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Inverse 3D Microscopy Rendering for Embryo Shape Inference with Active Mesh

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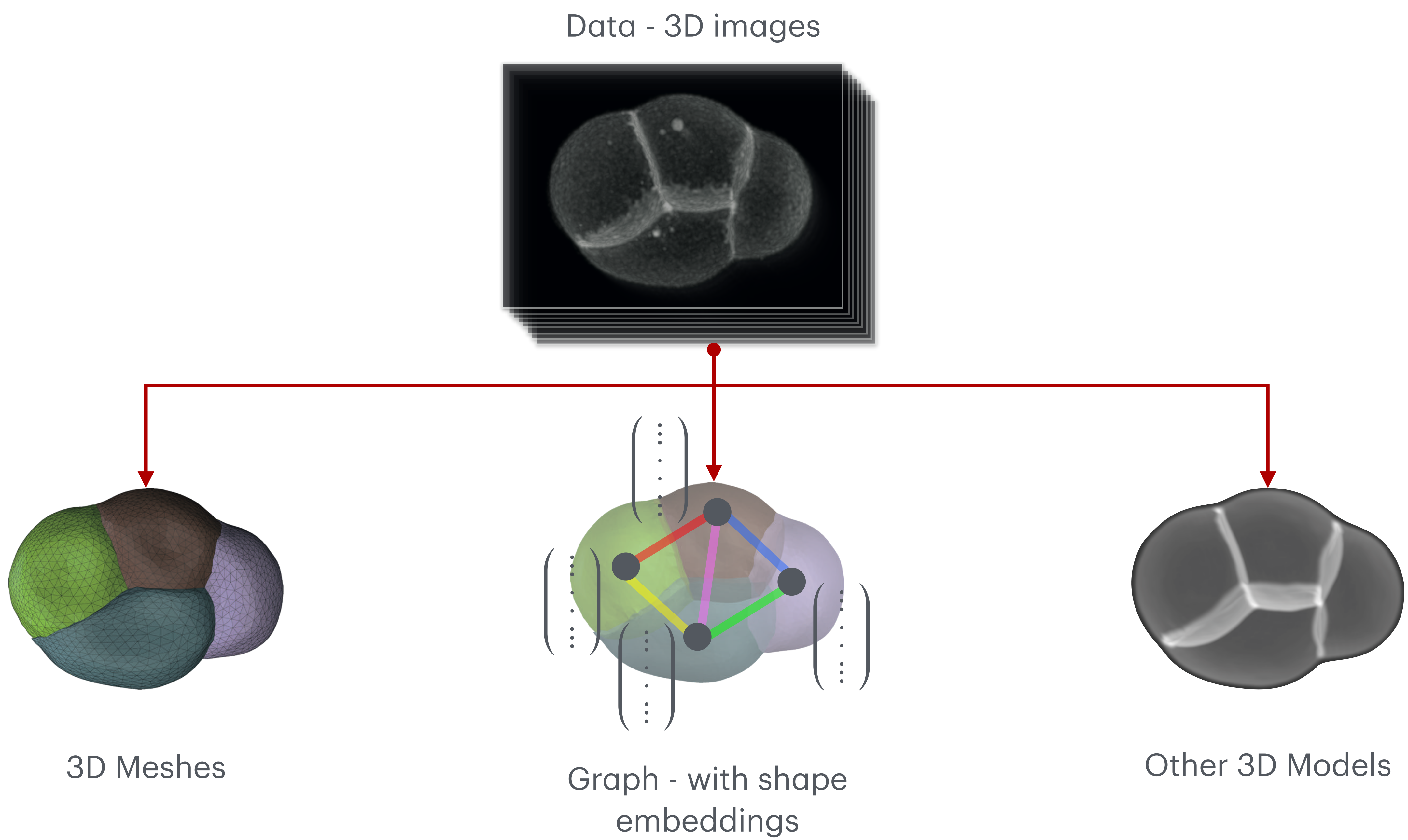
Encapsulate the Physical Shape of Embryos

