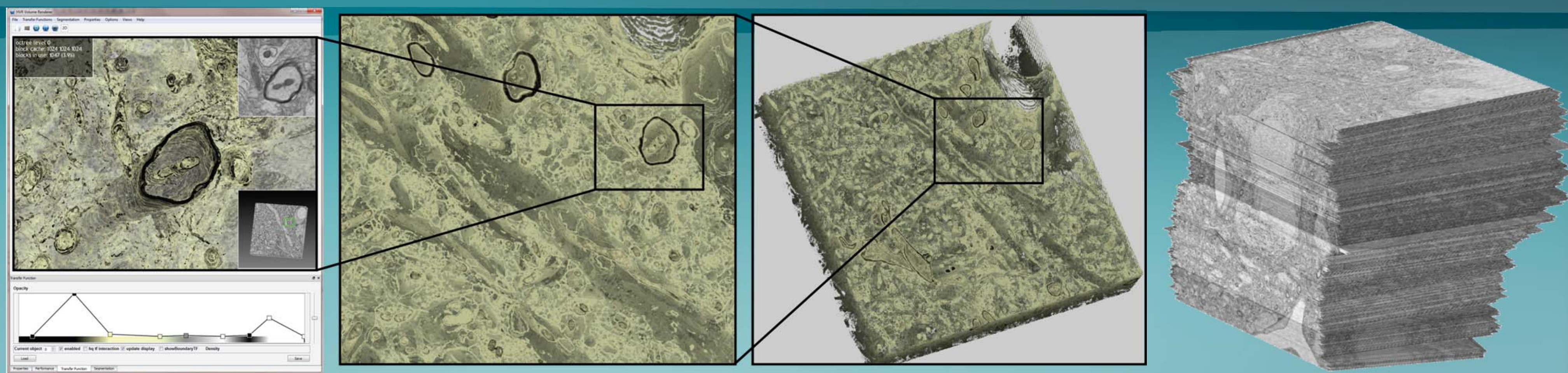
Interactive Volume Exploration of Petascale Microscopy Data Streams Using a Visualization-Driven Virtual Memory Approach



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HARVARD School of Engineering and Applied Sciences

The Connectome

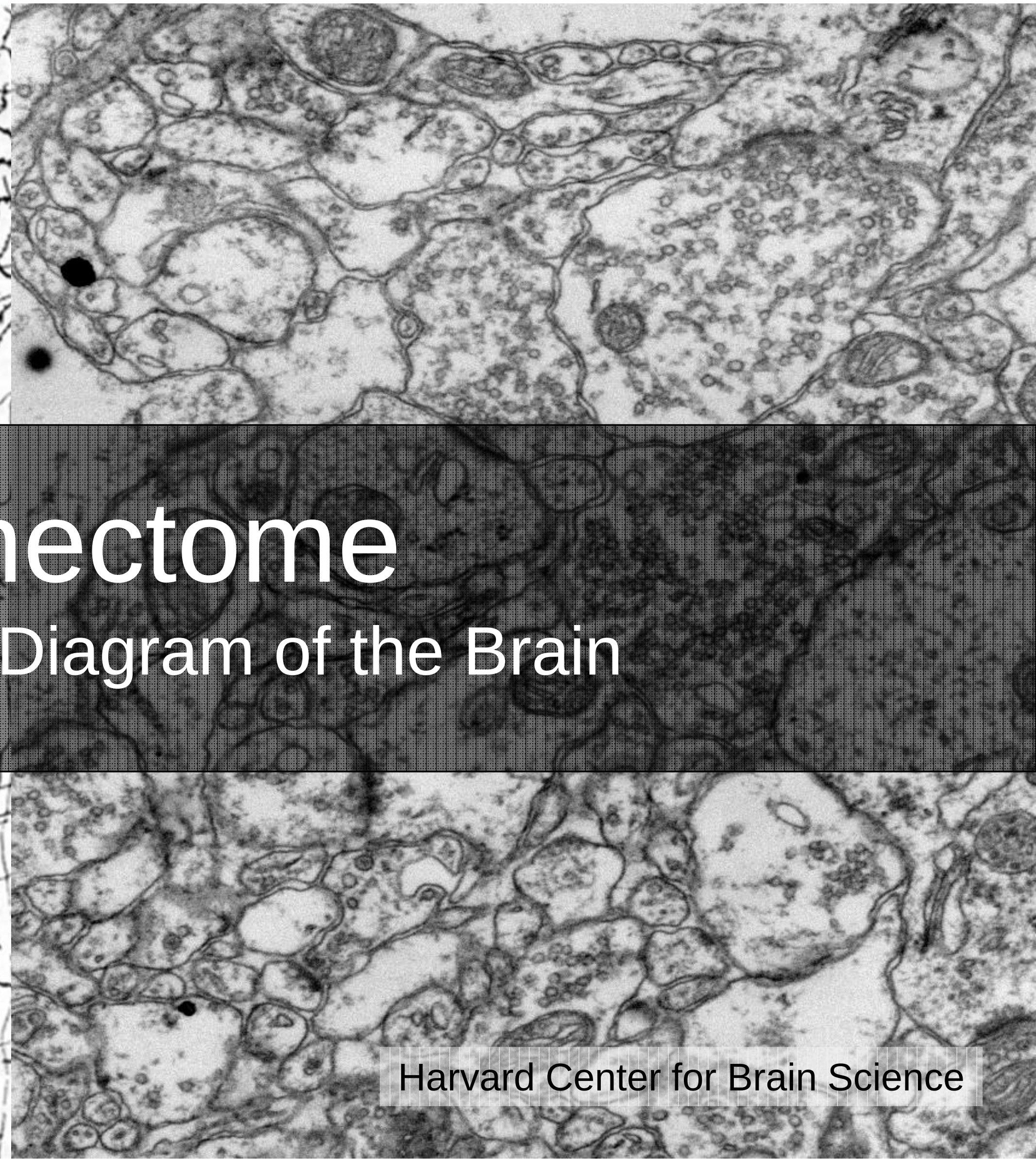
Discovering the Wiring Diagram of the Brain

Harvard Center for Brain Science

The Connectome

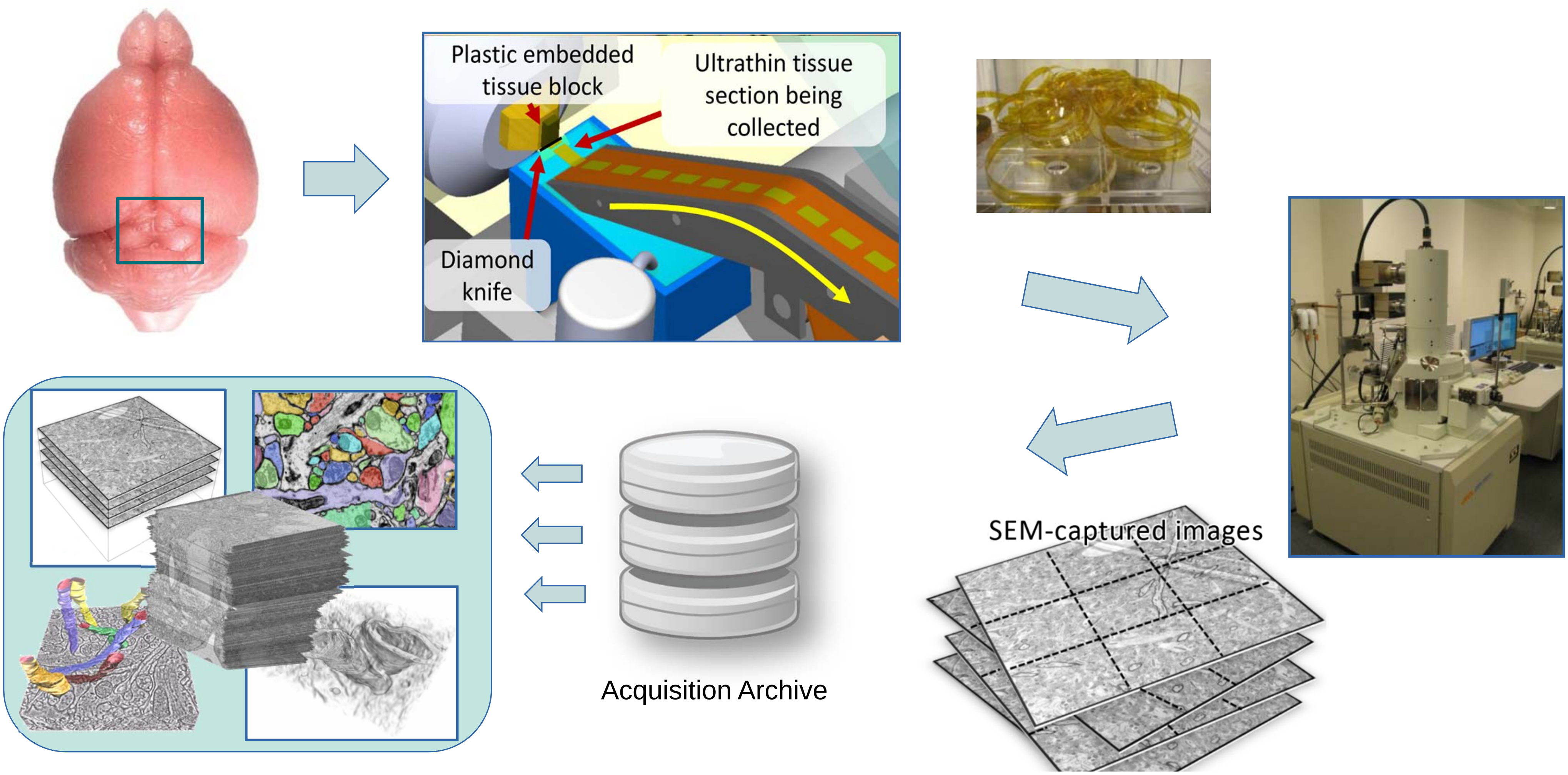
Discovering the Wiring Diagram of the Brain

