

# Filtering, cell center detection and cell segmentation by geometrical partial differential equations

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## Automatic image analysis

By **image analysis** we mean extraction of cell centers and shape of each cell from microscopy image.

By **automatic image analysis** we mean the image analysis performed by computer algorithms, without human inputs.

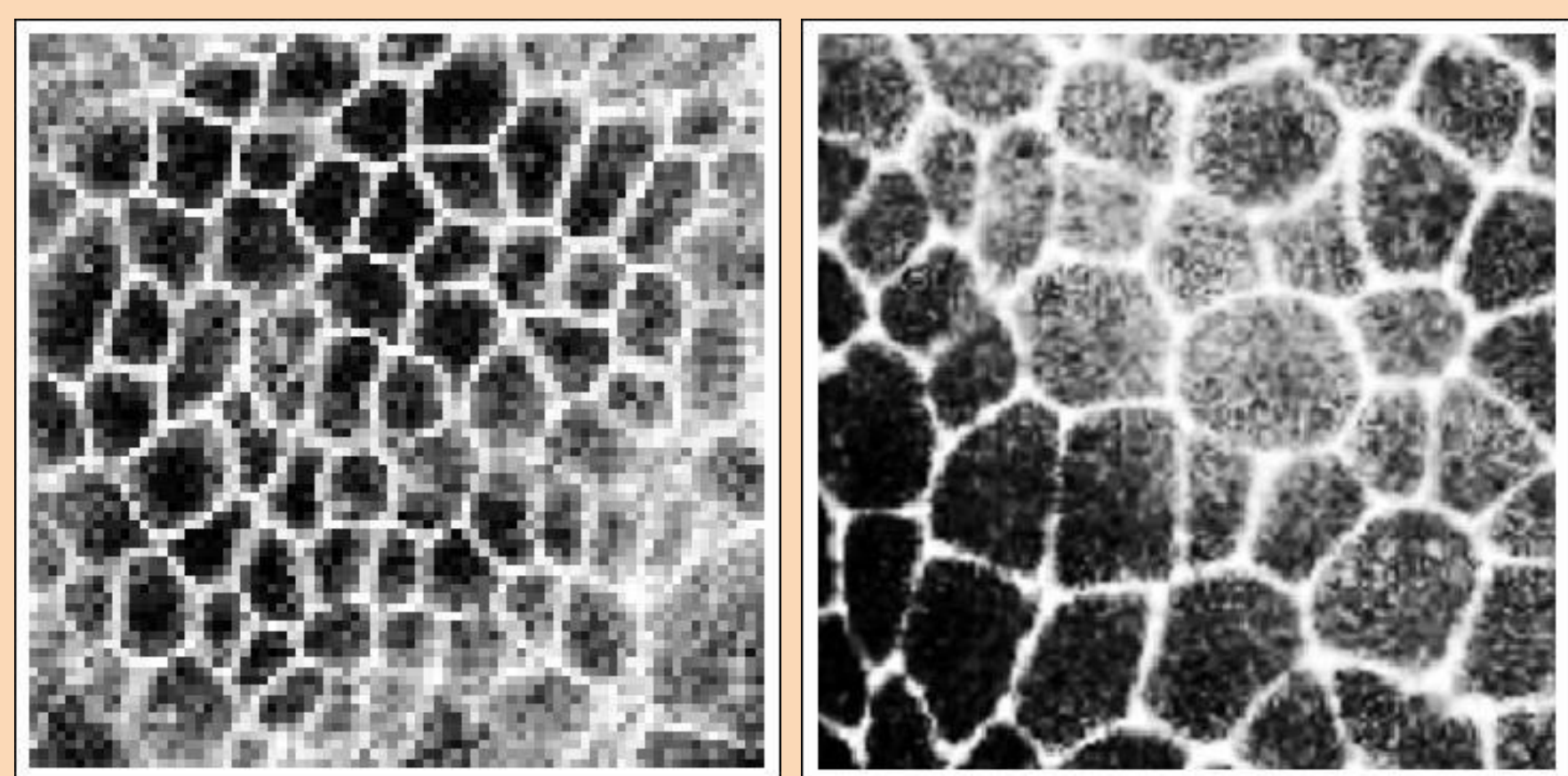
By **image processing chain** we mean interconnected chain of processes performing automatic image analysis. We identify these three image processing chain processes:<sup>[0]</sup>

- Filtering of the input image (using GMCF)
- Cell center identification (using LSCD)
- Segmentation of cell shapes (using GSUBSURF)