A Static Problem

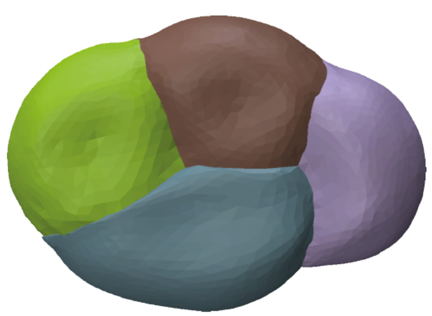


The Static Problem

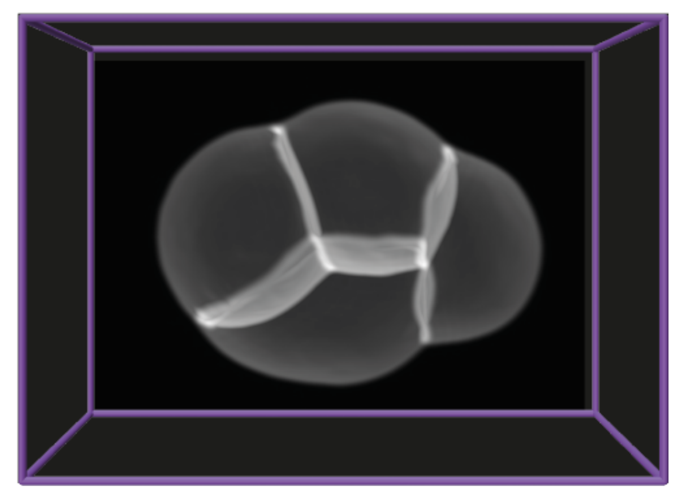
What is Rendering?

"*Rendering is the process of generating a photorealistic or non-photorealistic image from input data such as 3D models.*"

- Wikipedia definition of rendering for Computer Graphics



3D Mesh Model

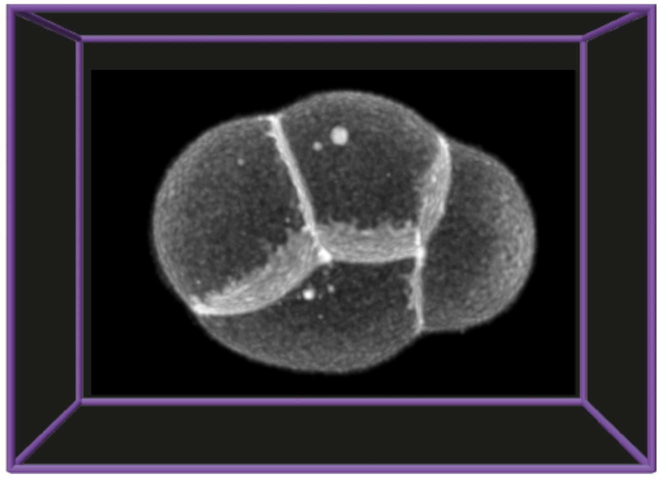


Rendered 3D Microscopy Image (Artificial)

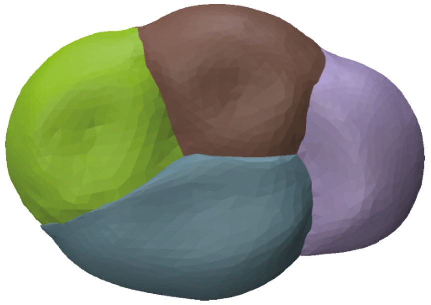
The Static Problem

What is Inverse Rendering?

Inverse rendering may therefore refer to the process of extracting/inferring such 3D models present in real images.



3D Microscopy Image
(Real)



3D Mesh Model

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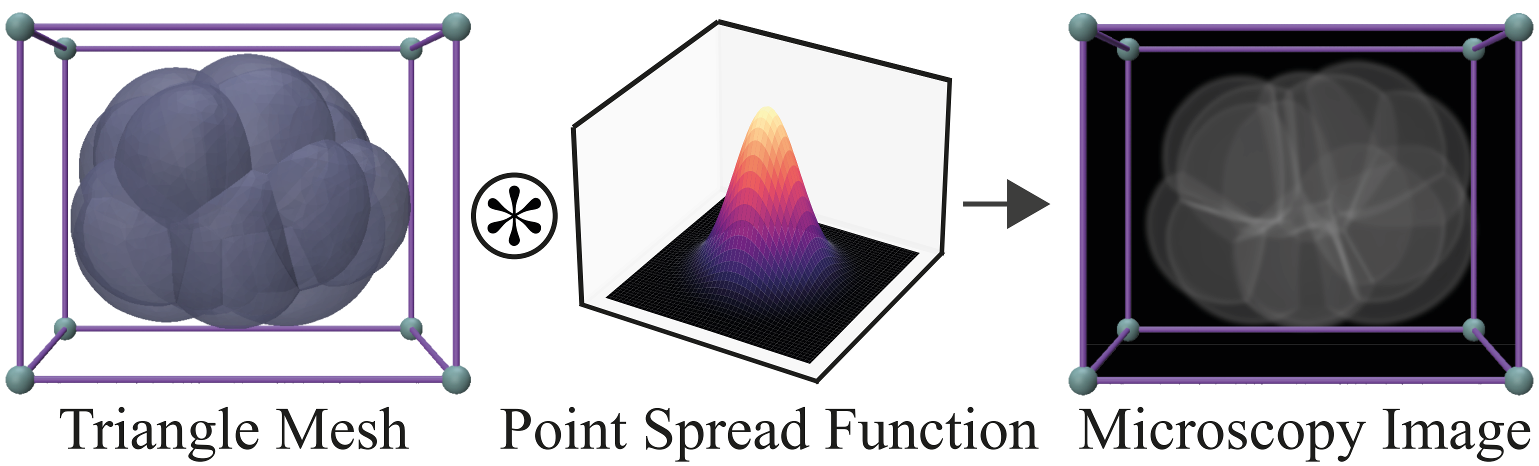
Rendering with a Point Spread Function

