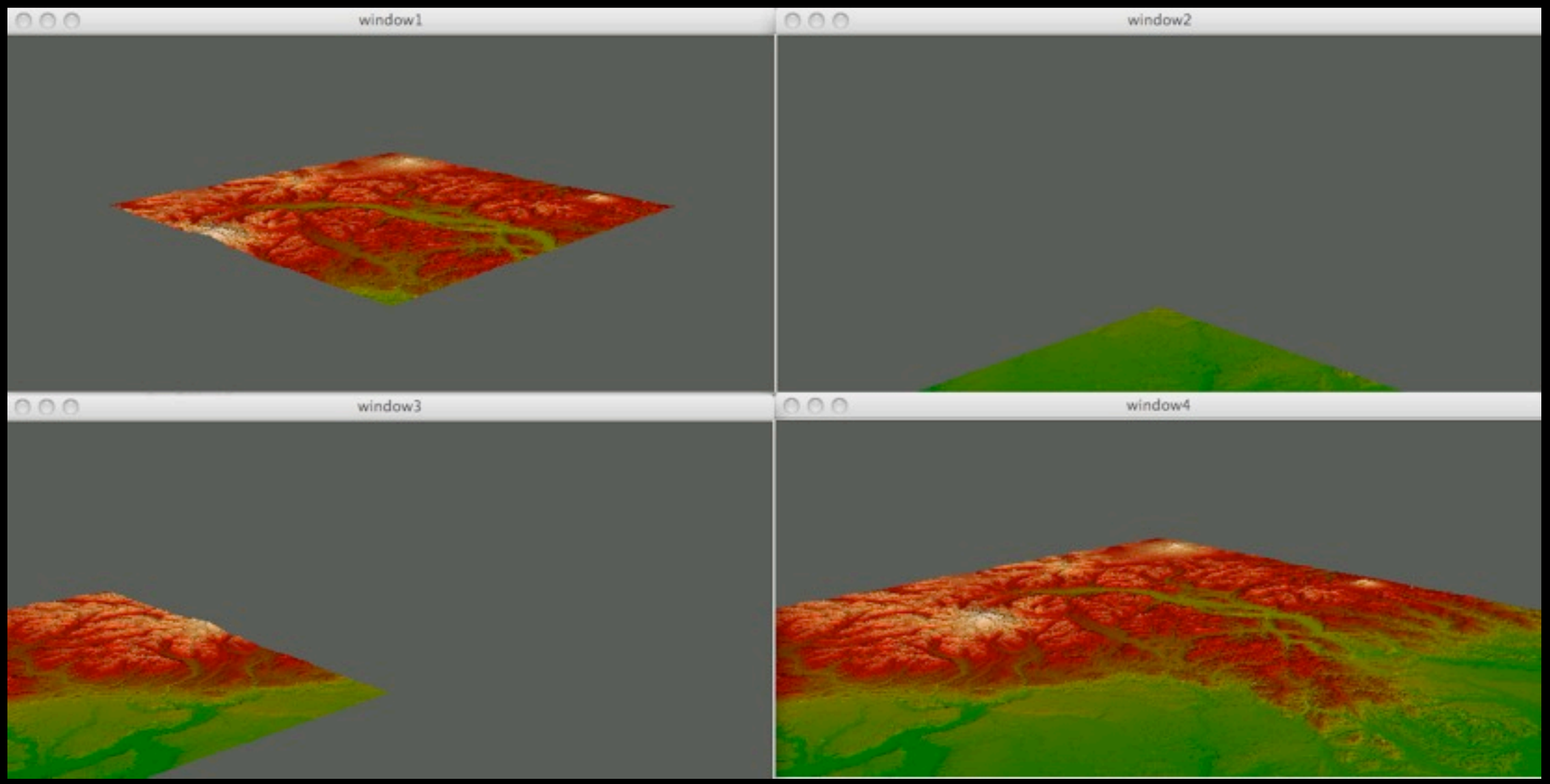
Quadtree Enumeration



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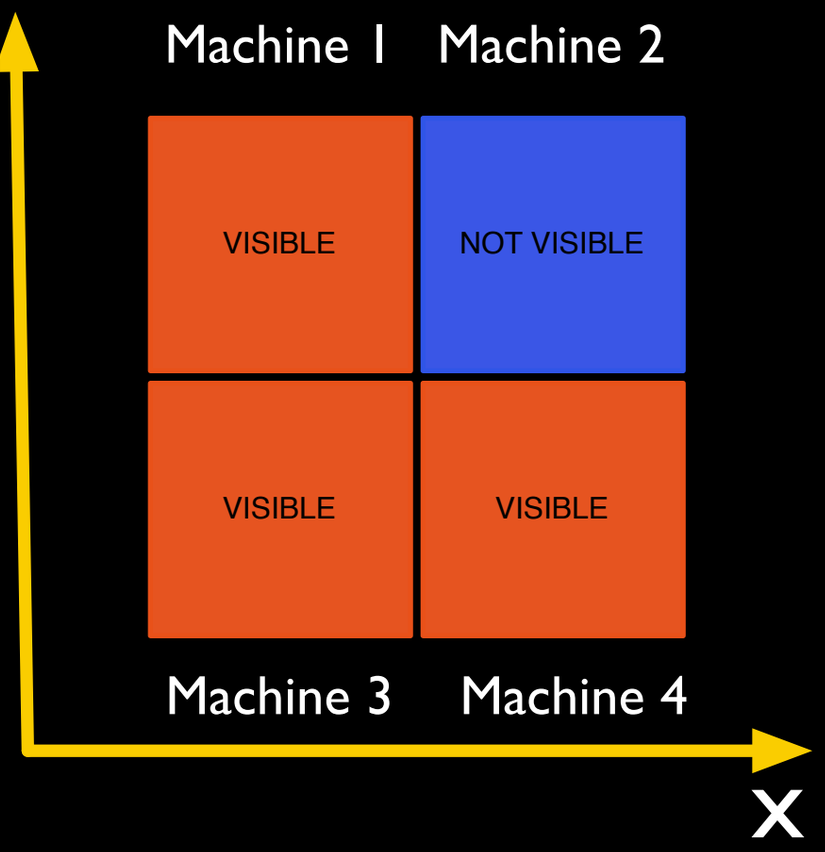
Quadtree Enumeration

- Evaluation:
  - More coherence in tree traversal
  - Less susceptible to changes upon rotation, translation
  - More uniformly distributed data
  - Can’t ensure that each machine gets similar amount of rendering data

Optimal Task Distribution

- In both Linear Enumeration and Quadtree Enumeration
  - Machine with no data visible will be idle



