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FORCE TECHNOLOGY

Sparse Layered Graphs for Multi-Object Segmentation

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We introduce Sparse Layered Graphs (SLG) for *s-t* graph cut segmentation of image data. Based on the widely used Ishikawa layered technique, it allows explicit object interactions, such as containment and exclusion with margins. Using limited prior knowledge we reduce the size of the graph, often by orders of magnitude, enabling us to solve large multi-object segmentation tasks, previously unsolvable using *s-t* graph cuts. Our method is general and can be used with different types of graph structures, including common grid-graphs or ordered multi-column graphs.

Geometric interactions

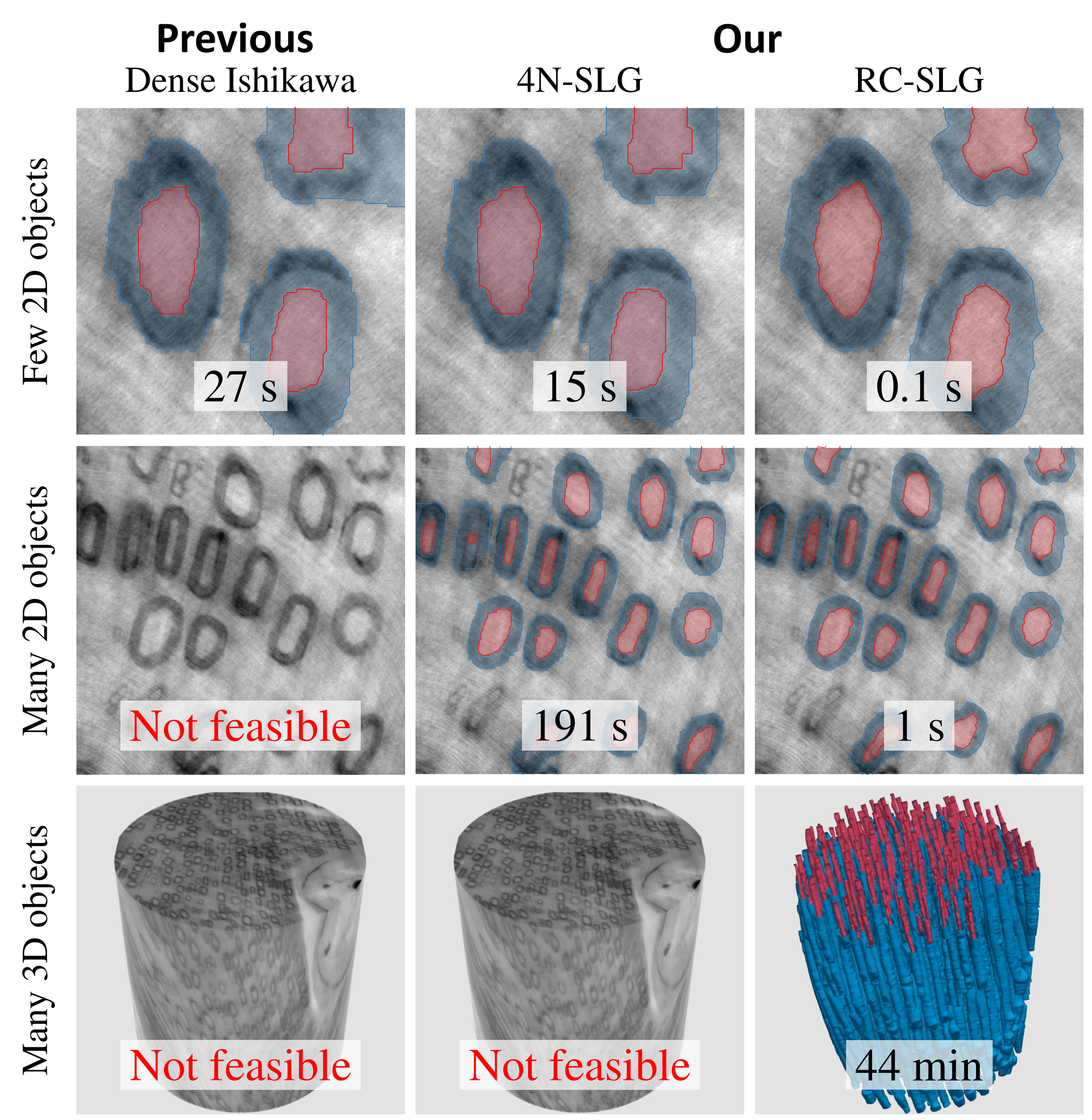
- **Containment** One object must be inside another object, with the possibility of specifying a minimum margin, d^i_{IJ}, between the objects, I and J.

