3D IMAGES of ZEBRAFISH EMBRYO: PDEs based FILTERING and SEGMENTATION

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DATA

- Project EMBRYOMICS FP6-2003-NEST-B-1
- confocal microscopy
- Gif sur Yvette
- nuclei and membranes of zebrafish embryo

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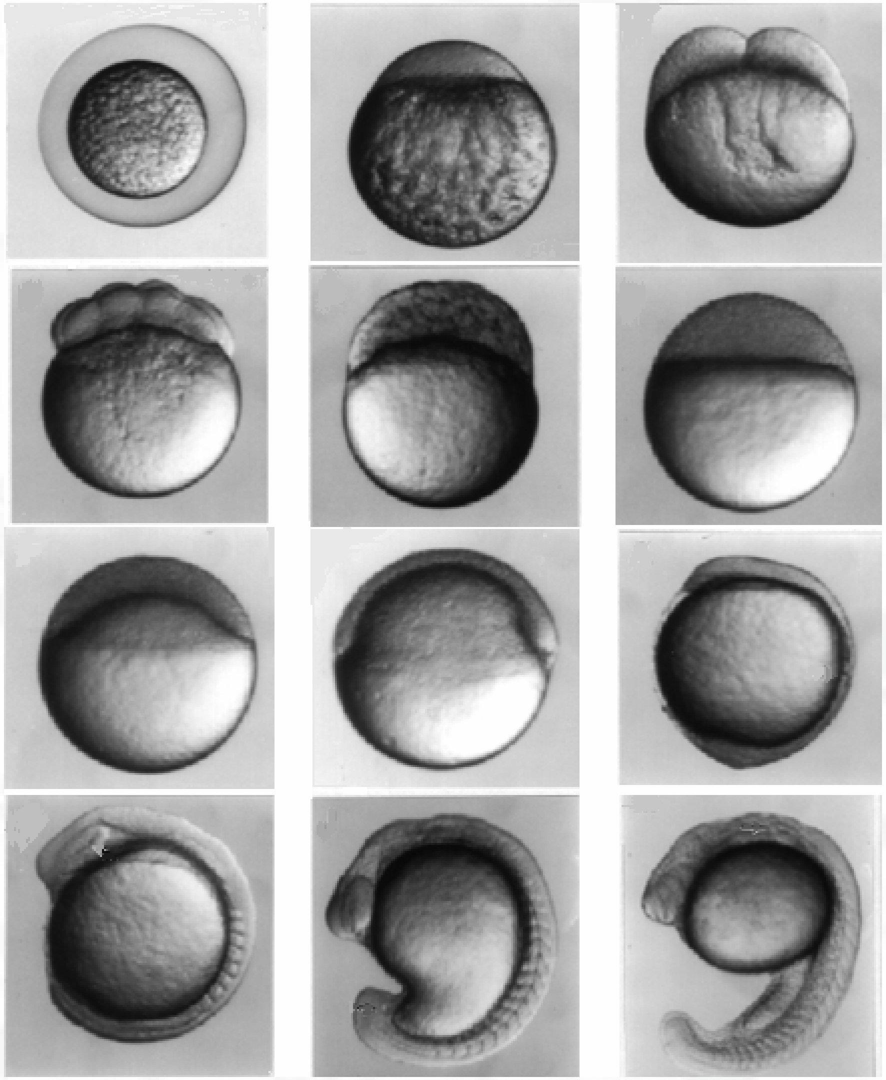
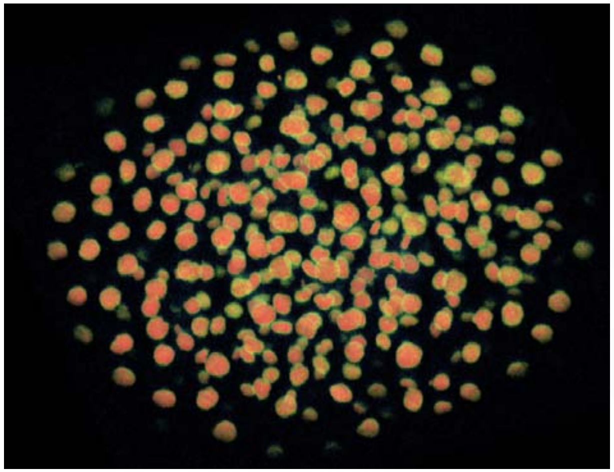
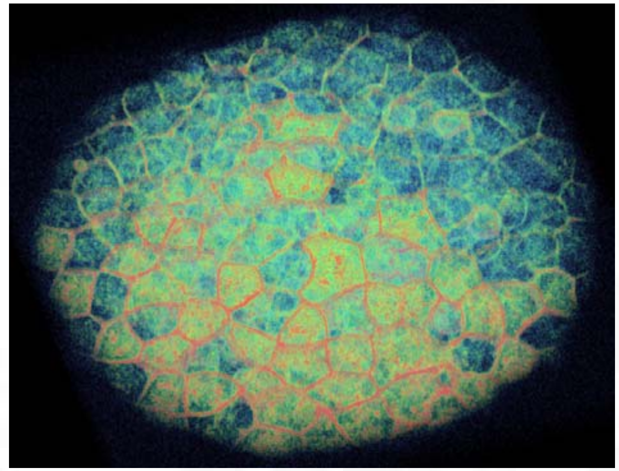
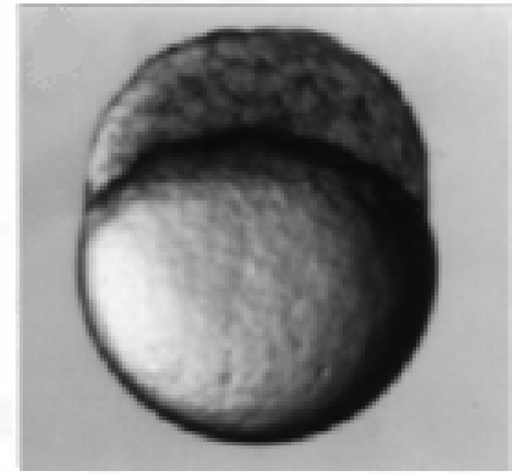


