ScaDS.AI
DRESDEN LEIPZIG
CENTER FOR SCALABLE DATA ANALYTICS
AND ARTIFICIAL INTELLIGENCE

Image segmentation

Robert Haase

Using materials from Marcelo Leomil Zoccoler and Johannes Soltwedel, PoL, TU Dresden

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

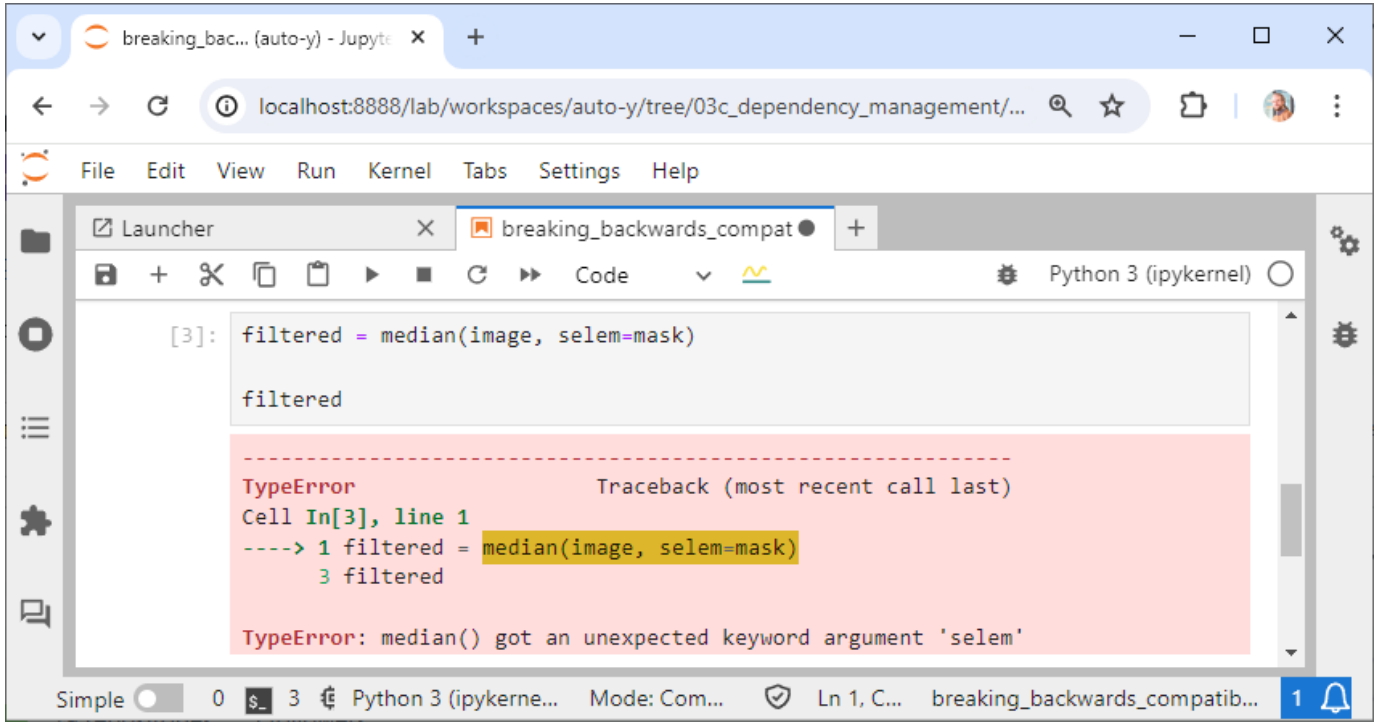
Diese Maßnahme wird gefördert durch die Bundesregierung aufgrund eines Beschlusses des Deutschen Bundestages. Diese Maßnahme wird mitfinanziert durch Steuermittel auf der Grundlage des von den Abgeordneten des Sächsischen Landtags beschlossenen Haushaltes.

Recap

How can one solve this problem?

A) By modifying the code

B) By not modifying the code



Quiz (recap)

- Which of the following is a band-pass filter?

Gaussian

Median

Top-hat

Difference of Gaussian

Quiz (recap)

- Which of the following is a denoising filter?

Gaussian

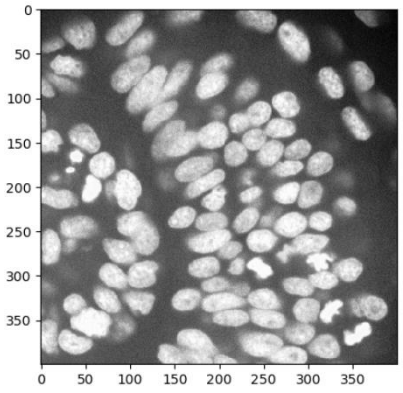
Median

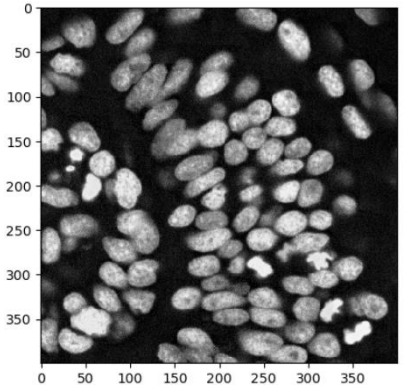
Top-hat

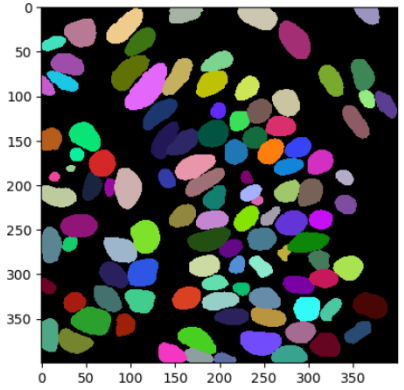
Difference of Gaussian

Lecture overview: Bio-image Analysis

- Image Data Analysis workflows
- Goal: **Quantify observations, substantiate conclusions with numbers**







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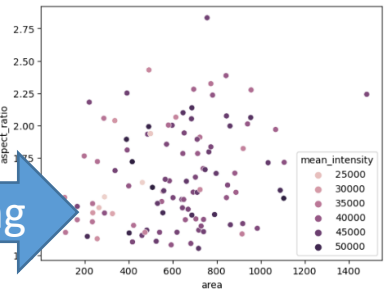
0	594.0	40572.809764	28.611591	26.537947
1	645.0	43764.872868	33.511511	24.566916
2	1105.0	51970.561991	45.232031	31.456308
3	718.0	47015.487465	31.023274	29.5
4	791.0	49132.515803	36.382253	27.7
...	...	...	...	
105	238.0	30477.126050	20.252197	15.2
106	615.0	32886.154472	41.030760	19.8
107	110.0	33042.445455	14.366347	9.5
108	222.0	43304.180180	25.370549	11.6
109	167.0	43378.808383		

Plotting



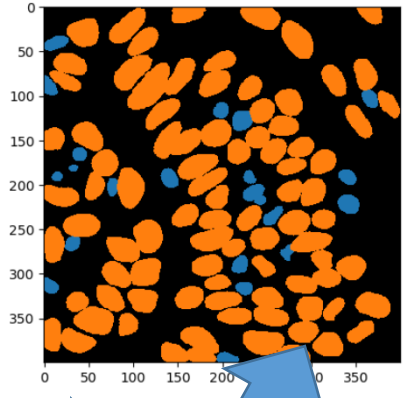


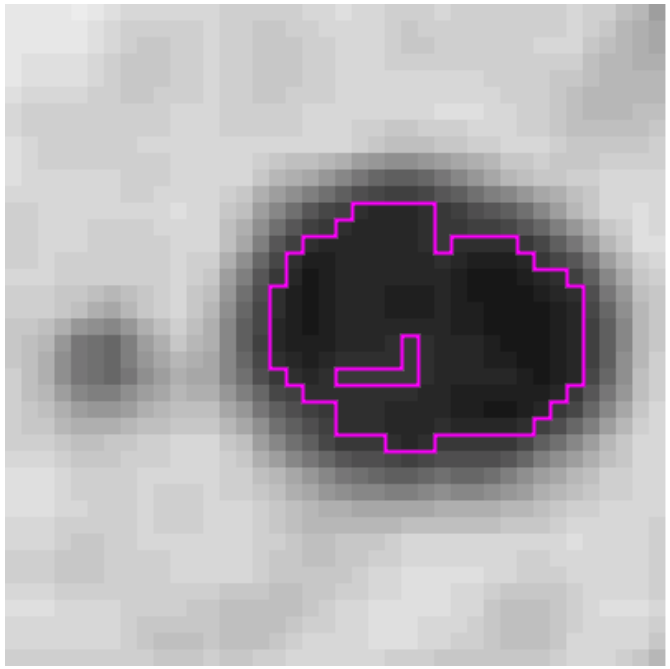
Image filtering → Image segmentation → Feature extraction → Object classification → Visualization

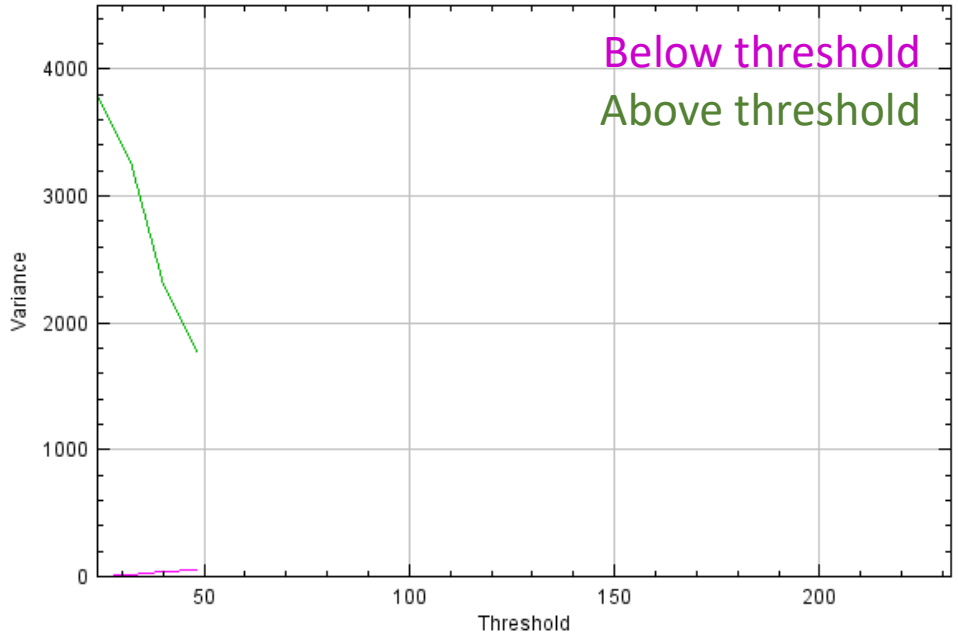
Thresholding: Otsu's method

- Searching for a threshold where the variance in both classes (above/below threshold) becomes minimal.