$$\theta_{ij}(0,1) = \infty \ , \ \|p(i) - p(j)\| \leq d^i_{IJ}$$

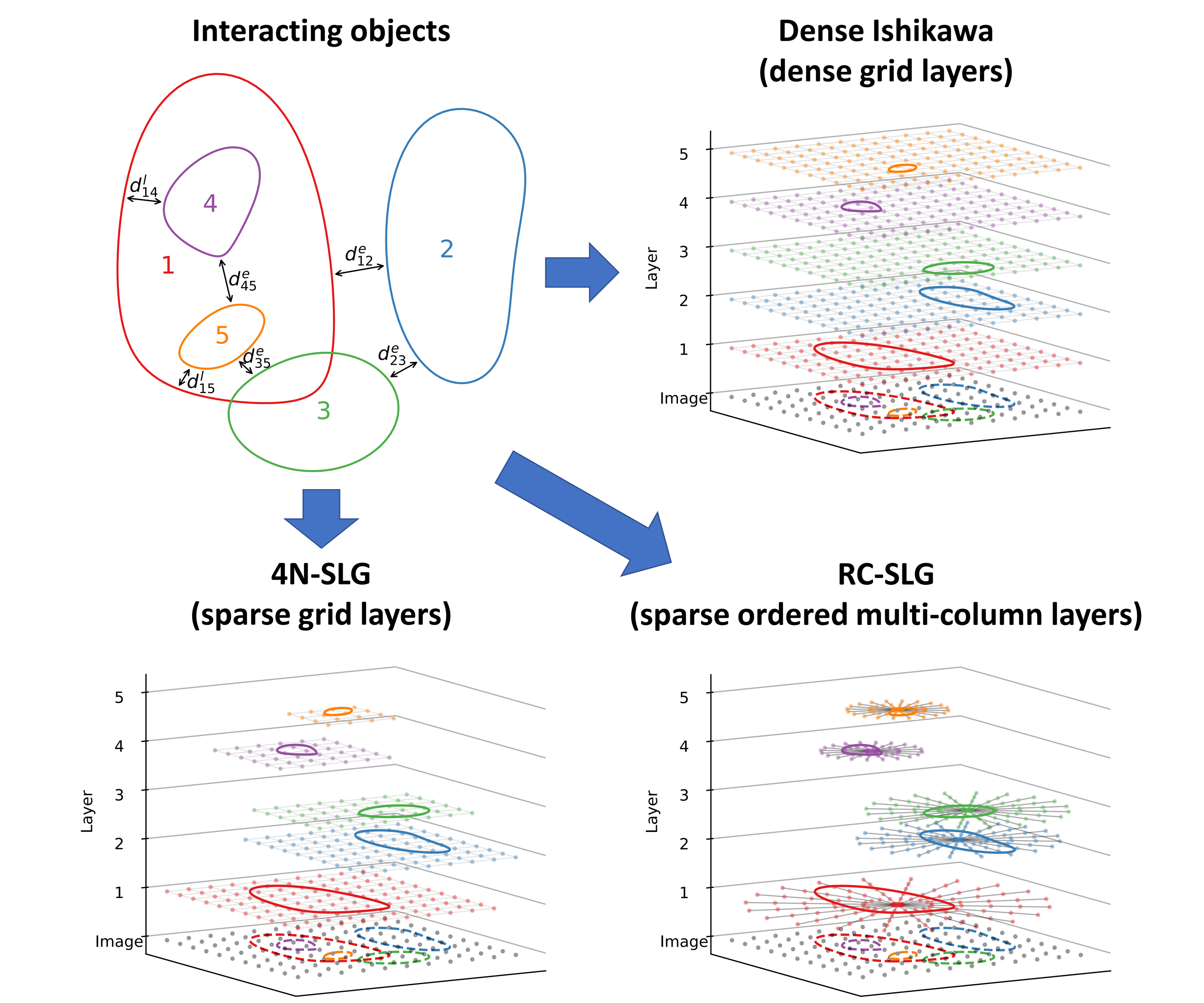
- **Exclusion** Two objects cannot overlap at any point, with the possibility of specifying a minimum distance, d^e_{IJ}, between the objects, I and J.