DATA







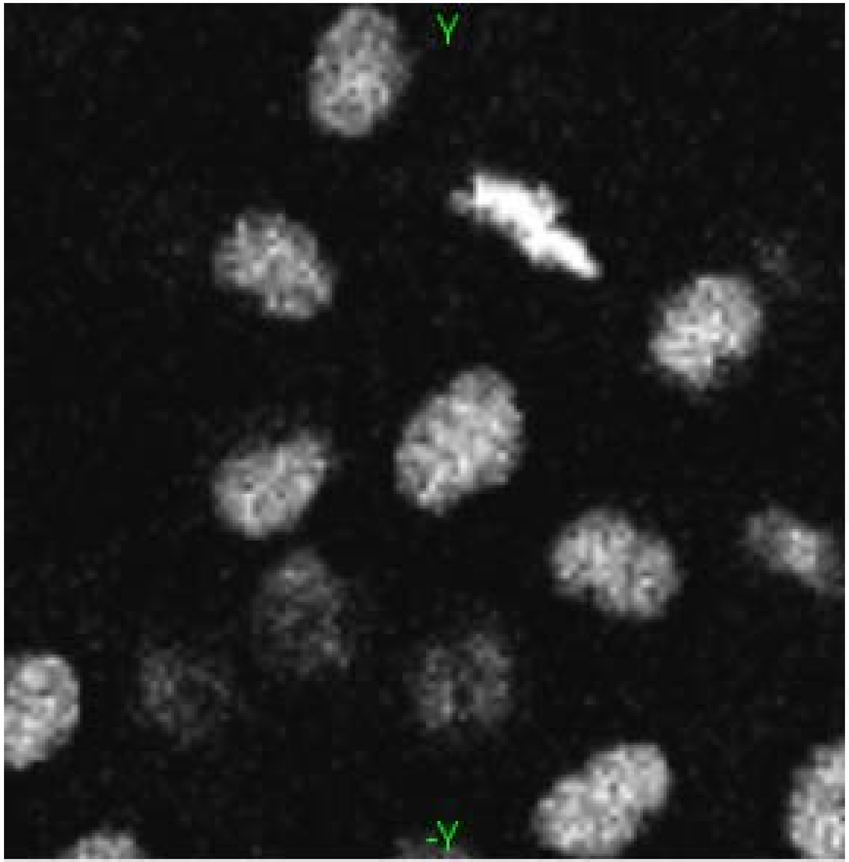
Leica confocal SP2 AOBS

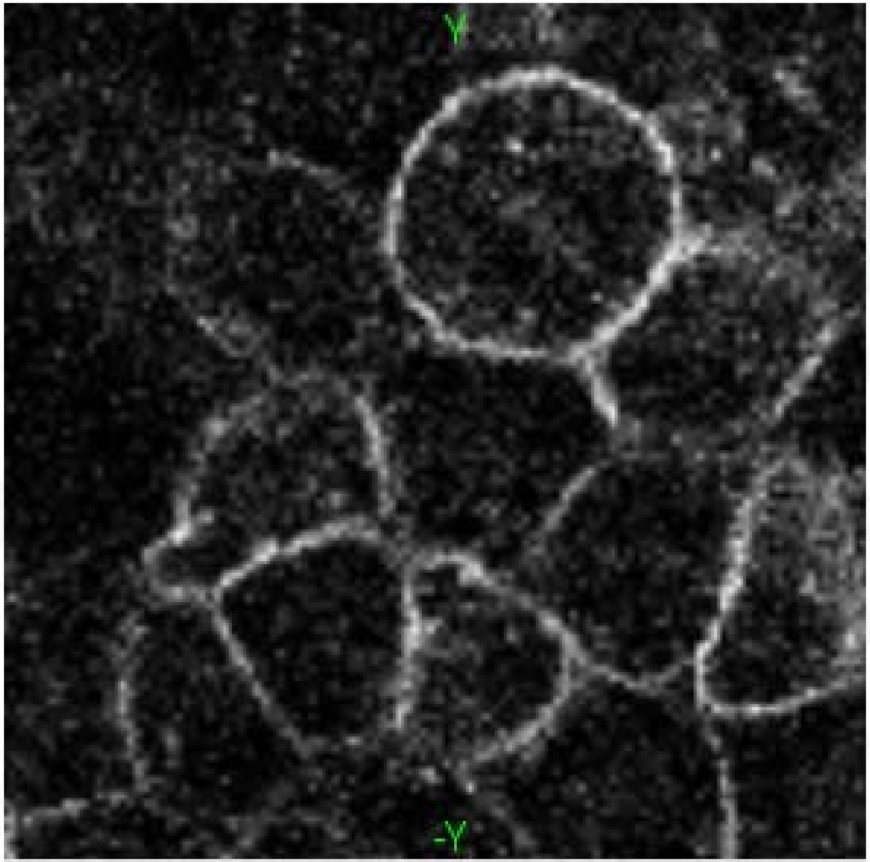
blastula peridod

5 hours development

Size in voxels:	512 x 512 x 30;
Sample spacing:	0.584793 x 0.584793 x 1.048915 μm^3/voxel;
Physical size:	299.41 x 299.41 x 31.47 μm^3;

