Multi-Layered Unstructured Mesh Generation

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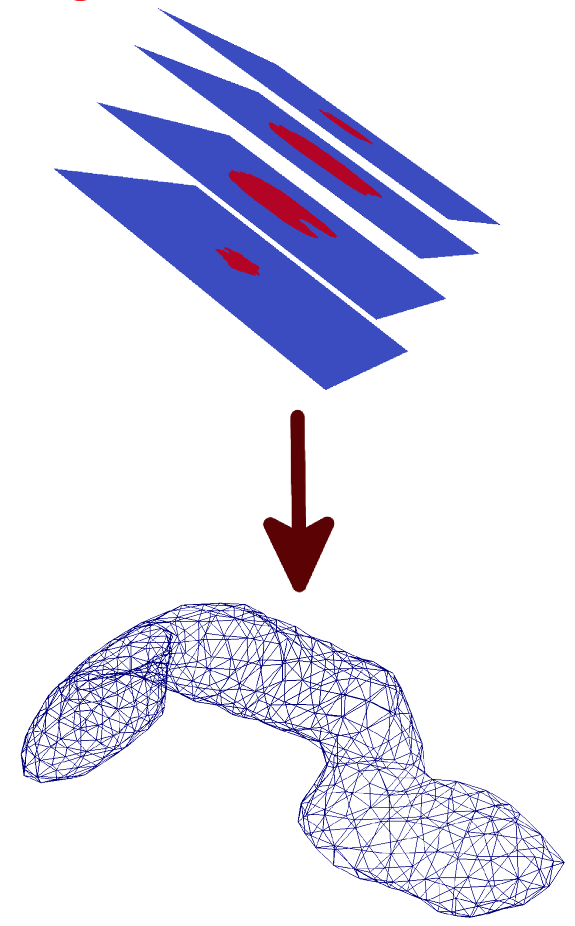
Introduction

- Input: Image
- Output: Mesh
- Faithful representation of the underlying object: Fidelity
- Well shaped tetrahedra: Quality
- Fidelity: symmetric Hausdorff distance, ambient isotopy
- Quality: aspect ratio, radius-edge ratio, size

Image to Mesh Conversion

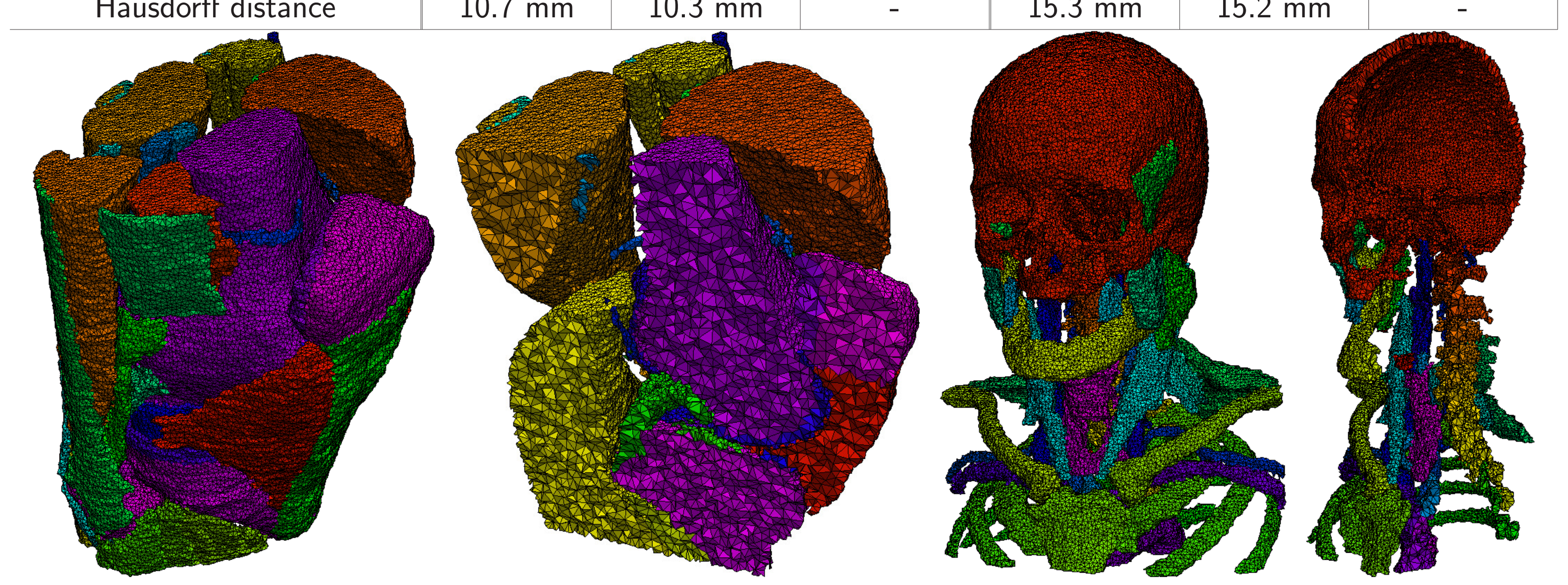


- Goal: scalability on thousands of cores!