$$Var(I) = \sum_{i \in I} g_i - \bar{g}_I \qquad \bar{g}_I = \sum_{i \in I} \frac{g_i}{n_I}$$

$Var(I)$ … Variance in image I
g_i … grey value of a pixel i
$\bar{g}_I$ … mean grey value of the whole image I
n_I … number of pixels in Image I





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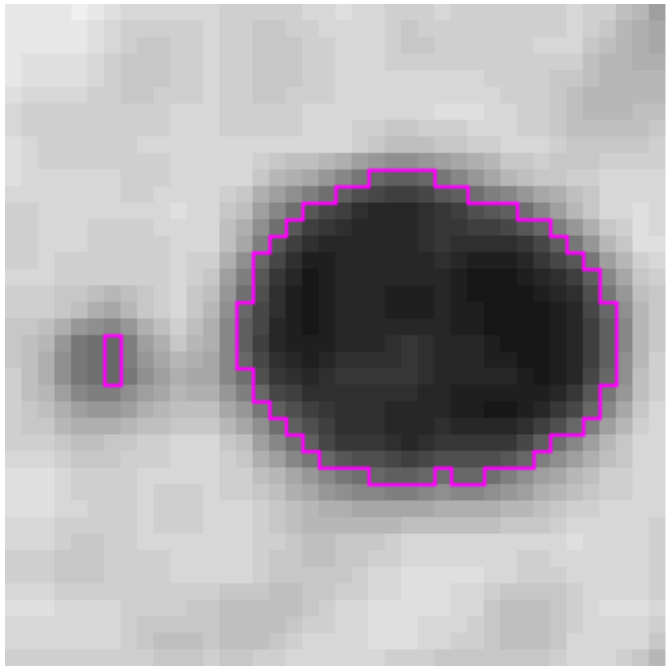

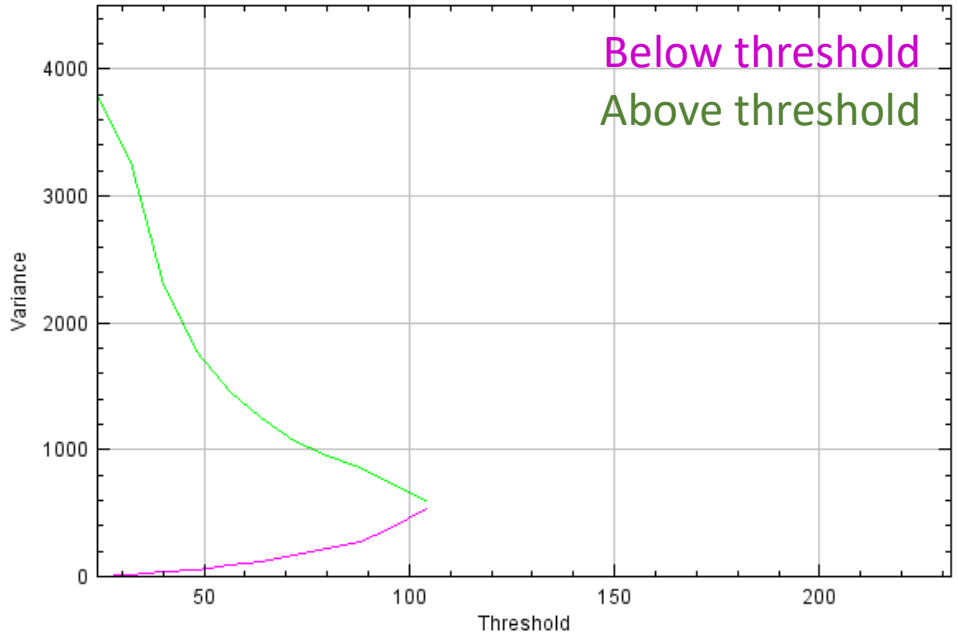

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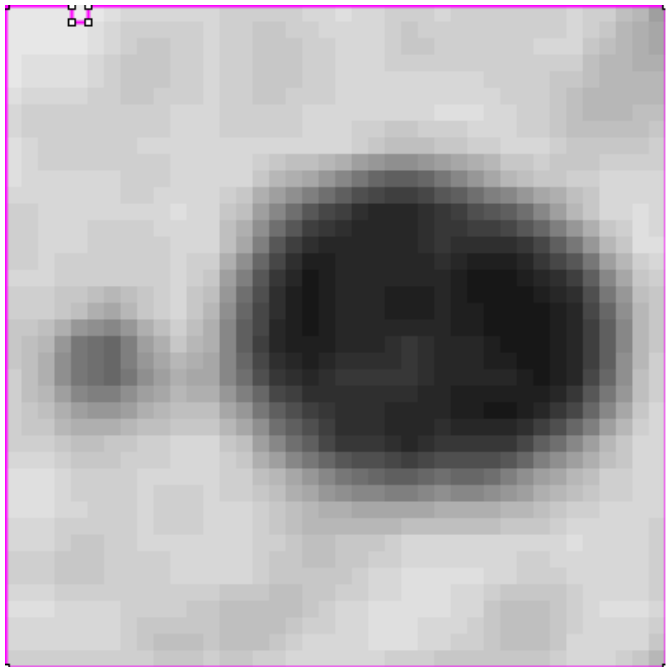
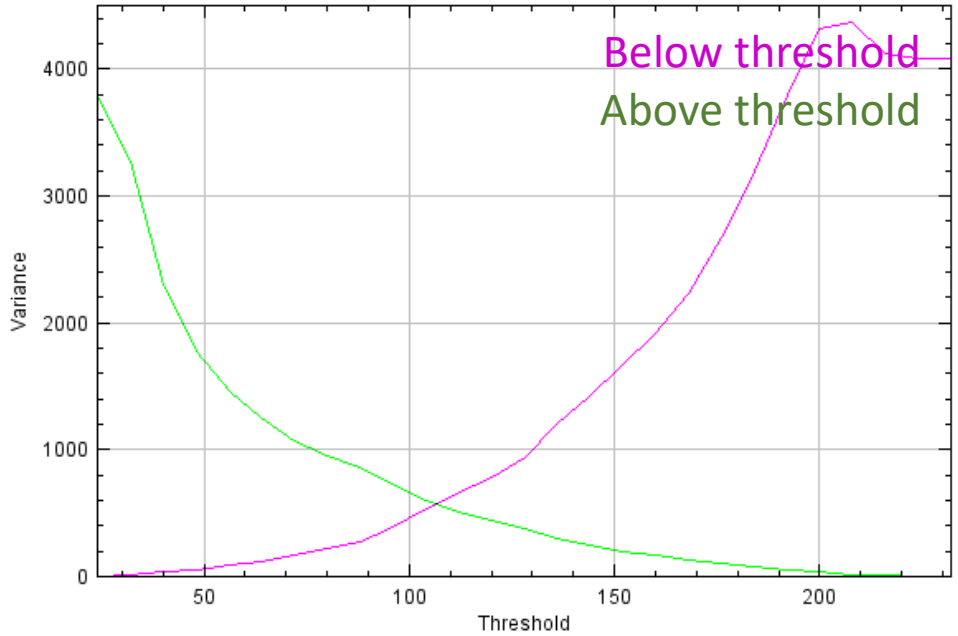
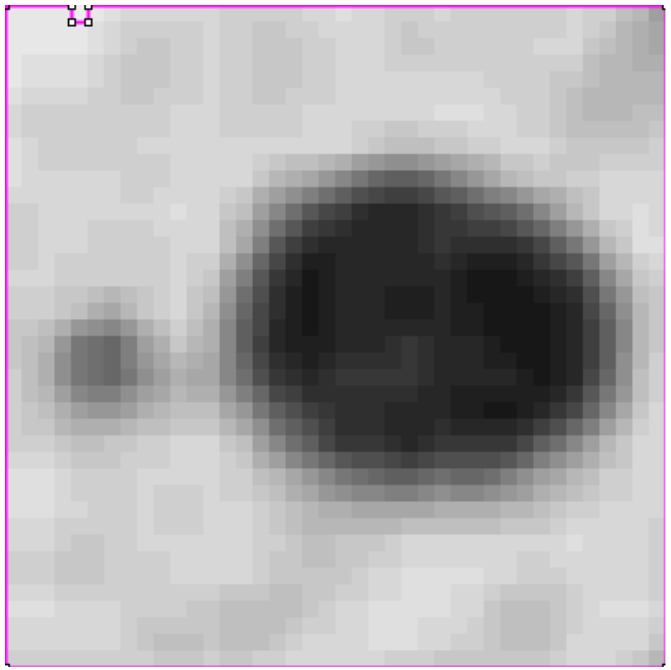


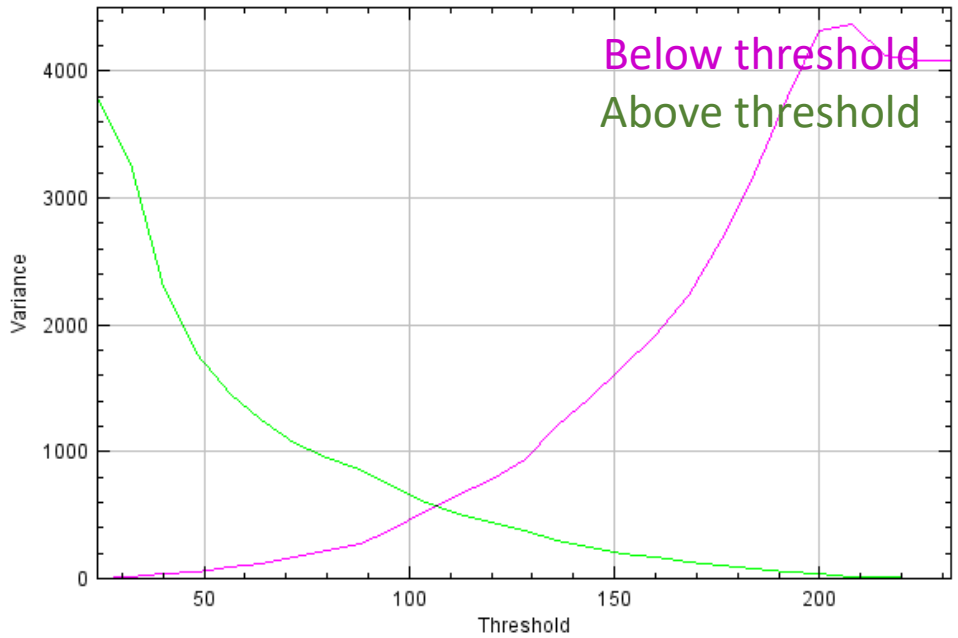


Thresholding: Otsu's method

- Searching for a threshold where the variance in both classes (above/below threshold) becomes minimal.
- Weighted (!) sum variance

$$Var'(I) = \frac{n_A}{n_I} Var(A) + \frac{n_B}{n_I} Var(B) \qquad I = A \cup B$$