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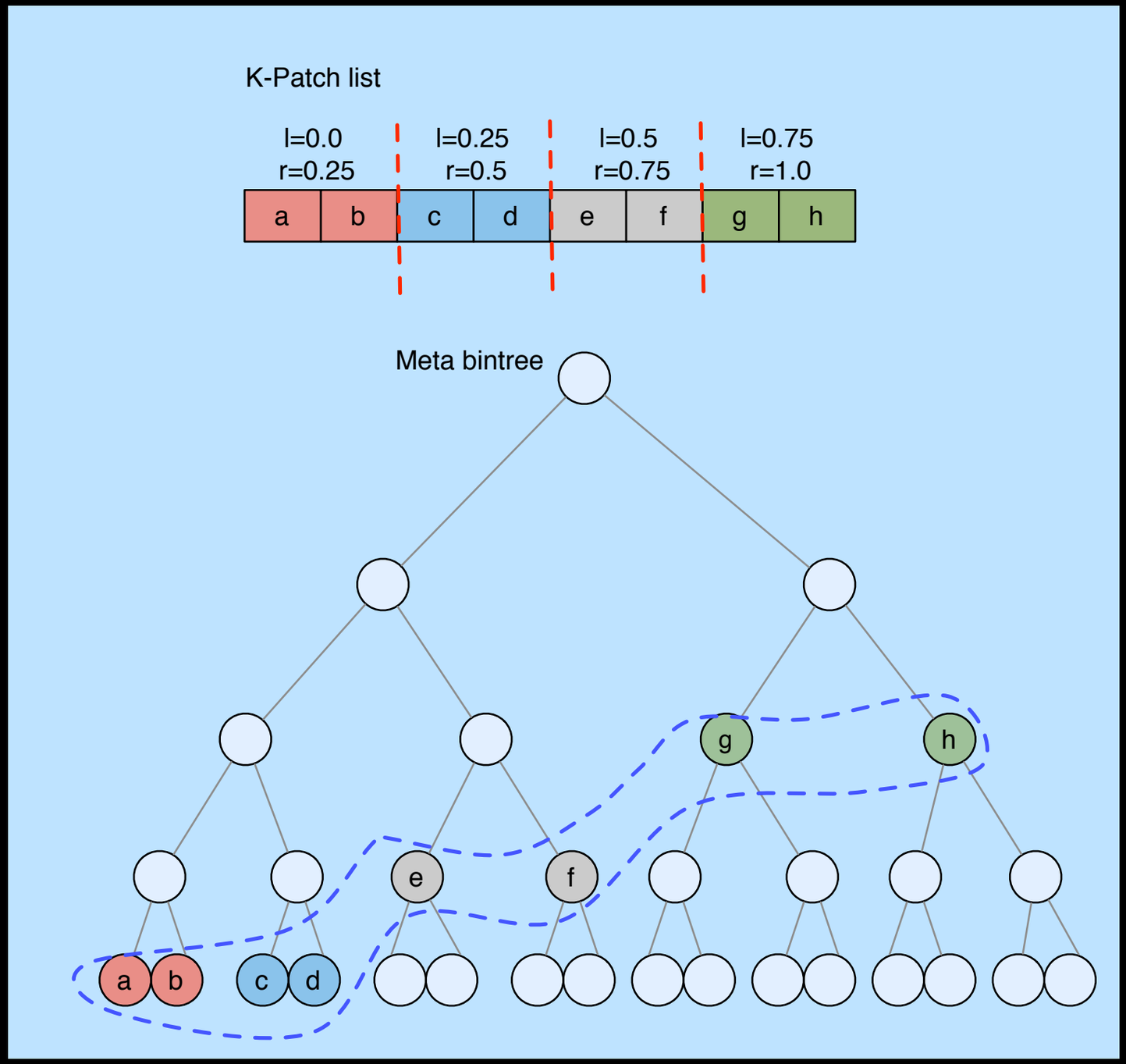
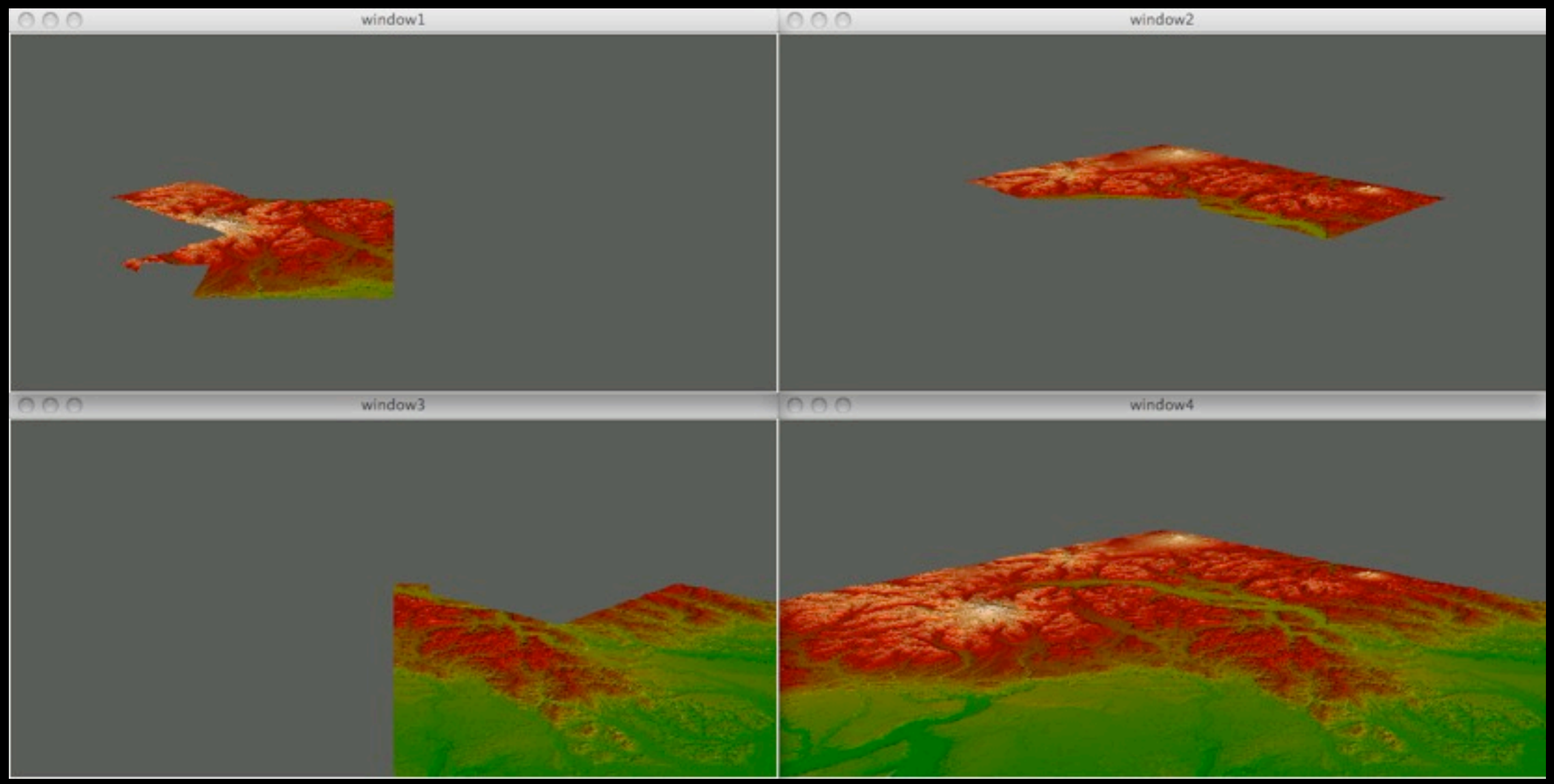
Active K-Patch Enumeration

- This is where RASTeR helps!
  - Each K-Patch has same number of triangles
- K-Patch list for a given frame similar on all machines
- Post K-Patch list selection, divide them equally among all machines
- Range R_i used for mapping
  - No inter-machine communication needed

Active K-Patch Enumeration



Active K-Patch Enumeration



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Active K-Patch Enumeration

- Evaluation:
  - Coherence in tree traversal
  - Less susceptible to changes upon rotation, translation
  - Uniformly distributed data
  - Ensures that each machine gets similar amount of rendering data
    - Automatic load balancing

Task Division Modes

- Sort-Last / Database Decomposition
- Sort-First / Screen Decomposition

Sort-First Decomposition

- Task division in screen space
- Each machine updates its frustum to the one its obtains from Equalizer server
- Different machines render mutually exclusive part of terrain
  - Final image assembly does not require z-depth or alpha-compositing
- Load balancing through Equalizer server