PURPOSE of the work



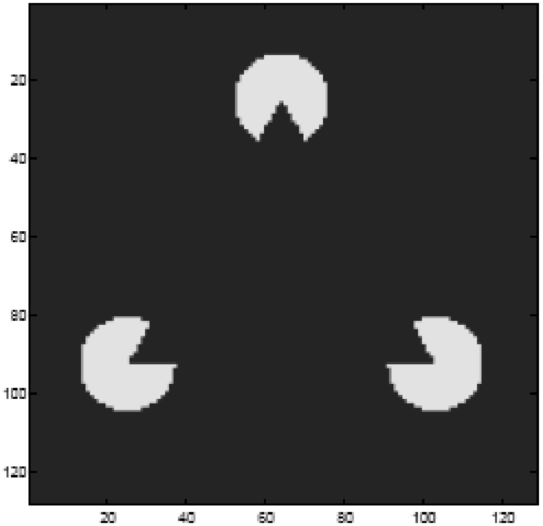


- Filtering: nuclei and membranes
- Segmentation: membranes

- PDEs based metods
- Subjective Surfaces

SUBJECTIVE SURFACES

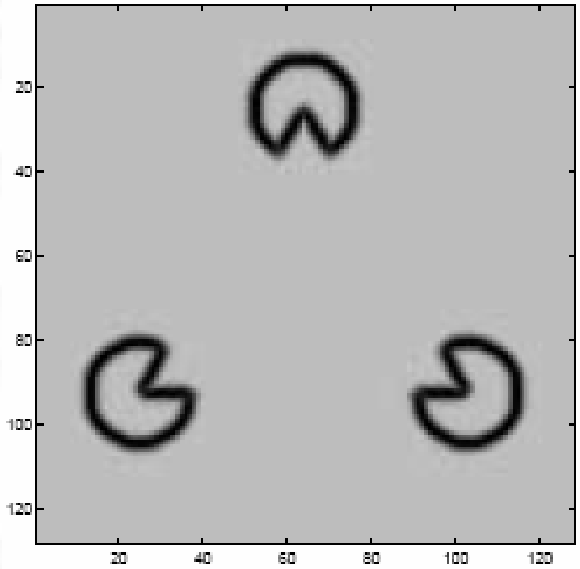
- A.Sarti, R.Malladi, J.Sethian (2000)
- A.Sarti, G.Citti (2000)
- Segmentation of objects with missing boundaries (membranes)
- Segmentation of apparent or subjective contours
- Kanisza Triangle
- Point of view of the observer
- Reference surface



LOW LEVEL FEATURES EXTRACTION

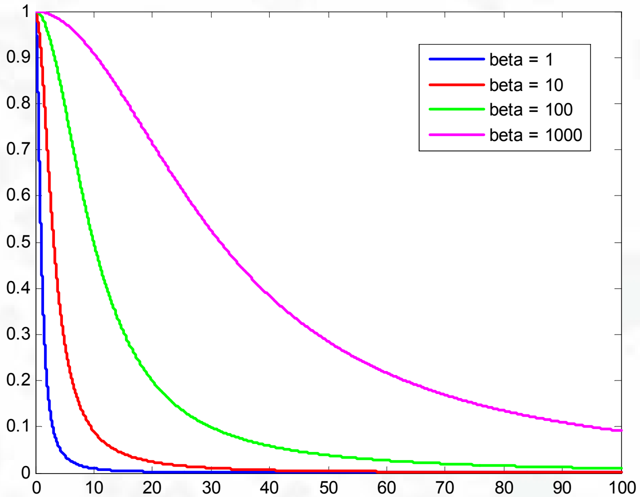
- Edge detector g:

$$g(x,y)=\frac{1}{1+\left|G_\sigma(x,y)*\nabla I(x,y,0)\right|^2/\beta}$$



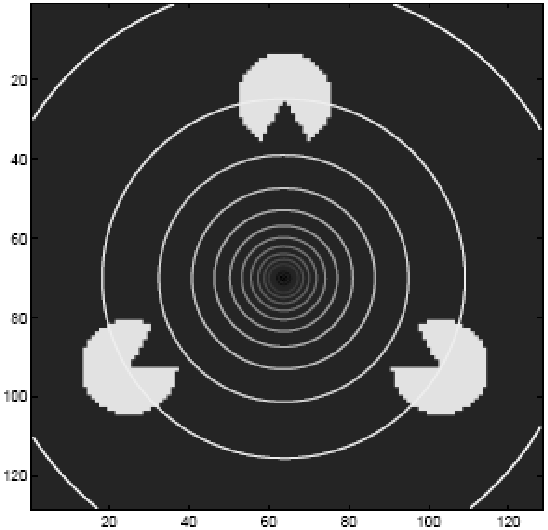
$$G_\sigma(\xi)=\frac{\exp\left(-(\xi/\sigma)^2\right)}{\sigma\sqrt{\pi}}$$