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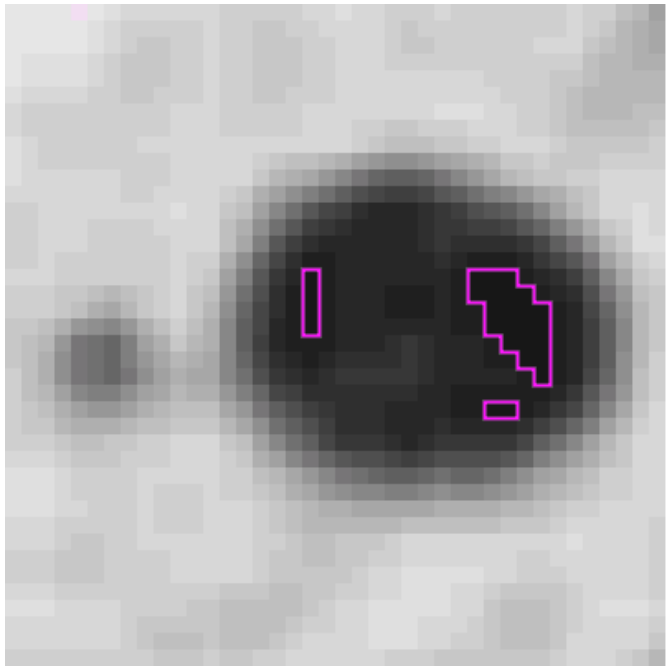

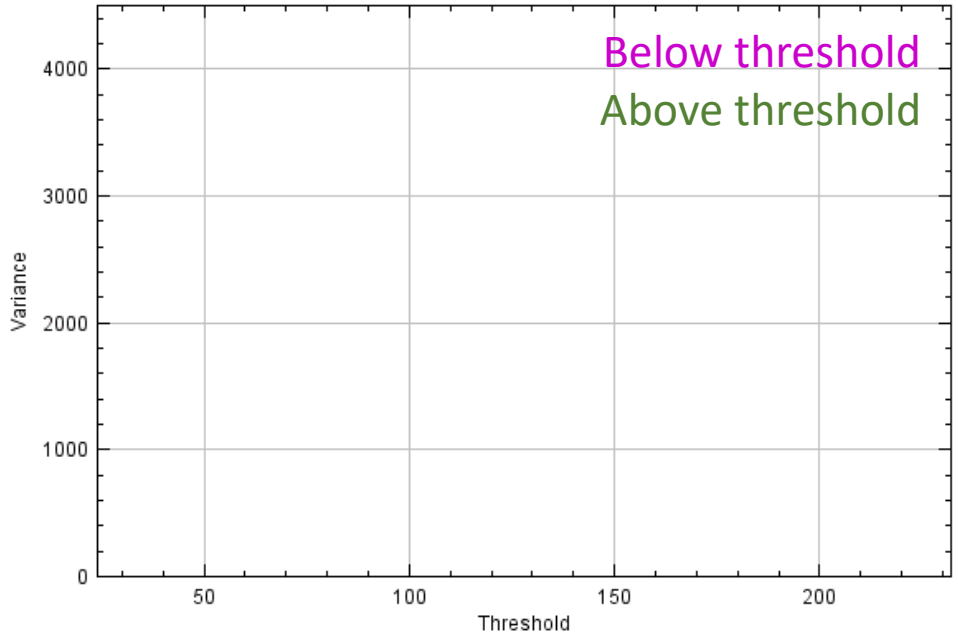

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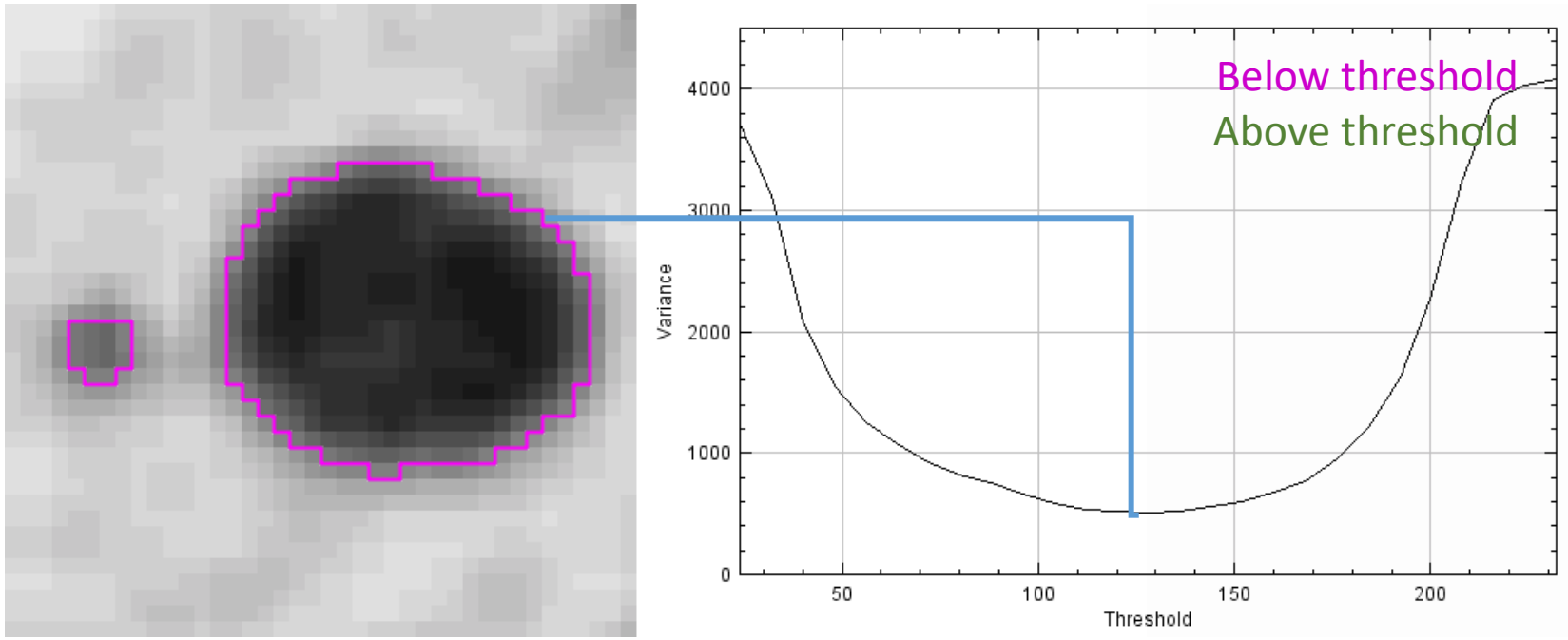


Thresholding: Citing

- Cite the thresholding method of your choice properly

"We segmented the cell nuclei in the images using Otsu's thresholding method (Otsu et Al. 1979) implemented in scikit-image (van der Walt et al. 2014)."

IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS, VOL. SMC-9, NO. 1, JANUARY 1979

A Threshold Selection Method from Gray-Level Histograms

NOBUYUKI OTSU

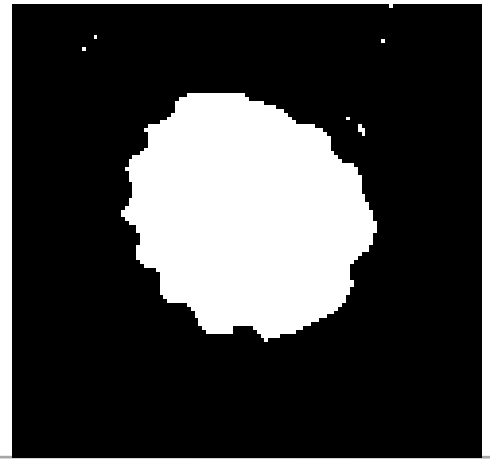
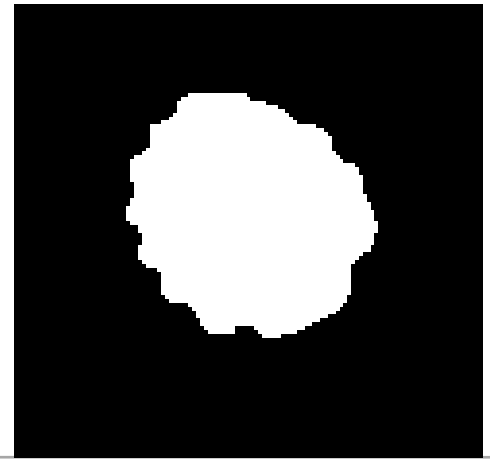
Abstract—**A nonparametric and unsupervised method of automatic threshold selection for picture segmentation is presented. An optimal threshold is selected by the discriminant criterion, namely, so as to maximize the separability of the resultant classes in gray levels. The procedure is very simple, utilizing only the zeroth- and the first-order cumulative moments of the gray-level histogram. It is straightforward to extend the method to multithreshold problems. Several experimental results are also presented to support the validity of the method.**

Refining masks

- Binary mask images may not be perfect immediately after thresholding.
- There are ways of refining them

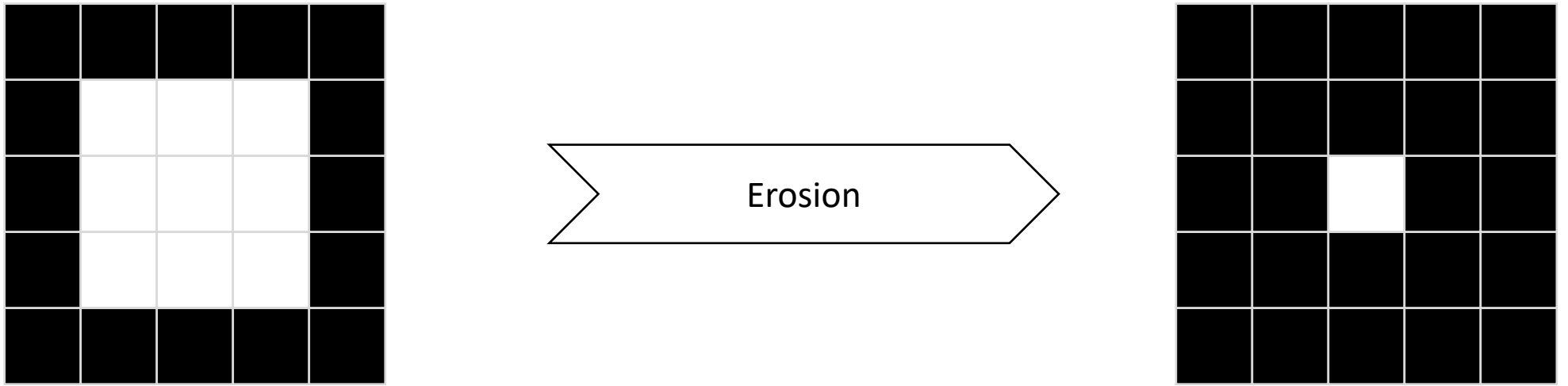
Thresholding → Closing → Opening



Erosion

- Erosion: Every pixel with at least one black neighbor becomes black.



Quiz

- Binary erosion is identical with which filter?