$$\theta_{ij}(1,1) = \infty \ , \ \|p(i) - p(j)\| \leq d^e_{IJ}$$

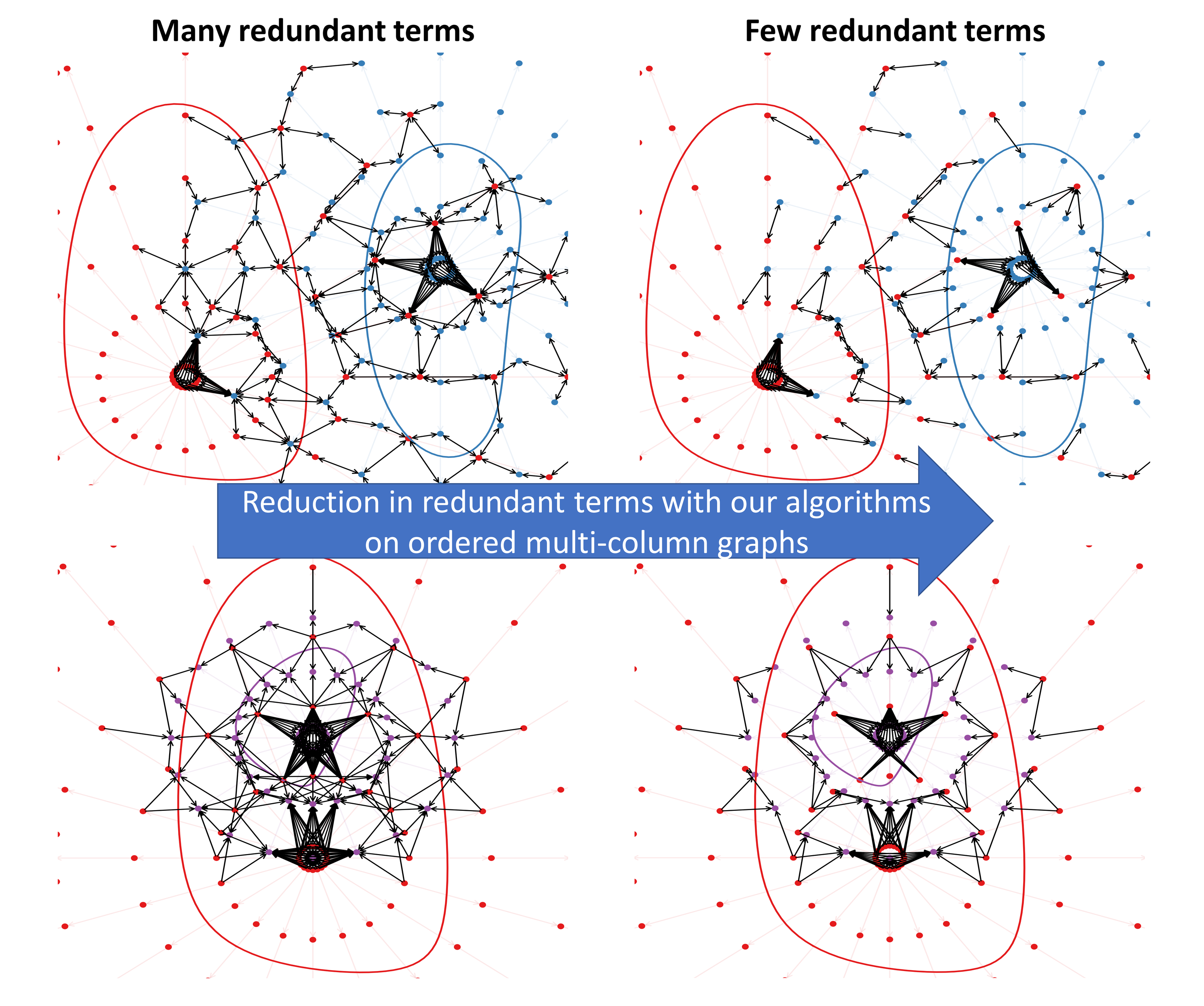
Segmentation of nerves in 2D and 3D showing scalability of SLGs