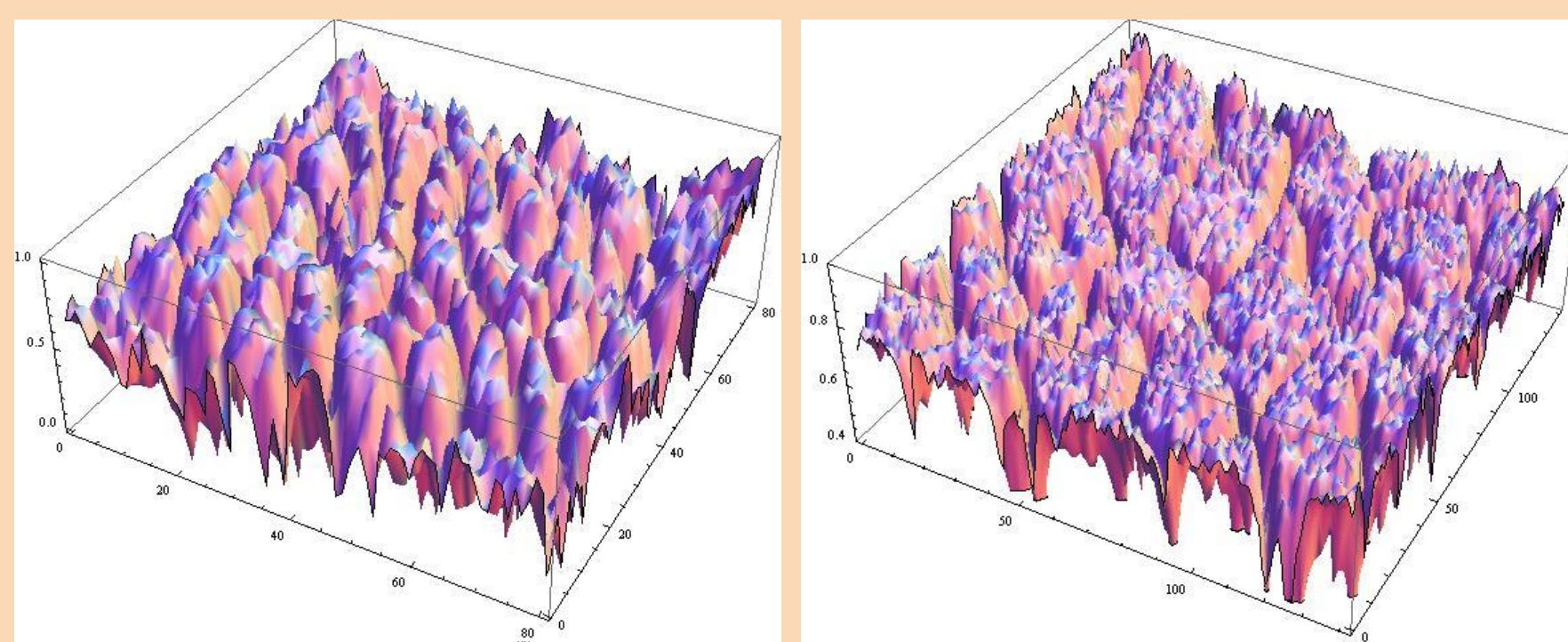
We also propose a way to **detect mitosis** in given data.

## Input data

The input data tested were in two dimensions + time, i.e. 2D video. Data contains cell membrane images of *drosophila* and *zebrafish*, both in phase of morphogenesis.



Input data – membrane images. Left – zebrafish, right – drosophila.



Input data shown as 3D plot of intensity function. Left – zebrafish, right – drosophila.

For better illustration of data properties, we are working with images after histogram equalization.

We thank to N.Peyri  ras (CNRS, Gif sur Yvette) and F.Graner (Institut Curie, Paris) for zebra-fish and drosophila testing data.

We also thank to Francois Graner for bringing our attention to trousers-like 2D + time image segmentation.

## 1. Filtering by GMCF<sup>[1]</sup>

**GMCF = Geodesic Mean Curvature Flow**

- removes noise structures
- preserves edges

GMCF equation:

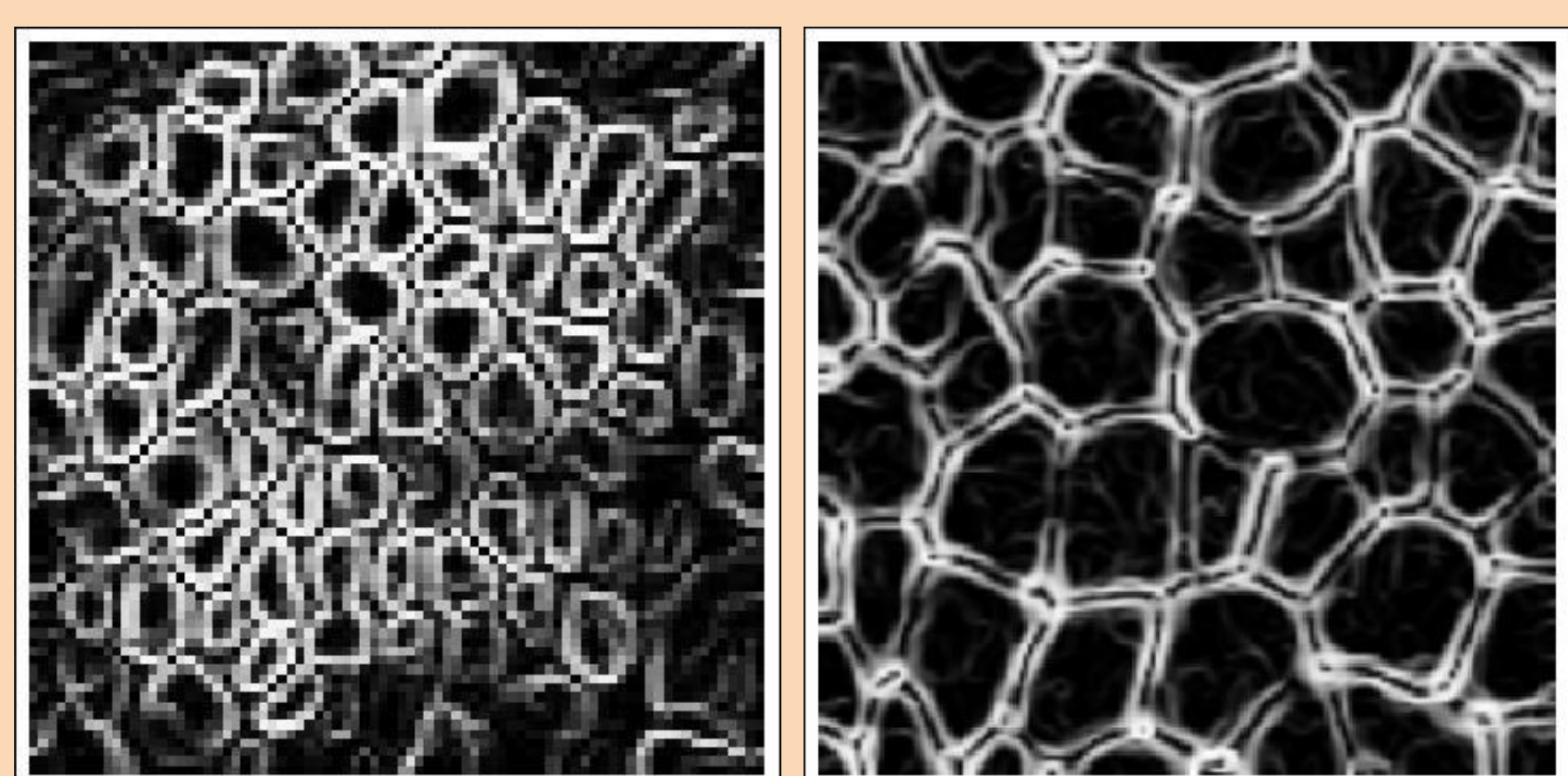
$$u_t - |\nabla u| \nabla \cdot \left( g \left( |\nabla G_\sigma * u| \right) \frac{\nabla u}{|\nabla u|} \right) = 0$$

