Scalable Ray Tracing Using the Distributed FrameBuffer

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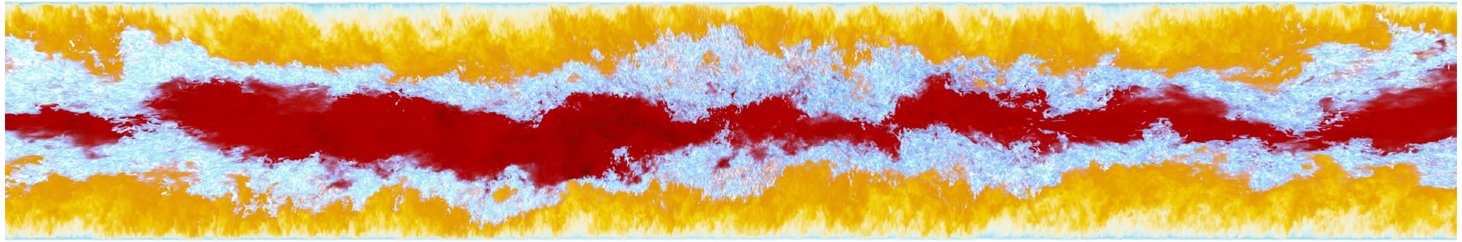
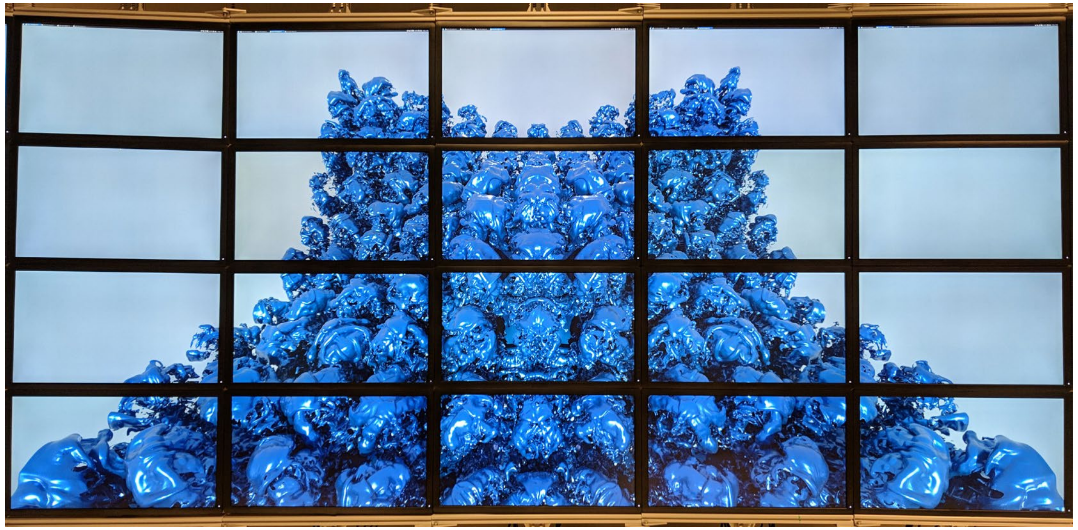
Challenging Rendering Problems Demand More Compute and Memory

- Expensive shading/geometry and high-resolutions require more compute for interactive rendering
- Large datasets (100+GB to TBs) cannot fit on one node
- In Situ visualization inherently requires multi-node rendering



951GB volume + 4.35B triangles at 4096x1024



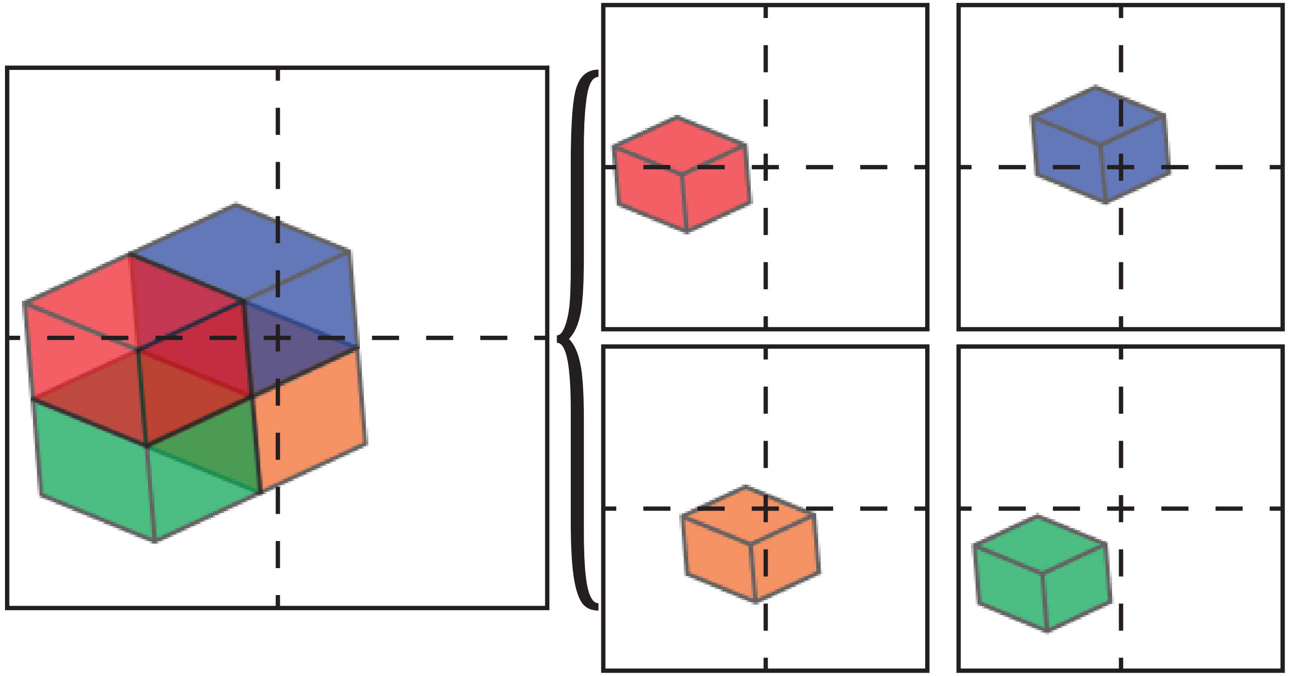
222M triangles w/ path tracing at 12800x5760

Prior Work

- Sort-last: Distribute sub-regions of **data** to render, sort partial images produced on each node
- Sort-first: Distribute sub-regions of **image** to render, sort objects before or during rendering
- Hybrid: Combine image and data work distributions

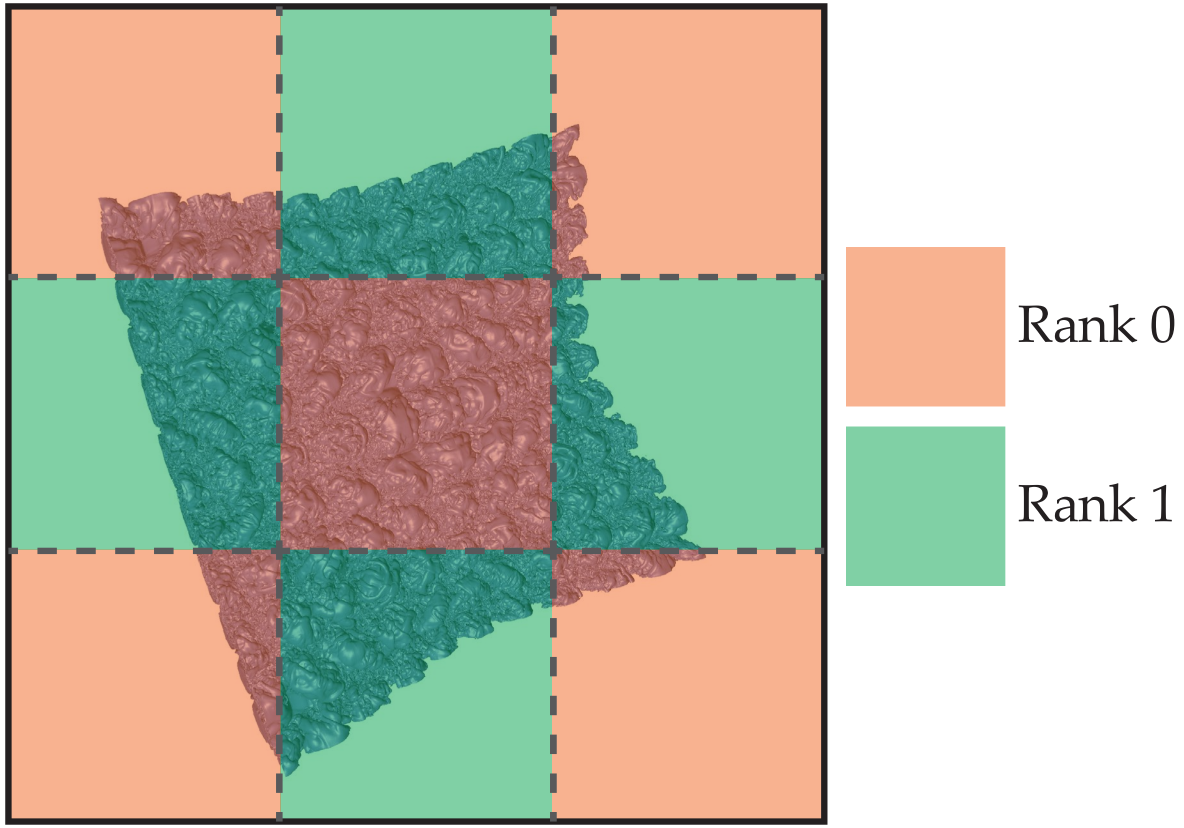
Sort-Last: Object-Space Work Distribution

- “Data-parallel” rendering
- Brick dataset and distribute among nodes, or using an existing distribution (in situ)
- Render each brick locally, composite partial images [Hsu 93; Ma et al. 94; Peterka et al. 09; Moreland et al. 11; Grosset et al. 15]



Sort-First: Image-Space Work Distribution

- "Image-parallel" rendering
- Work unit: Image tiles
- Load balancing [Wald et al. 01; Ize et al. 11]
- Large data: page from disk or network into cache on-demand [Wald et al. 01; DeMarle et al. 03, 04 & 05; Ize et al. 11]



Limitations of Prior Work

- Purpose-built solutions for each approach (sort-last, sort-first)
- Widely available software for sort-last [Moreland et al. 11] imposes restrictions on the data-distribution between nodes
- Sort-first methods can bottleneck on the master process at high-resolutions
- Widely used methods do not overlap image compositing/processing with rendering

Our Contributions

- A flexible and scalable parallel framework to run image compositing and processing tasks for distributed renderers

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- A set of parallel rendering algorithms built on this approach, covering standard use cases and more complex configurations

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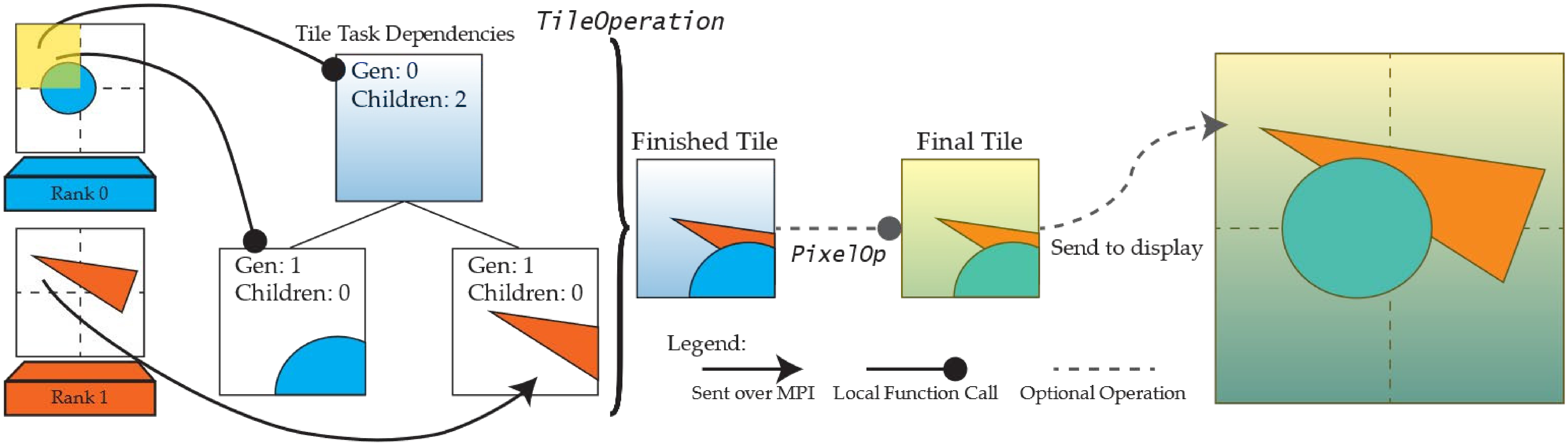
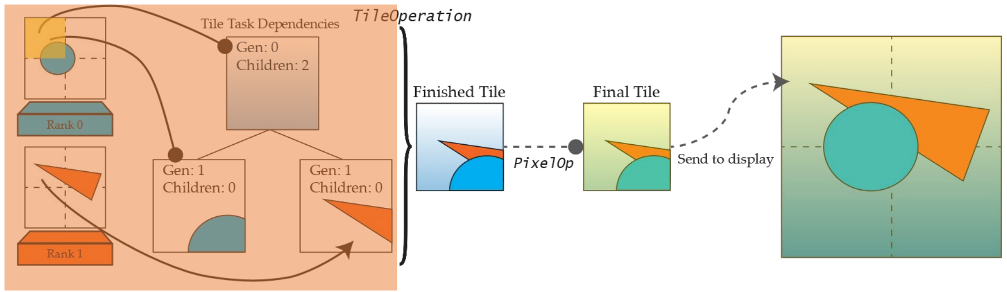
- A flexible and scalable parallel framework to run image compositing and processing tasks for distributed renderers
- A set of parallel rendering algorithms built on this approach, covering standard use cases and more complex configurations
- An extension of OSPRay to implement a distributed API, exposing the parallel rendering capabilities to end users