Ramón y Cajal, 1905



Harvard Center for Brain Science

Connectome Workflow



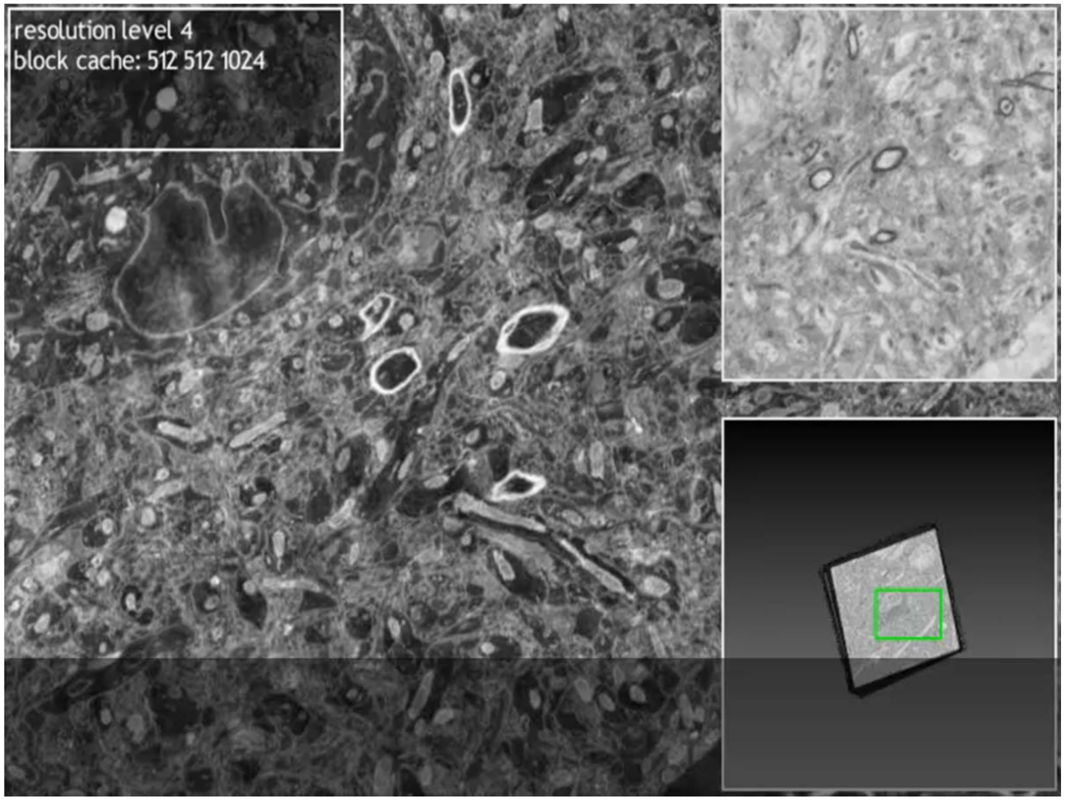
Electron Microscopy (EM) Volumes

- Required for tiny structures (synapses, vesicles, …)
  - Pixel resolution : 3 to 5 nm
  - Slice thickness : 30 to 50 nm
- 1 mm^3
  - 200k x 200k images x 20k slices
  - 40 Gpixels x 20k = 800 Tvoxels
  - 800 TB
- 40 Mpixels / second
  - ~8 months

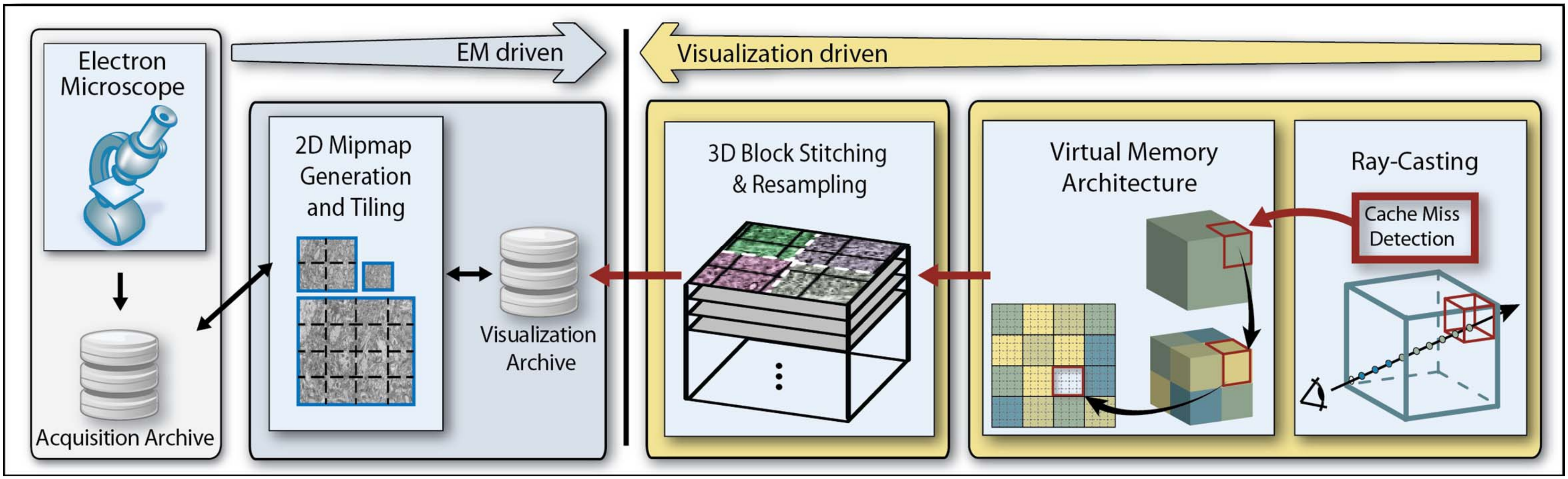
Our System

- Interactive EM volume exploration
  - Visualization-driven system design
  - Scales to petascale volumes

- Major design properties
  - Ray-cast in virtual volume space
  - Avoid pre-computation of 3D multi-resolution structure
  - Accept a continuous stream of microscope image data