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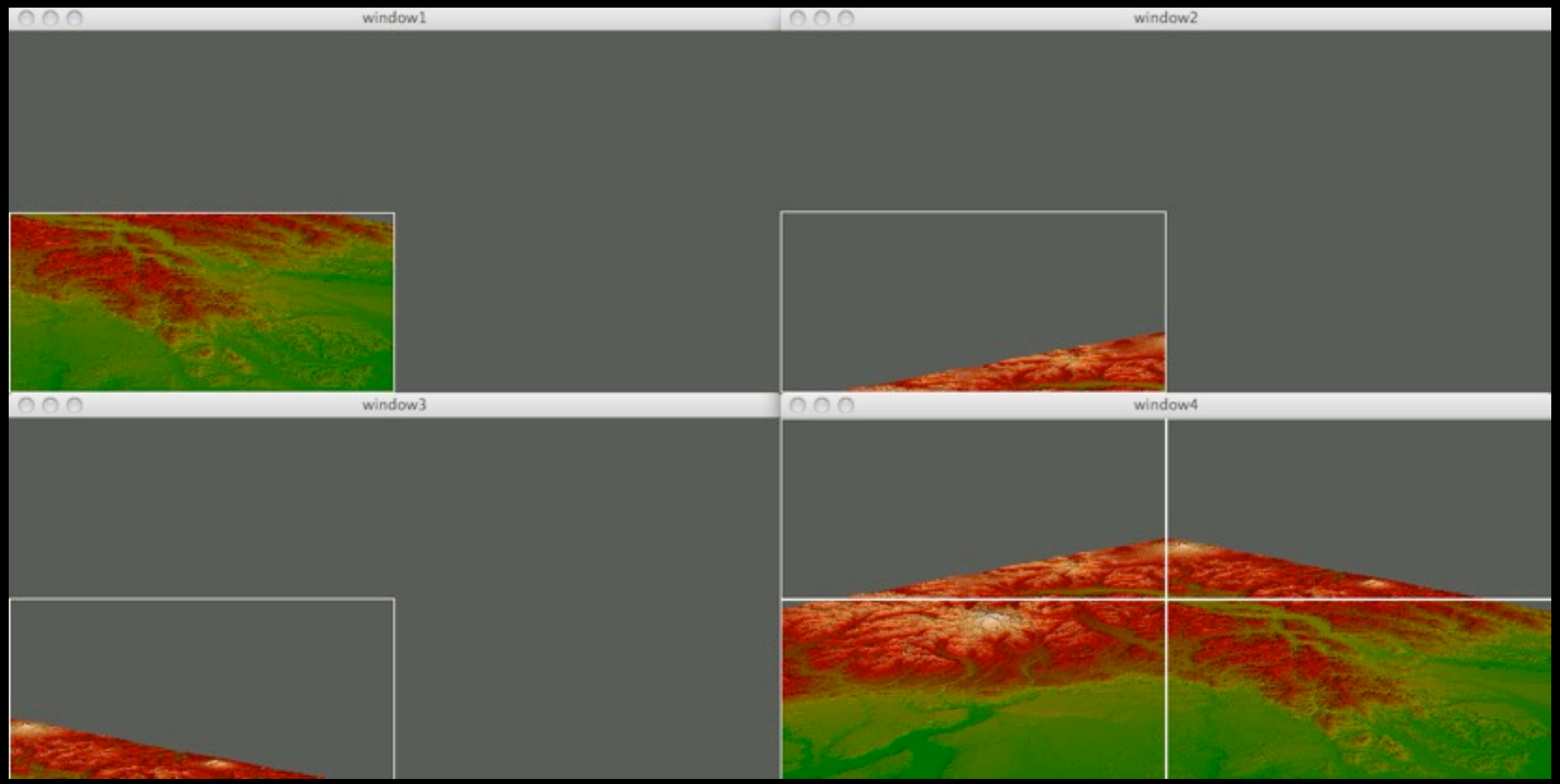
Sort-First Decomposition



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Results

- Equalizer and RASTeR : C++ / GLSL
- 10 Linux Machines in Cluster:
  - 2 Gbit/s Myrinet for Image Compositing
  - 1 Gbit/s network for data-retrieval
  - Dual 2.2 GHz AMD Opteron CPU
  - 4 GB RAM
  - GeForce 9800 GX2 graphics

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Results - DB Decomposition

- Linear Block and Quadtree Enumeration
  - Need load balancing from Equalizer server
  - Do not provide scalable sort-last rendering
- Active K-Patch enumeration
  - Provides automatic load-balancing
  - Performance scales with # of machines