Constructing a Sparse Layered Graph



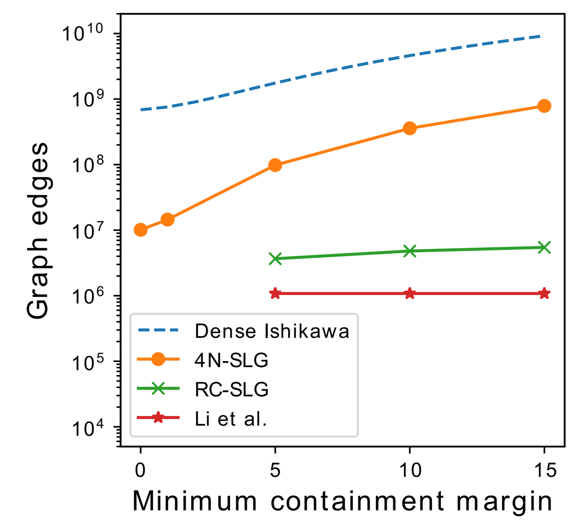
Reducing number of terms/edges further



Nerve segmentation

- Dense Ishikawa is not feasible for more than a few objects due to size of graph.
- 4N-SLG reduces graph size compared to dense Ishikawa, providing scalability and performance.
- Radially resampled ordered multi-column graphs (e.g. RC-SLG and Li *et al.*) reduce graph size even further (1-3 orders of magnitude for simple 2D image).
- Geometric interaction and smoothness constraints enable accurate segmentations.
- Scalability of RC-SLGs allow multi-object segmentation of large 3D volumes (e.g. 2048^3) with hundreds of interacting objects within reasonable time.

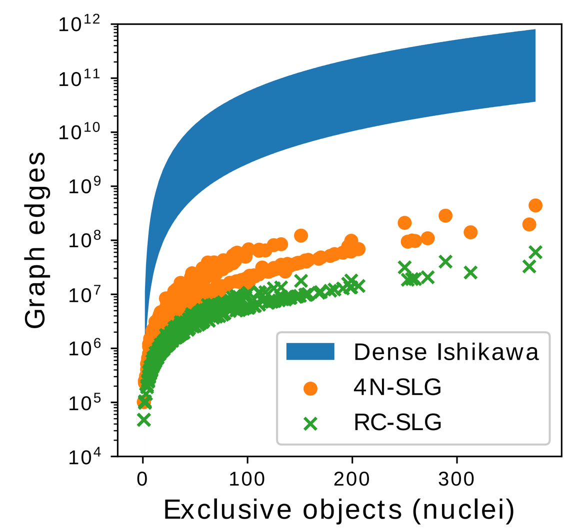
	4N-SLG		RC-SLG		Li *et al.*	
Nodes (mil.)	2.46		0.58		0.28	
	Min	Max	Min	Max	Min	Max
Edges (mil.)	6.8	1425	3.6	6.1	1.1	1.1
Time (s)	1.95	545	0.48	2.70	0.19	0.74
F1	0.91		**0.94**		0.92	
Precision	**0.95**		0.93		0.90	
Recall	0.90		**0.96**		0.95	



Nuclei segmentation

- Ordered multi-column graphs (e.g. RC-SLG) are versatile and can be used for segmenting structures of varying sizes and intensities without changing parameters.
- The shape constraint of the RC-SLG makes it more accurate than the 4N-SLG (grid) for segmenting similarly shaped objects.
- The reduced size of the RC-SLG makes it significantly faster and less memory intensive than the grid-based methods (e.g. 4N-SLG).
- Even with many exclusive objects, unlabeled nodes are rare and little impact on accuracy.
- RC-SLGs could be used for geometrically constrained post-processing of segmentations, where approximate positions and sizes have already been determined.

	4N-SLG		RC-SLG	
Per image	Mean	Max	Mean	Max
Nodes (mil.)	2.25	19.2	0.71	6.08
Edges (mil.)	14.6	442	3.12	60.3
Time (s)	2.55	69.5	1.02	26.1
Per mask	Mean	Max	Mean	Max
Unlabelled	3.2	428	0.48	876
Per mask	Mean	Std.	Mean	Std.
F1	0.48	0.32	**0.85**	0.12
Precision	**0.97**	0.09	0.85	0.13
Recall	0.40	0.34	**0.89**	0.16



Segmentation results for five of the 670 images of nuclei segmented using RC-SLG (same parameters used for all images)