Parallel Image-to-Mesh Conversion (PI2M)

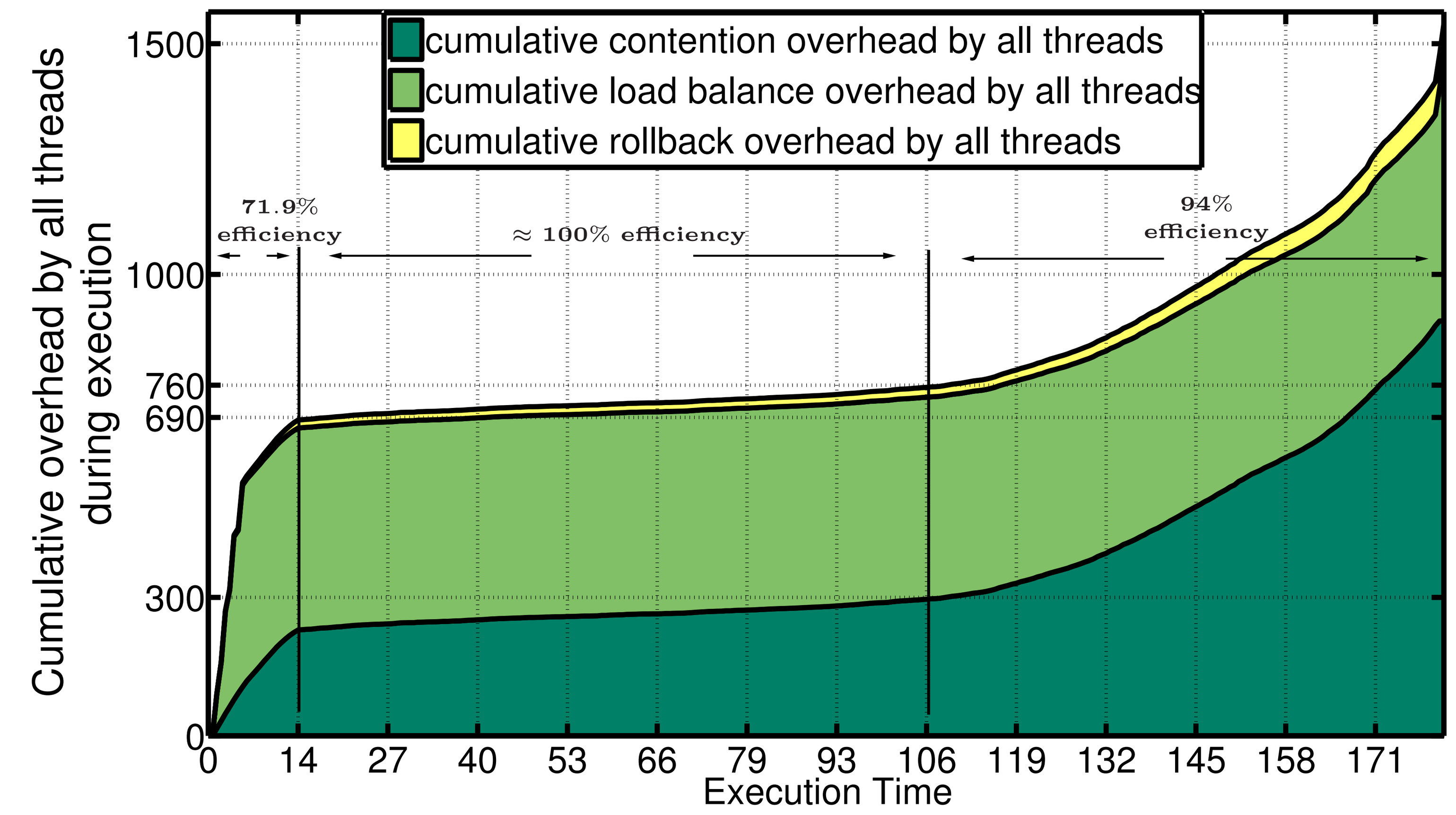
Statistics regarding the single-threaded performance and the quality/fidelity achieved by PI2M and CGAL. PI2M includes the extra overhead introduced by synchronization, contention management, and load balancing to support the (potential) presence of other threads.