0	0	0	0	0
0	1	1	1	0
0	1	1	1	0
0	1	1	1	0
0	0	0	0	0

Erosion

0	0	0	0	0
0	0	0	0	0
0	0	1	0	0
0	0	0	0	0
0	0	0	0	0

Mean

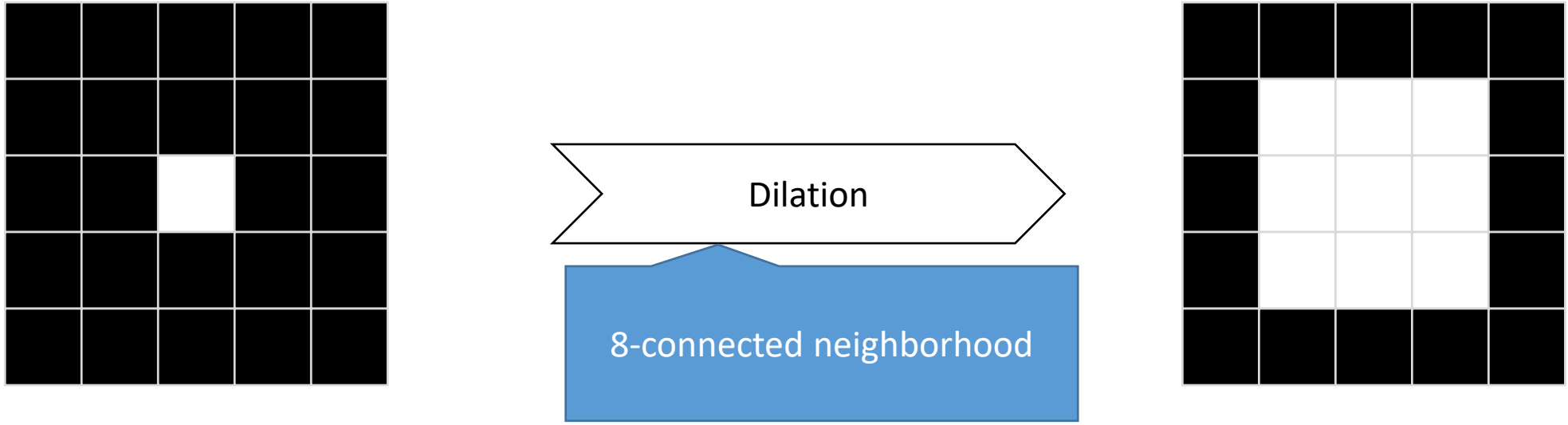
Median

Minimum

Maximum

Dilation

- Dilation: Every pixel with at least one white neighbor becomes white.



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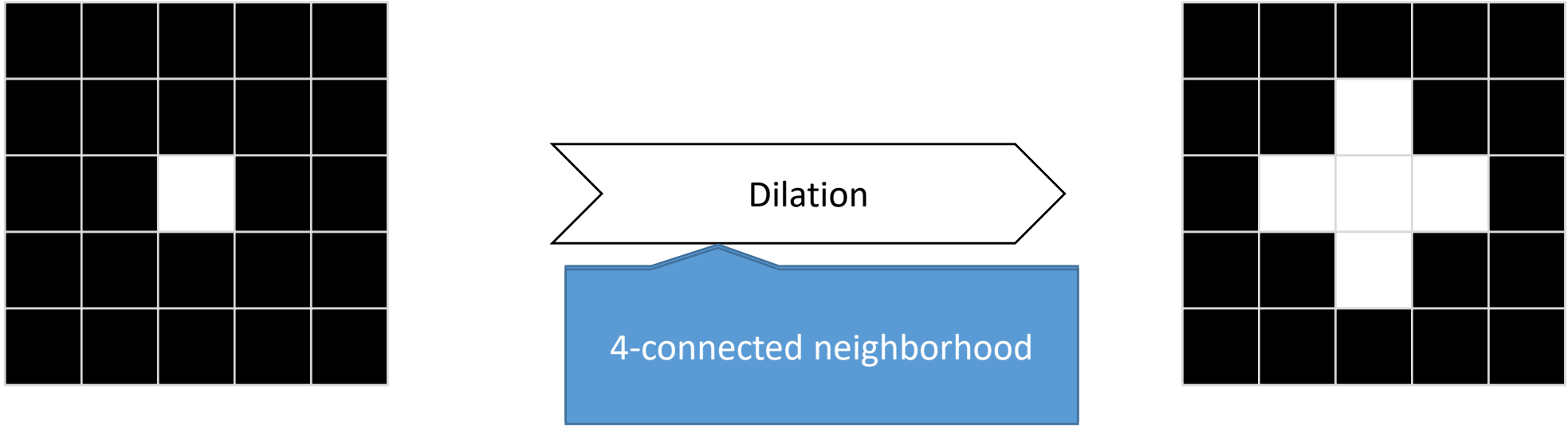
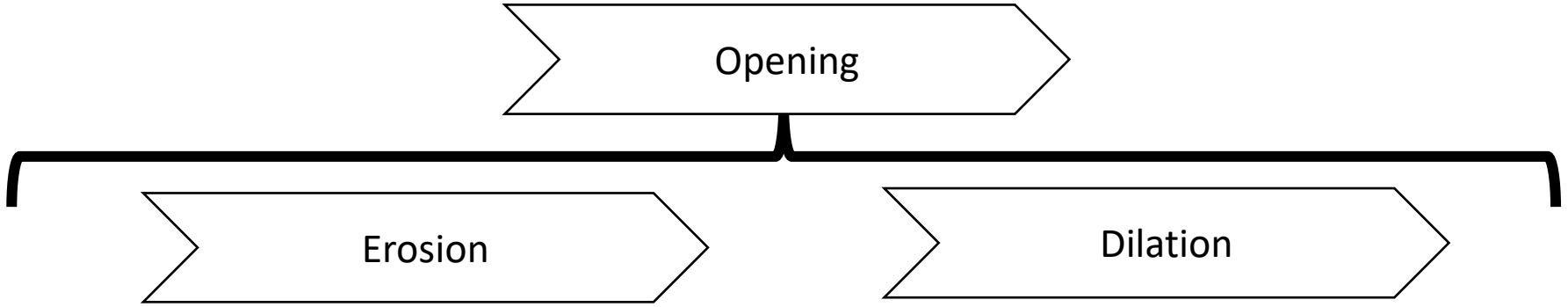
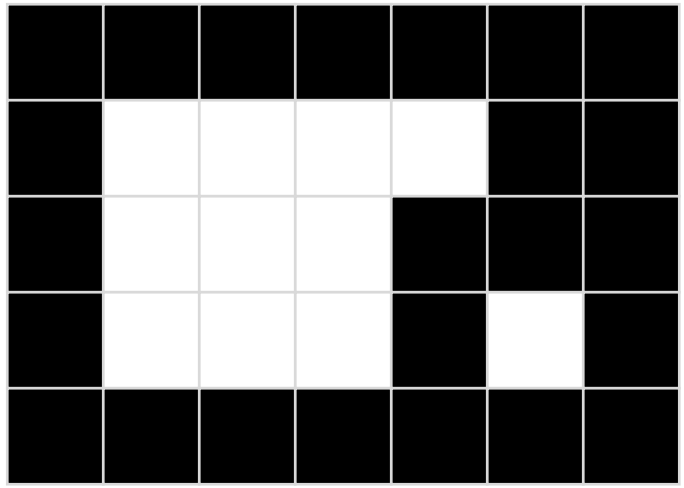
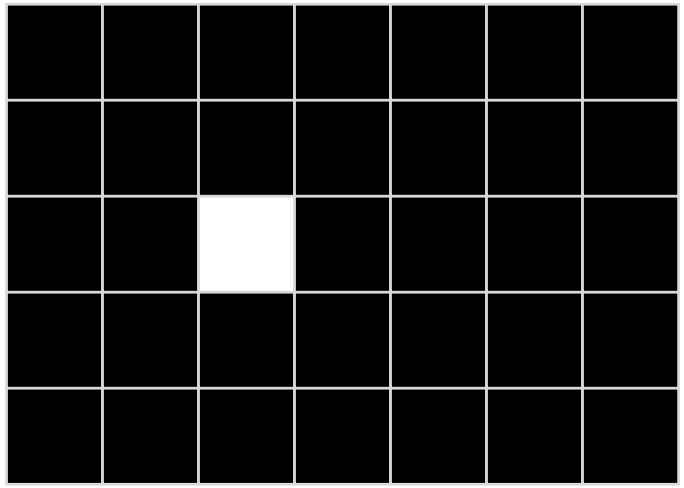


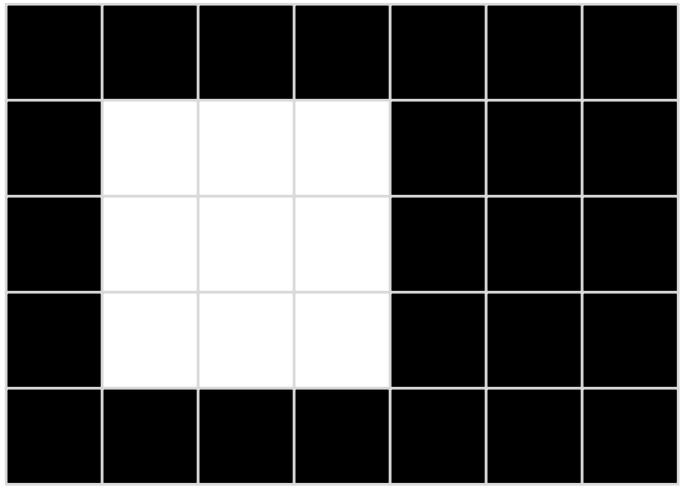
Opening

- Erosion and dilation combined allow correcting outlines.