System Overview



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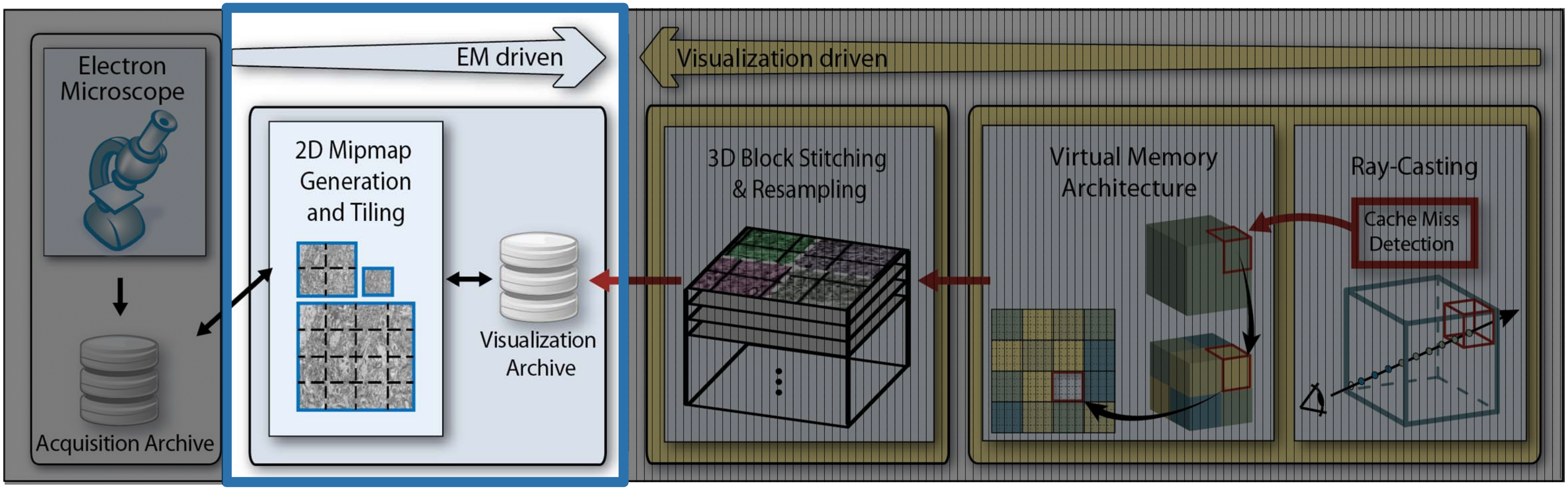
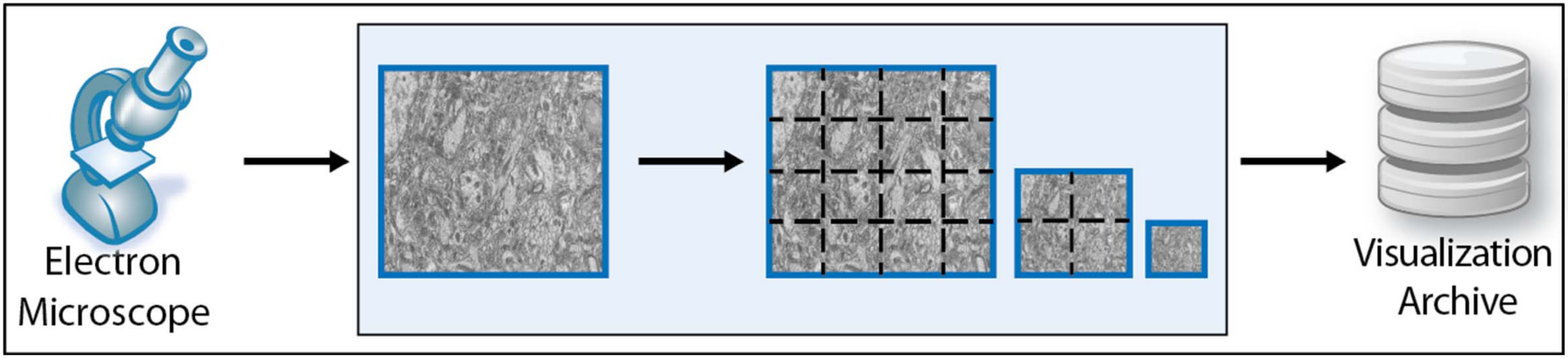


Raw Tile Processing

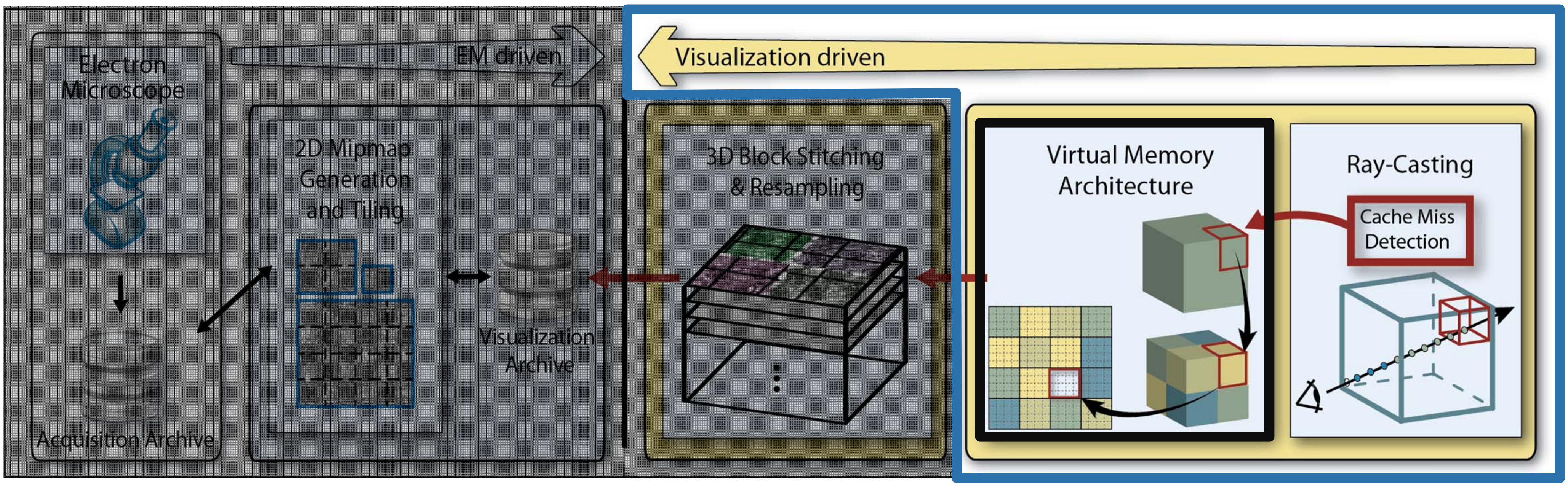
Raw Tile Processing

Each EM tile is processed independently of all other tiles



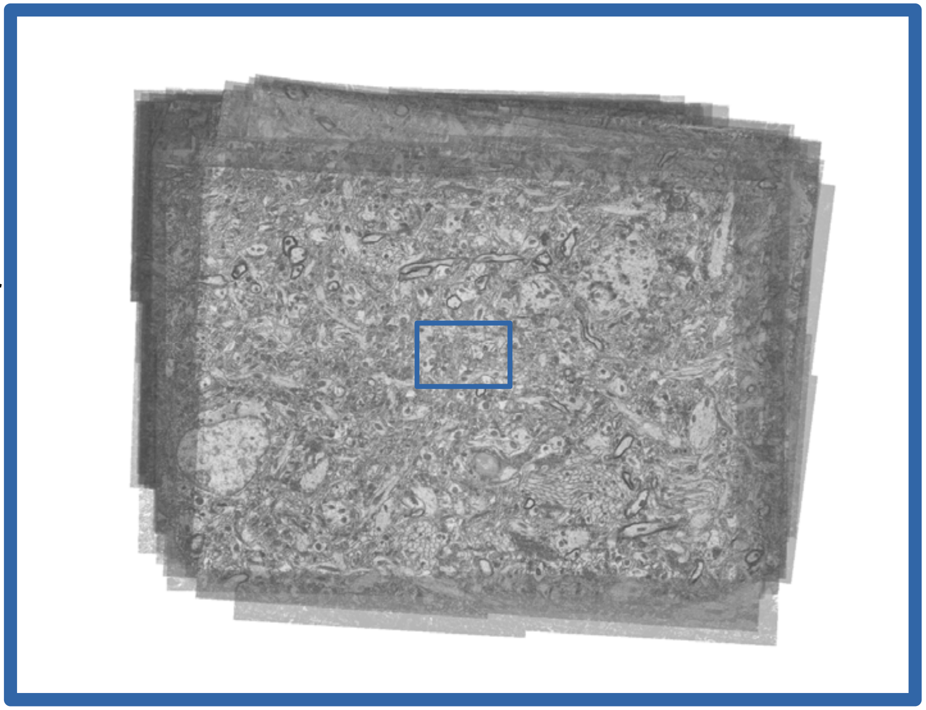
- EM tile: 12,000 x 12,000; sub-tiles: 128 x 128
- 2D mipmap construction, sub-tiling, compression have to keep up
- EM rate: 40 Mpixels / second: new tile every 3.6 seconds