	knee atlas			head-neck atlas		
	PI2M	CGAL	TetGen	PI2M	CGAL	TetGen
#tetrahedra / seconds	67,609	40,069	98,658	96,464	29,077	61,903
time	6.5 secs	10.9 secs	4.4 secs	10.3 secs	34.1 secs	16.0 secs
#tetrahedra	439,458	436,749	434,095	993,583	991,509	990,446
max radius-edge ratio	2	4.4	18.6	2	11.2	93.4
smallest boundary planar angle	17.4°	24.6°	18.0°	15.8°	2.4°	15.3°
(min, max) dihedral angles	(4.6°, 170.1°)	(2.5°, 176.3°)	(2.9°, 173.0°)	(4.5°, 170.2°)	(4.1°, 173.9°)	(0.4°, 172.0°)
Hausdorff distance	10.7 mm	10.3 mm	-	15.3 mm	15.2 mm	-



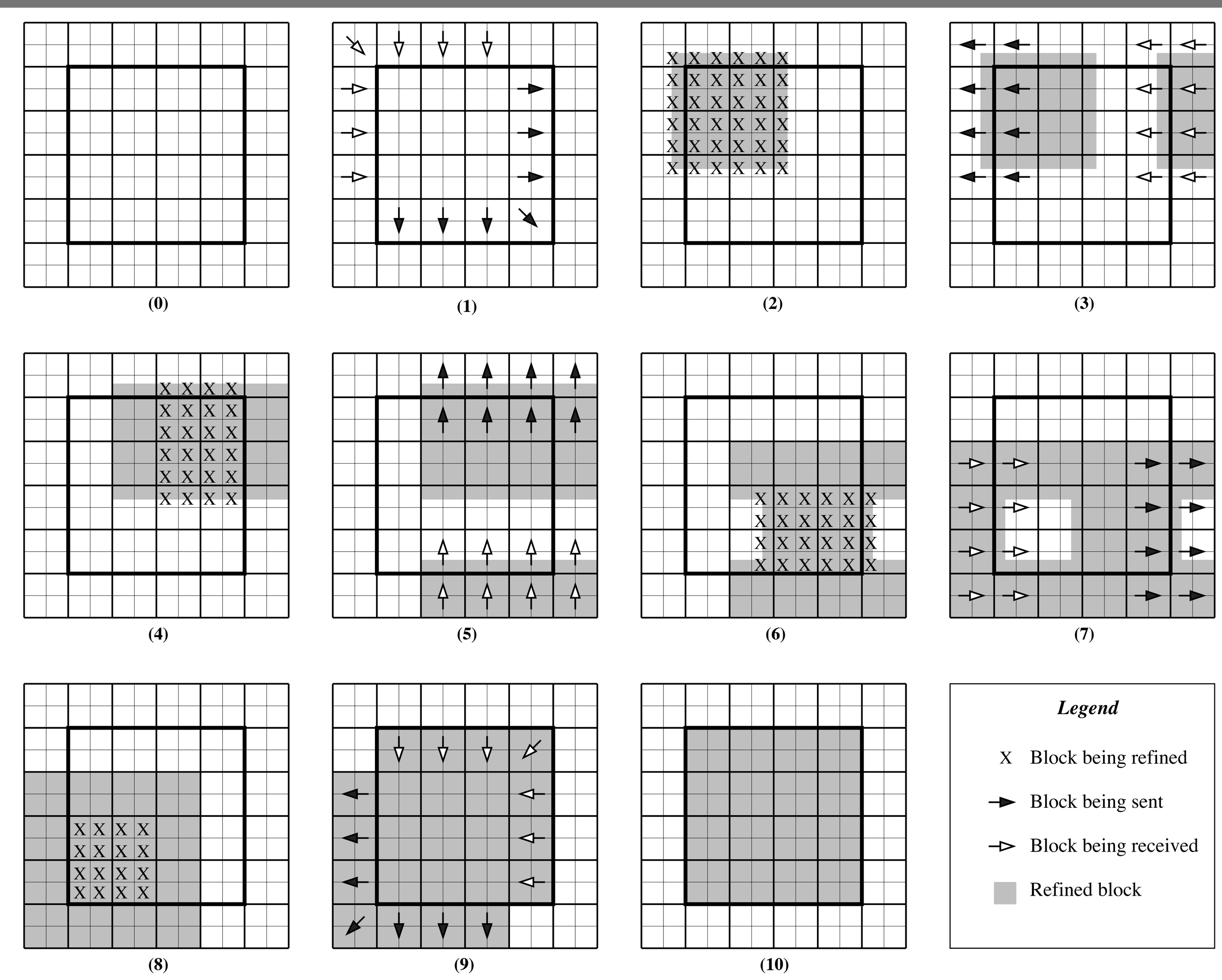
- Excellent Single-Threaded performance
- Scalability for up to 100 cores