The Distributed FrameBuffer

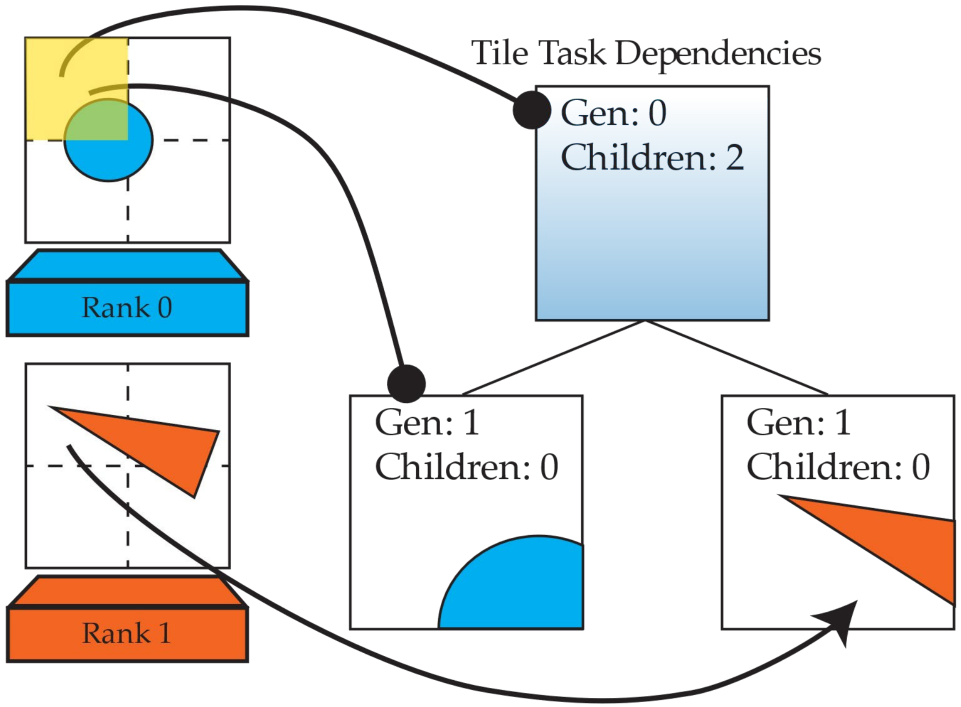
The DFB Tile Processing Pipeline



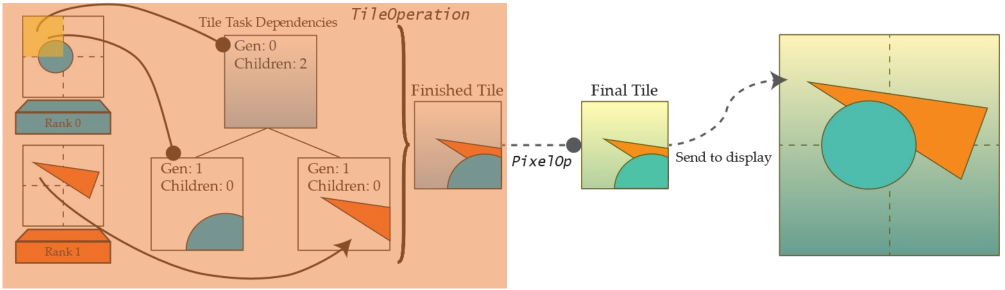
Tile Task Dependencies



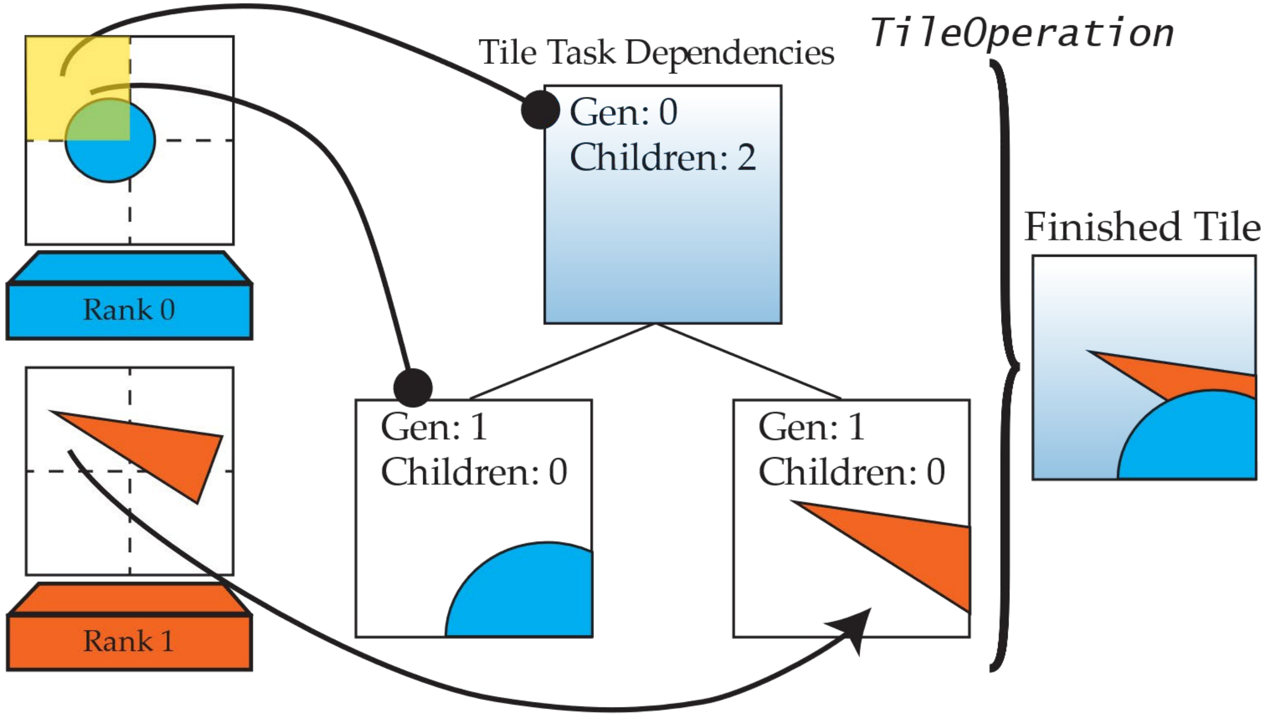
- Rendered input tiles can build a per-tile task dependency tree at runtime
- Tree construction and dependency tracking is managed by the TileOperation



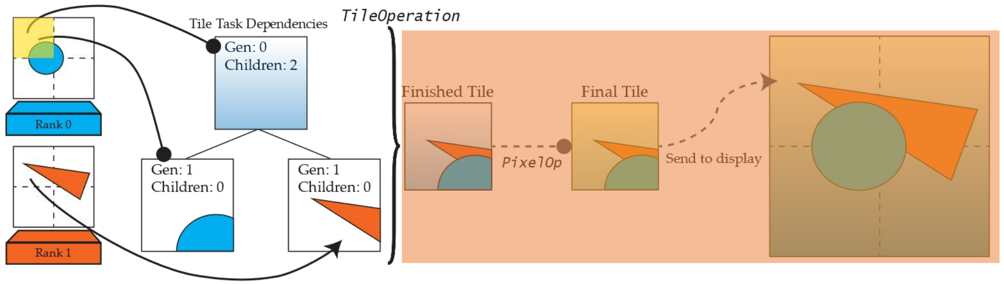
Tile Operations



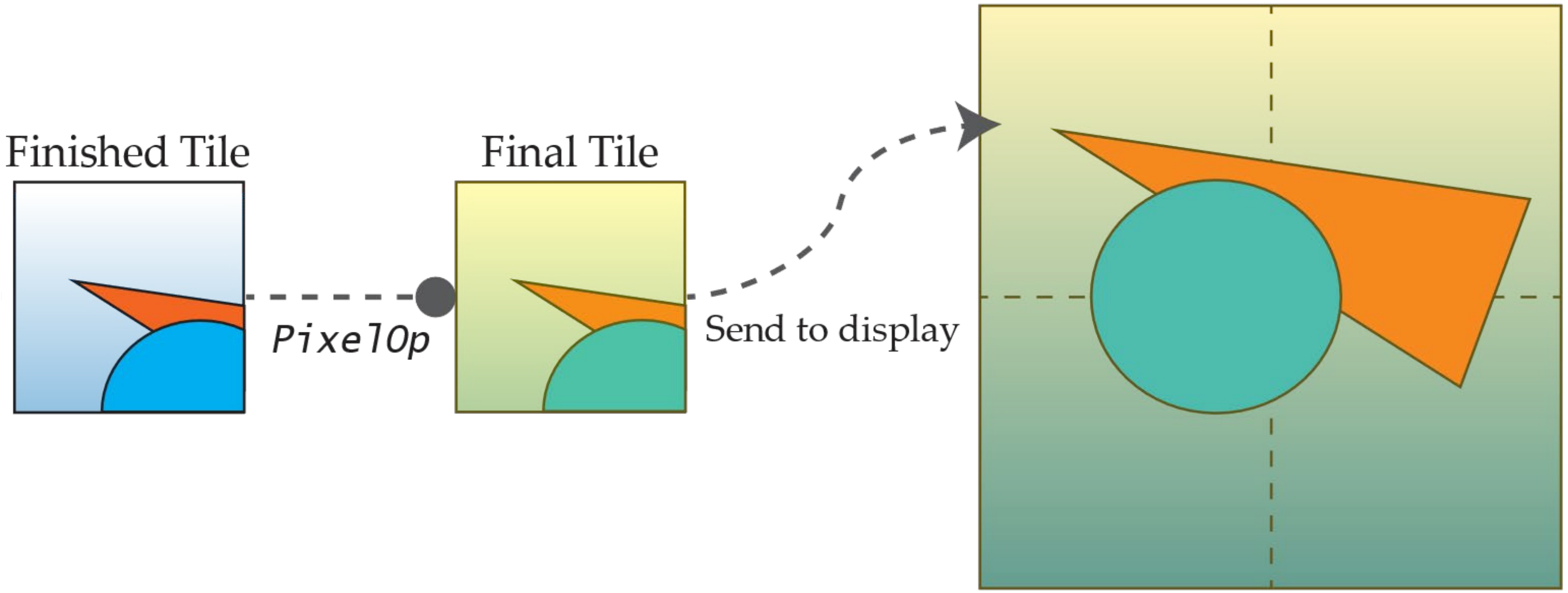
- Specifies how tiles should be combined to form the final image from the input tree
  - E.g., averaging, depth sorting, alpha-compositing



Pixel Operations



- Optional additional post-processing can be added via PixelOps
  - Tone mapping, denoising, etc.
  - Re-routing tiles to a display wall
- Independent of the Renderer and TileOperation



Asynchronous MPI Messaging Layer

- Communication runs on a background thread on each process, using non-blocking MPI
- DFB tile and pixel operations executed on background threads as dependencies are recieved
- Tile messages compressed with Snappy [Google]
- Final tiles are gathered to the master process with MPI_Gatherv