Function  $g$  with its argument is called **edge detection function** and has values:

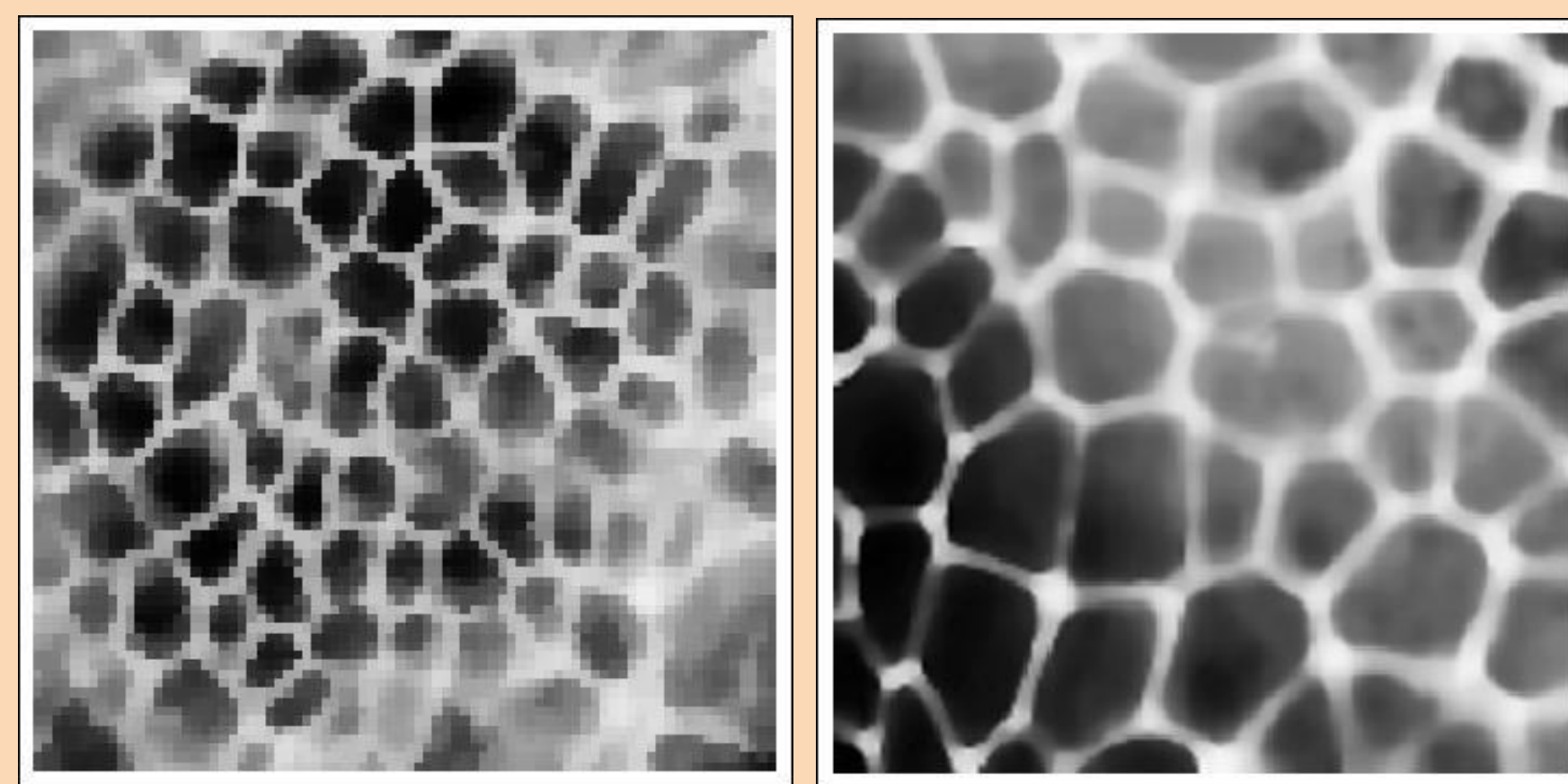
- $\approx 0$  if given pixel belongs to edge
- $\approx 1$  otherwise