System Overview



Octree Traversal vs. Virtual Memory Access

viewport

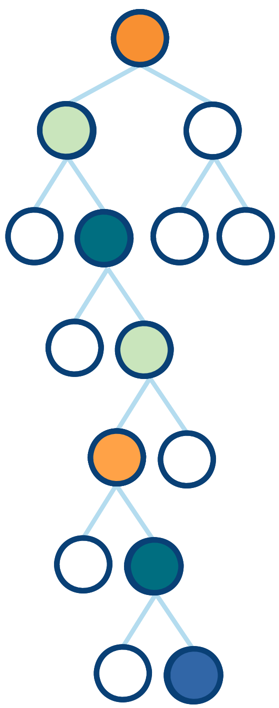


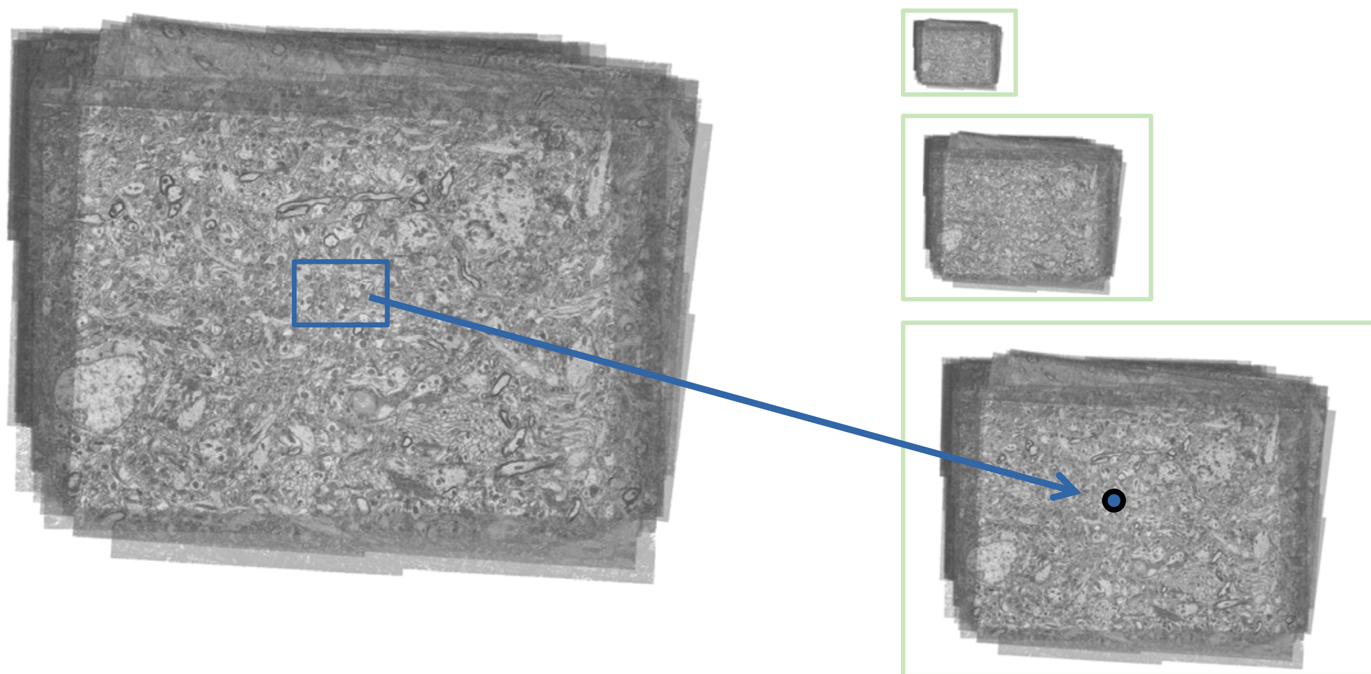
zoomed-in view

Octree Traversal vs. Virtual Memory Access

octree traversal

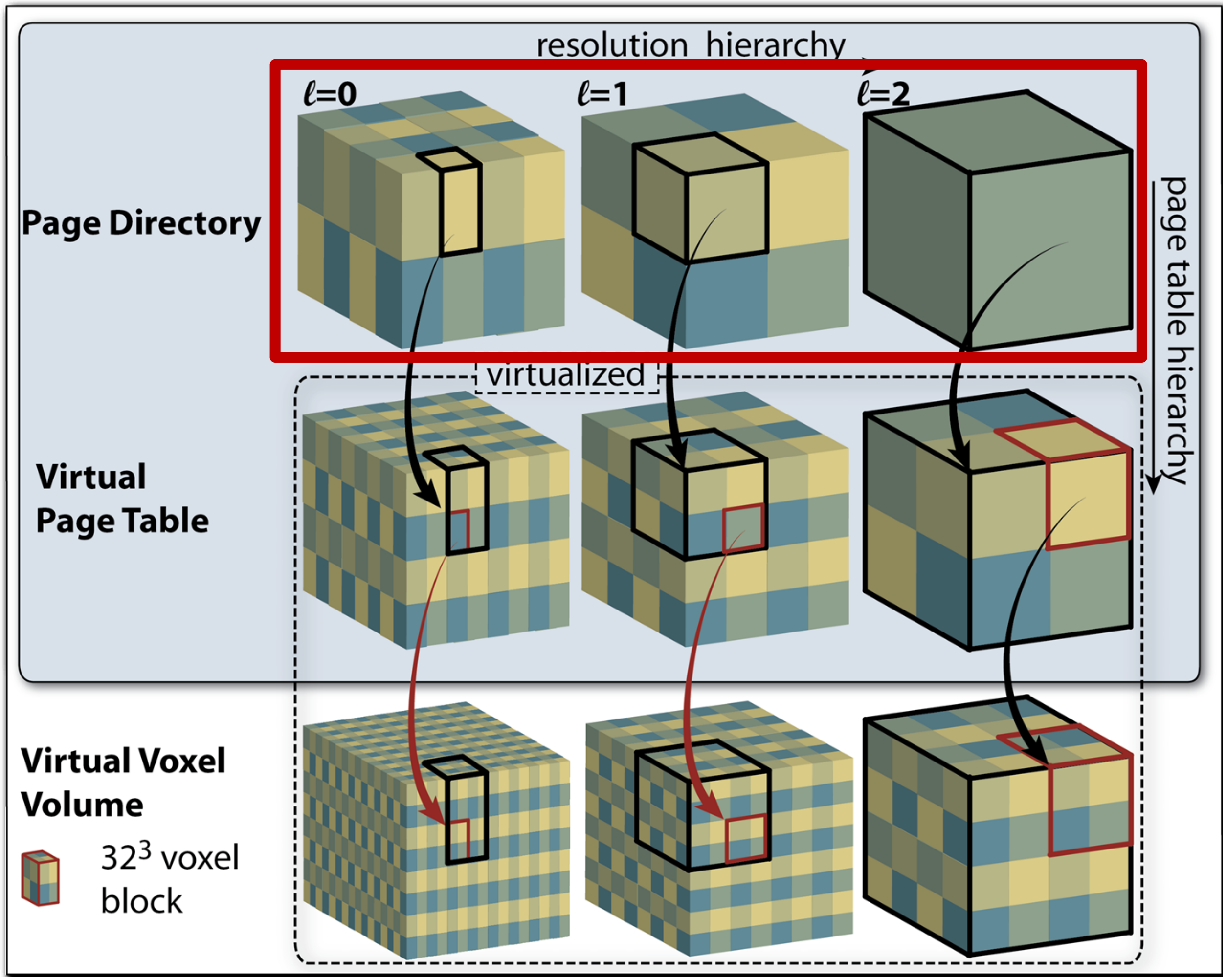
virtual memory access





zoomed-in view

Virtual Memory Architecture



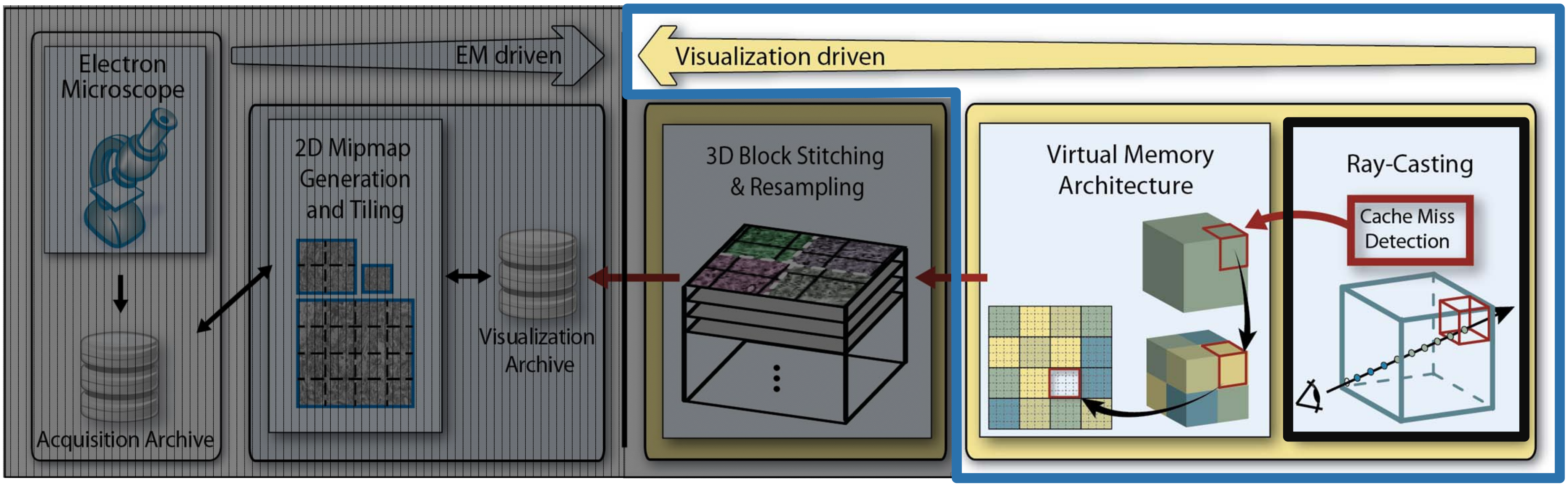
multi-resolution page directory