Rendering with the Distributed FrameBuffer

Anatomy of a Distributed Renderer

- Distributed Renderer = Renderer + TileOperation
- *Renderer*: Render local data to create tile task inputs
- *TileOperation*: Interpret and combine tile task inputs to make the finished image

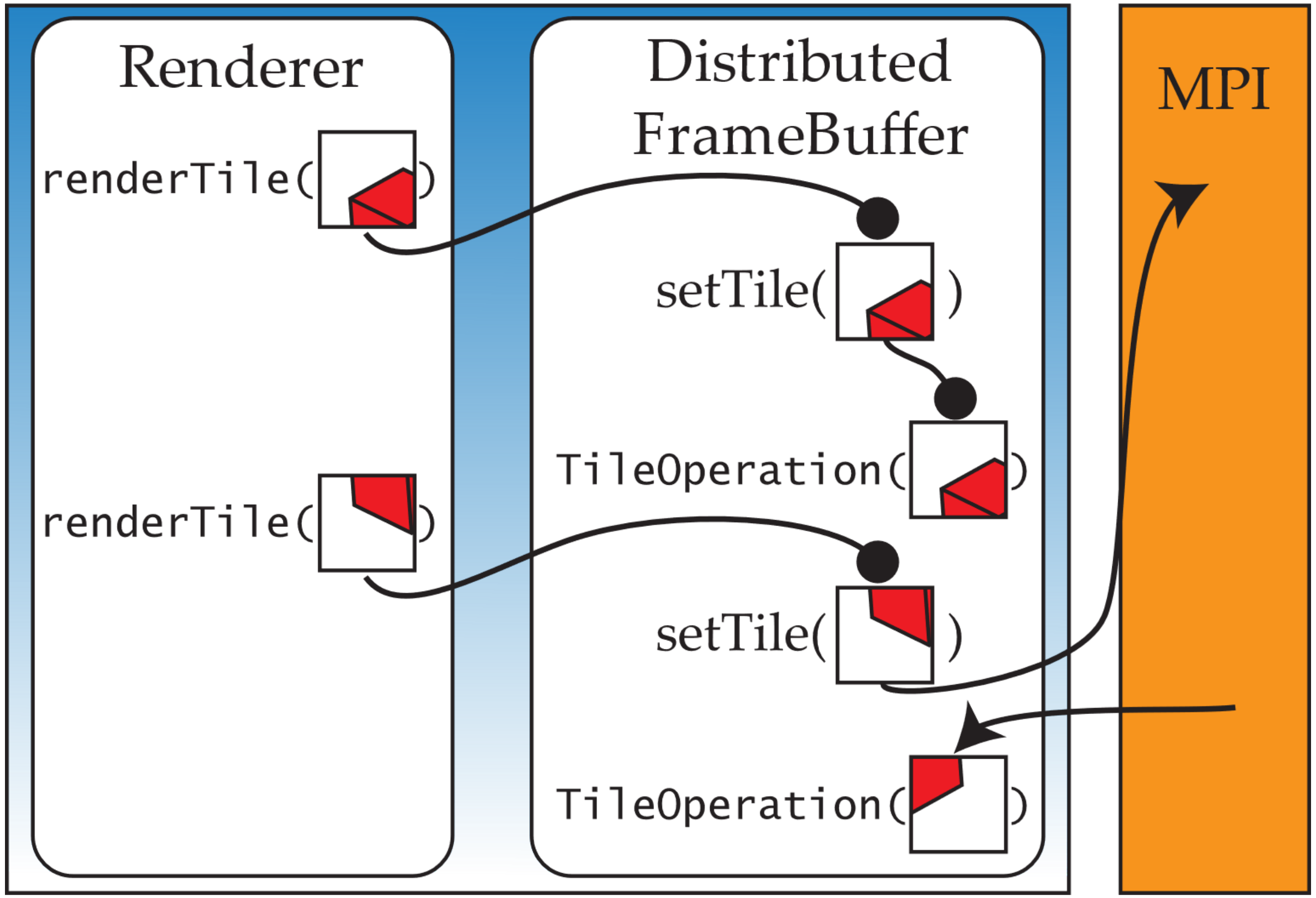
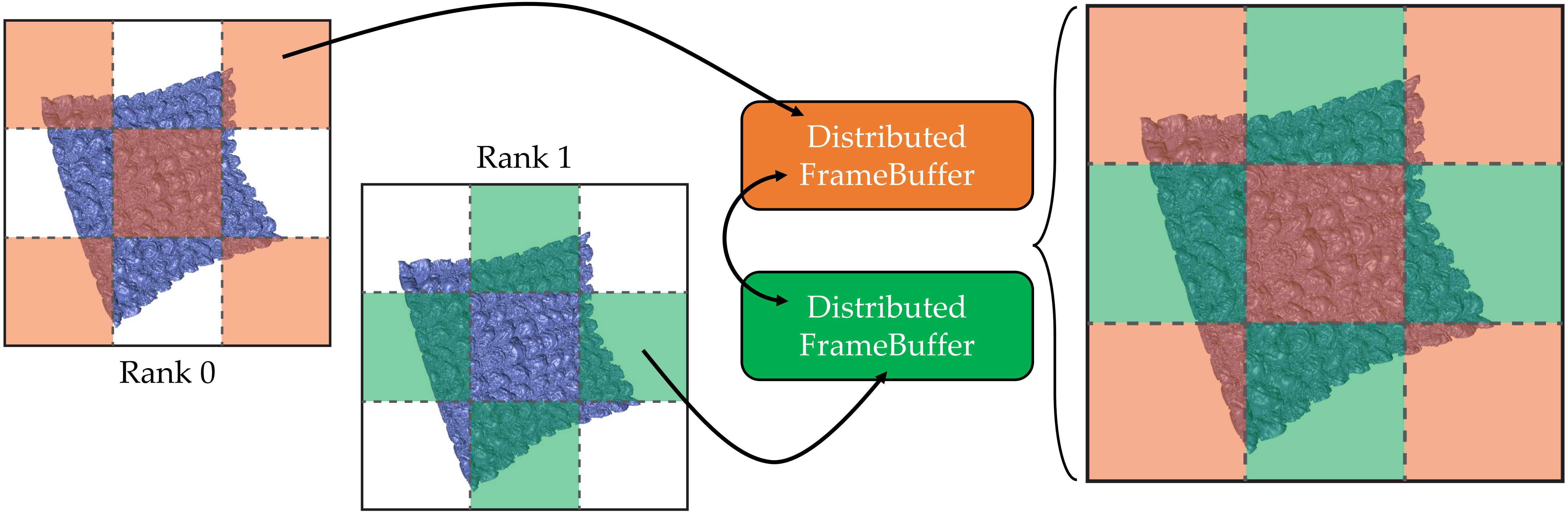


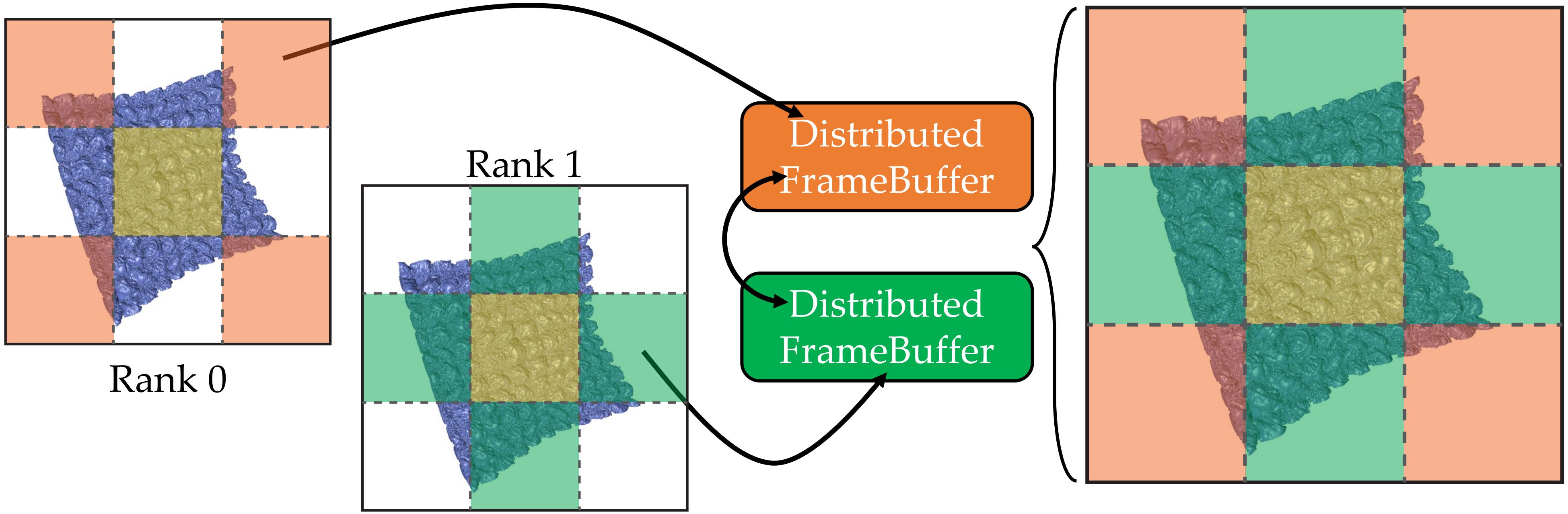
Image-Parallel Rendering

- Renderer: Assign each tile to be rendered by a unique process
- TileOperation: Expect a single input tile, forward to output



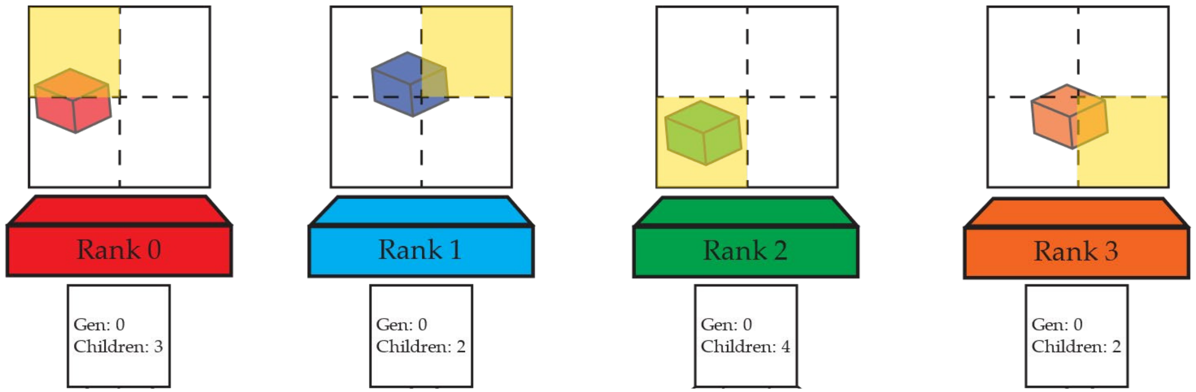
Load Balancing Image-Parallel Rendering

- Renderer: Assign each tile to be rendered by **one or more processes**
- TileOperation: Expect a **varying number** of input tiles **and average them together**



Sort-Last Data-Parallel Rendering

- Renderer: Render local data for tiles it touches, and a background tile for the tiles owned by the process



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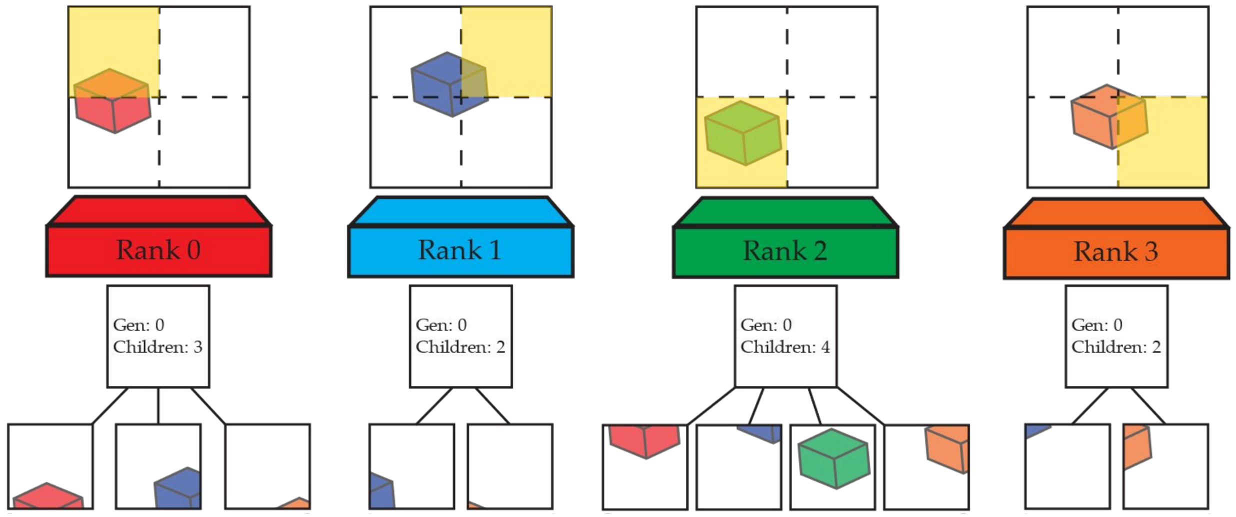