Gaussian Kernel:
minimal size of details



SUBJECTIVE SURFACES

- Selection of the point of view
- Construction of a reference surface

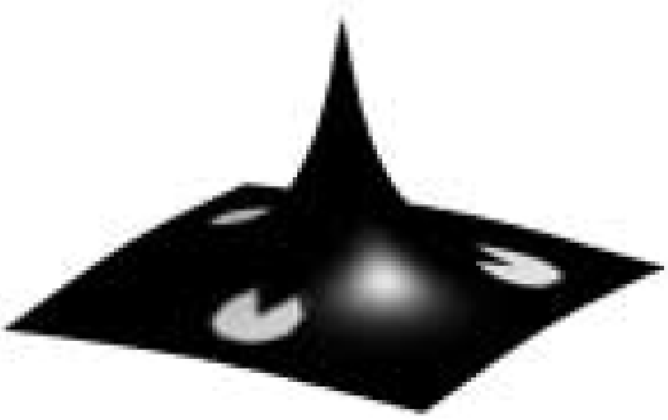


$I : (x, y) \rightarrow I(x, y)$ real positive function in $\Omega \subset R2$

Φ: distance or peak function in Ω

$S := \text{graph}\{ \Phi \} := \{ (x,y, \Phi(x,y)) : (x, y) \in \Omega \}$

$S :=$ 2D manifold embedded in (R^3, h)



$$h = \begin{pmatrix} g & 0 & 0 \\ 0 & g & 0 \\ 0 & 0 & \frac{g}{\varepsilon} \end{pmatrix}$$

Riemannian metric in (R^3, h)

SUBJECTIVE SURFACES

- Selection of the point of view
- Construction of a reference surface

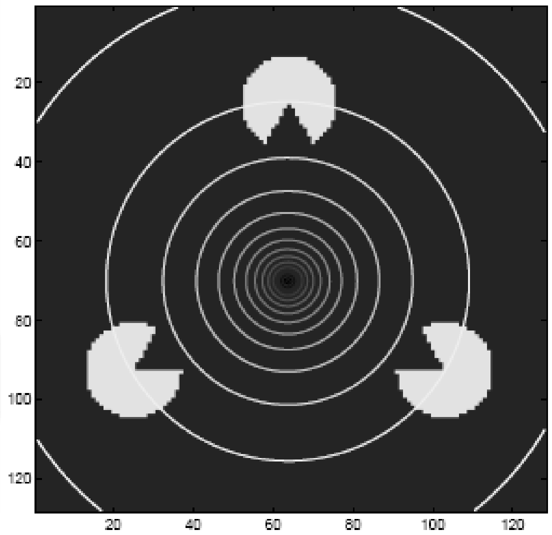
I : (x, y) → I(x, y) real positive function in $\Omega \subset$ R2

Φ: distance or peak function in Ω

S := graph { Φ } := { (x,y, Φ(x,y)) : (x, y) ∈ Ω }

S := 2D manifold embedded in (R^3, h)

$$A_g = \int_S \frac{g(x,y)}{\sqrt{\varepsilon}} \sqrt{\varepsilon + \Phi_x^2 + \Phi_y^2}\, dxdy$$



SUBJECTIVE SURFACES

- Selection of the point of view
- Construction of a reference surface
- Evolution of the surface with mean curvature flow

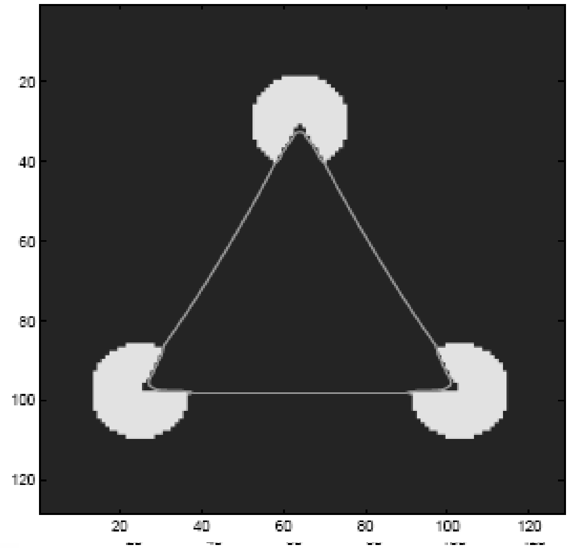
$$\frac{\partial S}{\partial t} = H \cdot \nu$$

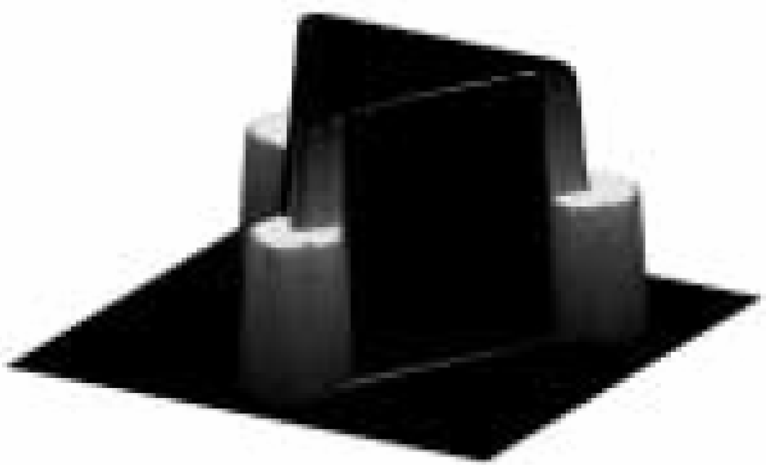
-H: mean curvature of S in (R^3, h)