Scalability of Virtual Memory Architecture

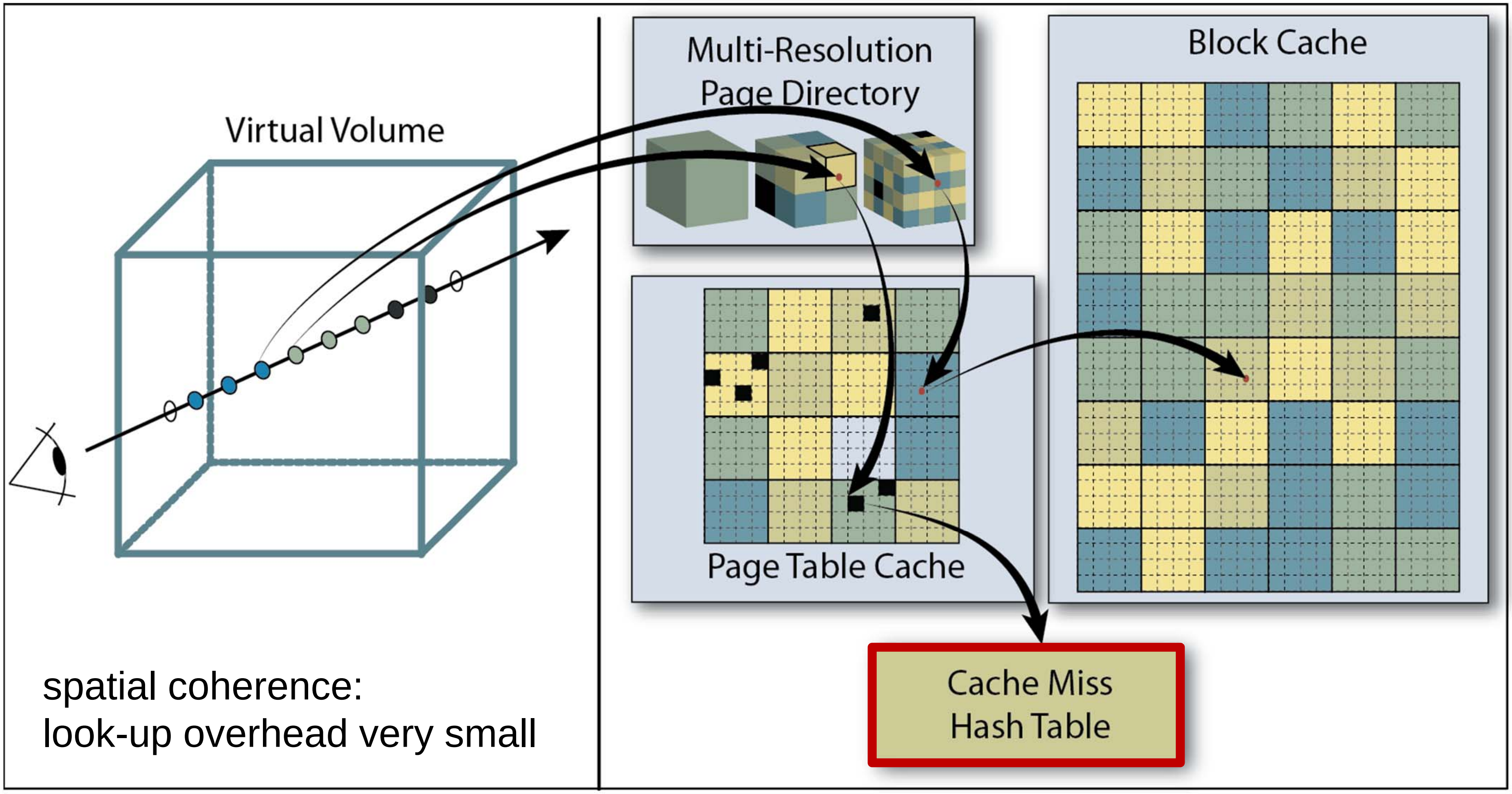
resolution	size	resolution hierarchy	page table hierarchy	page directory
32,000 x 32,000 x 4,000	4 TB	11 levels	2 levels	32 x 32 x 4
128,000 x 128,000 x 16,000	196 TB	13 levels	2 levels	128 x 128 x 16
512,000 x 512,000 x 64,000	15 PB	15 levels	3 levels	16 x 16 x 2
2,000,000 x 2,000,000 x 250,000	888 PB	17 levels	3 levels	64 x 64 x 8