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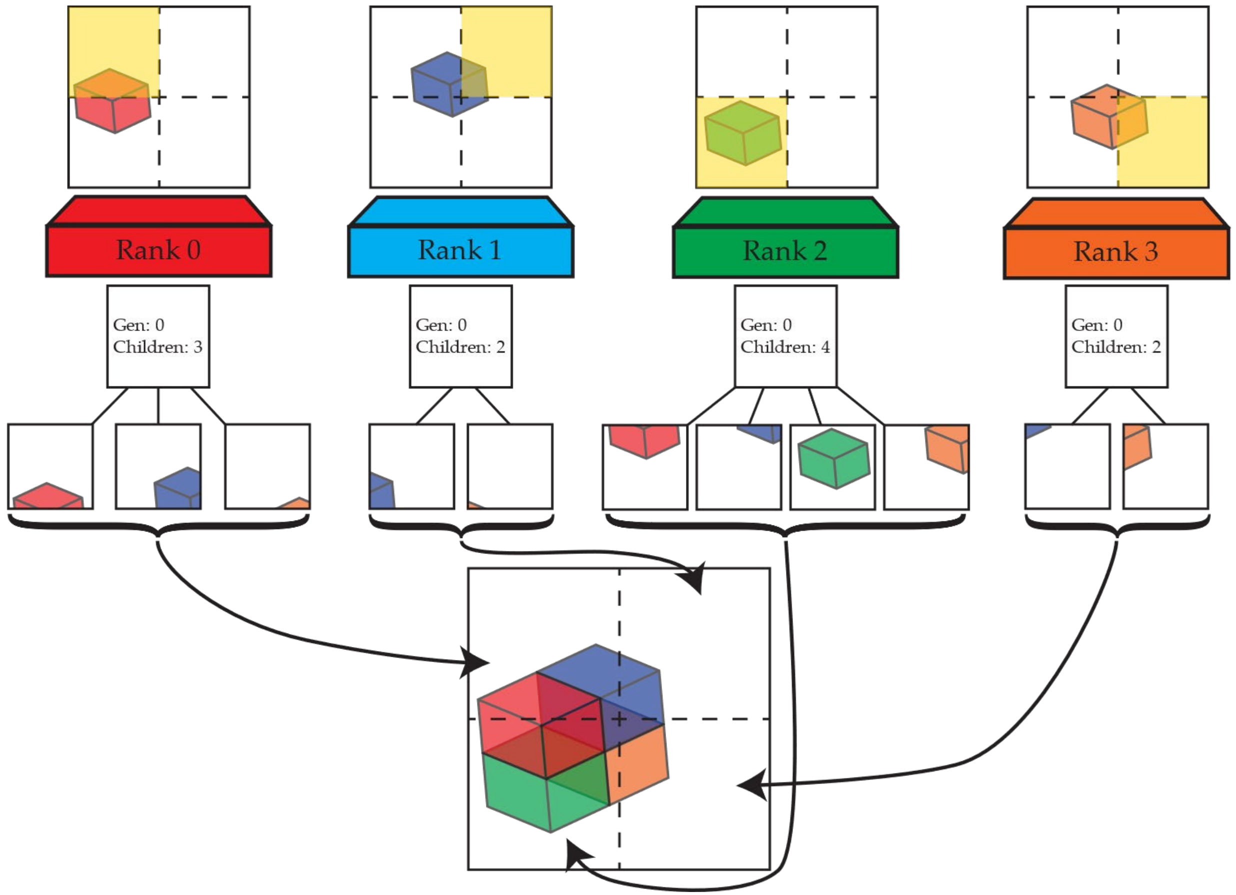
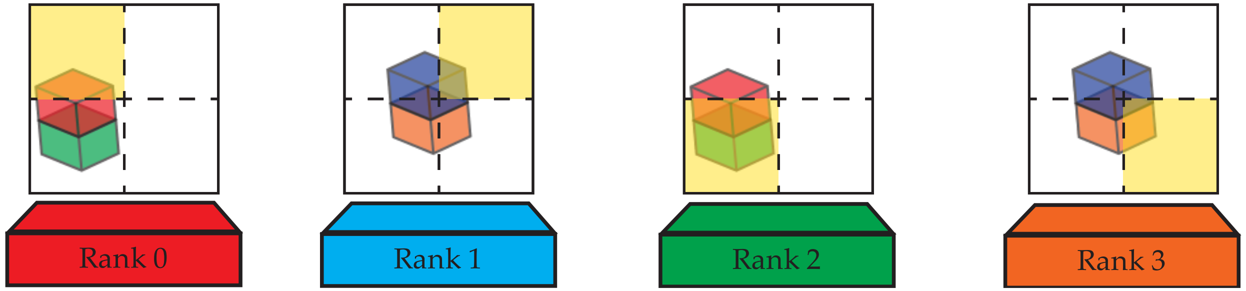


Rendering Hybrid Data Distributions

- Load balance data-parallel rendering by partially replicating data among nodes



Rendering Hybrid Data Distributions

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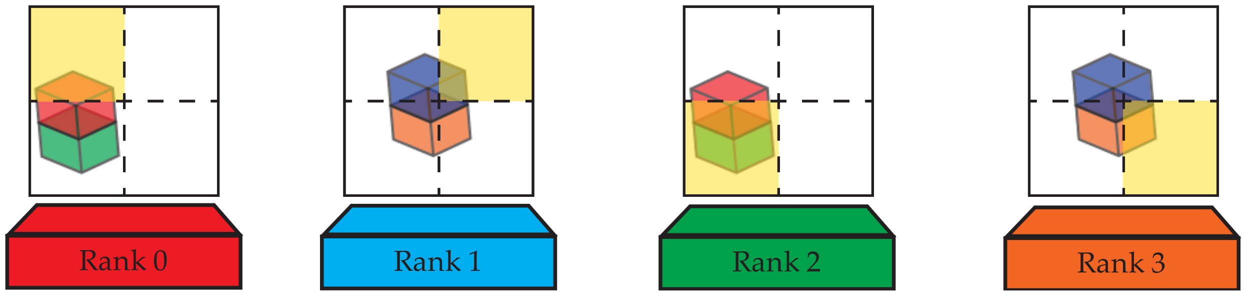

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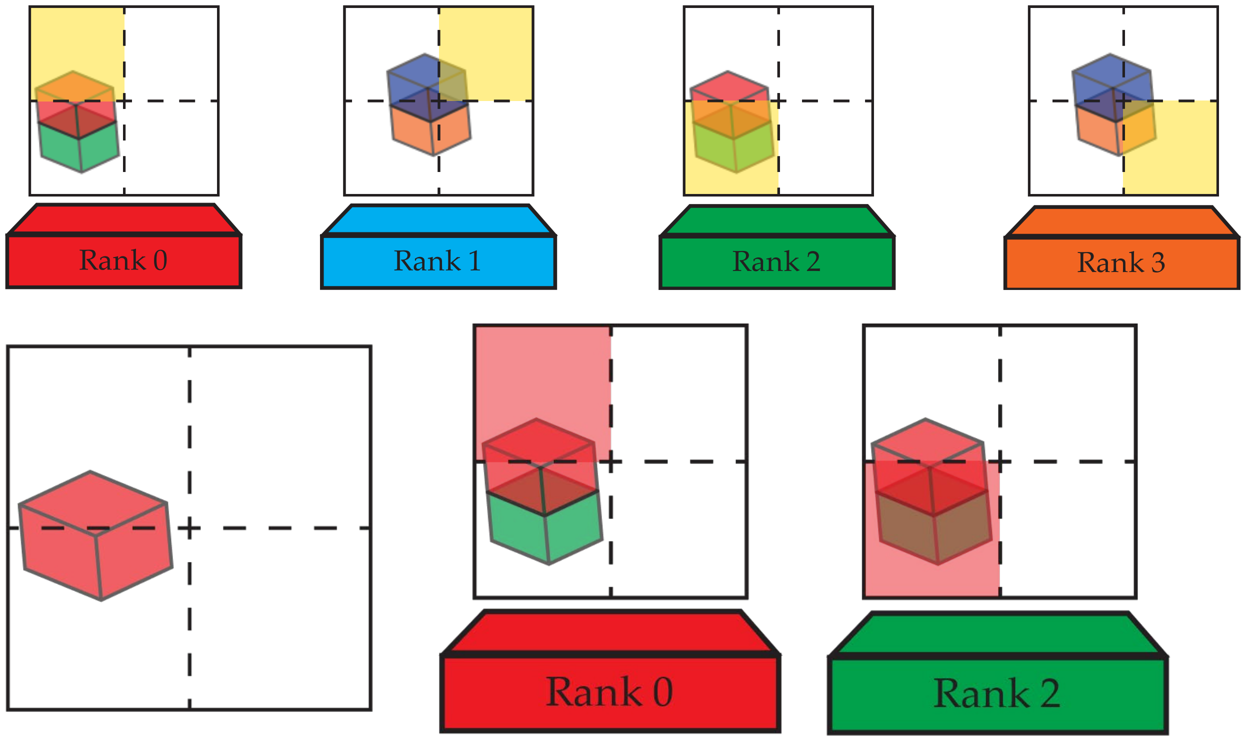

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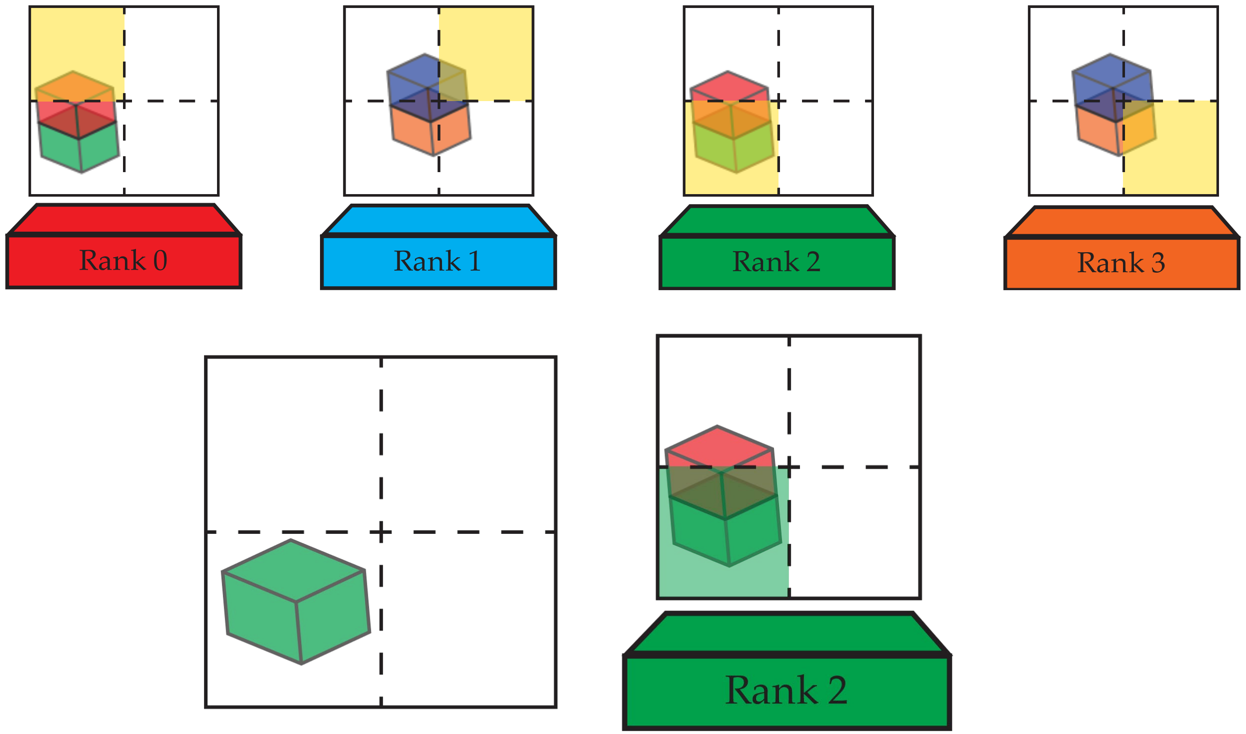