We use this edge detector equation: (with  $s = |\nabla G_\sigma * u|$ )

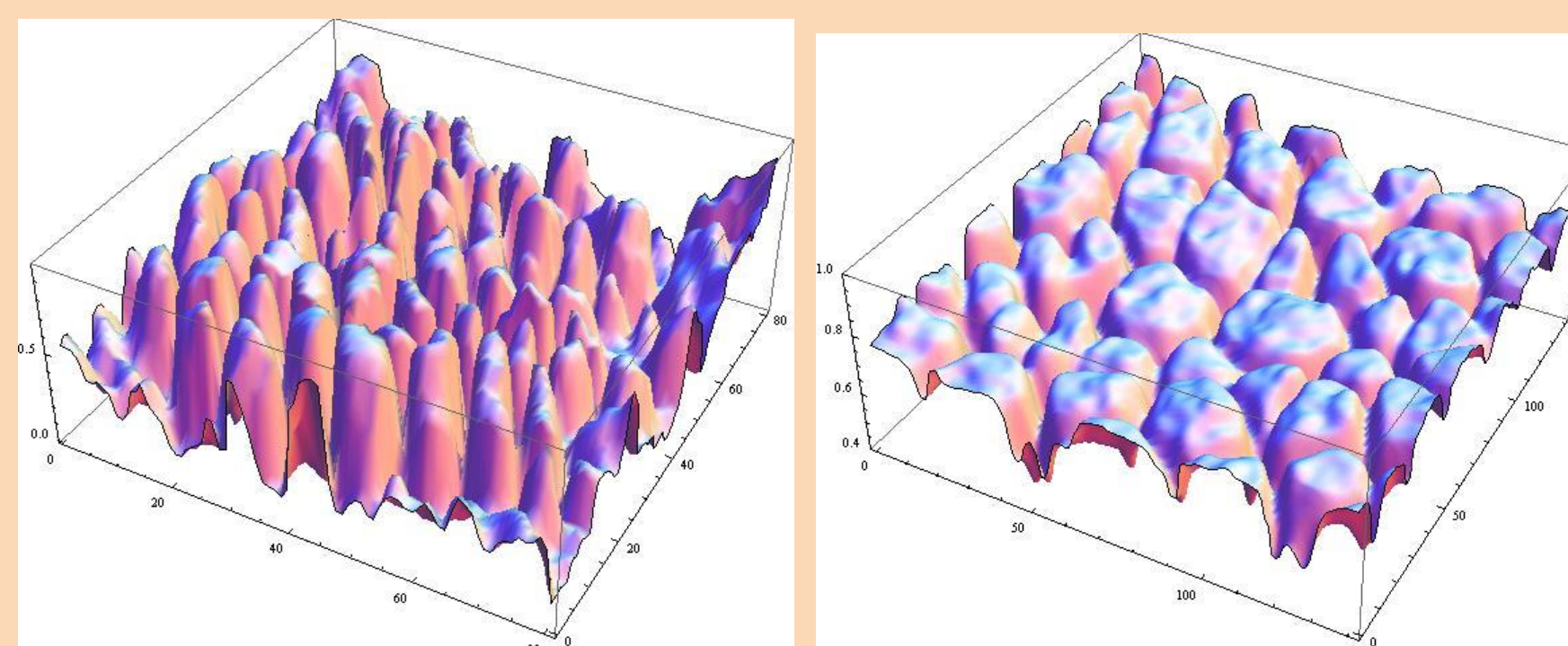
$$g(s) = \frac{1}{1 + ks^2}, k > 0$$



Demonstration of edge detection function. Low intensity is white, high intensity is black. Left – zebrafish, right – drosophila.



Data filtered by GMCF. Left – zebrafish, right – drosophila.



GMCF filtered data as 3D plot. Left – zebrafish, right – drosophila.

## 2. Cell center identification by LSCD<sup>[2]</sup>

Goal of this step is obtaining list of approximate cell centers.

**LSCD = Level Set Center Detection**

LSCD equation:

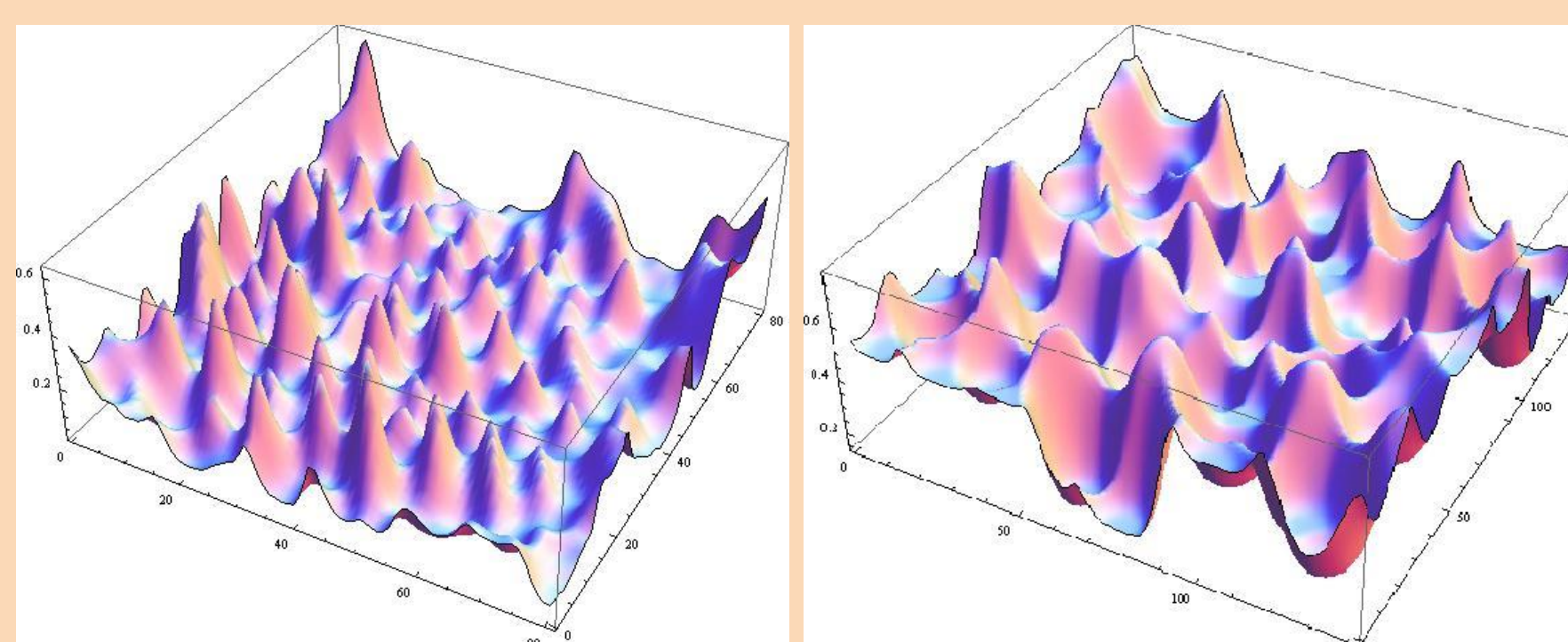
$$u_t - \delta |\nabla u| - \mu |\nabla u| \nabla \cdot \left( \frac{\nabla u}{|\nabla u|} \right) = 0$$

- All contours advect in the direction of inner normal, and the *speed*  $V$  of this advection is also a function of their *curvature*  $k$ :