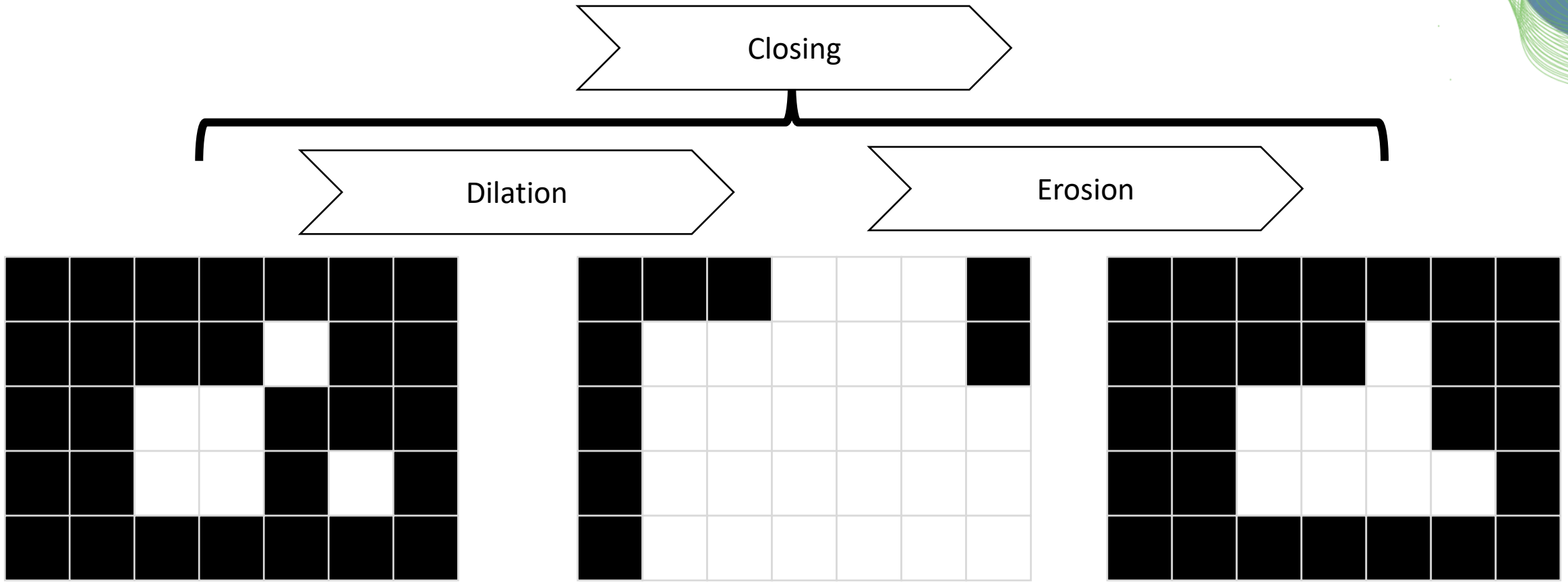






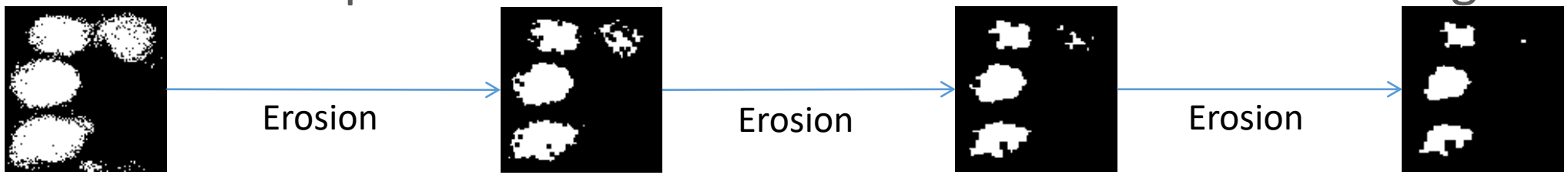
Closing

- Erosion and dilation combined allow correcting outlines.



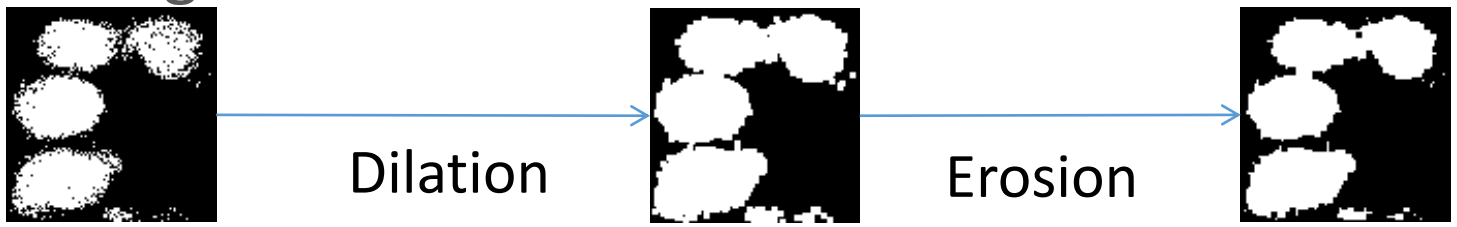
Chaining erosion and dilation

- Erosion: Set all pixels to black which have at least one black neighbor.



- Dilation: Set all pixels to white which have at least one white neighbor.

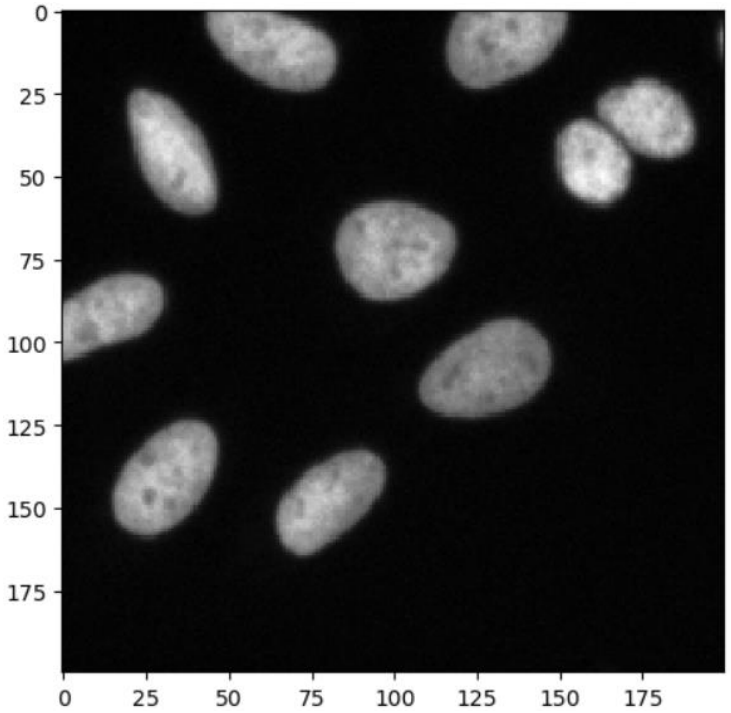
- Closing: Dilation + Erosion



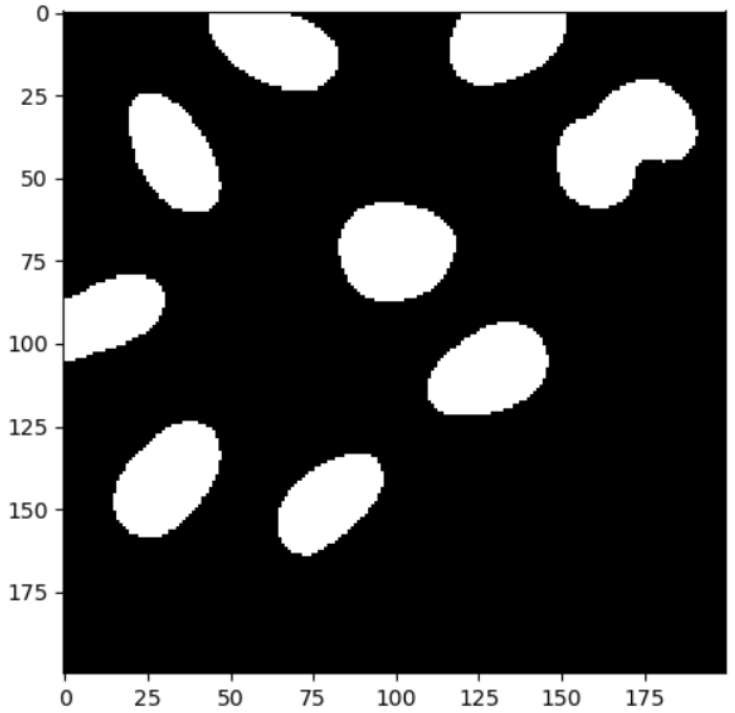
- Opening: Erosion + Dilation

Terminology

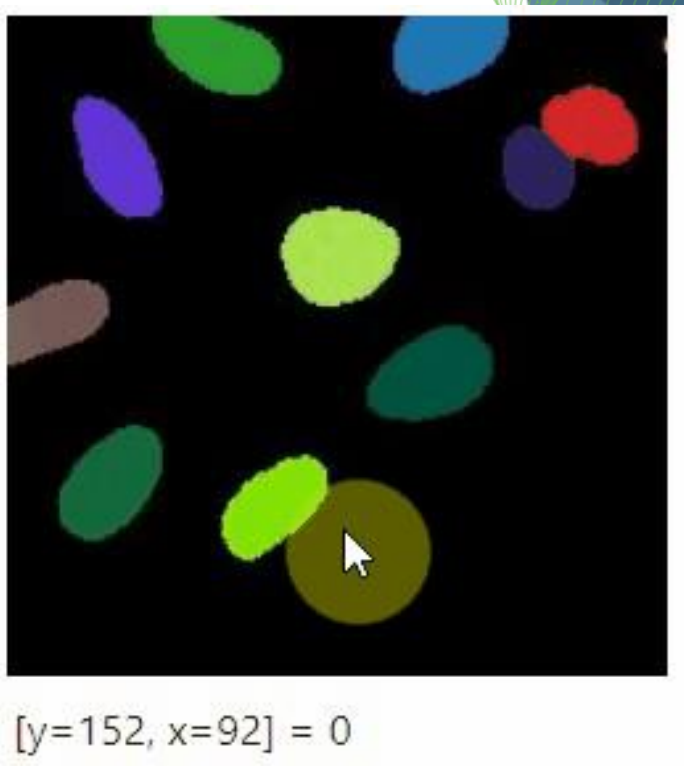
Intensity image



Binary image

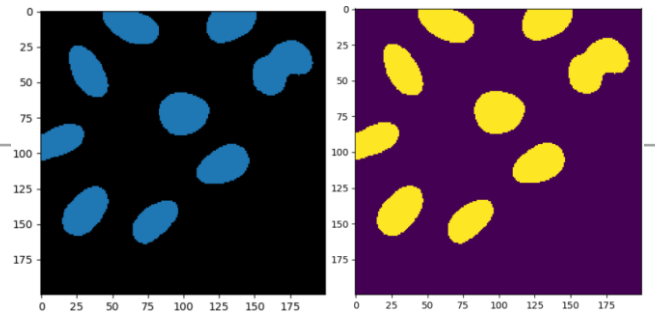


Label image



[y=152, x=92] = 0

No matter how they are displayed



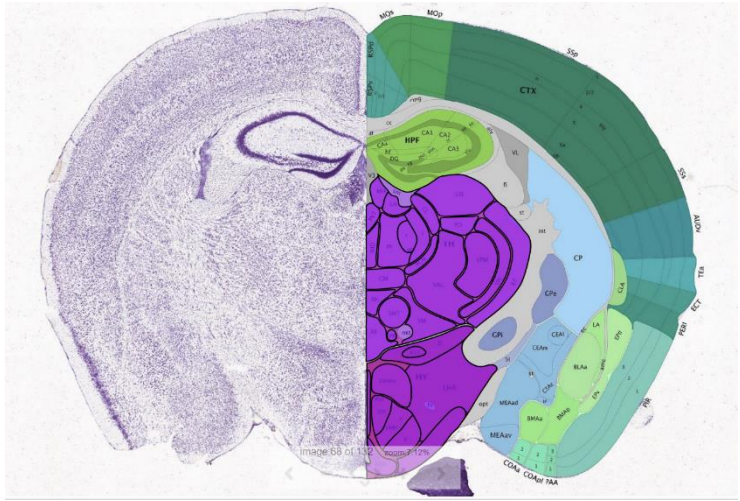
Terminology

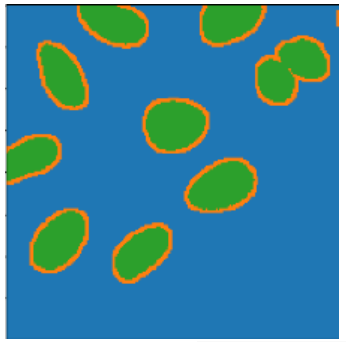
Instance segmentation

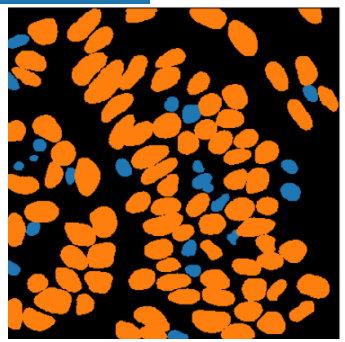
Instances:

- Cells, nuclei, cats, dogs, cars, trees

Semantic segmentation







Regions:

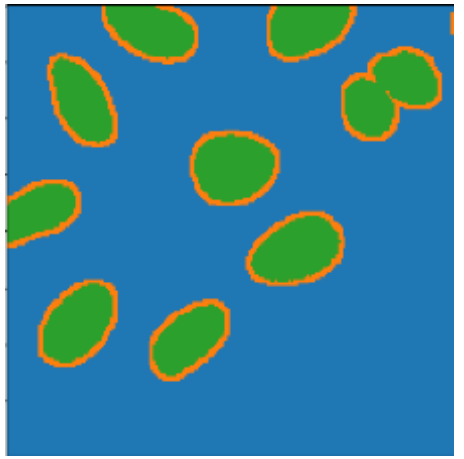
- Anatomical, geographical
- All pixels belonging to the same type of object have the same value

Source: Allen Mouse Brain Atlas [dataset]. Available from mouse.brain-map.org. Allen Institute for Brain Science (2011).

Terminology

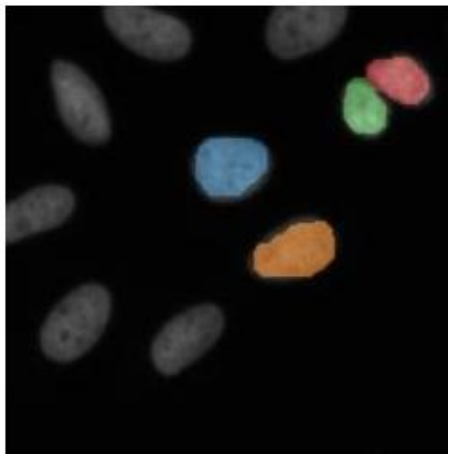
- Annotations are typically drawn by humans (e.g. to train machine learning models)

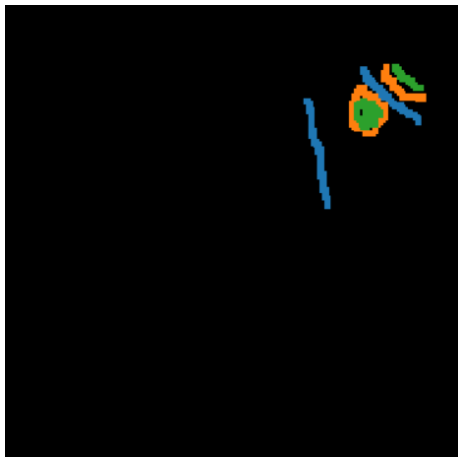
Instance segmentation



Semantic segmentation

Sparse instance annotation

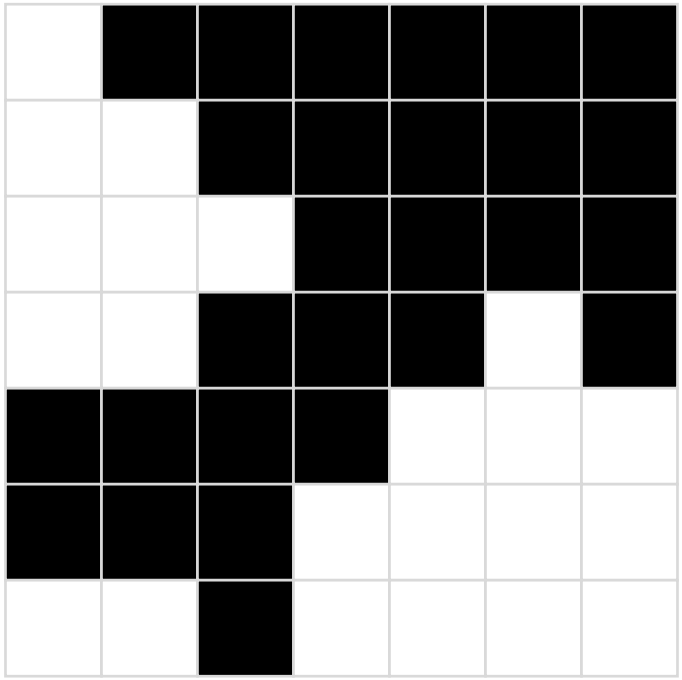




Sparse semantic annotation

Connected component labelling

- In order to allow the computer differentiating objects, connected component analysis (CCA) is used to mark pixels belonging to different objects with different numbers
- Background pixels are marked with 0.
- The maximum intensity of a labelled map corresponds to the number of objects.



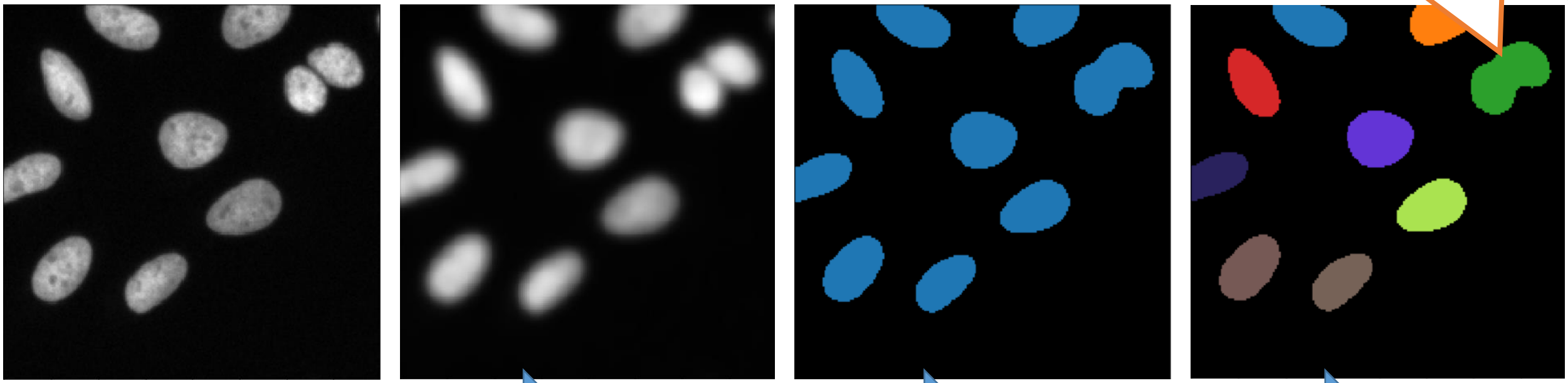
CCA

1	0	0	0	0	0	0
1	1	0	0	0	0	0
1	1	1	0	0	0	0
1	1	0	0	0	3	0
0	0	0	0	3	3	3
0	0	0	3	3	3	3
2	2	0	3	3	3	3

Common image segmentation workflows

- Presumably the most common segmentation algorithm used for fluorescent microscopy images:
  - Gaussian blur, Otsu's Threshold, Connected Component Labeling

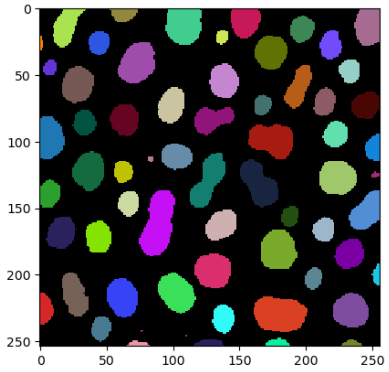
Limitation: Dense objects



Denoising → Binarization → Labeling

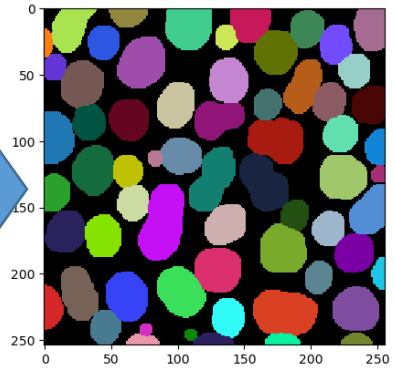
Voronoi-Tesselation

- For separating objects using spatial constraints (not intensity-based)