- voxel blocks: 32^3 voxels
- page table blocks: 32^3 page table entries

System Overview

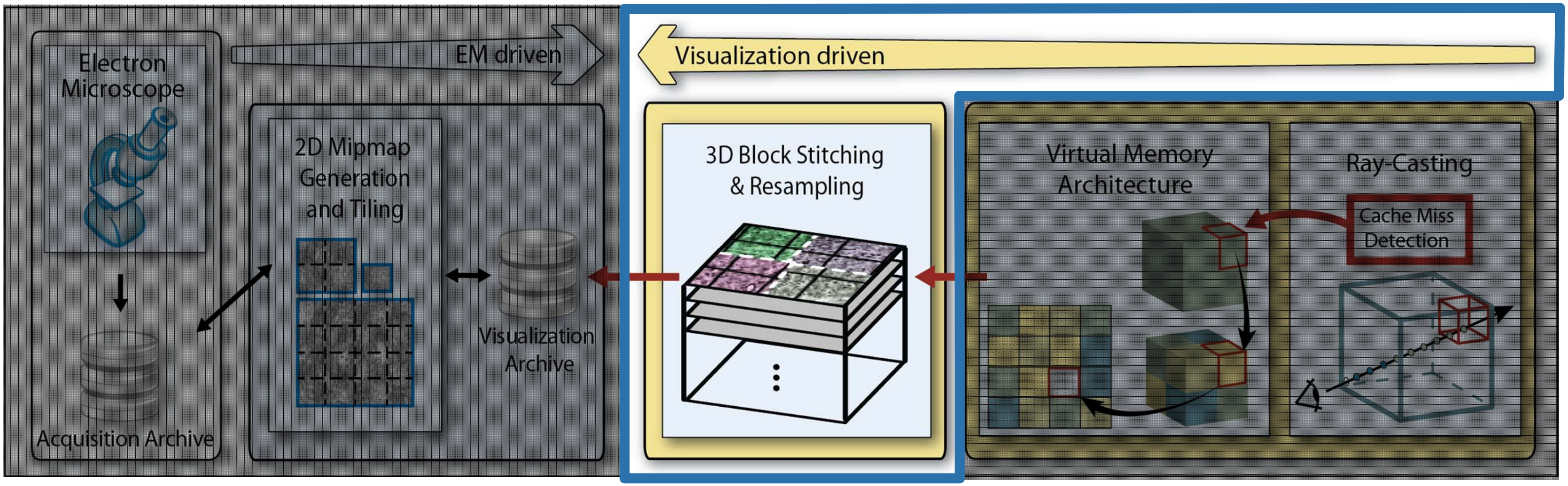


Visualization-Driven Architecture

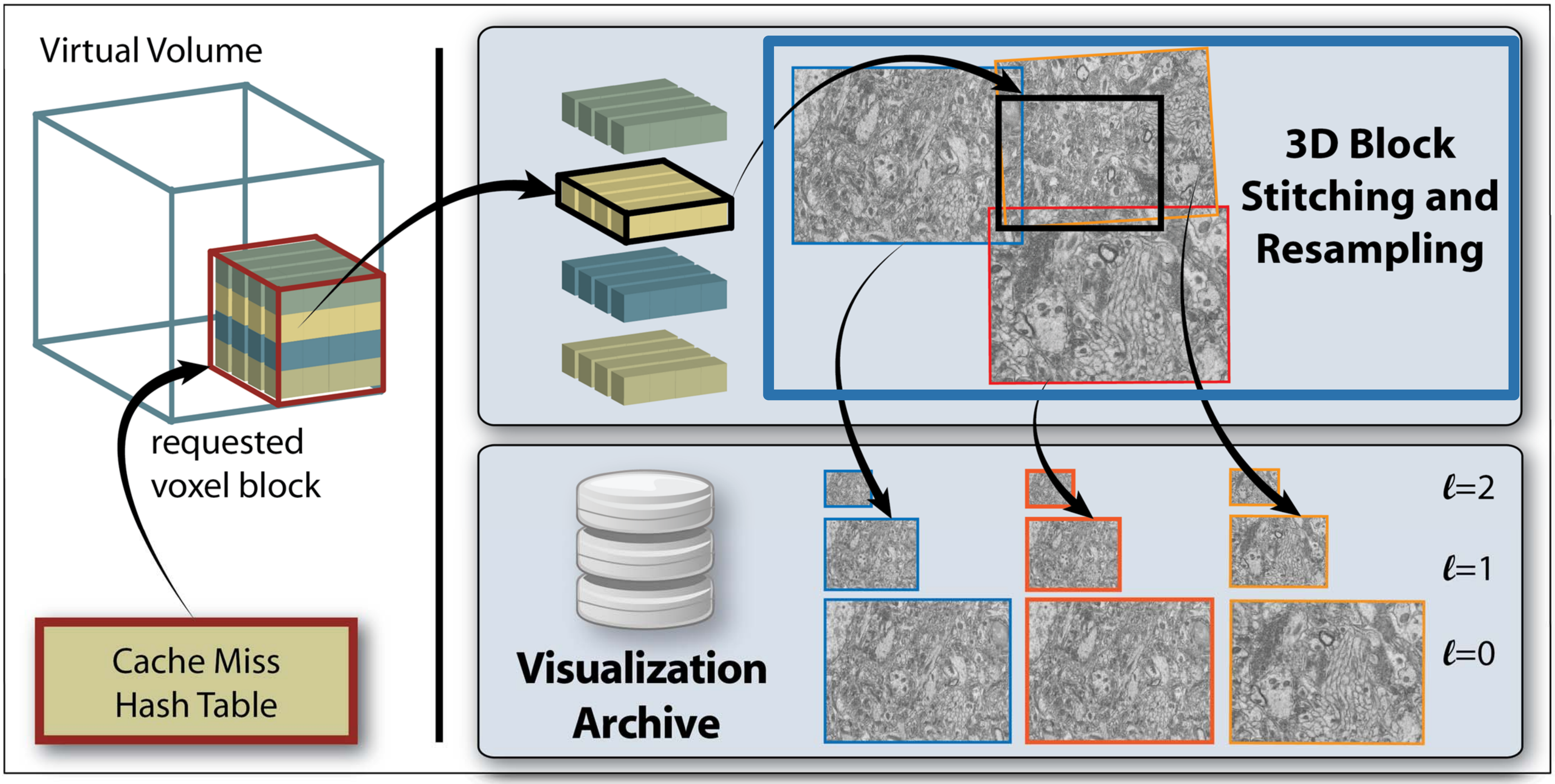


spatial coherence:
look-up overhead very small

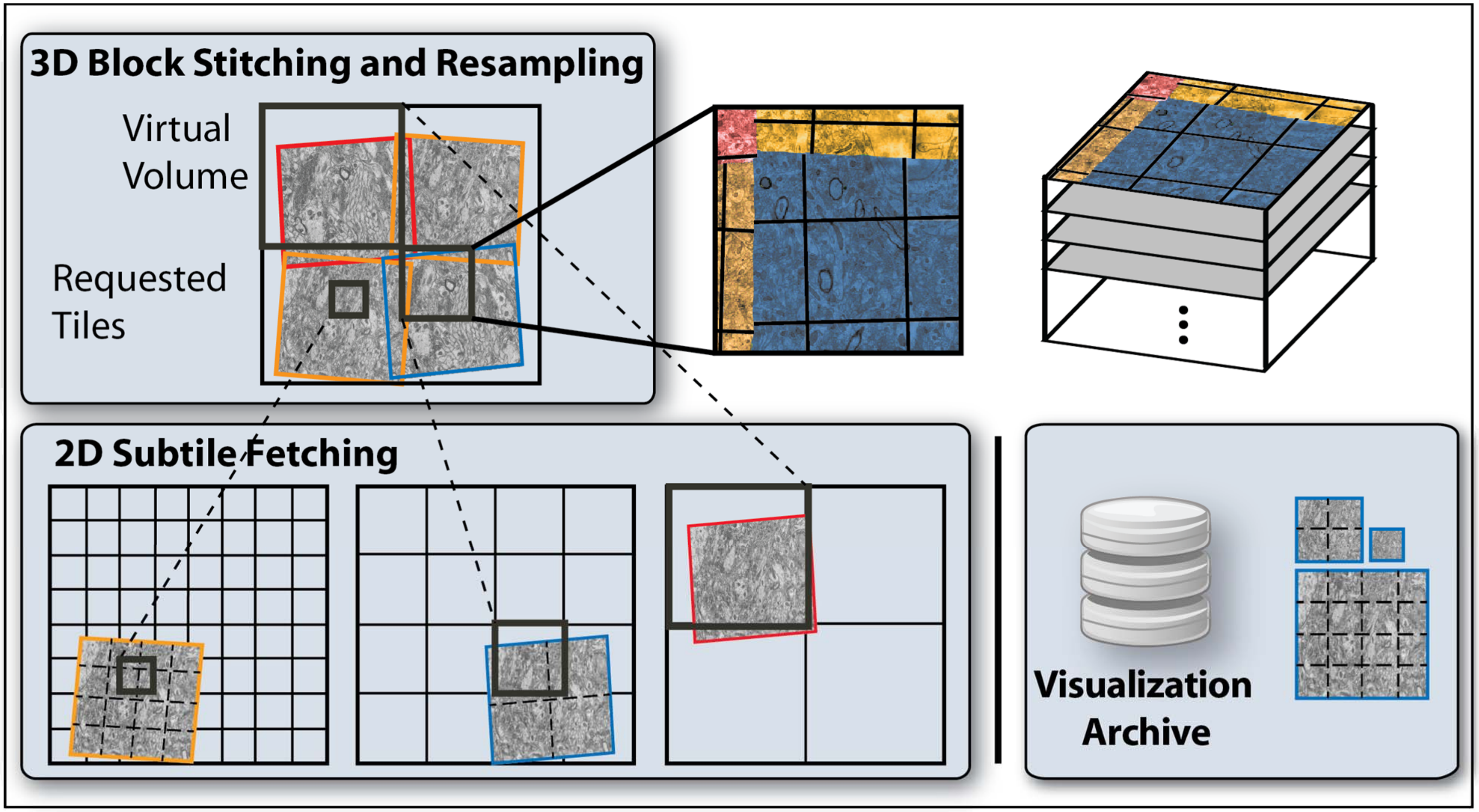
System Overview



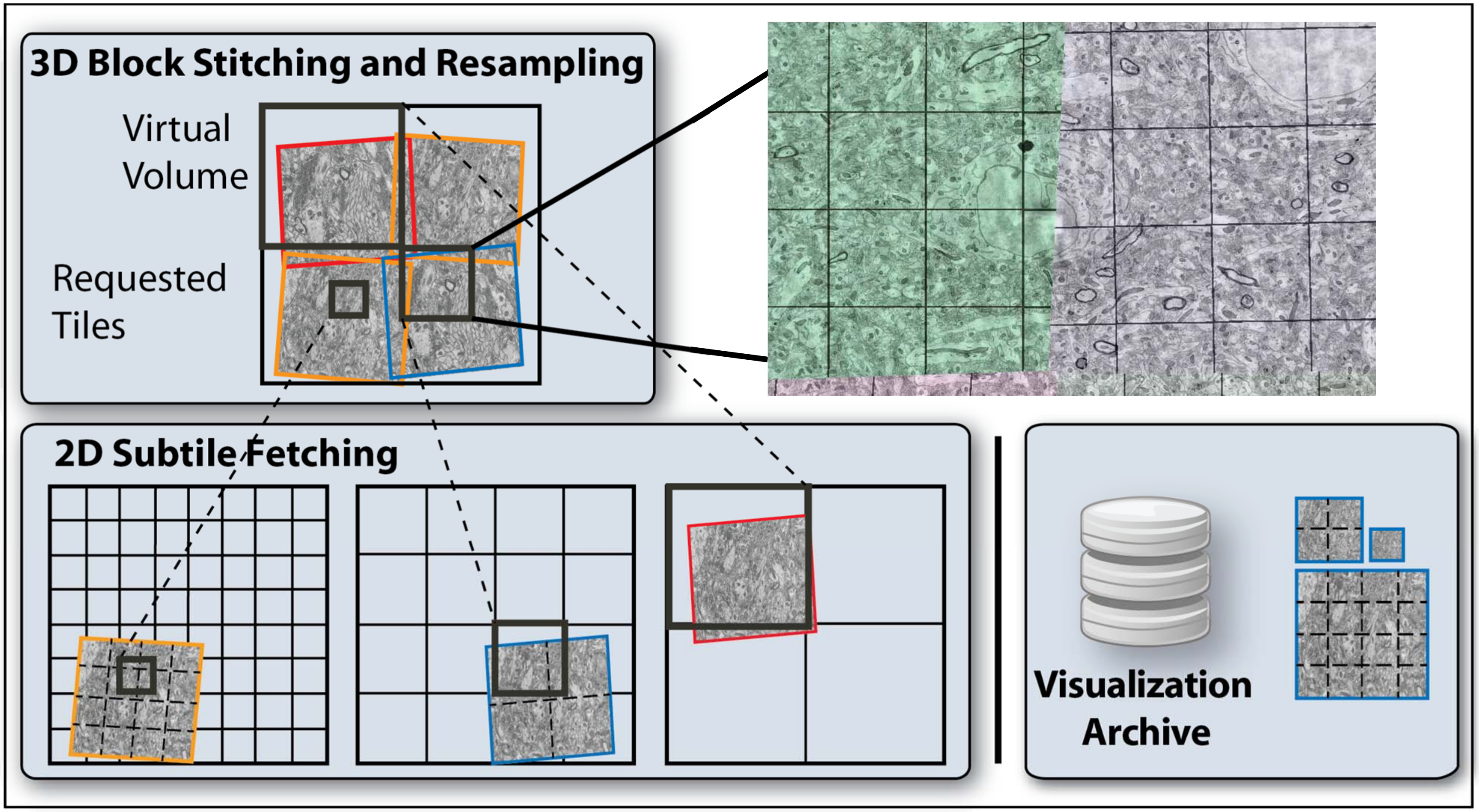
Visualization-Driven Architecture



Visualization-Driven Stitching