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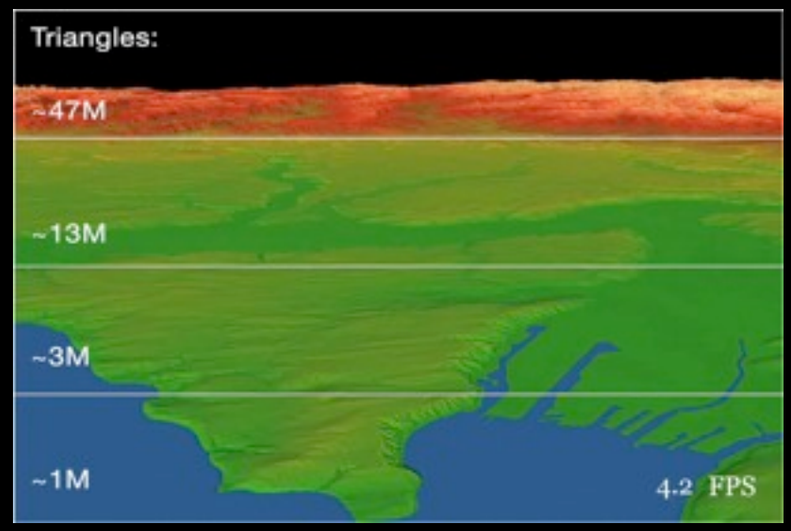
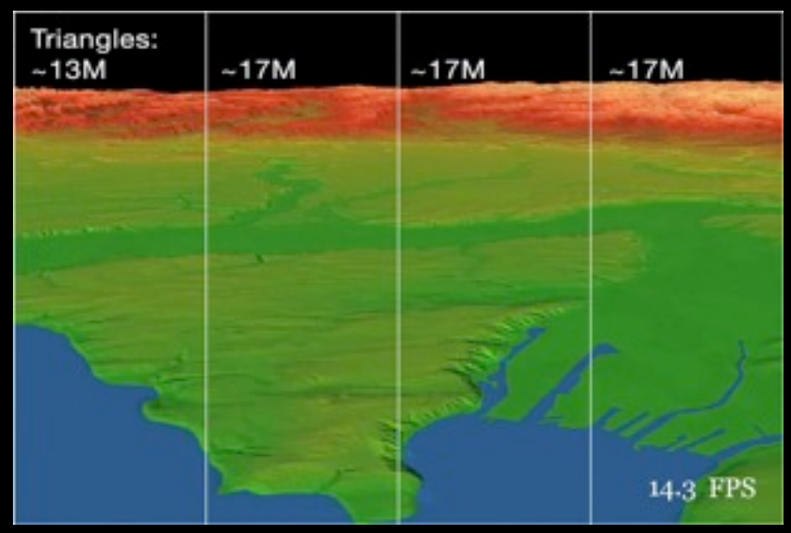
Movie

Results - 2D Decomposition

- 2 kinds of 2D decomposition
  - Vertical Tiling
    - Uneven distribution of data per tile
  - Horizontal Tiling
    - More even distribution of data per tile