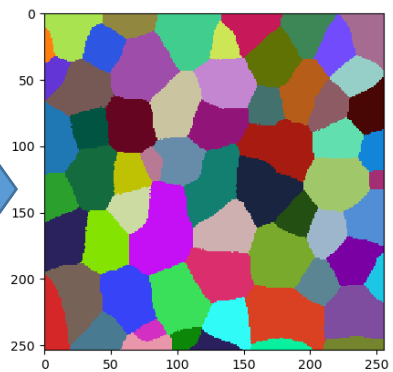


Label-image

Dilate labels

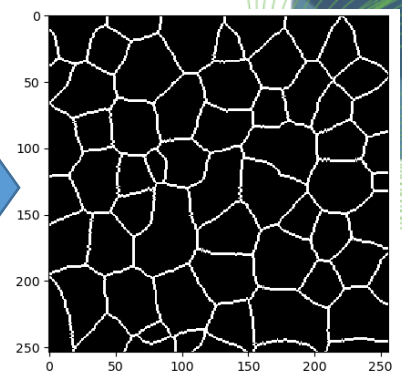


Dilate labels



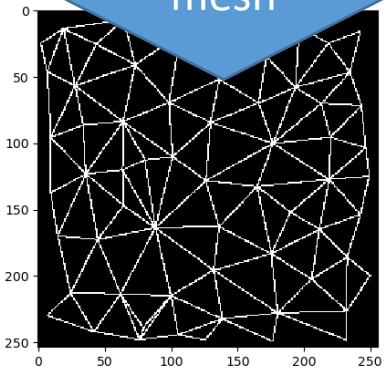
Voronoi-label-image

Edge detection

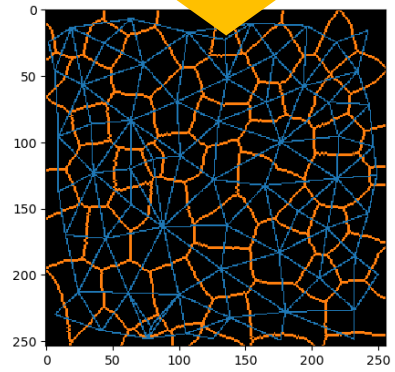


Label-edge-image

Centroid mesh



Touching neighbor mesh

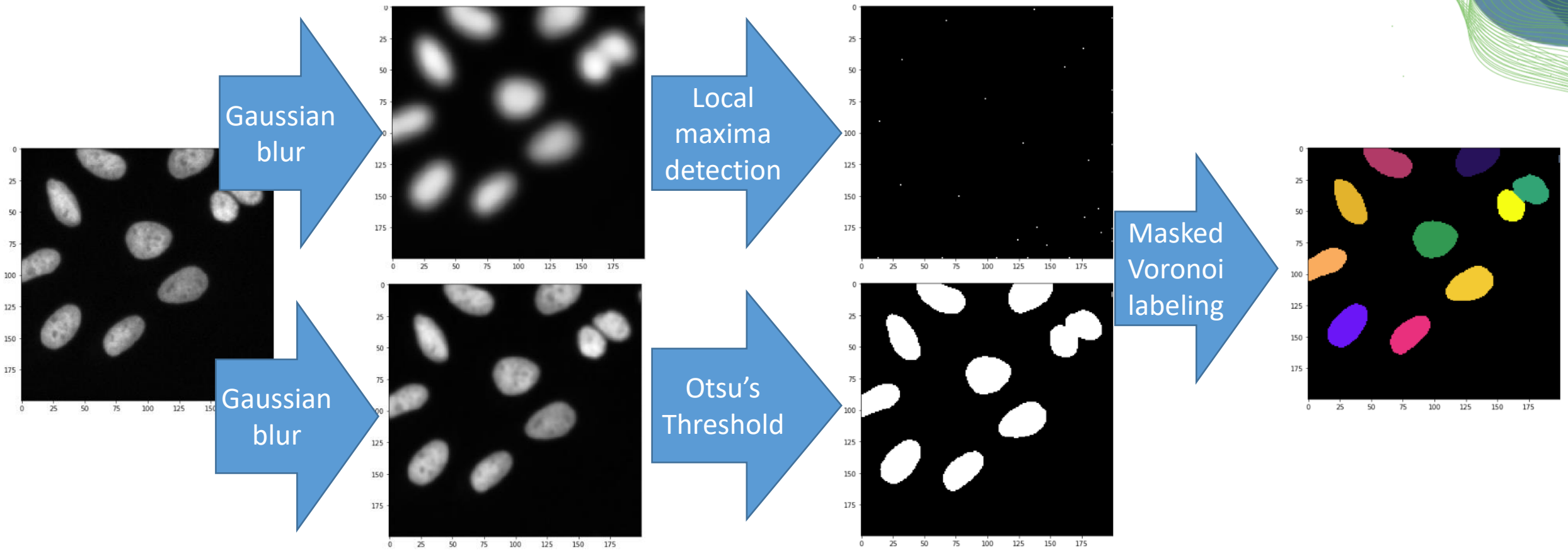


Voronoi-Tesselation

Delauney-Triangulation

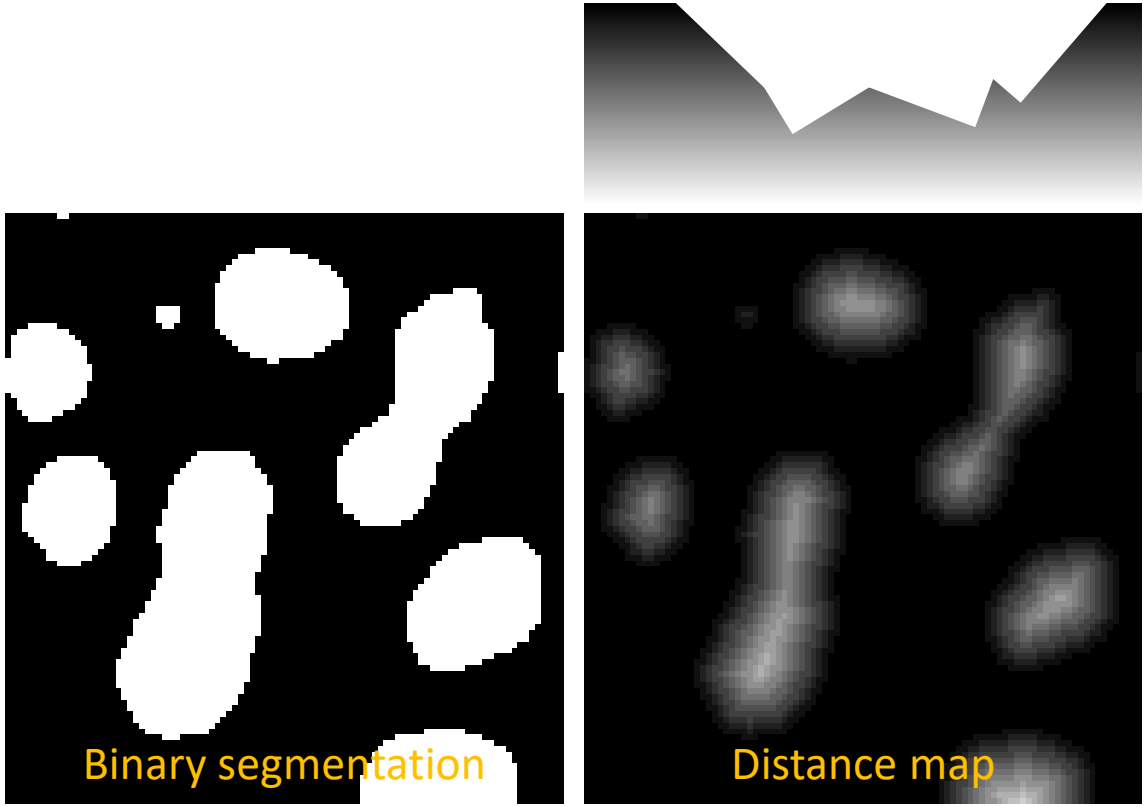
Common image segmentation workflows

- Combination of Gaussian blur, Otsu's Threshold and Voronoi-labeling



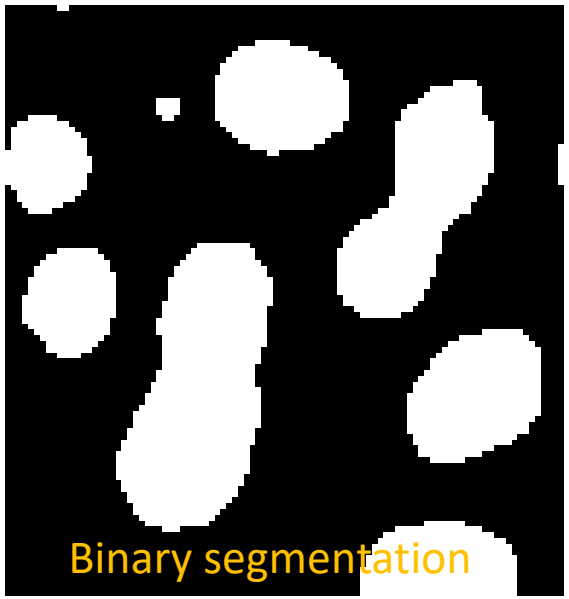
Watershed

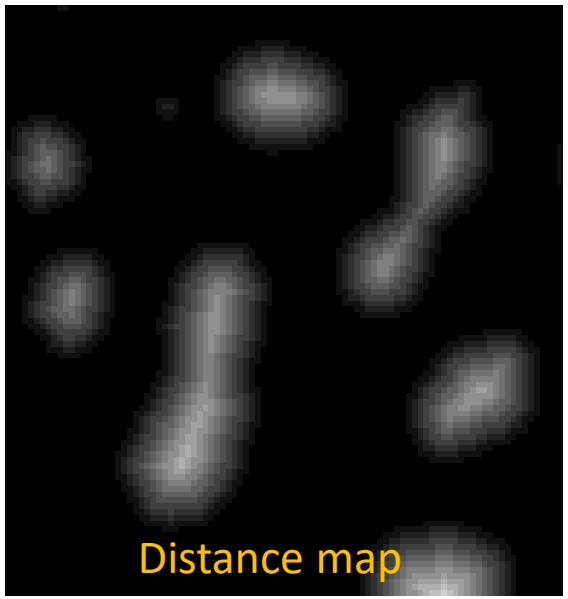
- The watershed algorithm for binary images allows cutting one object into tow where it’s reasonable.



Watershed

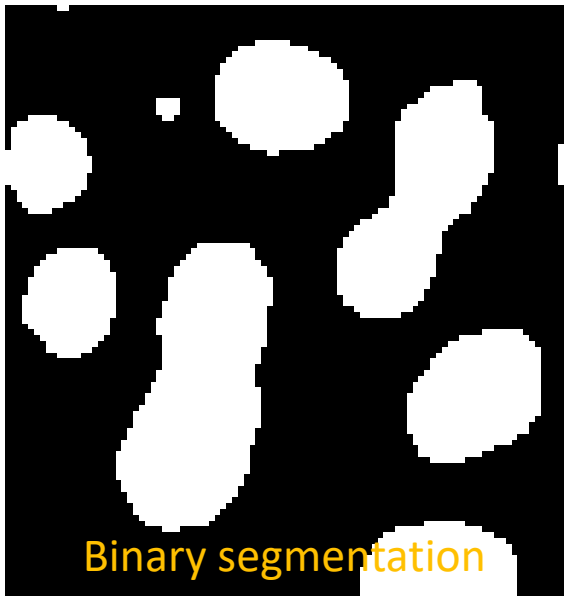
- The watershed algorithm for binary images allows cutting one object into tow where it’s reasonable.

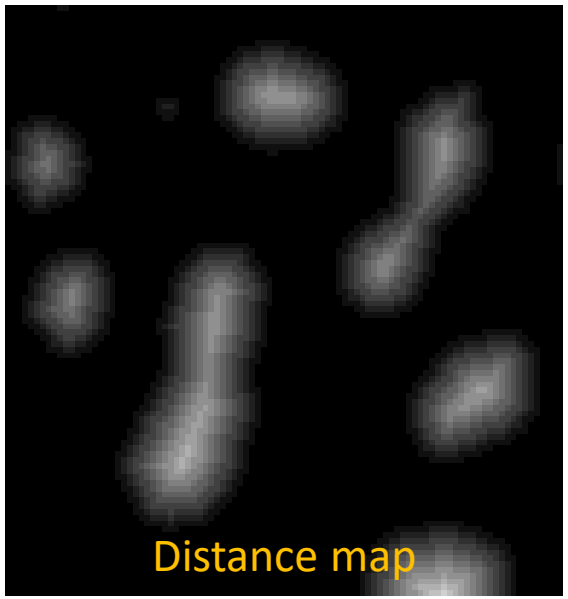


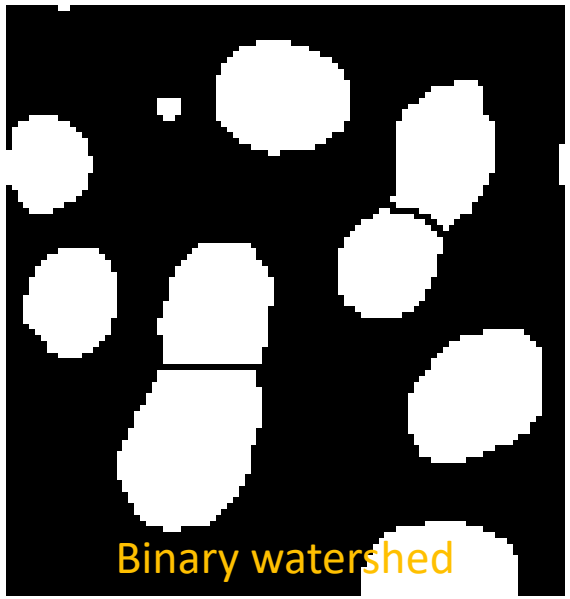


Watershed

- The watershed algorithm for binary images allows cutting one object into two where it's reasonable.
- The distance-maps are typicall made from binary images. It does not take the original image into account!