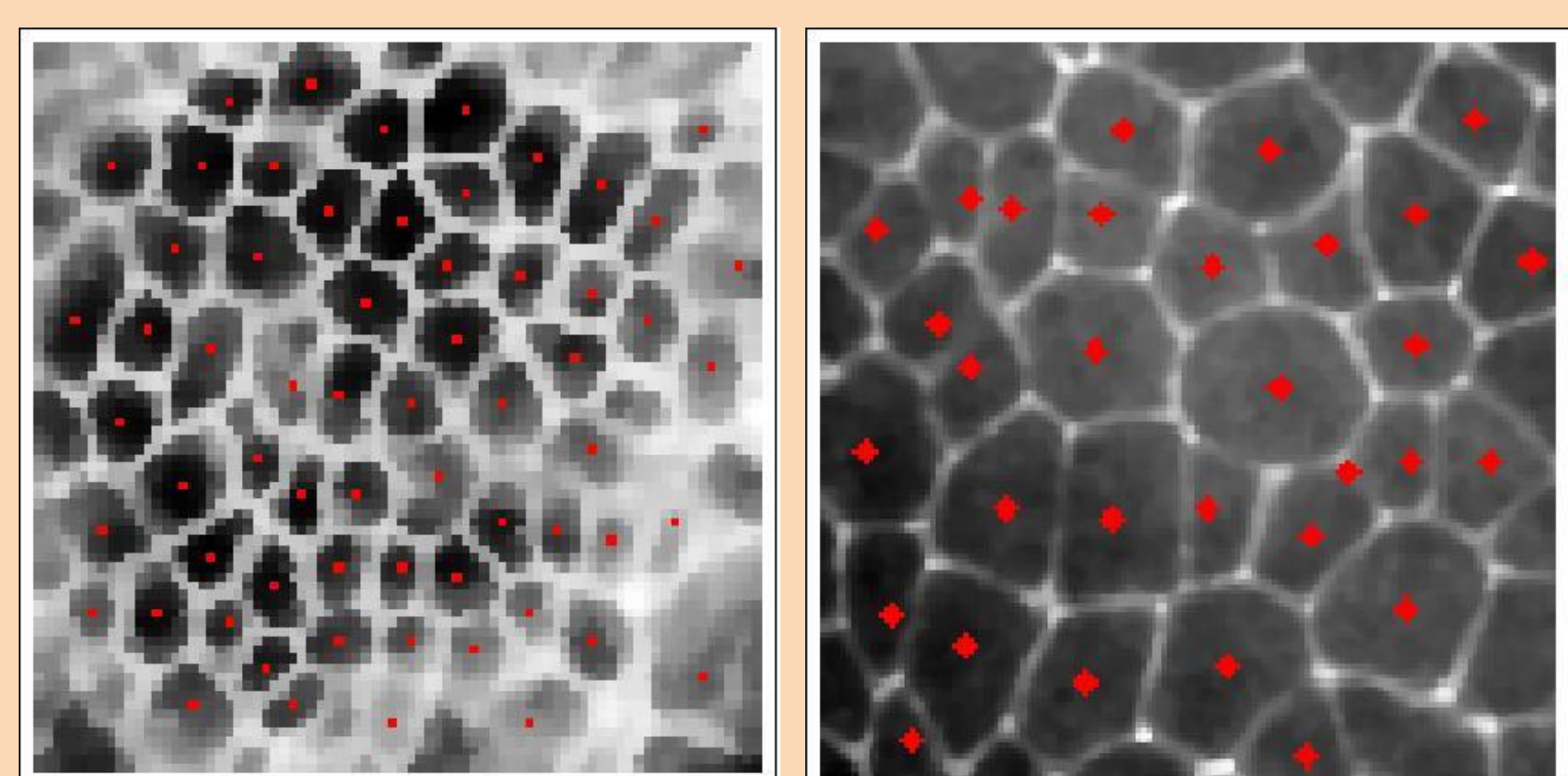
$$V = \delta + \mu k$$

for some positive constants  $\delta$  and  $\mu$ .

- Small contours (those of noise artifacts) implode rapidly fast
- Larger (those of cell structures) are observable for a longer period of time
- Taking local maximae of these images gives us geometric centers of cells



3D plot of intensity function after LSCD. Local maximae represent approximate cell centers pretty well. – these are plotted as red dots in the image below. Left – zebrafish, right – drosophila.



Identified cell centers. Red dots are approximate cell centers – they are the local maximae of 3D plots in the previous figure. Left – zebrafish, right – drosophila.

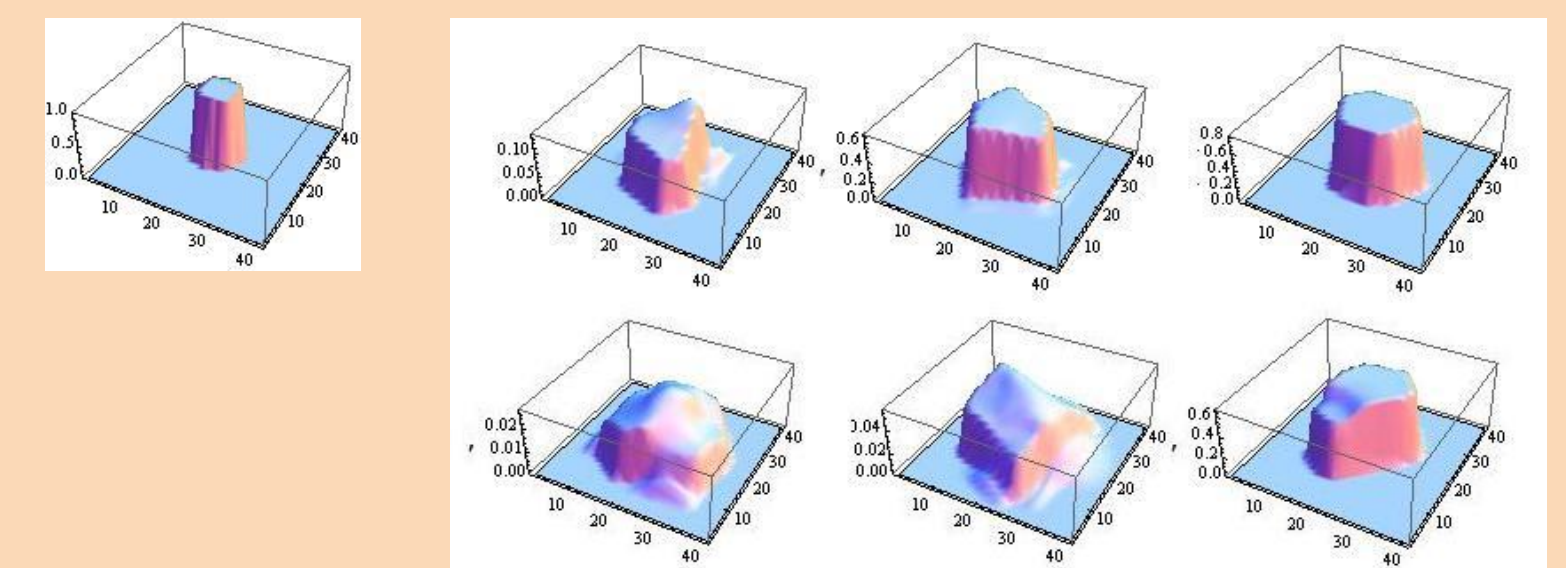
## 3. Segmentation by GSUBSURF<sup>[3],[4]</sup>

Goal of segmentation is to take a cell center and say, what is the area covered by this cell.