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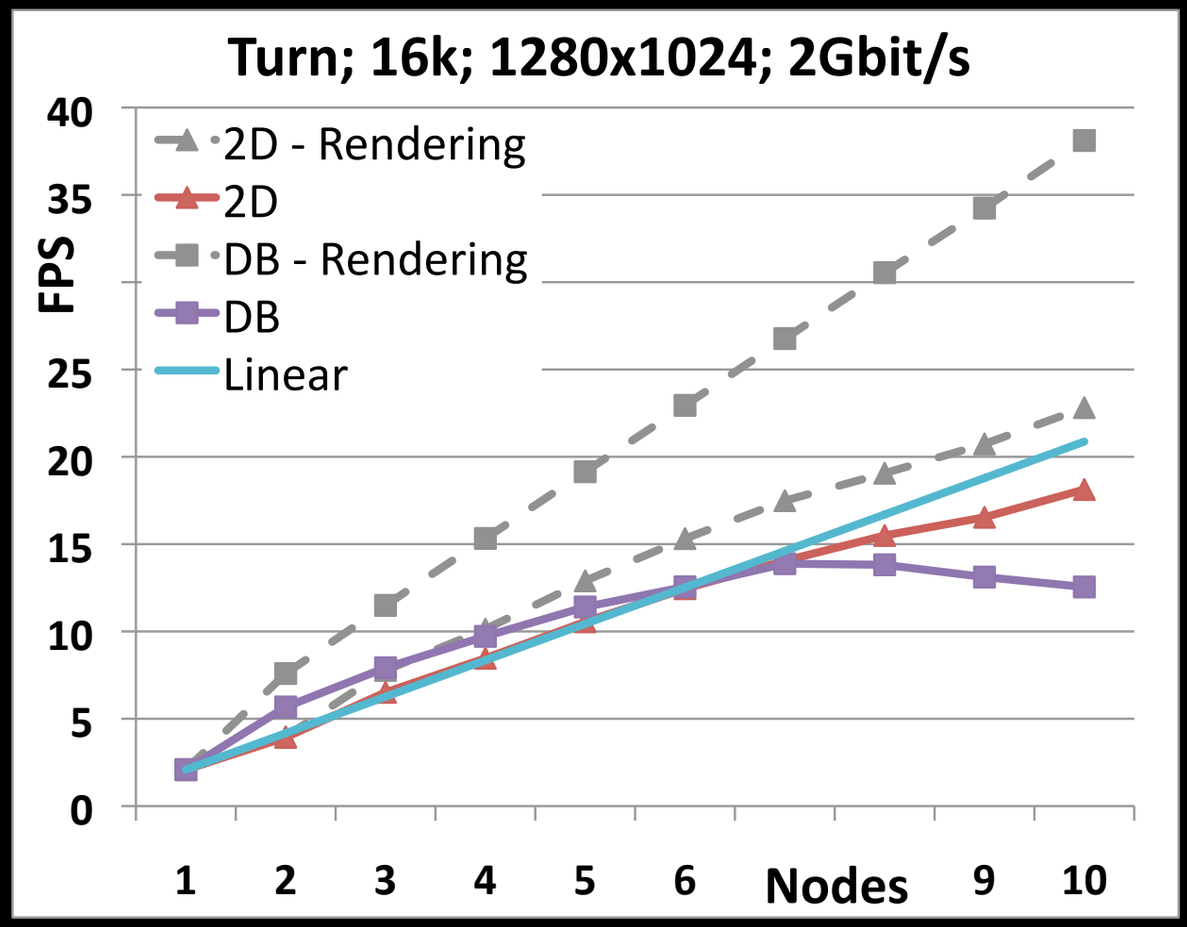
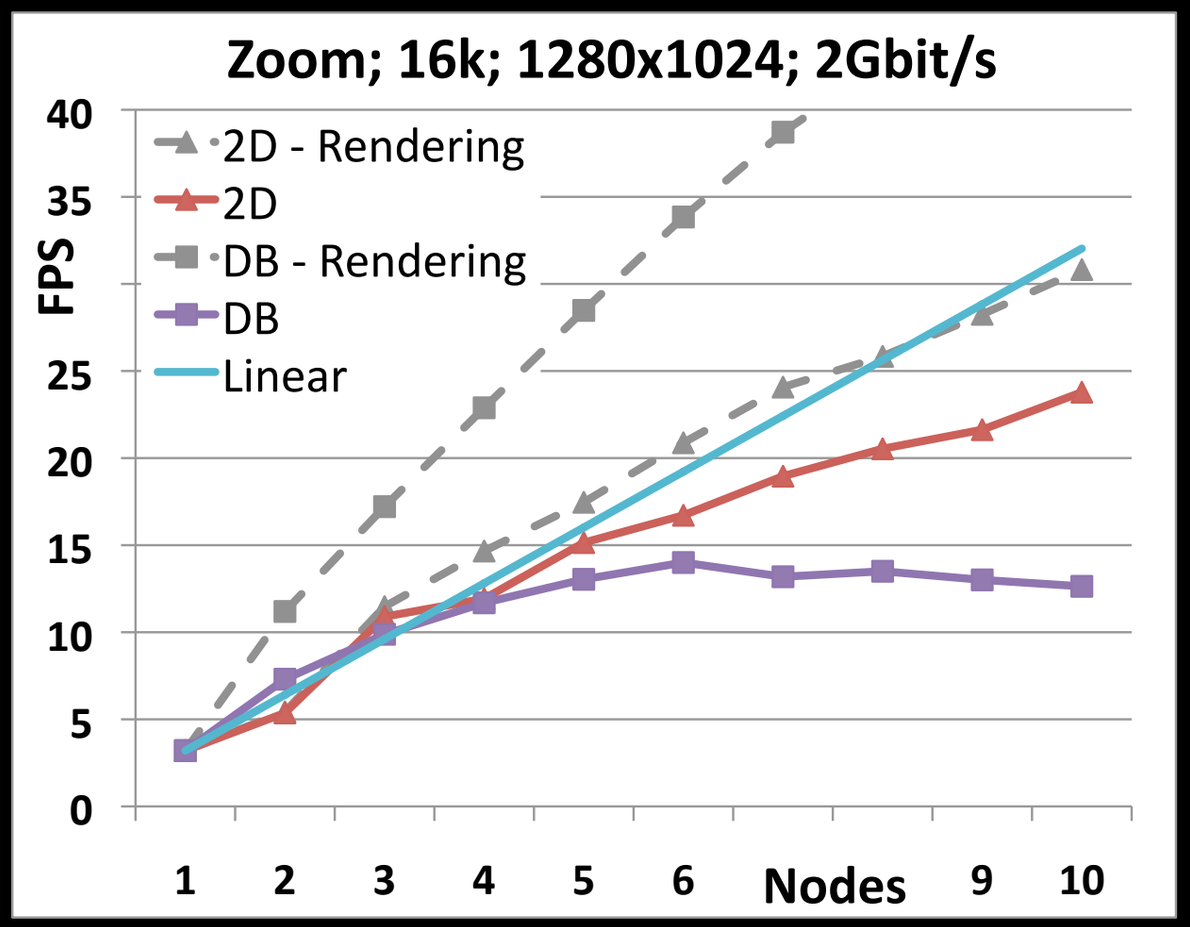
Puget Sound : 16 k X 16 k