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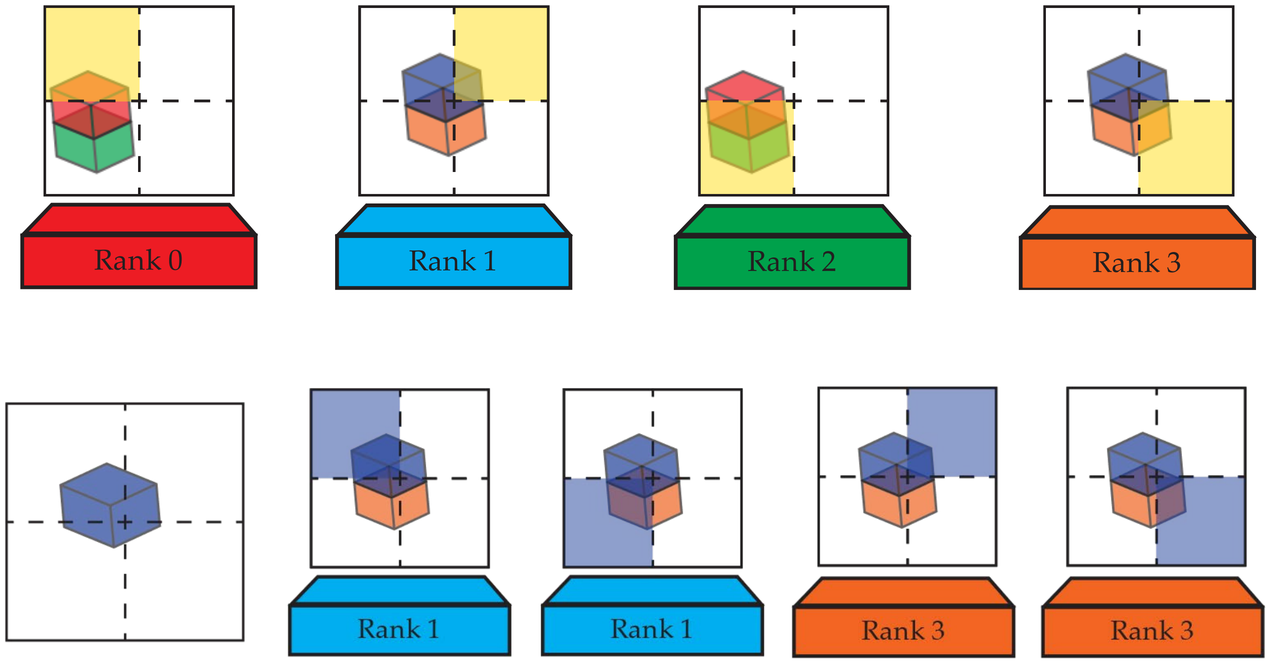

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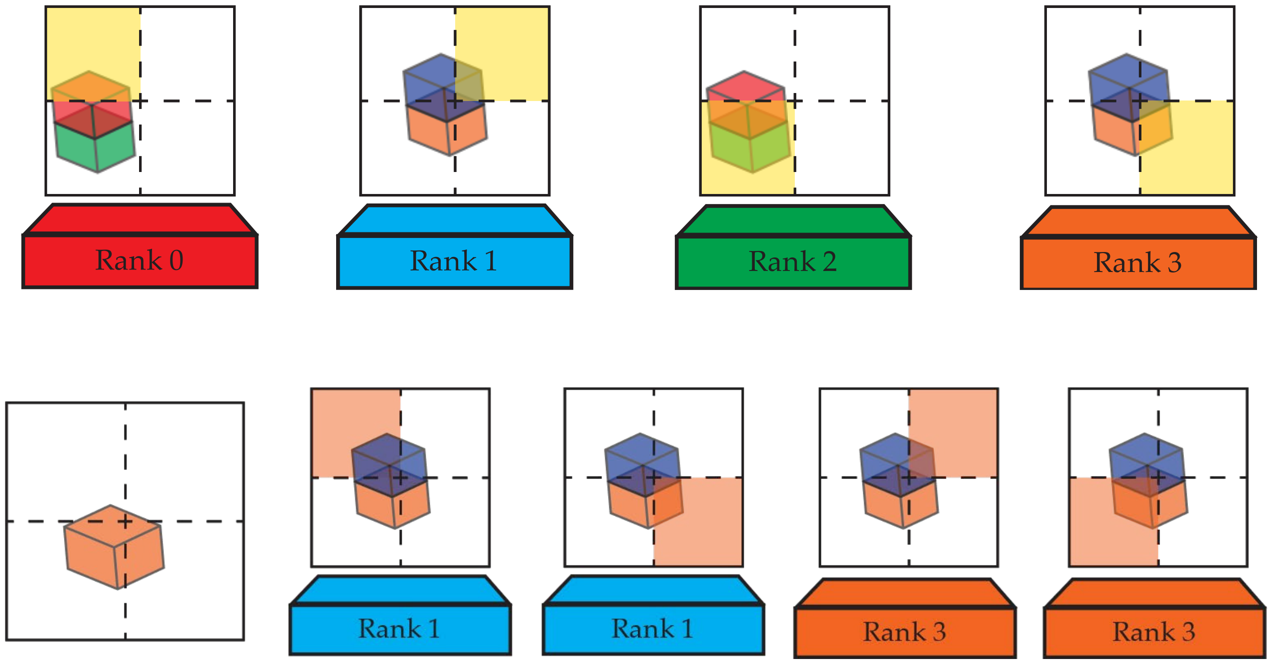

Rendering Hybrid Data Distributions

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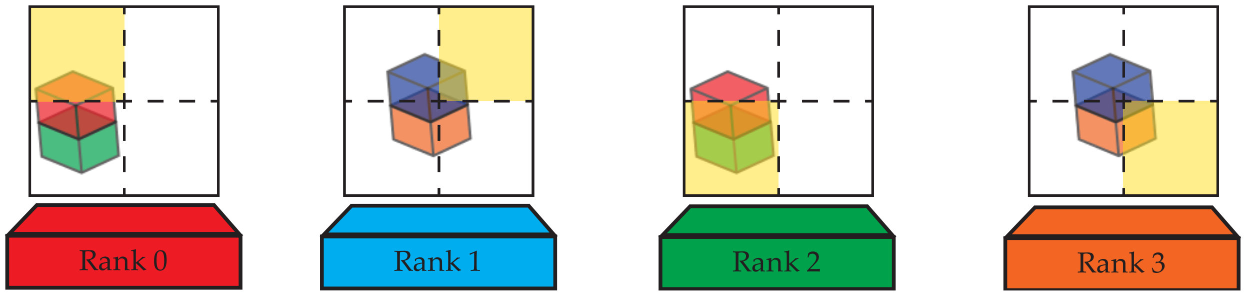
- TileOperation: Identical to typical sort-last cases



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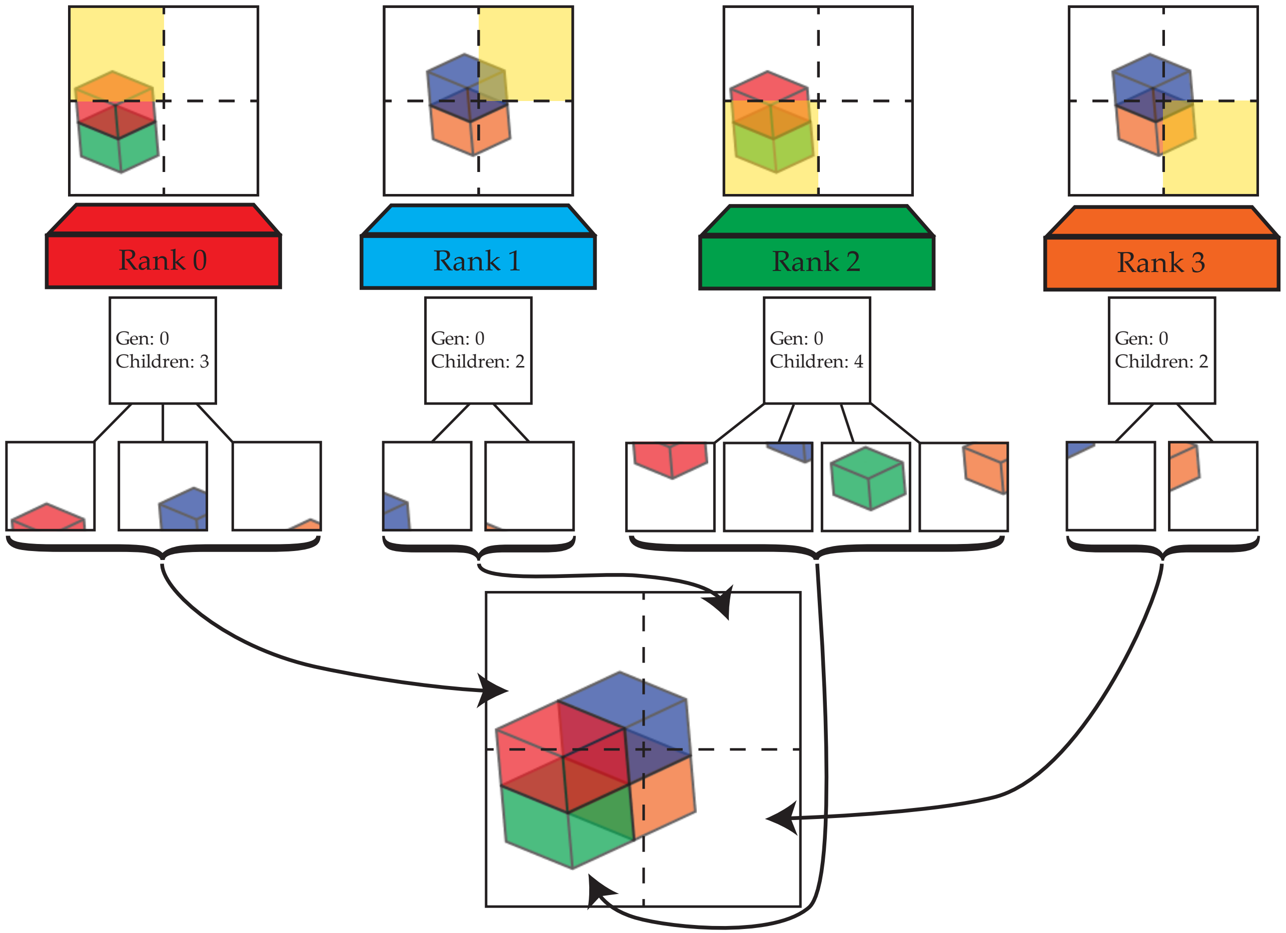


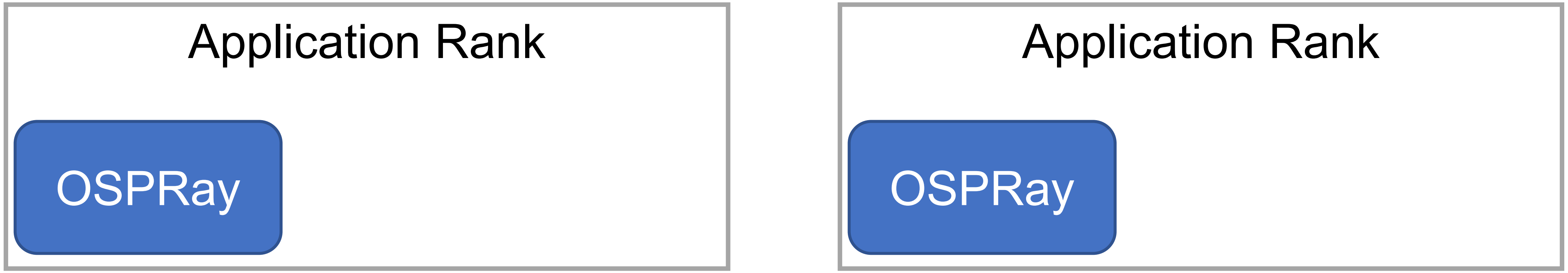
Scalable Support for Display Walls

- Route tiles directly to the display wall from the tile owner in the pixel operation
- Skip bottleneck of aggregating large images to the master

A Data-Distributed API for OSPRay

Distributed Rendering Support in OSPRay

- Extend OSPRay with a new MPIDistributedDevice API backend
- Distributed data abstracted as a set of OSPModels (bricks) with possible replication
- Supports existing OSPRay geometry and volume modules rendered as local data, composited with DFB