- A microscope's PSF characterises how a single point of light is imaged
- Rendering is modelled as convolution of fluorophore density with the PSF
- A Gaussian PSF is commonly used: $h(z) = \frac{e^{-\frac{1}{2}z^T\Sigma^{-1}z}}{\sqrt{(2\pi)^3 \det \Sigma}}$



[3]Reference: Ichbiah S., Sinha A., Delbary F., Turlier H. - ICCV 2025.
« Inverse 3D Microscopy Rendering for Cell Shape Inference with Active Mesh »

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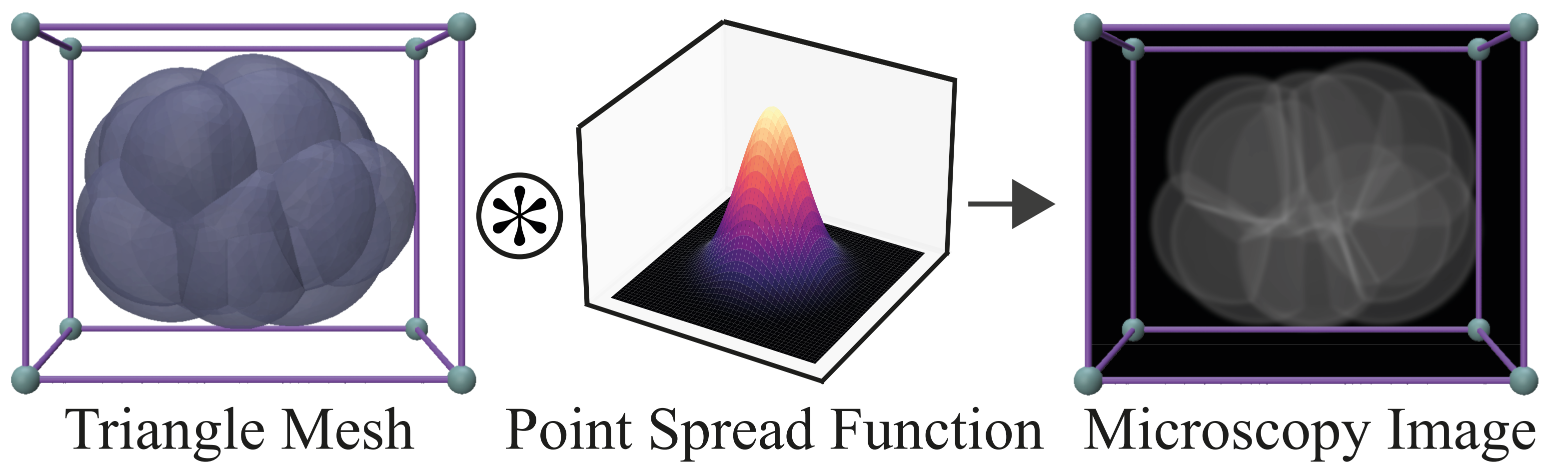

$$u_\alpha(p) = (u_\Lambda * h)(p)$$
$$= \int u_\Lambda(x) h(p - x)\, d^3x$$

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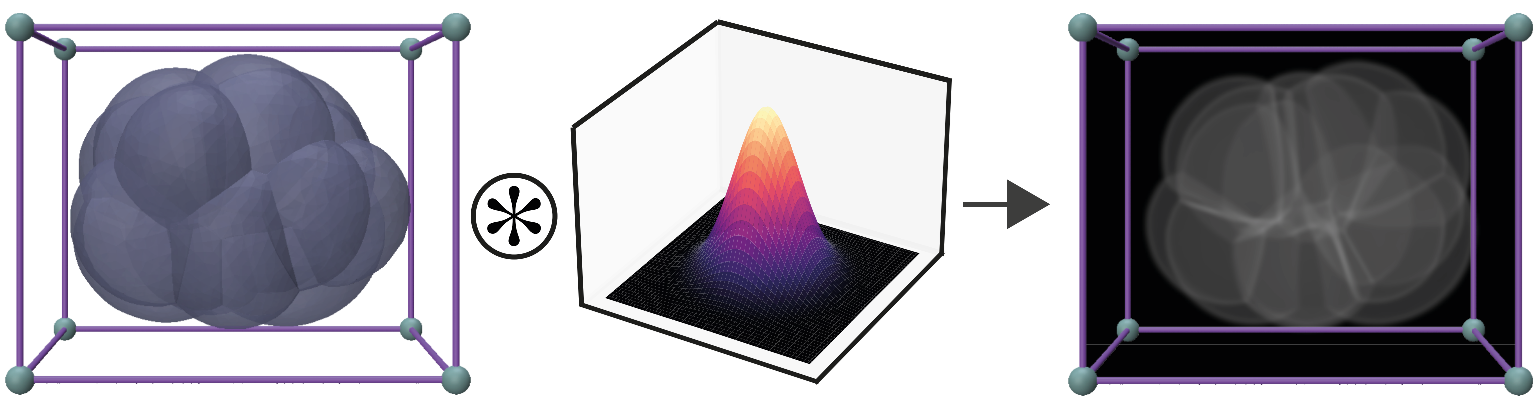
Rendering with a PSF in the Fourier domain