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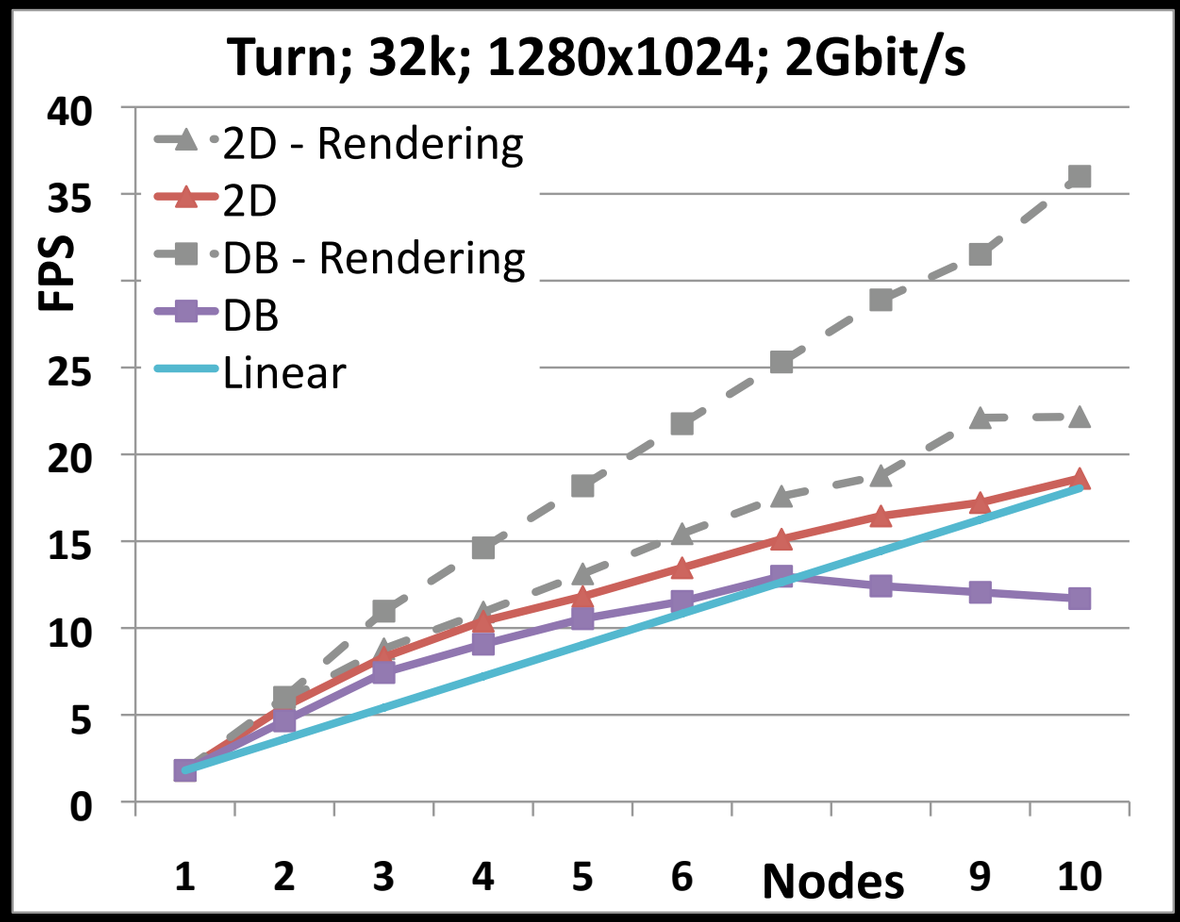
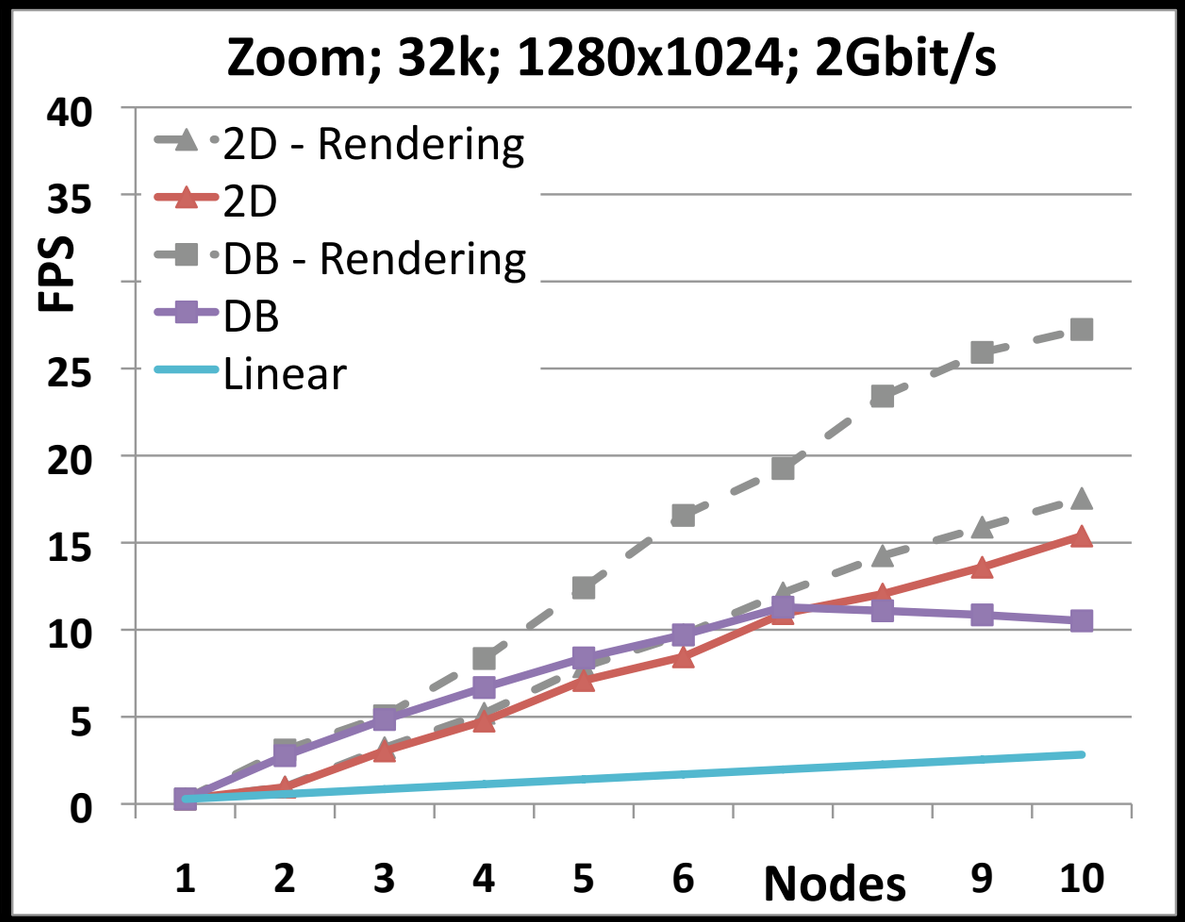
SRTM : 32 k X 32 k