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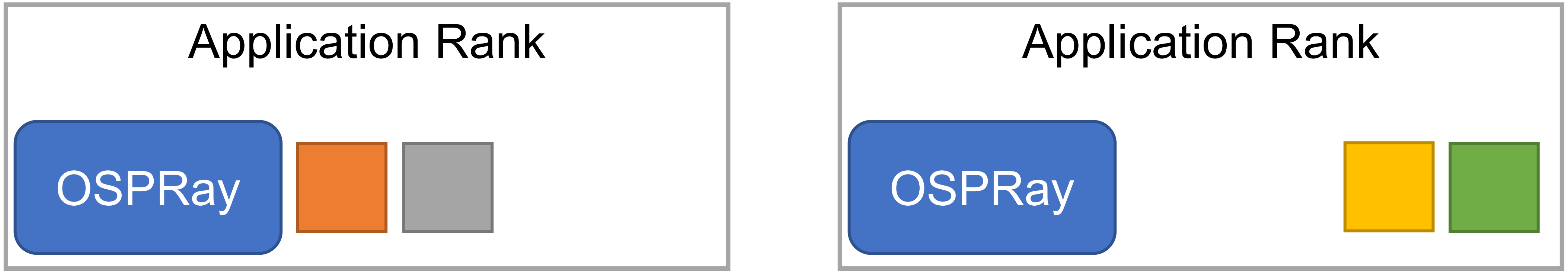

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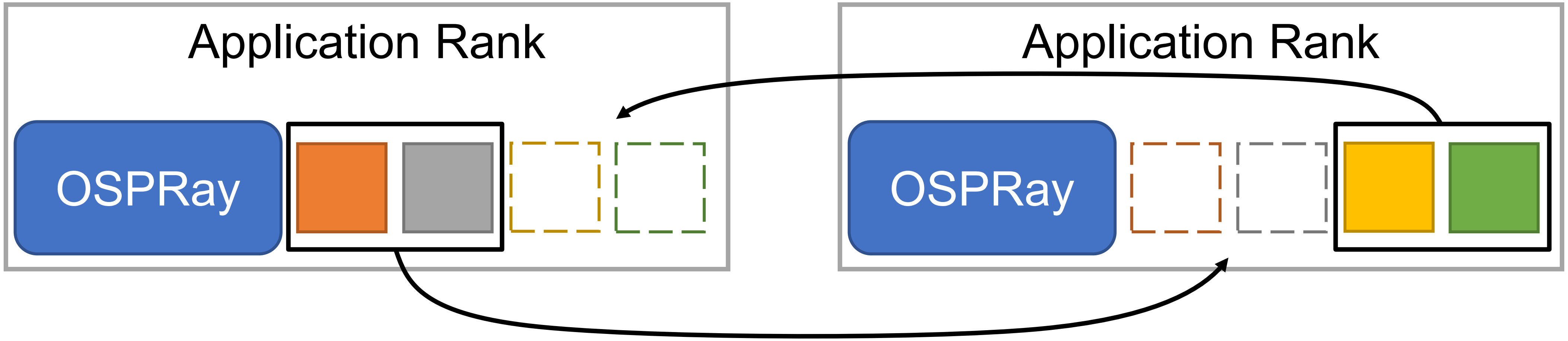

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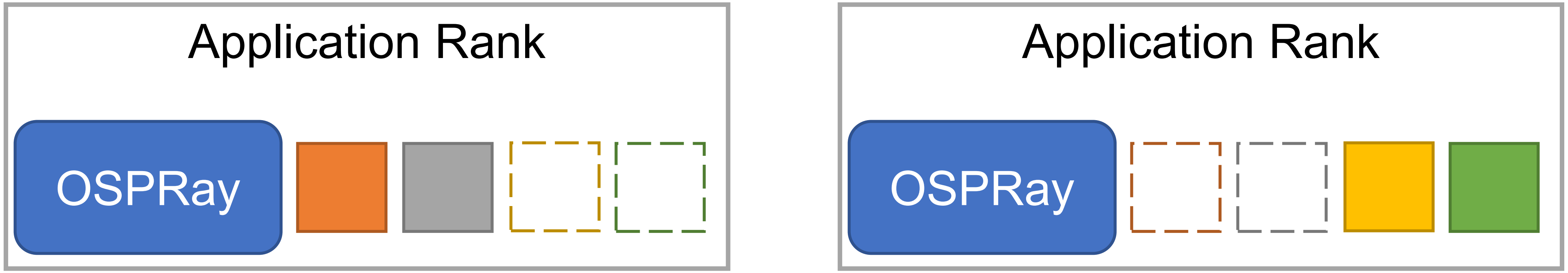


Results

Benchmark Configurations

- Run on:
  - TACC *Stampede2* KNL & SKX
  - ANL *Theta* KNL
- Similar KNL nodes, but very different networks
- Benchmarks use one process per-node and threads for on-node parallelism
- All benchmarks render a rotation around the dataset

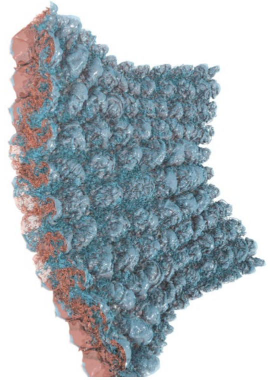
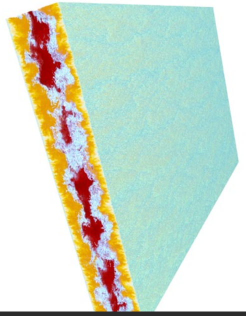
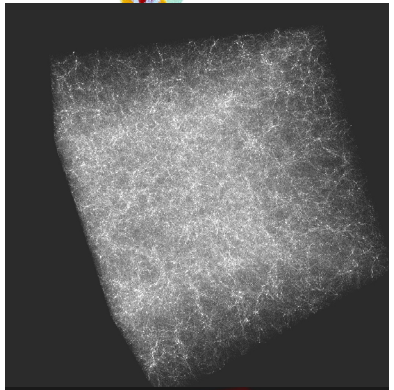
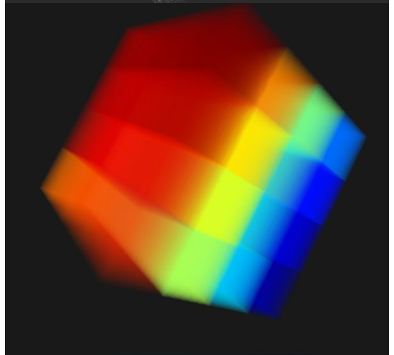
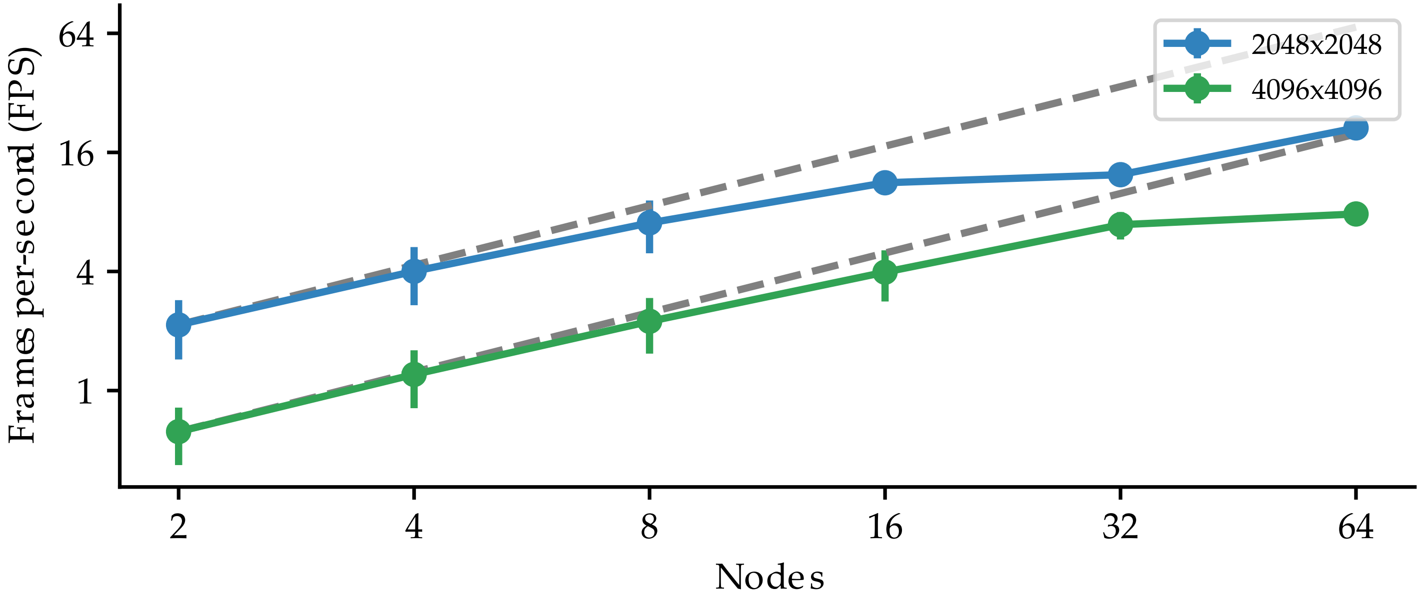
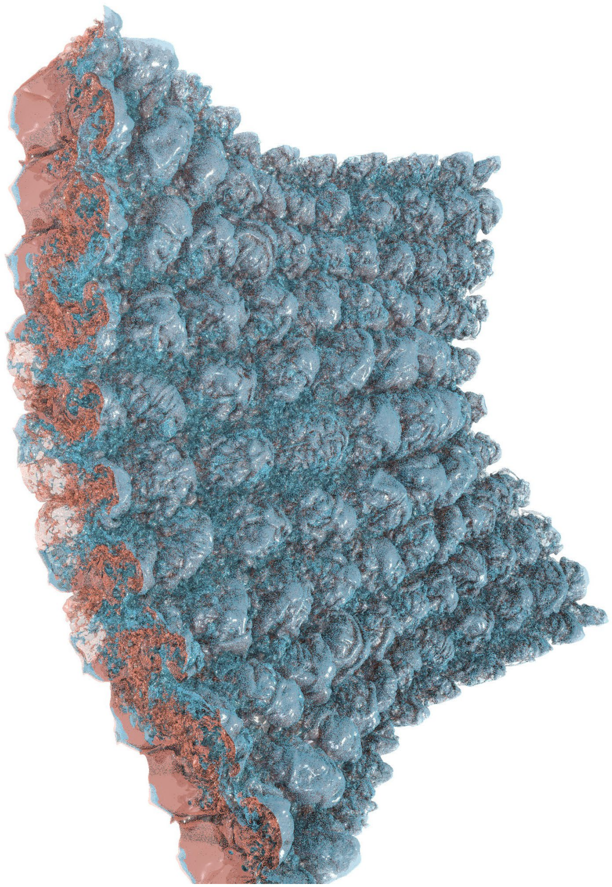





Image-Parallel Rendering Scalability

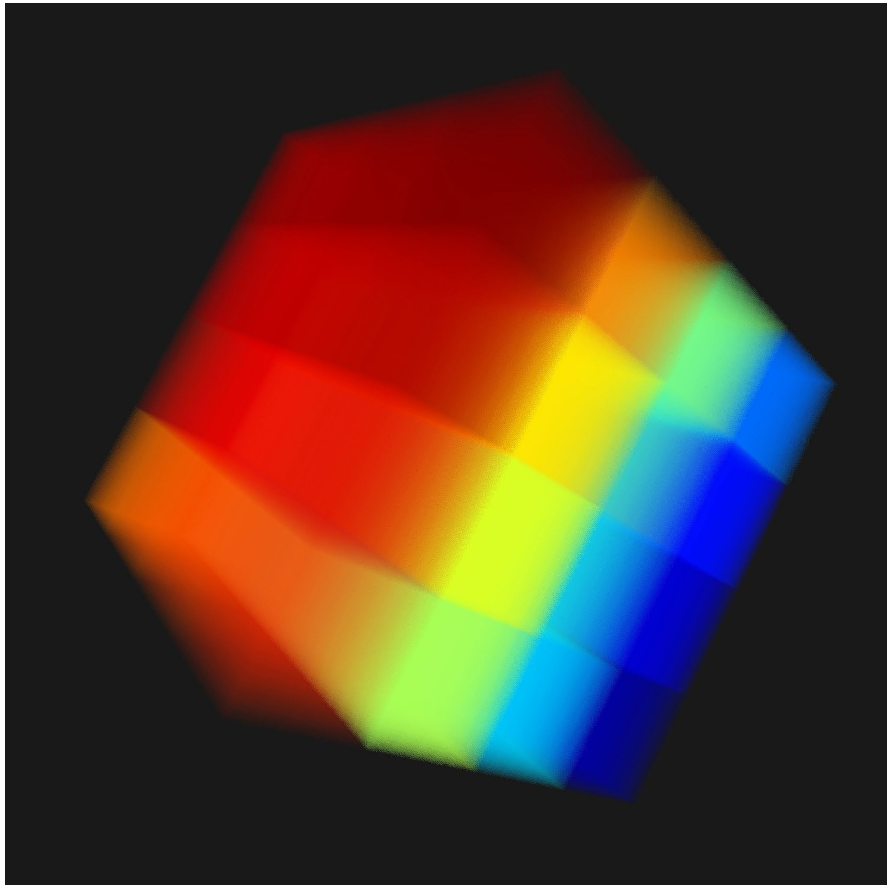
- Two transparent isosurfaces on the Richtmyer-Meshkov, 516M triangles
- Shadows and ambient occlusion
- *Stampede2* SKX