- Convolution in real space becomes multiplication in Fourier space
- Enables efficient rendering and gradient-based optimization
- The output is then inverse Fourier transformed to obtain the synthetic image



$$\hat{u}_\alpha(\xi) = \hat{u}_\Lambda(\xi) \cdot \hat{h}(\xi)$$
$$\hat{h}(\xi) = e^{-\frac{1}{2}\xi^T \Sigma \xi}$$

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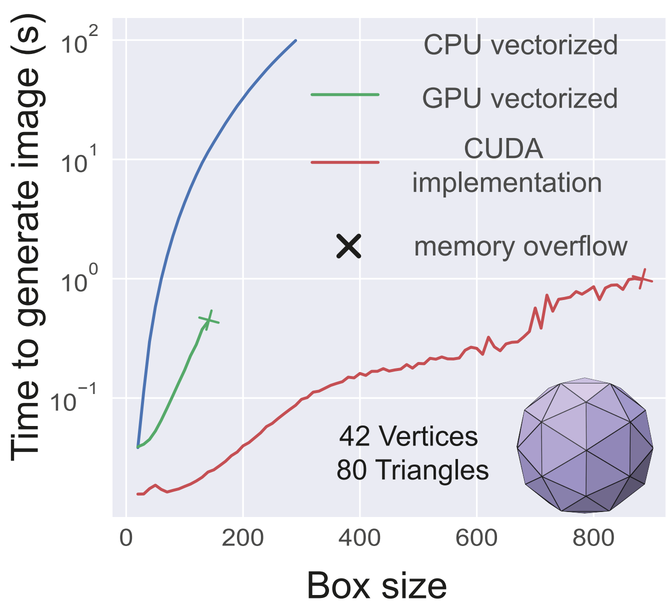
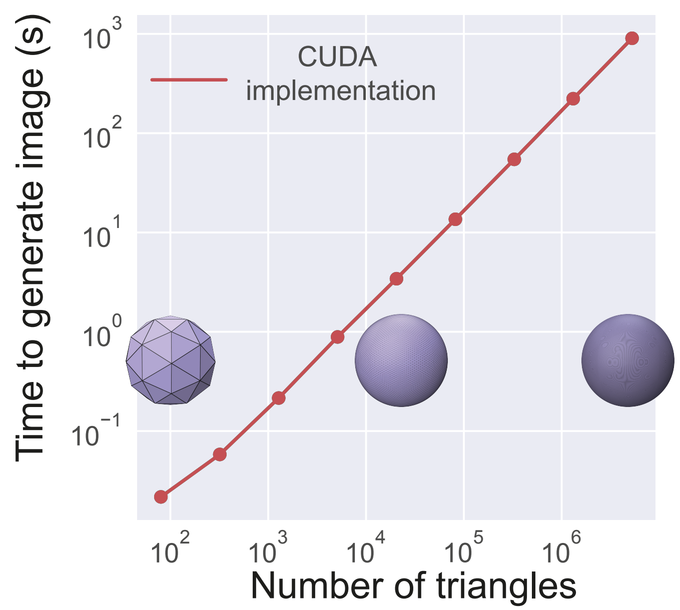
Rendering with a PSF in the Fourier domain

- Performing this operation in the Fourier domain reduces the complexity from - $O(n^6)$, to $O(n^3 . log(n^3))$





- **Major Contribution**: Analytical formula to compute Fourier transform of triangular meshes (without singularities)