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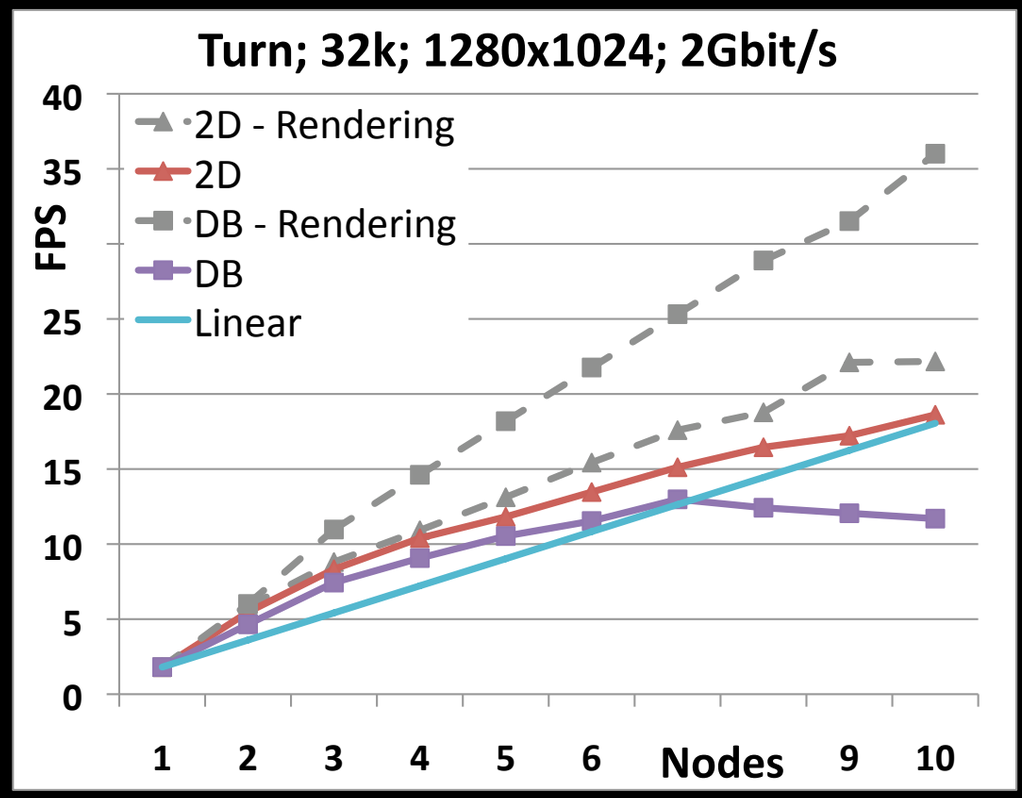
Performance Analysis

- Pure rendering scales at least linearly
- Pure rendering scales better in Sort-Last



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Performance Analysis

- Overall rendering performance also depends on compositing
  - Reading partial images
  - Transmission over network
  - Assembling at destination machine
- Sort-last transmits twice the amount of data per frame than sort-first

Results - 2D Decomposition

Display Wall Configuration

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Conclusion

- We have presented:
  - Parallel solution for real-time multi-resolution out-of-core terrain visualization
  - Efficient LOD based adaptive solution for automatic load balancing
- We have addressed:
  - Challenges in distributed environment

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Thank You!


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