-v: inner normal of S in (R^3, h)

SUBJECTIVE SURFACES

- Selection of the point of view
- Construction of a reference surface
- Evolution of the surface with mean curvature flow
- Surface attracted by the existing boundaries
- Piecewise constant solution: minimum of A_g
- Segmentation





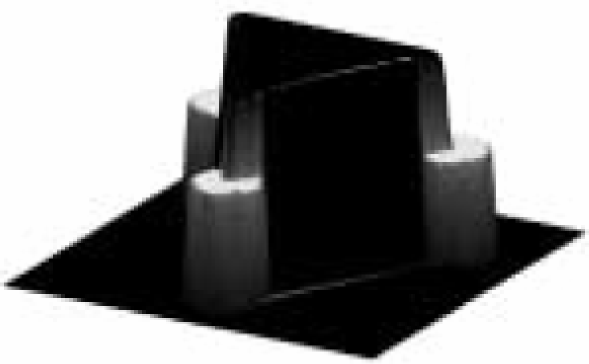
MODEL EQUATION

$$H = g\frac{(\varepsilon+\Phi_x^2)\Phi_{yy} + (\varepsilon+\Phi_y^2)\Phi_{xx} - 2\Phi_x\Phi_y\Phi_{xy}}{(\varepsilon+\Phi_x^2+\Phi_y^2)^{3/2}} + \frac{g_x\Phi_x + g_y\Phi_y}{(\varepsilon+\Phi_x^2+\Phi_y^2)^{1/2}}$$

$$\frac{\partial S}{\partial t} = H\cdot v \longrightarrow \frac{\partial \Phi}{\partial t} = H\cdot\left|\nabla\Phi\right|$$

-H: mean curvature of S in (R^3, h)

-v: inner normal of S in (R^3, h)



MINIMUM of Ag

MODEL EQUATION

K

$$\frac{\partial \Phi}{\partial t} = g \cdot \frac{\left(\varepsilon + \Phi_x^2\right)\Phi_{yy} + \left(\varepsilon + \Phi_y^2\right)\Phi_{xx} - 2\Phi_x \Phi_y \Phi_{xy}}{\left(\varepsilon + \Phi_x^2 + \Phi_y^2\right)^{3/2}} \cdot \left|\nabla \Phi\right| + g_x \Phi_x + g_y \Phi_y$$

$$\frac{\partial \Phi}{\partial t} = g \cdot K \cdot \left|\nabla \Phi\right| + \nabla g \cdot \nabla \Phi$$ SEGMENTATION

$$\frac{\partial I}{\partial t} = g \cdot K \cdot \left|\nabla I\right| + \nabla g \cdot \nabla I$$ FILTERING

- R.Malladi, J. Sethian, B. Vemuri (1995);
- V.Caselles, R. Kimmel, G.Sapiro (1997);
- A.Sarti, C.Solòrzano, S.Lockett, R.Malladi (2000);

FILTERING

- Mean curvature

$$\begin{cases} I_t = K \cdot |\nabla I| \\ I(x, y, z, t) = \bar{I} \\ I(x, y, z, 0) = I_0(x, y, z) \end{cases}$$

- Geodesic curvature

$$\begin{cases} I_t = g \cdot K \cdot |\nabla I| + \nabla g \cdot \nabla I \\ I(x, y, z, t) = \bar{I} \\ I(x, y, z, 0) = I_0(x, y, z) \end{cases}$$

- 3D + time space

$$\begin{cases} I_t = clt \cdot \left(g \cdot K \cdot |\nabla I| + \nabla g \cdot \nabla I \right) \\ I(x, y, z, t) = \bar{I} \\ I(x, y, z, 0) = I_0(x, y, z) \end{cases}$$

clt : = Curvature Lambertian Trajectory

3D + TIME

$$\begin{cases} I_t = clt \cdot \left(g \cdot K \cdot \left|\nabla I\right| + \nabla g \cdot \nabla I\right) \\ I(x,y,z,t) = \bar{I} \\ I(x,y,z,0) = I_0(x,y,z) \end{cases}$$