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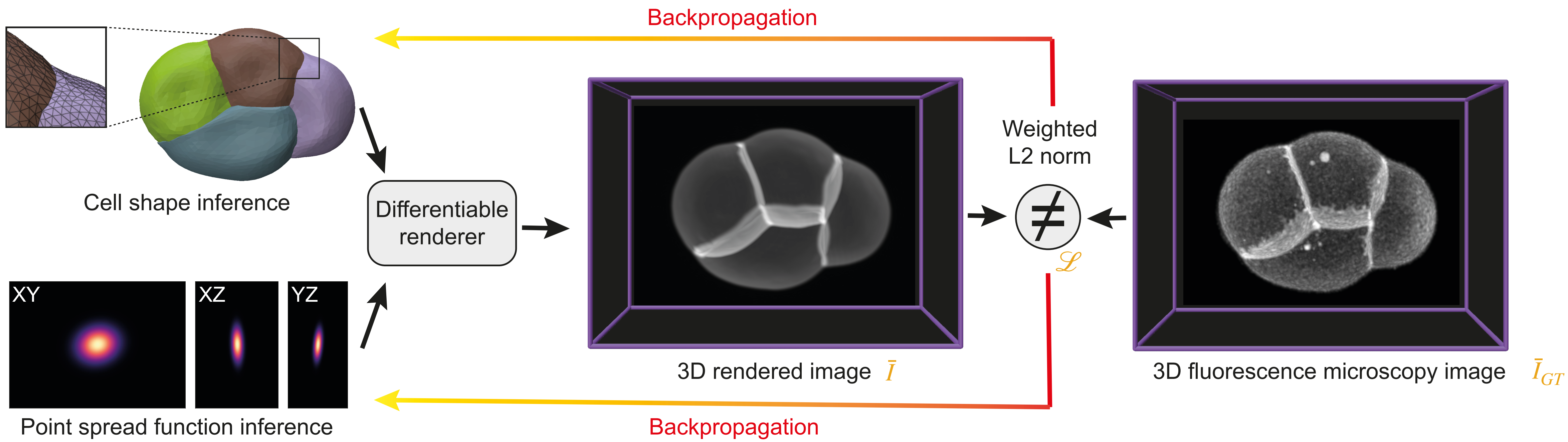
Methodology



$$\mathcal{L} = \left\langle \left(\bar{I} - \bar{I}_{GT}\right)^2, \bar{I}_{GT} \right\rangle$$

[3]Reference: Ichbiah S., Sinha A., Delbary F., Turlier H. - ICCV 2025.

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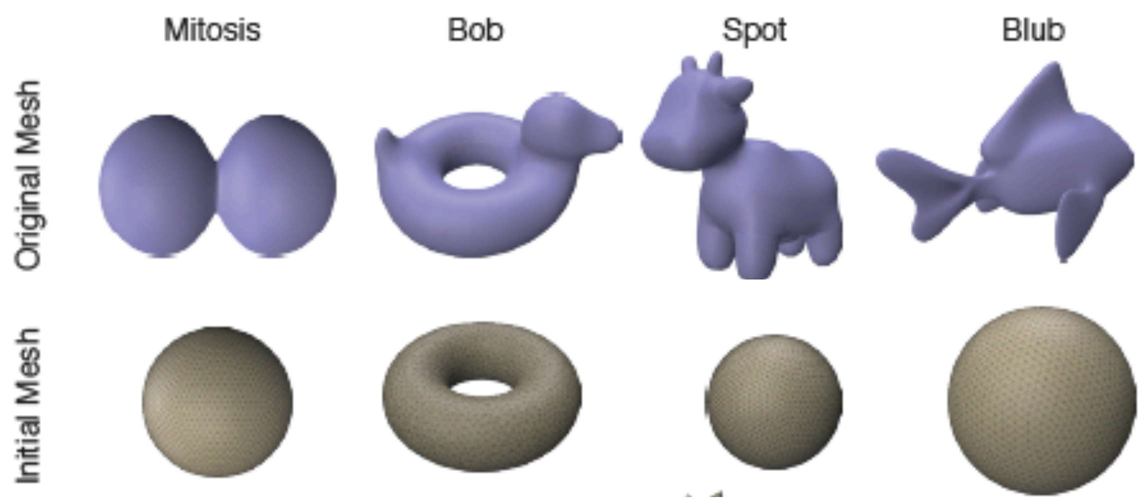
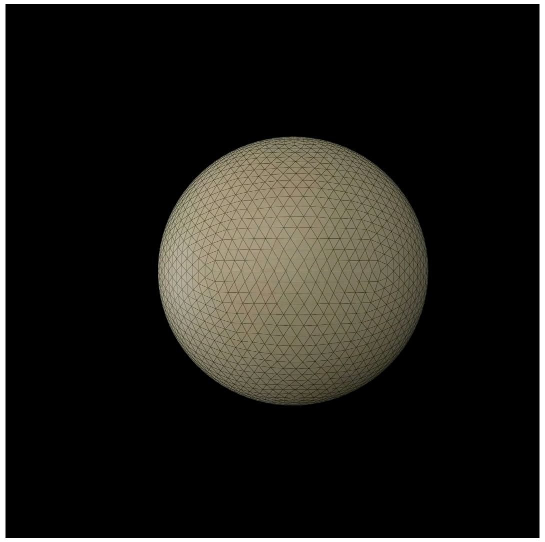
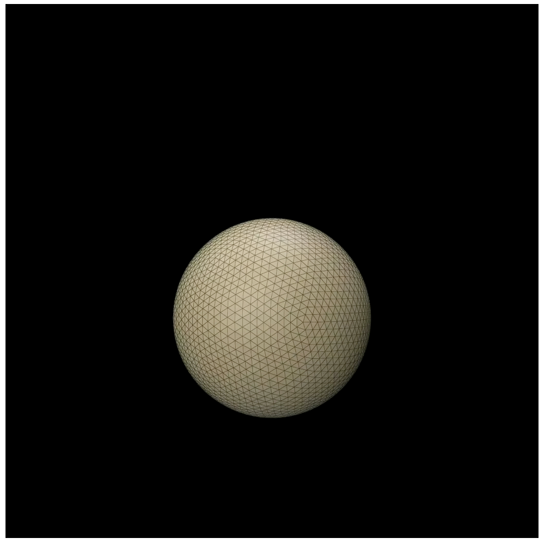
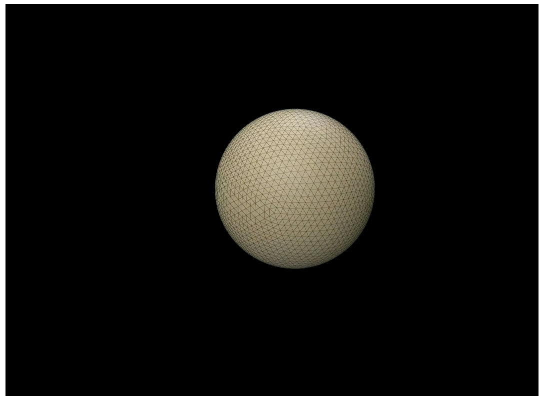
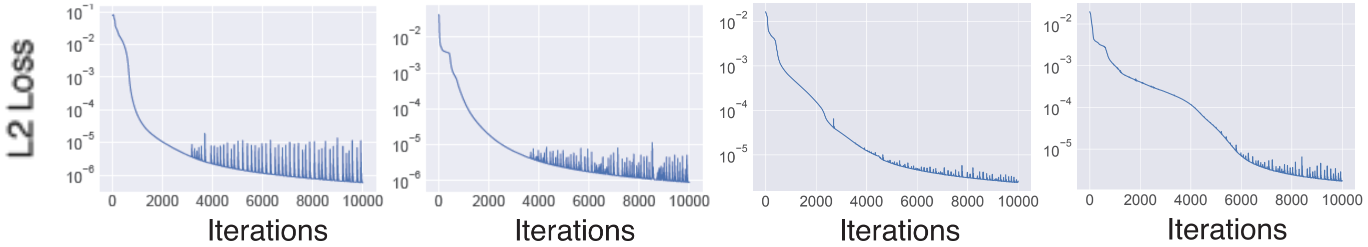
Single Object Benchmark