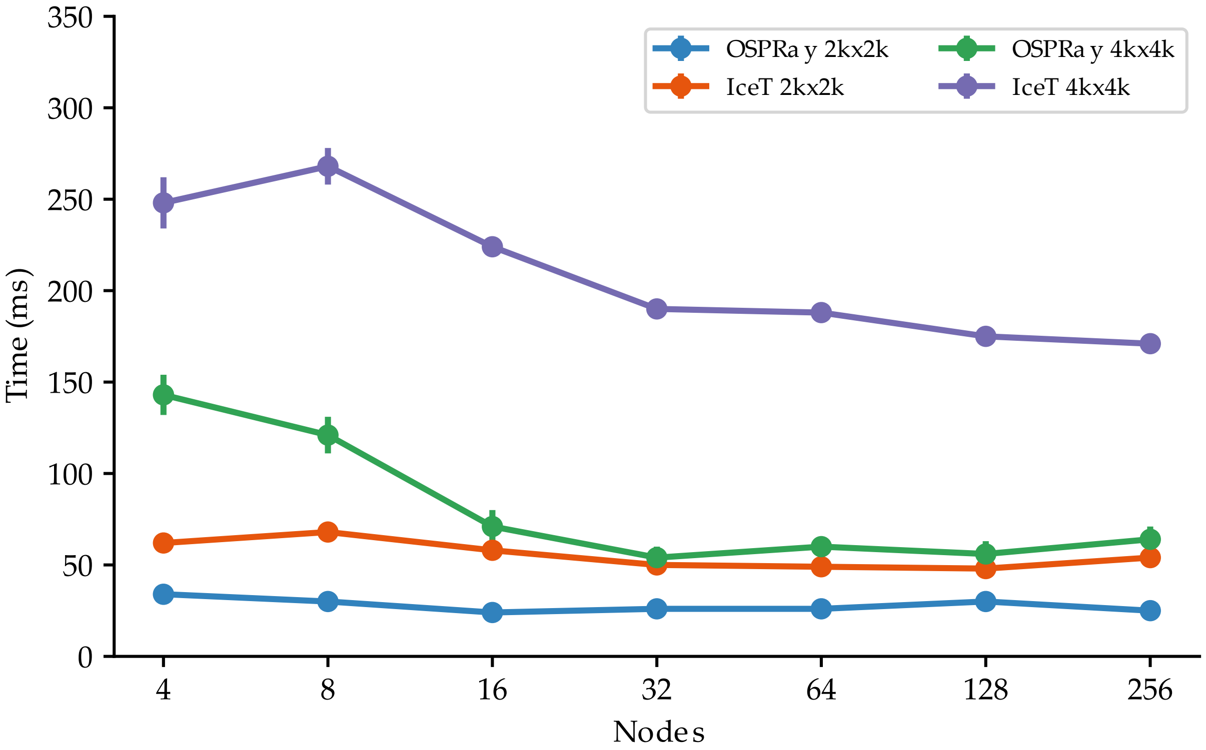


Data-Parallel Rendering: Compositing Benchmark vs. IceT

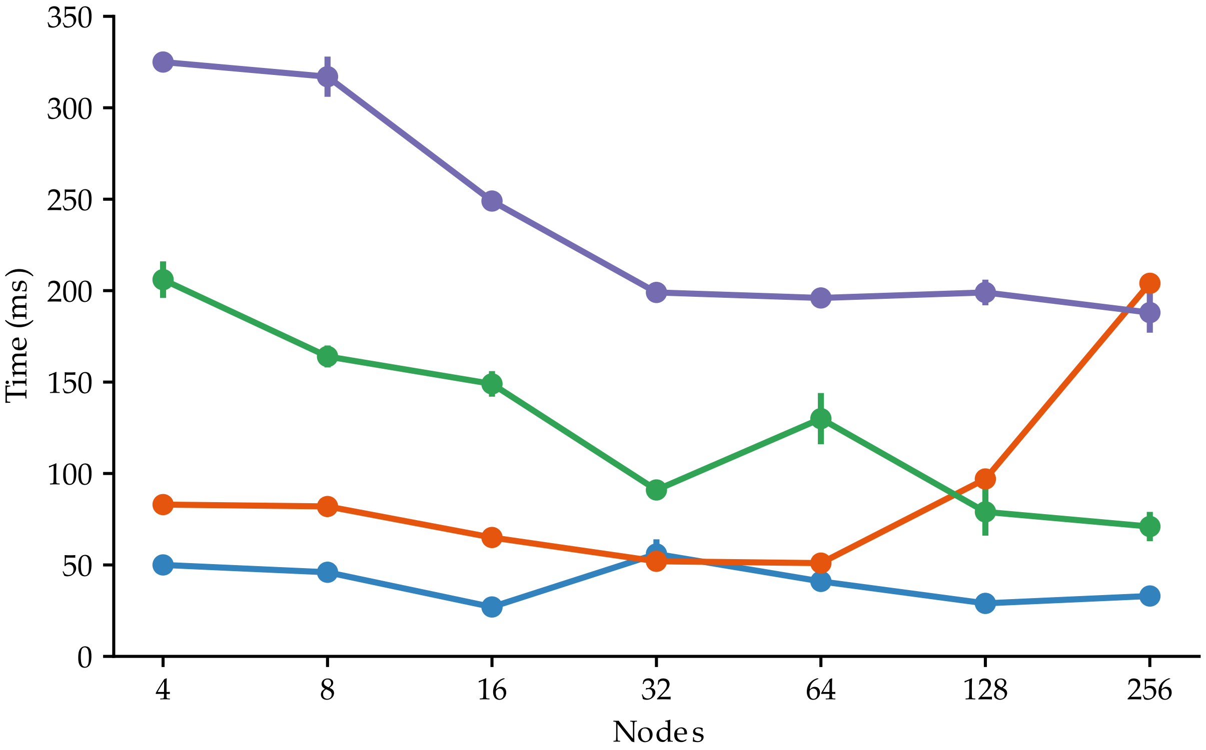
- Modify data-parallel renderer in OSPRay to use IceT for direct comparison
- Synthetic dataset with 64^3 volume brick per-node
- Also allows comparison between network architectures, job schedulers, system differences



IceT Comparison: Overall Performance

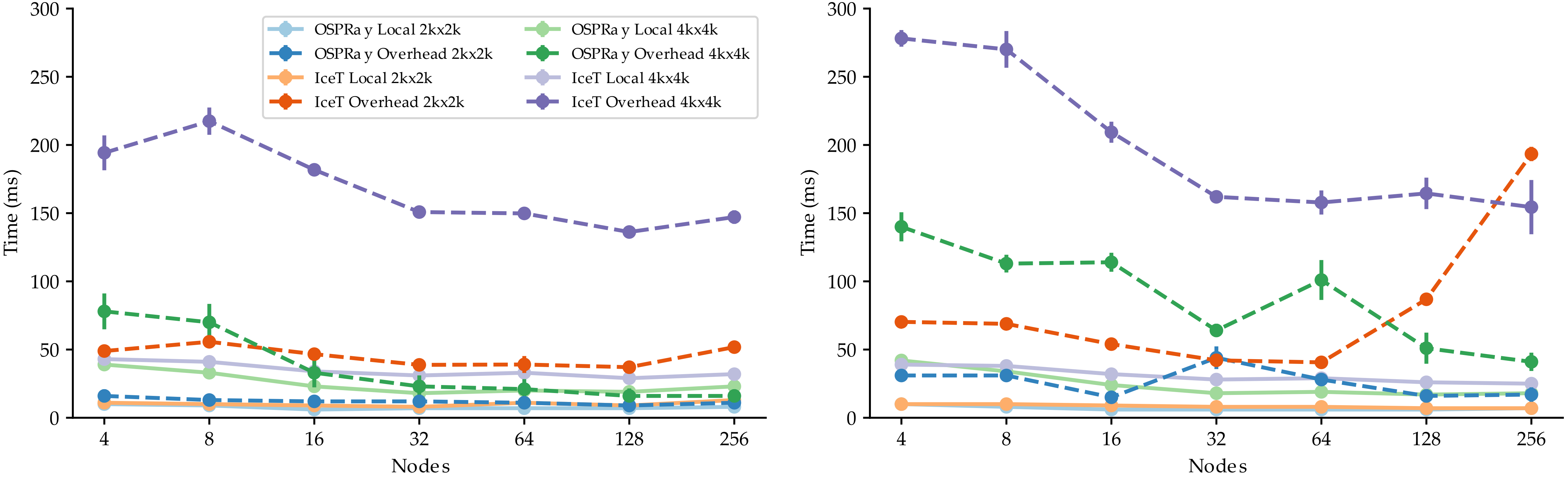


Theta KNL



Stampede2 KNL

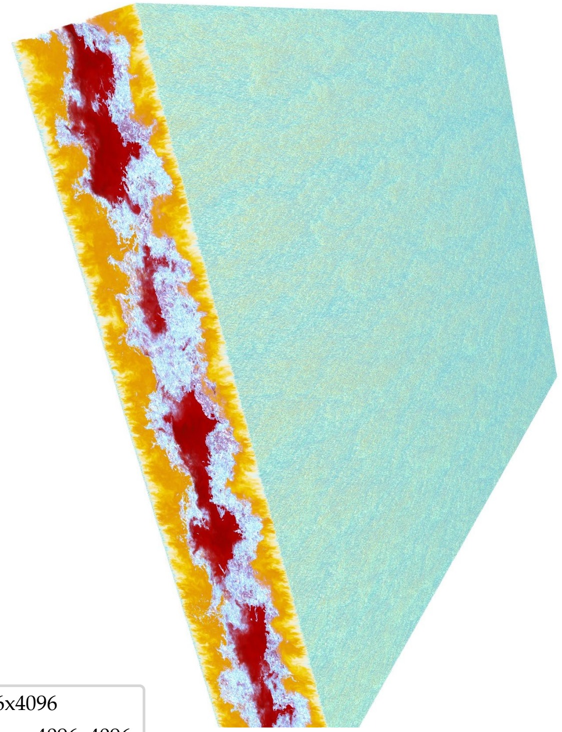
IceT Comparison: Timing Breakdown

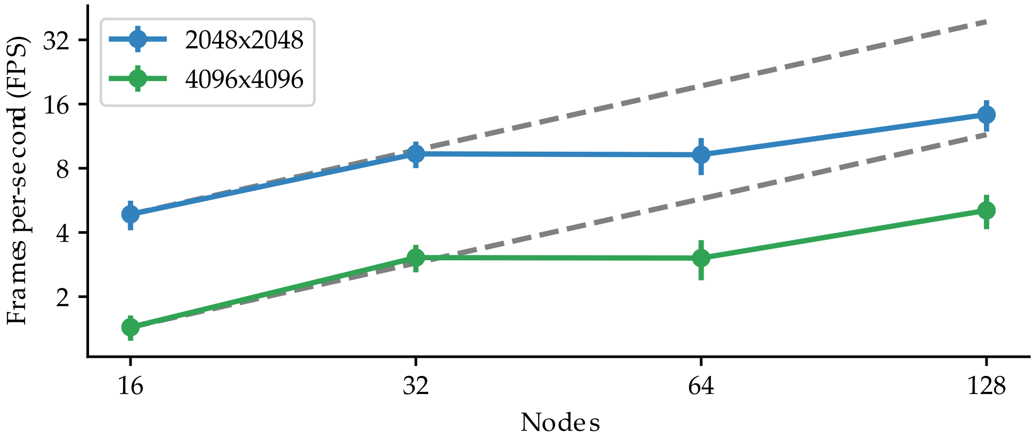


Theta KNL *Stampede2* KNL

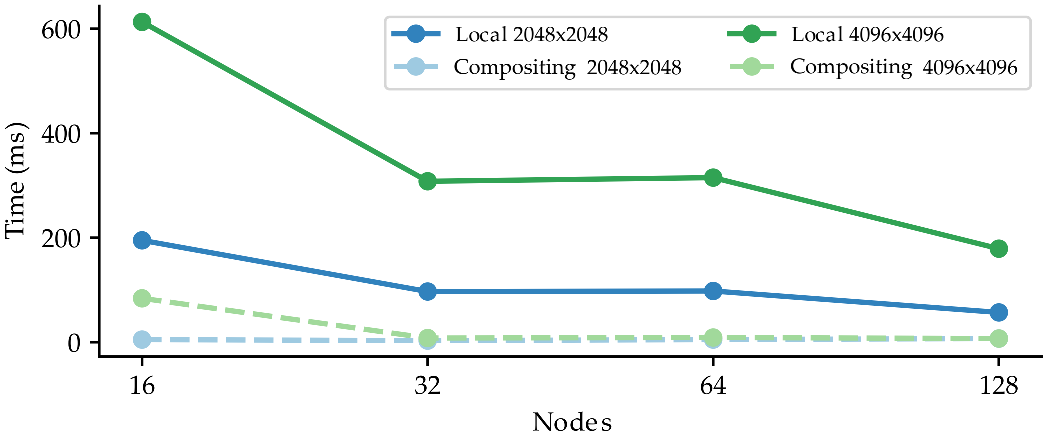
Data-Parallel Rendering: DNS Volume with Isosurfaces