Visualization-Driven Stitching

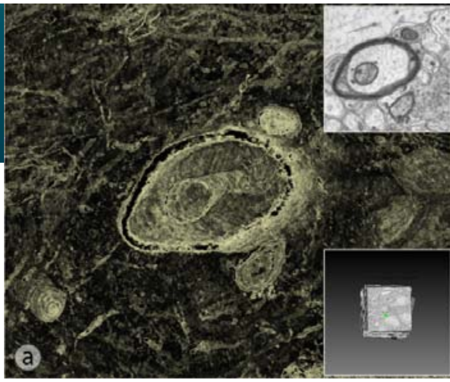


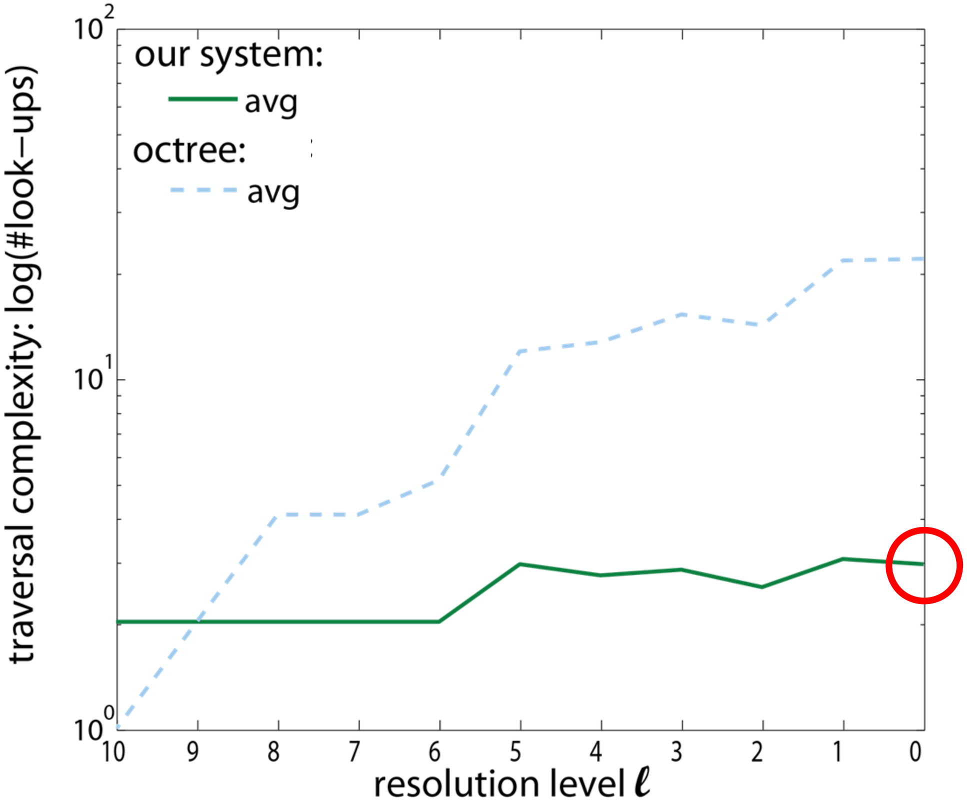
Rendering Performance

volume	size	transfer function	page table hierarchy [fps]	octree hierarchy [fps]
mouse cortex	955 GB	#1	75	61
		#2	12	9
hippocampus 1	92 GB	#1	77	63
		#2	19	15
hippocampus 1	43 GB	#1	72	58
		#2	22	13

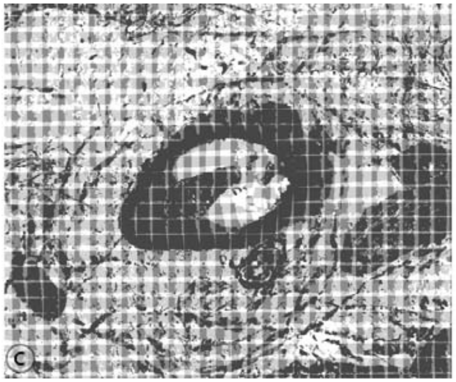
- NVIDIA Quadro 6000; 1024 x 768 viewport; everything resident in cache