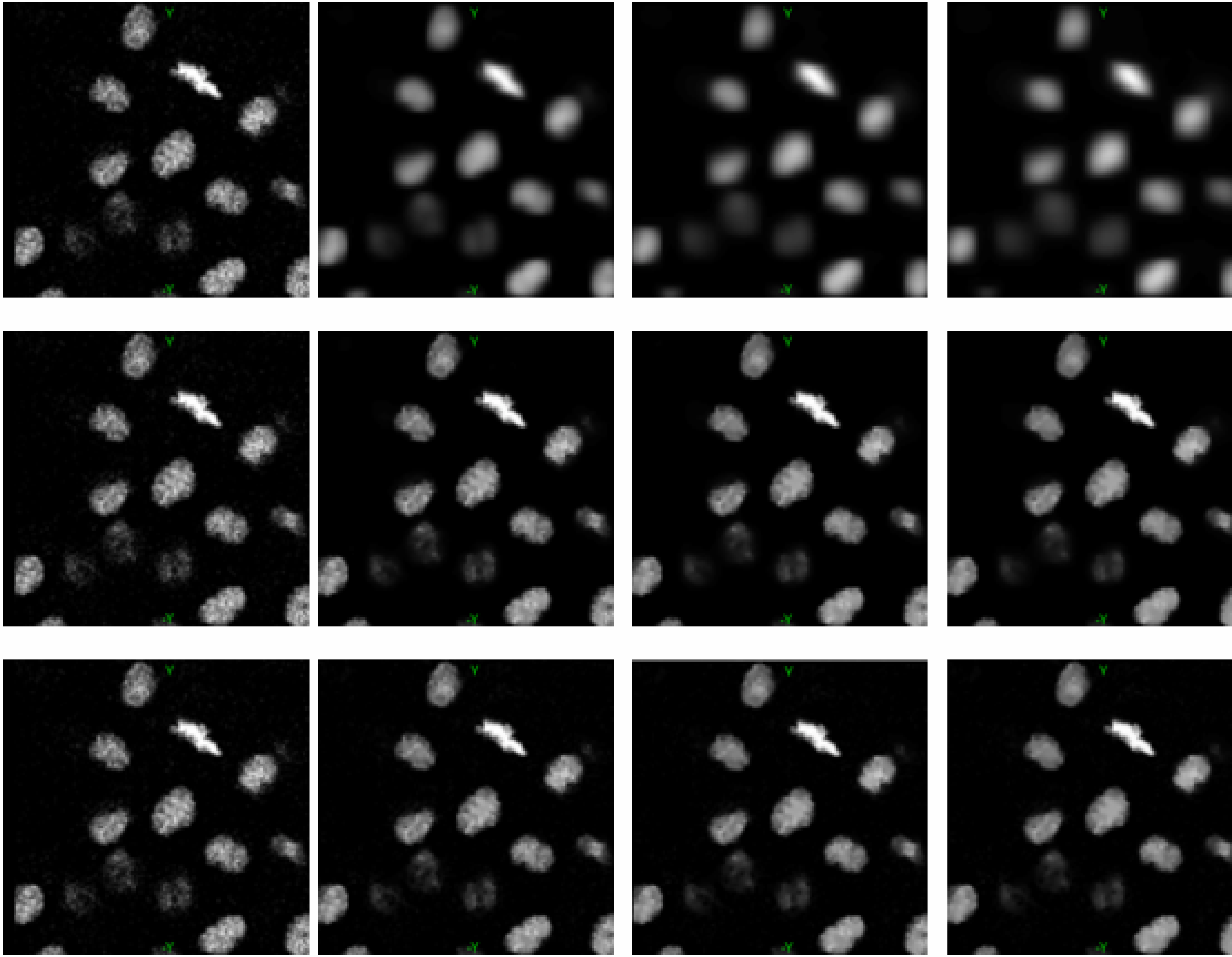
- F.Guichard (1994)
- Lambertian structures
- motion locally Galilean in time
- measure of coerence in time
  for moving structures

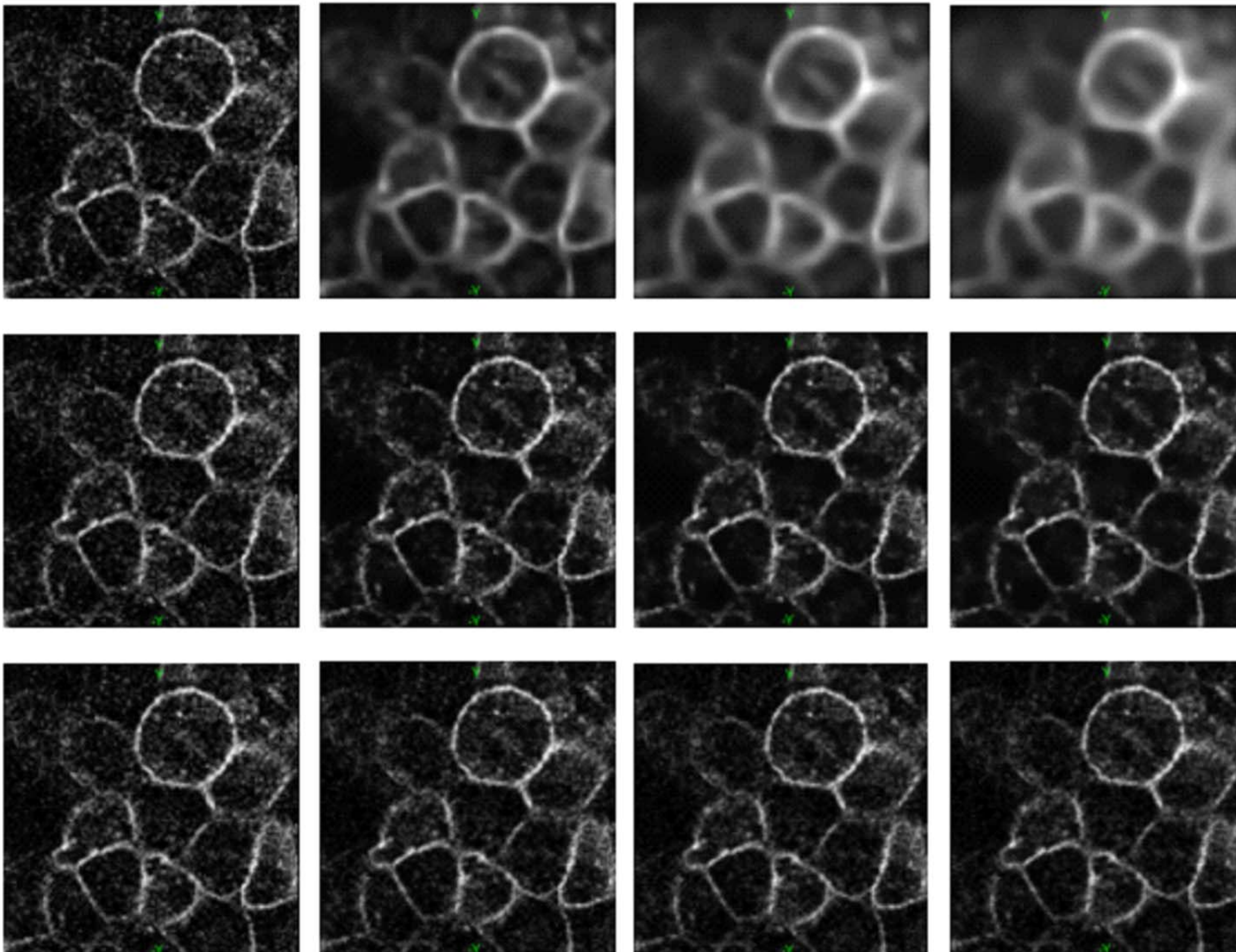
$$clt(I) = \min_{w_1, w_2} \frac{1}{(\Delta\tau)^2} \left(\left|\langle \nabla I, w_1 - w_2 \rangle\right|\right) + \left|I(x - w_1, \tau - \nabla\tau) - I(x,\tau)\right| + \left|I(x + w_2, \tau + \nabla\tau) - I(x,\tau)\right|$$