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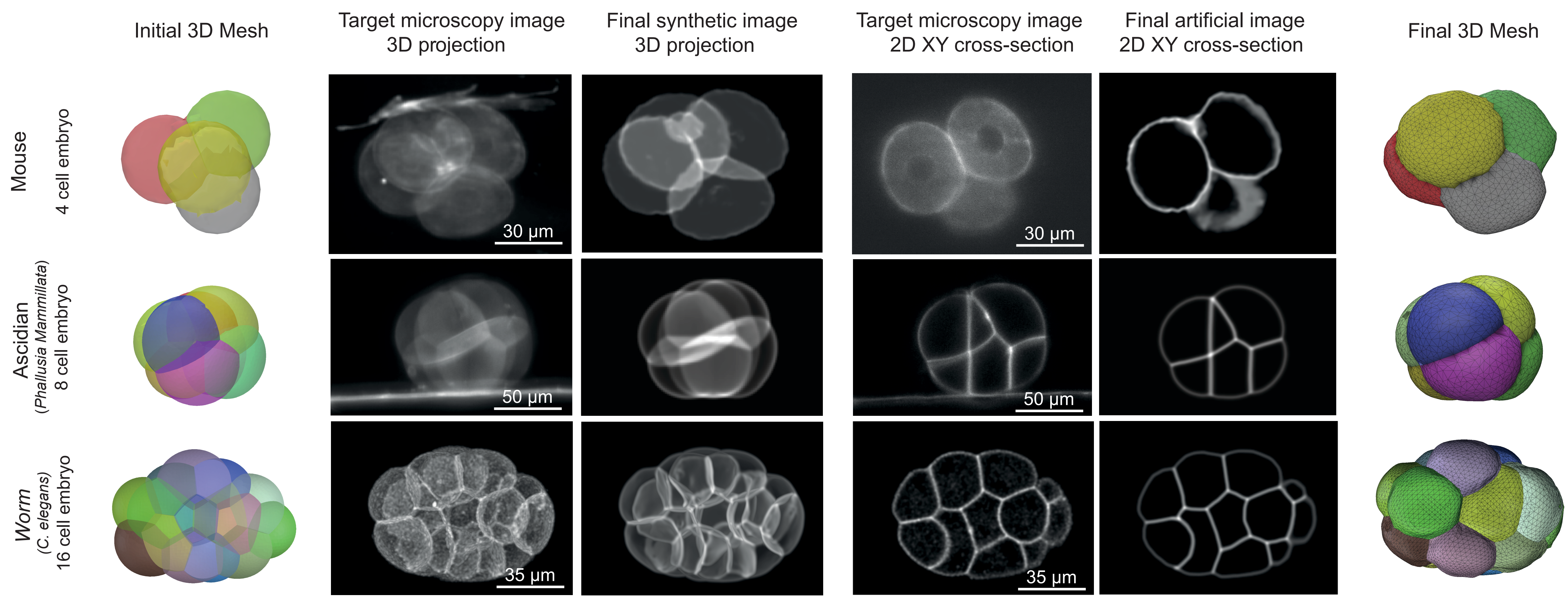
Young Embryos Benchmark - Cross Species