- DNS single-precision volume 10240x7680x1536 (451GB)
- Two transparent isosurfaces, 5.43B triangles total
- *Stampede2* KNL





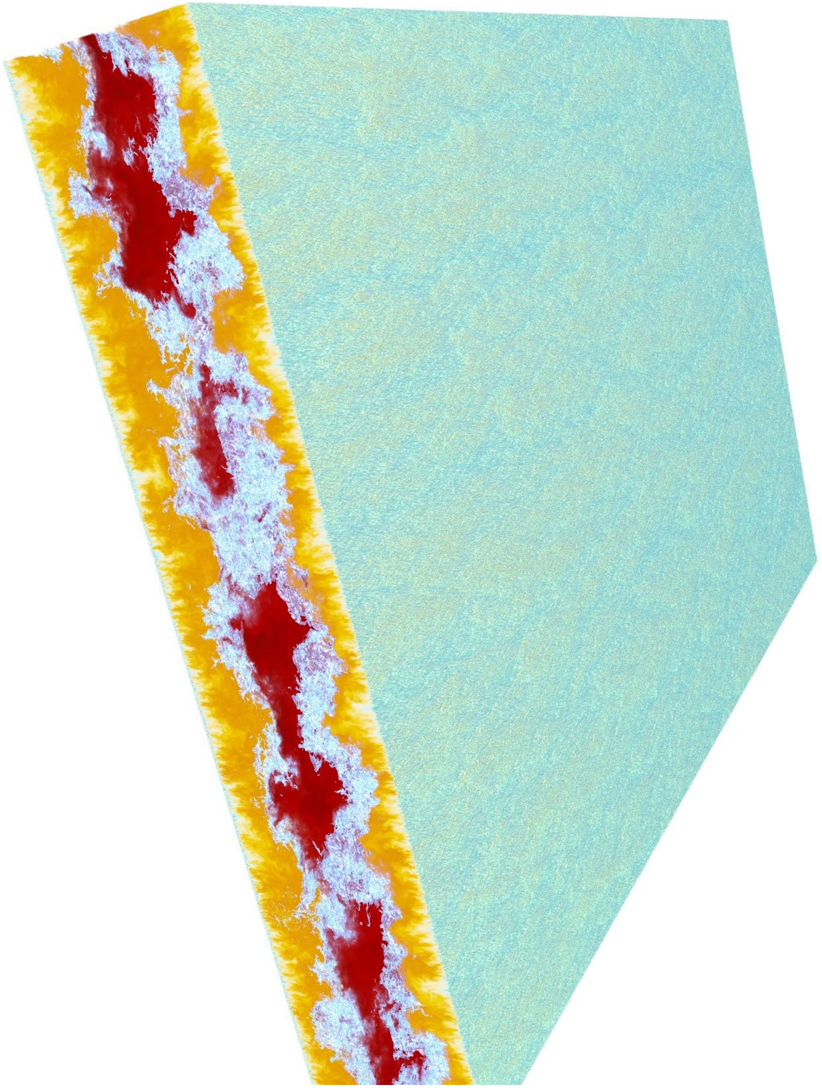
Overall Performance



Timing Breakdown

Hybrid-Parallel Rendering Performance

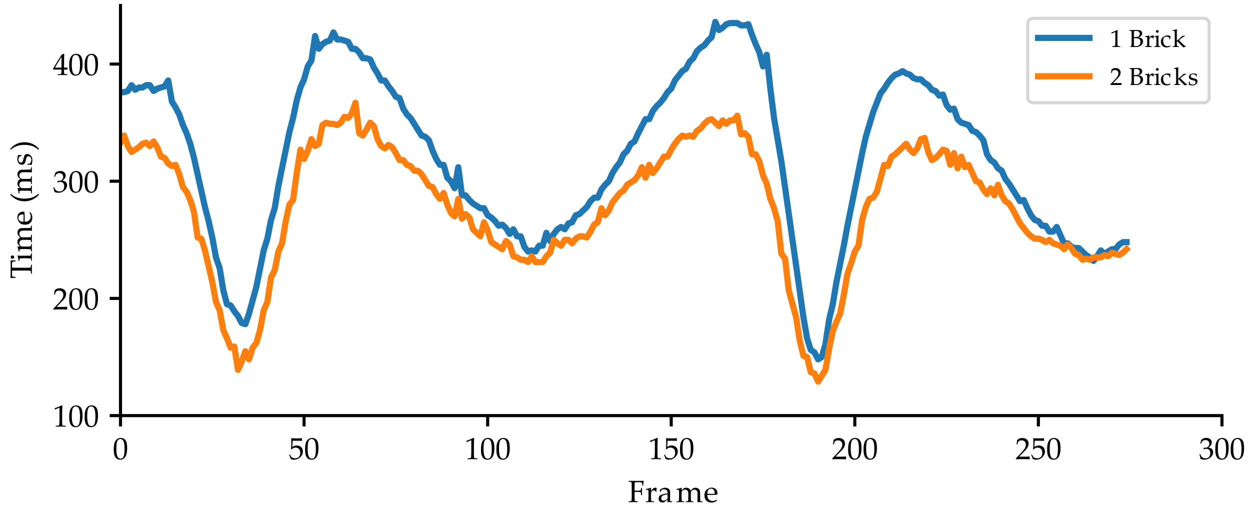
- Partially replicate bricks of data among nodes to improve load balancing



Hybrid-Parallel Rendering Performance

- Partially replicate bricks of data among nodes to improve load balancing
- 64 nodes: 2 bricks per/node

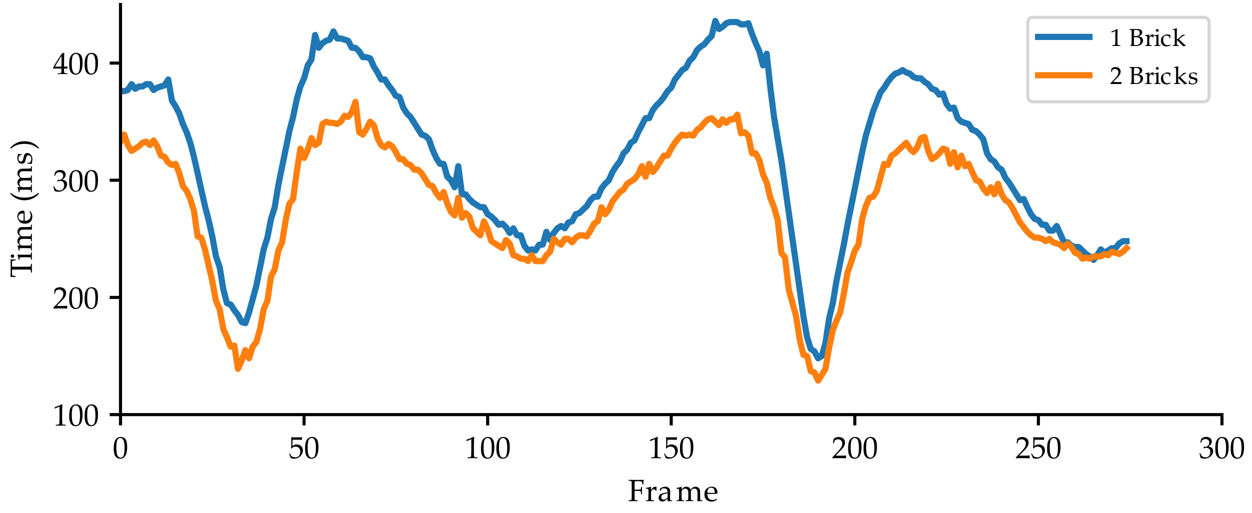
64 KNL Nodes



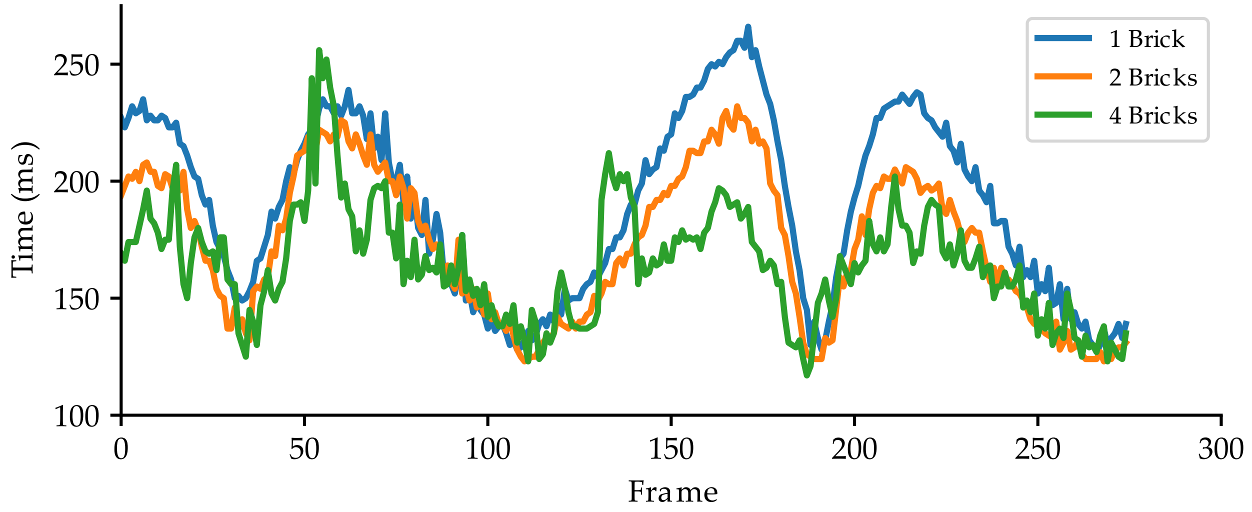
Hybrid-Parallel Rendering Performance

- Partially replicate bricks of data among nodes to improve load balancing
- 64 nodes: 2 bricks per/node
- 128 nodes: 2 or 4 bricks per/node

64 KNL Nodes

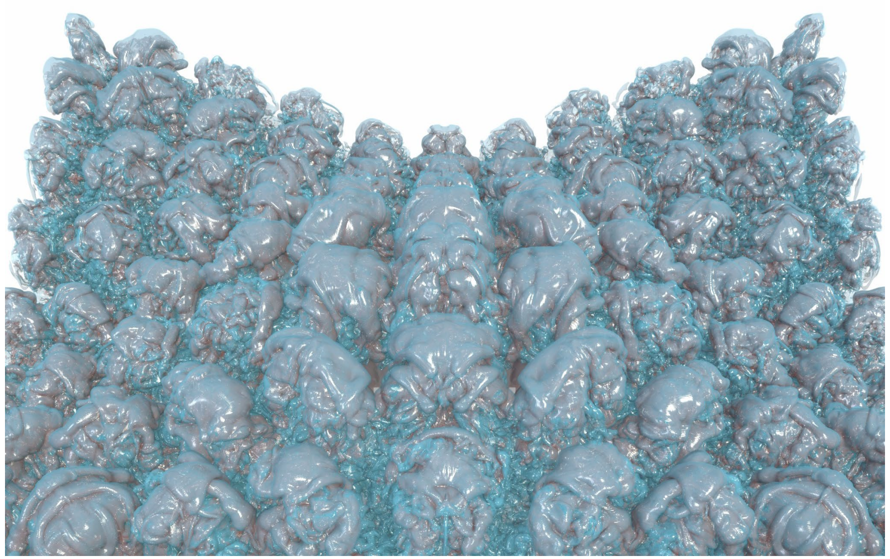


128 KNL Nodes



Thanks!

- DFB and Distributed API out now in OSPRay 1.8.0!



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