- w_1, w_2 arbitrary vectors in R^3
- $\Delta\tau$ time increment

$\Delta\tau + \tau$: next frame

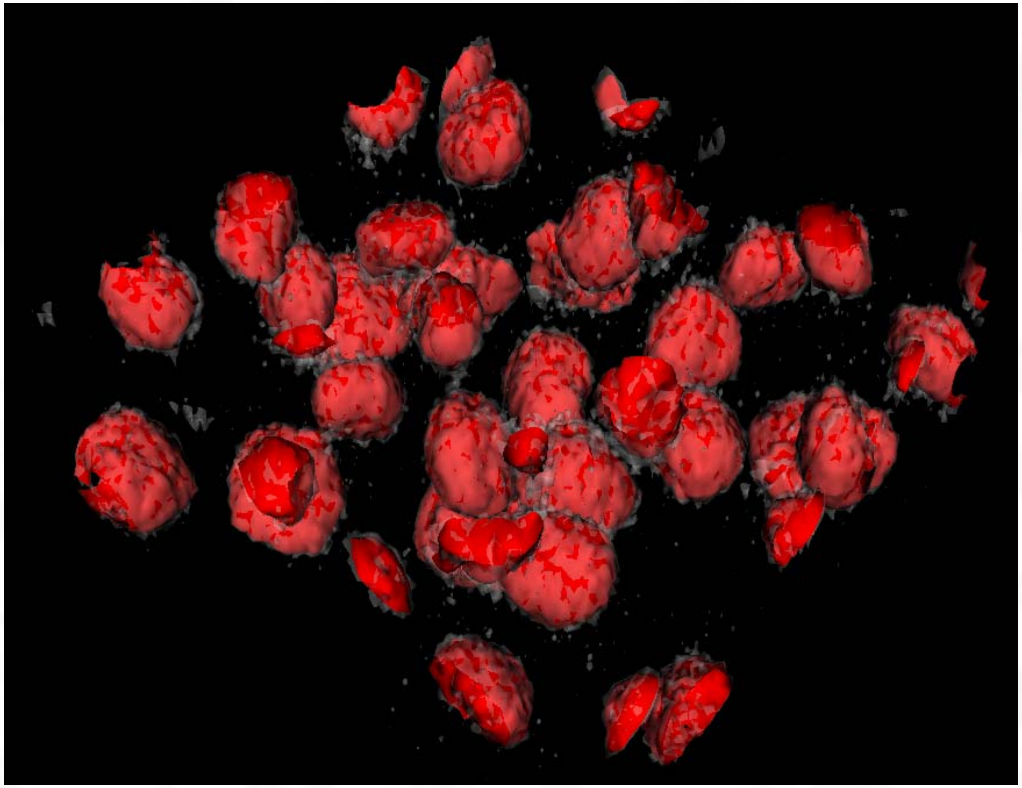
$\Delta\tau - \tau$: previous frame





GEODESIC CURVATURE FILTERING:

$$\begin{cases} I_t = g \cdot K \cdot |\nabla I| + \nabla g \cdot \nabla I \\ I(x, y, z, t) = \bar{I} \\ I(x, y, z, 0) = I_0(x, y, z) \end{cases}$$



ε = 0.1;

σ = 0.05;

β = 100;