Bottleneck: memory latency



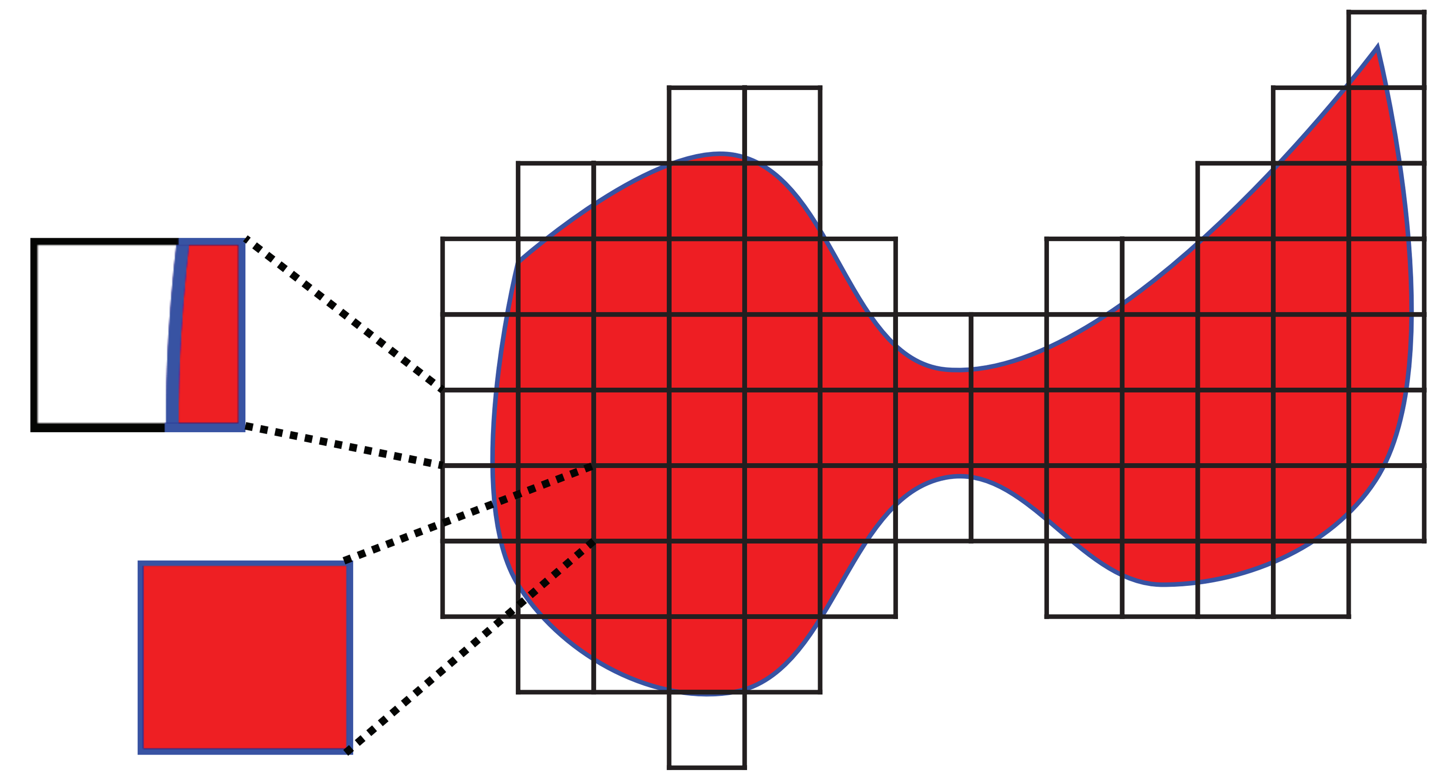
- Considering zero overhead for load balancing and contention, the 106s-14s=92s is far from perfect...
- Many small packages increase traffic pressure

Data Decomposition



- Impose an upper limit R for the elements' circumradii
- Data subdomains of size R
- Non-adjacent subdomains are safely independent
- Improves data locality
- 69% efficiency on 10 cores
- Data Locality + PI2M: $10^2 \times 6.9 = 690$ concurrency in a rack of 10 nodes

Domain Decomposition



- Data Decomposition alleviates intensive memory pressure, but it does not eliminate it
- Domain Decomposition separates memory banks
- Delaunay admissible medial axis domain decomposition is difficult in 3D or 4D
- Introduce artificial boundaries that do not hurt fidelity
- 66% efficiency on 48 cores
- Domain Decomposition + Data Locality + PI2M: $10^2 \times 6.9 \times (0.66 \times 48) \approx 22,000$ concurrency in an enclosure of 48 racks

Acknowledgements

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