Hierarchy Traversal Complexity





hierarchy look-ups

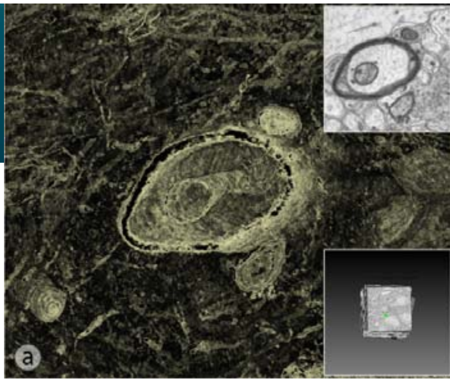


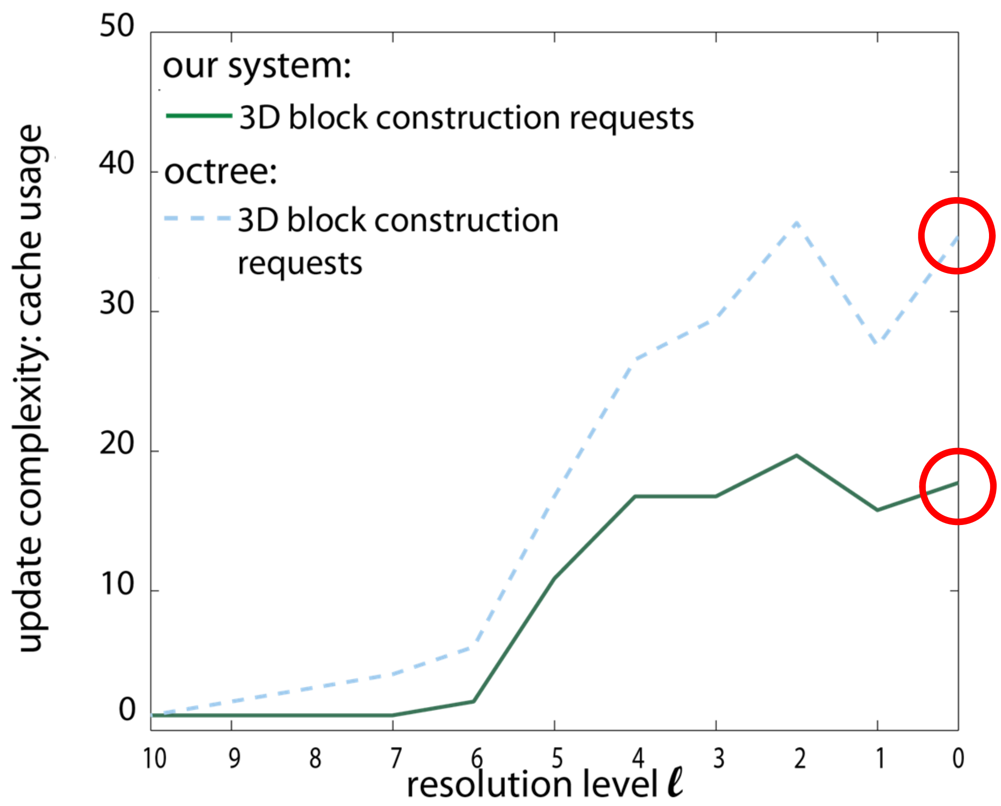
octree traversal

page table hierarchy traversal

avg: 2~3

Block Construction Complexity



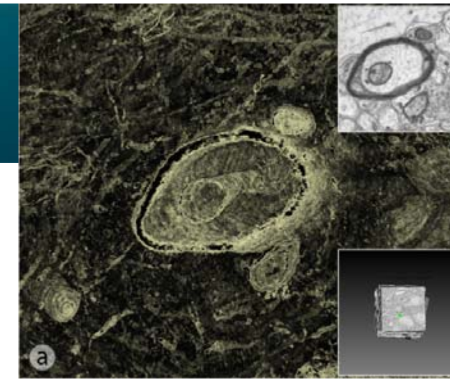


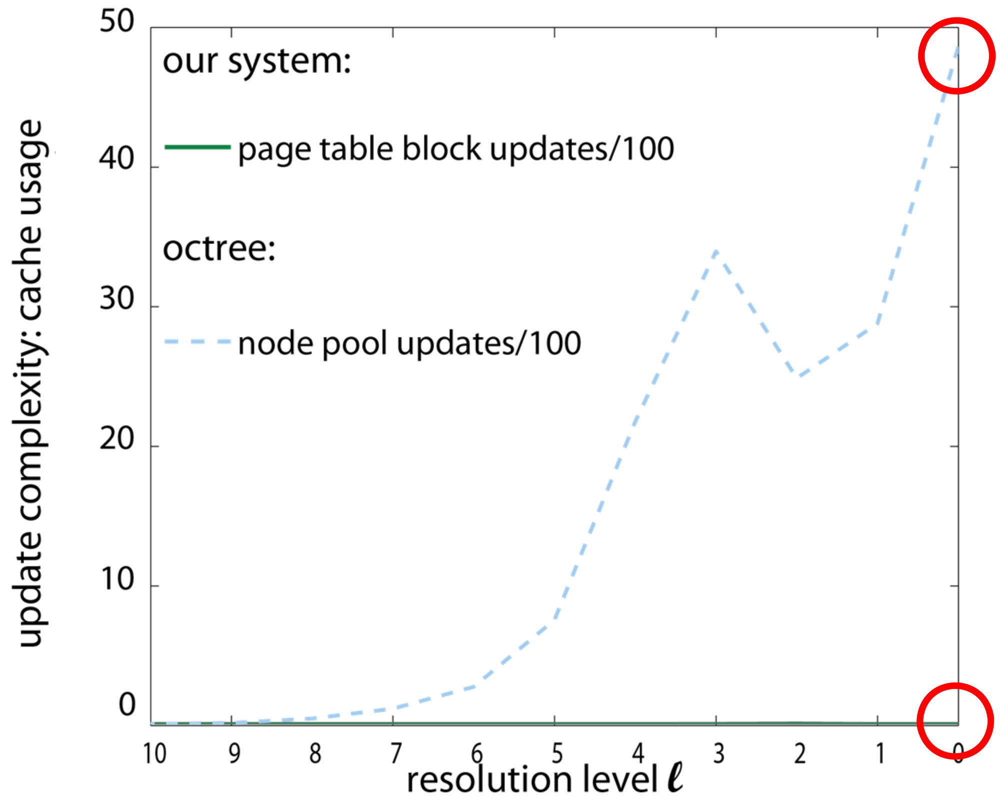
36 block requests

18 block requests

512 x 512 x 32 blocks

Node / Page Table Update Complexity



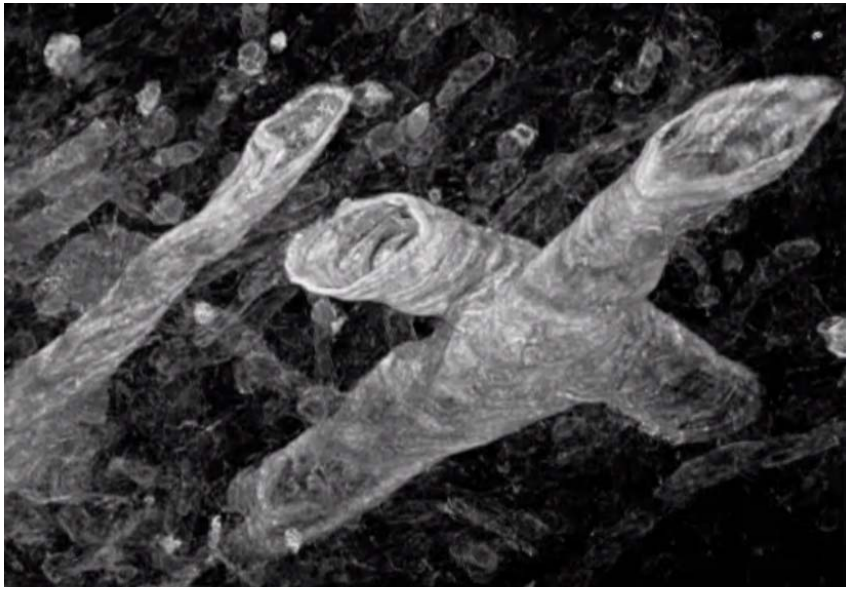


5000 node pool updates

4 page table block updates

Conclusions

- Visualization-driven 3D data construction
  - **Decouples** visualization from data acquisition
  - Incomplete, continuously streaming data
- Virtual memory architecture
  - **Decouples** resolution hierarchy from hierarchy traversal in ray-caster
  - Better scalability than octree traversal
- Limitations
  - Latency of 3D data construction
  - All visible data must fit into the cache (can be circumvented with several strategies)



Thank You for Your Attention!

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Acknowledgments:

Jens Schneider (KAUST)
Thomas Theussl (KAUST)
Klaus Engel (Siemens)
Florian Link (MeVis)

Vienna Science Fund WWTF
Intel VCI
Google, NVIDIA