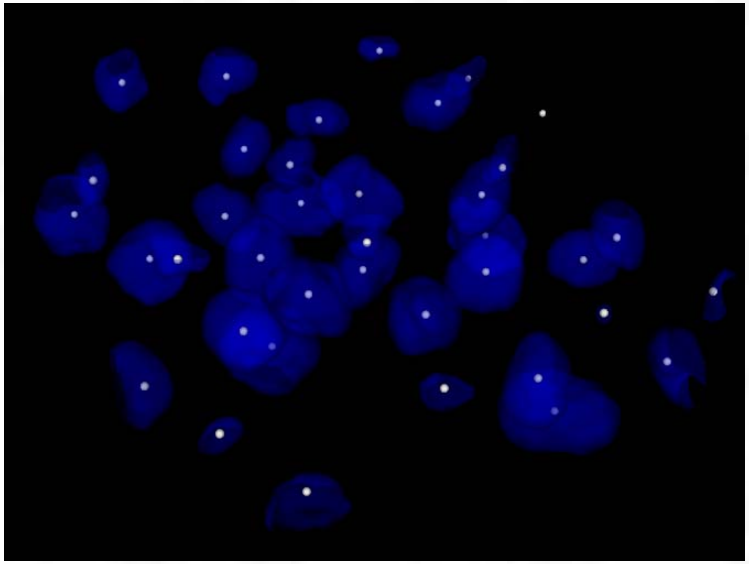
dt = 0.01;

500 scale steps;

SEGMENTATION

SELECTION OF THE POINT OF VIEW

- a point in the center of every membranes
- nuclei inside membranes
- centers of nuclei
- filtered data: isosurface centers



SEGMENTATION

$$\frac{\partial \Phi}{\partial t} = \mu \cdot g \cdot K \cdot \left| \nabla \Phi \right| + \nu \cdot \nabla g \cdot \nabla \Phi$$

$\Phi_0 = -\alpha/D$, $\alpha = 255$;

50000 scale steps with $dt = 0.01$;

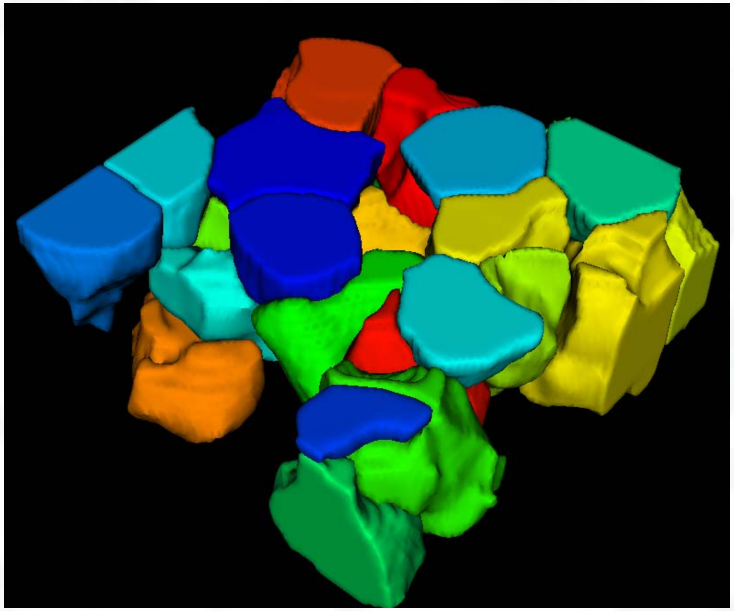
$\varepsilon = 1.0$ first 10000 scale steps;

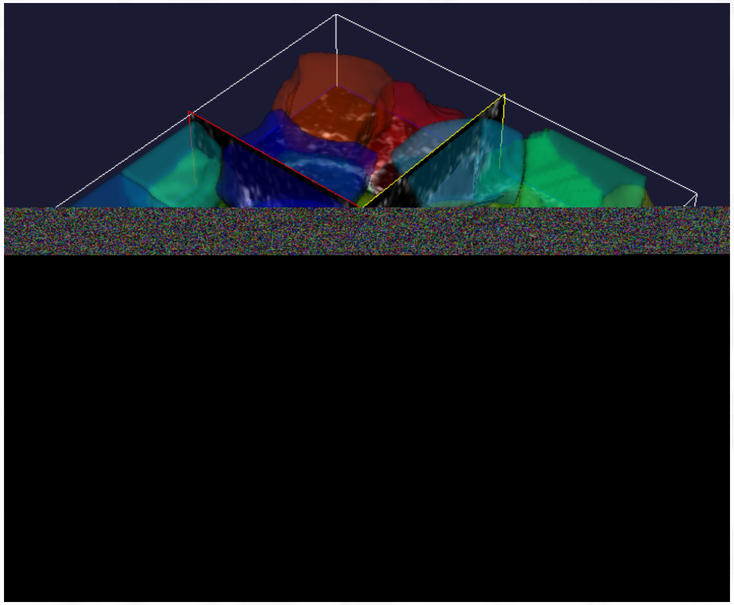
$\varepsilon = 1.0e^{-6}$ next 40000 scale steps;

$\sigma = 1$;

$\mu = 0.1$;

$\nu = 10$;





WORK IN PROGRESS….

FINITE VOLUME METHOD

- speed improvement
- semi-implicit scheme

VALIDATION

- Manual segmentation
- Gold standard
- Distance between the gold and the original
- Distance between the gold and the filtered

THANK YOU

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