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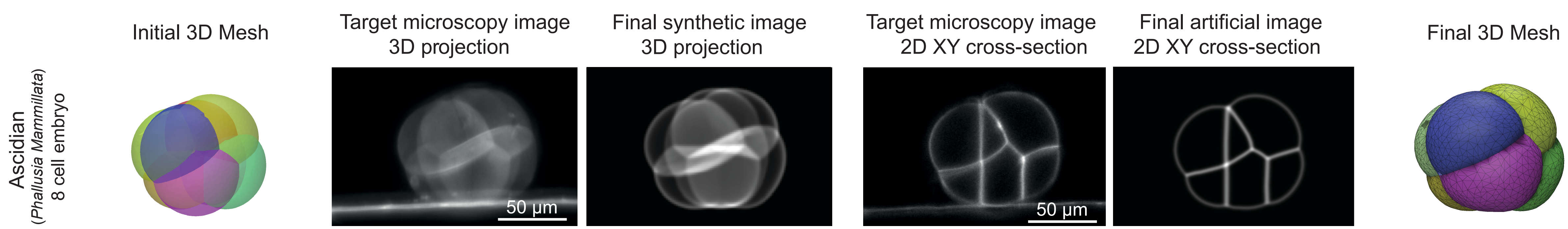

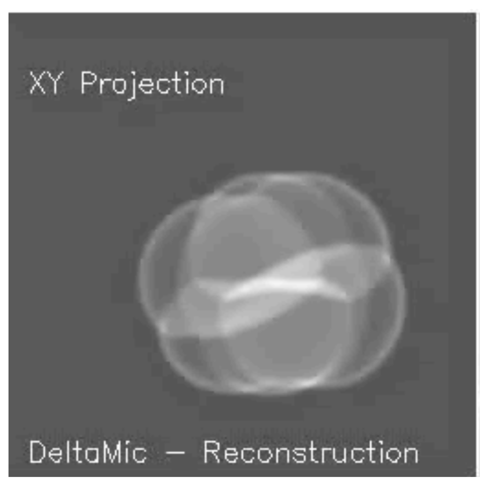

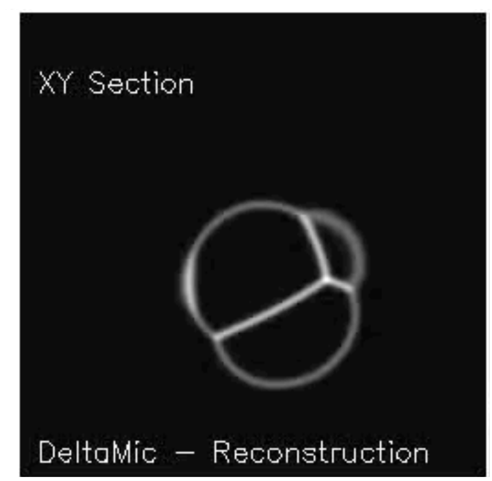

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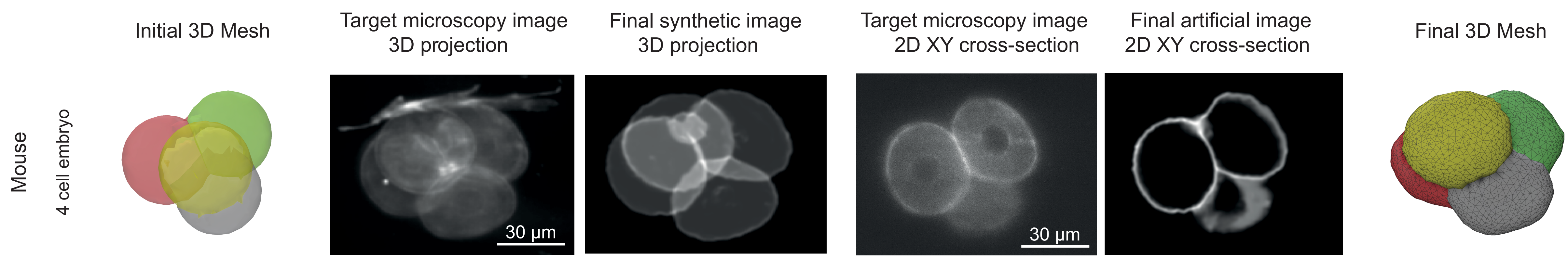

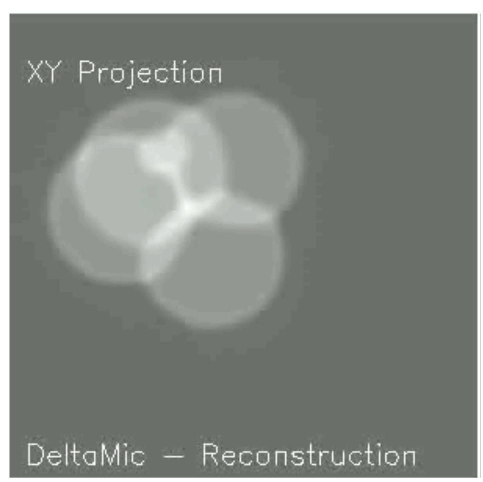

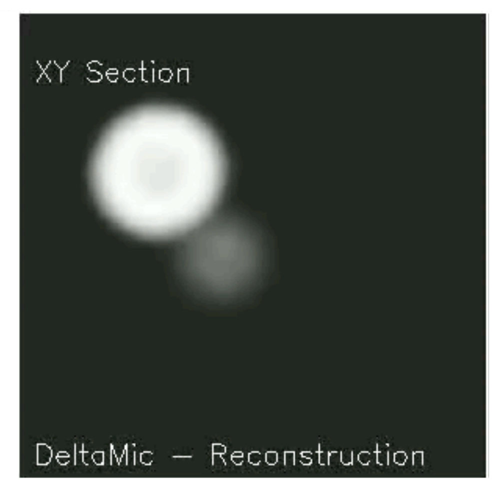