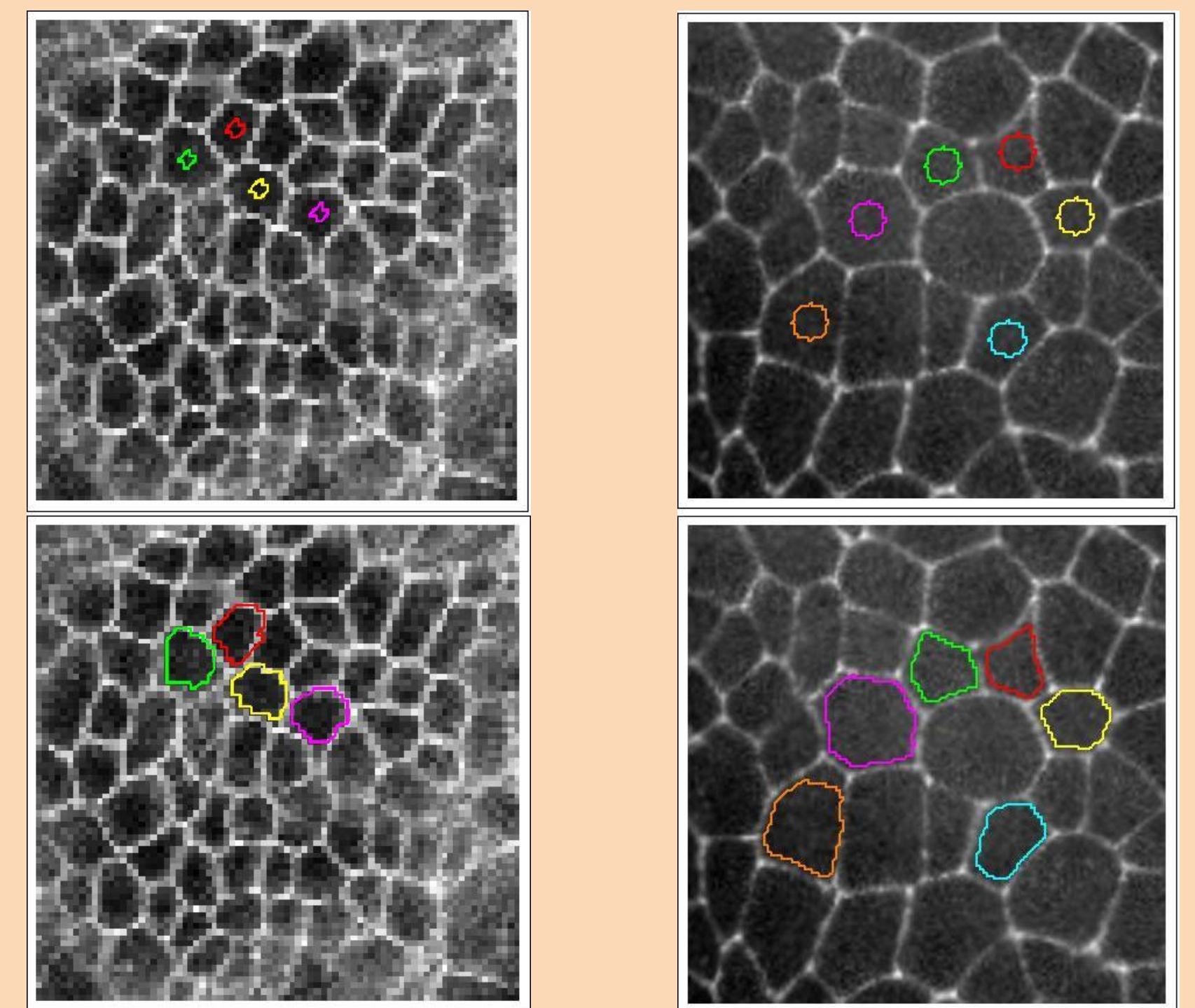
**GSUBSURF = Generalized SUBjective SURFace**

GSUBSURF equation:

$$u_t - w_{diff} g |\nabla u| \nabla \cdot \left( \frac{\nabla u}{|\nabla u|} \right) - w_{con} \nabla g \cdot \nabla u = 0$$



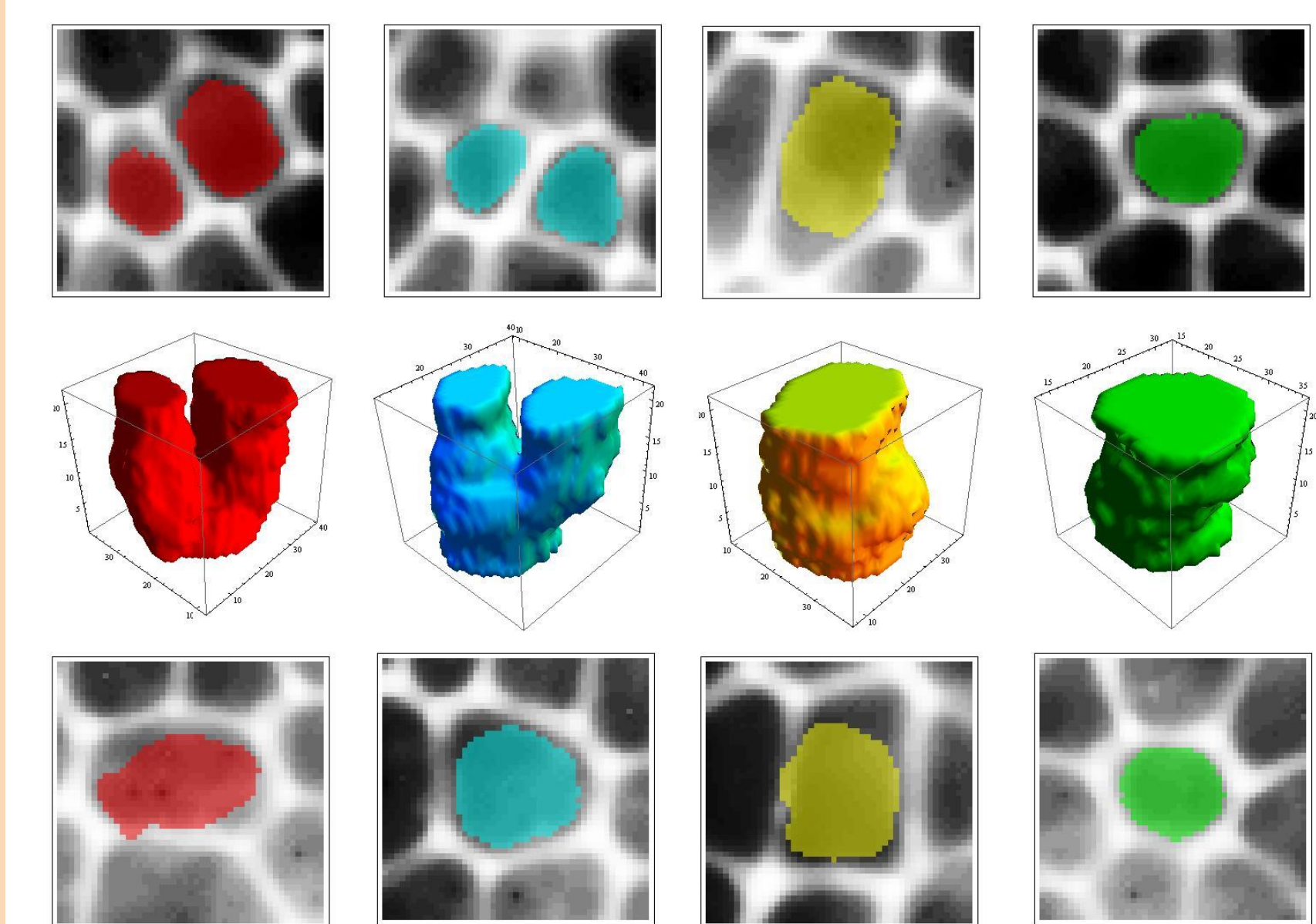
Drosophila segmentation. Top – initial segmentation function, bottom – final segmentation for cells marked below.



Top – initial segmentation contour, bottom – final segmentation contour. Left – zebrafish, right – drosophila.

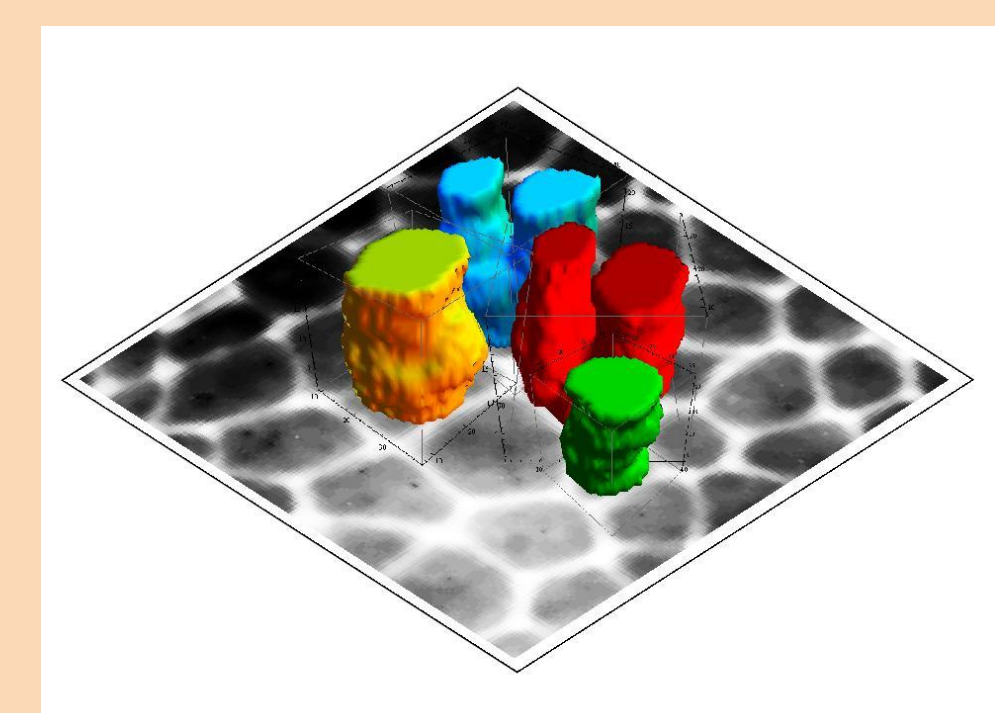
## Mitosis detection

The goal is to find splitting of two cells in space and time to detect mitosis. We consider 2D + time video as a 3D image and try to find trousers-like shapes – again using GSUBSURF as segmentation algorithm. Mitosis happens, where two 'leg-parts' split.



Four drosophila cells and their segmentation considering time. Bottom – cell at time  $t = 35$ , top – cell at time  $t = 55$ , center – what happens 'in between'.

We observe first and second cell forming a trousers-like shape in space and time, which means cell division. The other two do not divide in this period.



Same cells as above, now shown in correct positions in image at time  $t = 35$ .

## References

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