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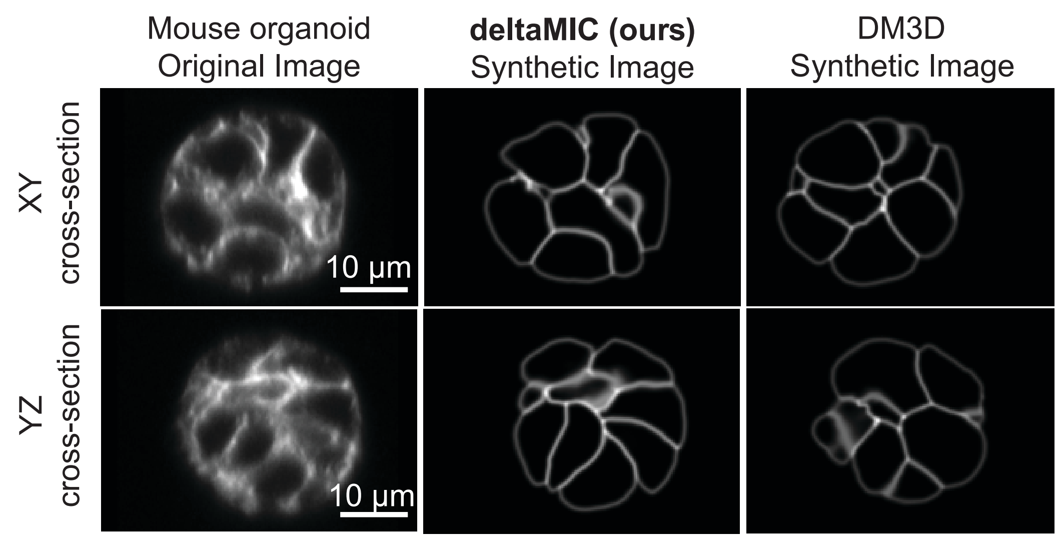
Mouse Organoids Benchmark - DM3D



Metric	**DeltaMIC**	DM3D
MSE ↓	$\mathbf{0.0020} \pm 0.0005$	0.0125 ± 0.0011
SSIM ↑	$\mathbf{0.8021} \pm 0.1165$	0.7101 ± 0.0282
PSNR ↑	$\mathbf{26.9423} \pm 1.2332$	19.0535 ± 0.6427

[3]Reference: Ichbiah S., Sinha A., Delbary F., Turlier H. - ICCV 2025.