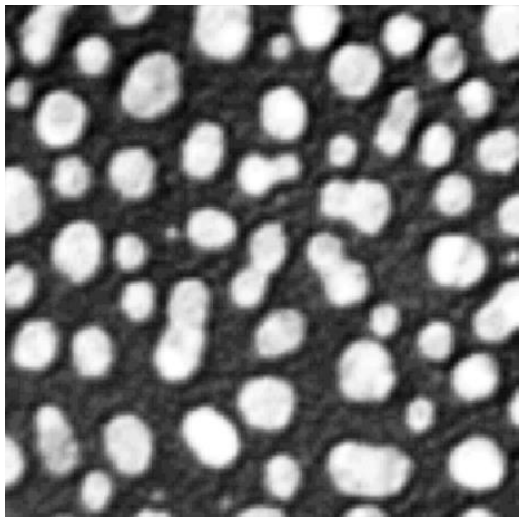


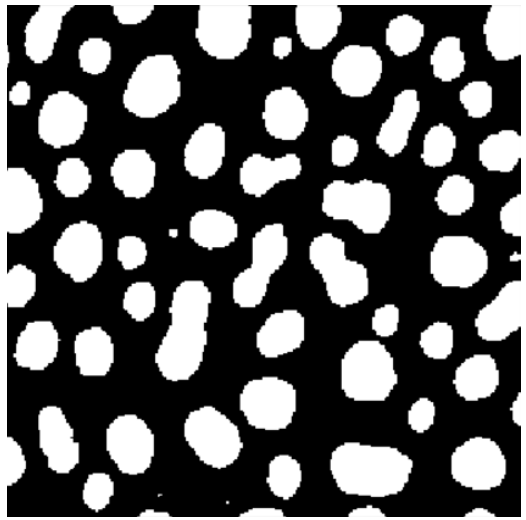




Watershed use-cases

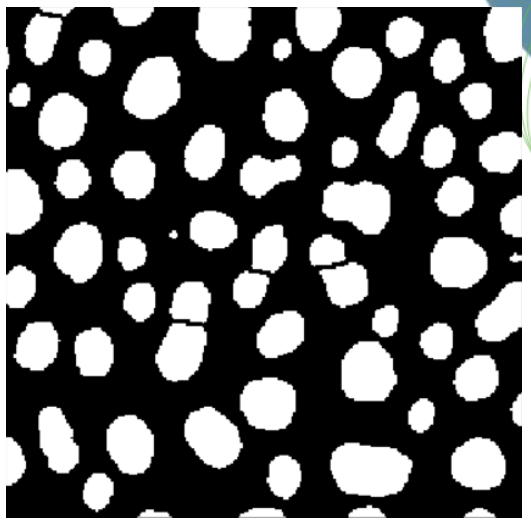
- Split dense objects



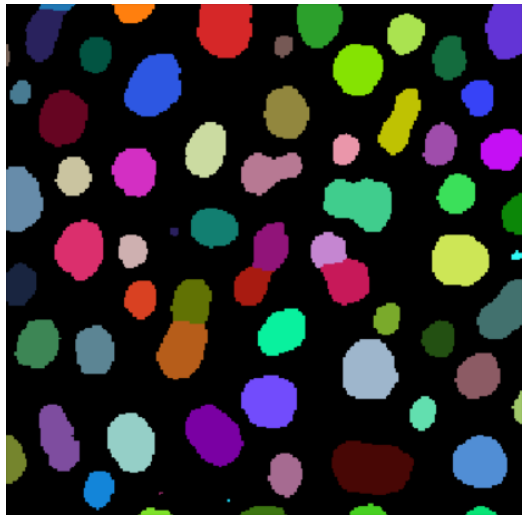


Binarization

Watershed

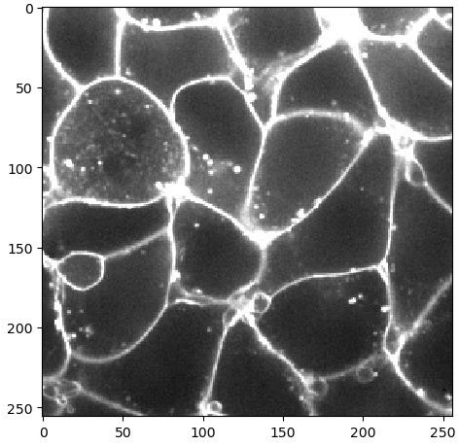


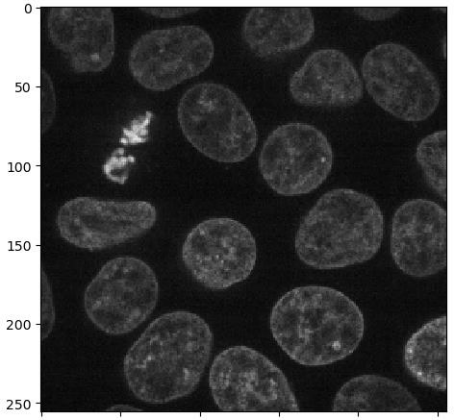
Watershed

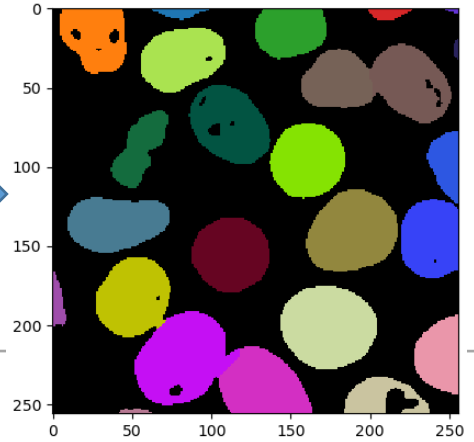


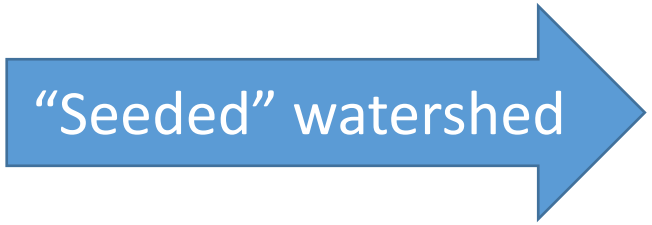
Watershed use-cases

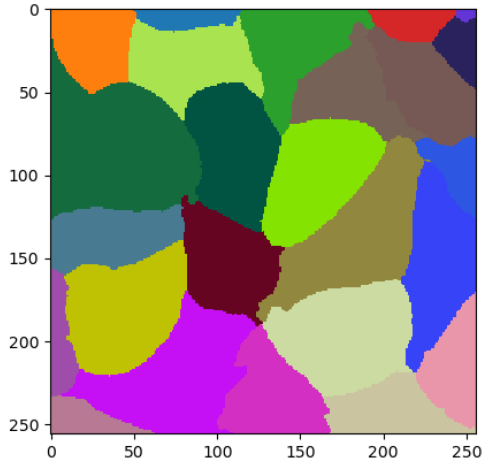
- Seeded watershed: Flood regions from pre-defined seeds
- Example: Flood cells from nuclei positions





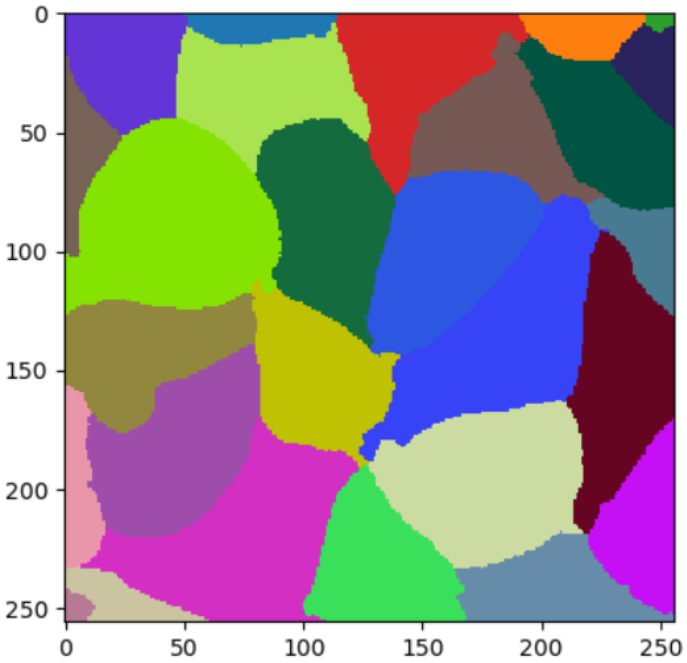




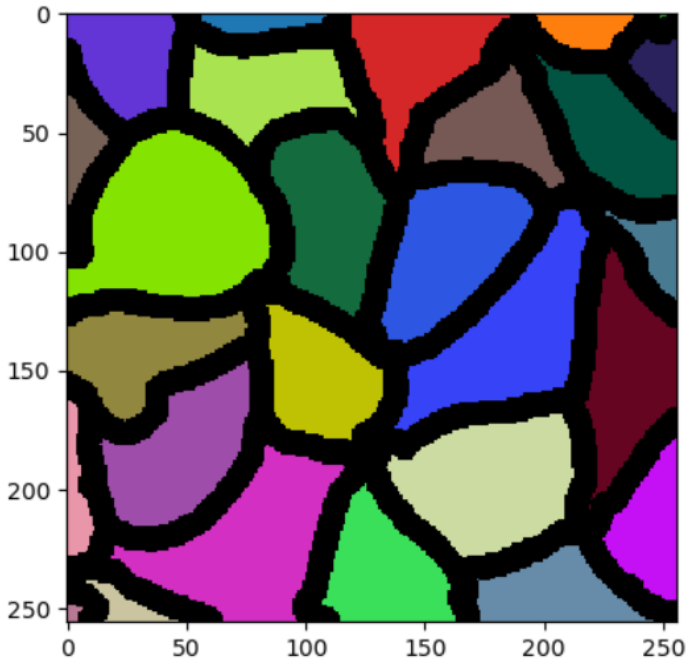


Label post-processing / morphological operations

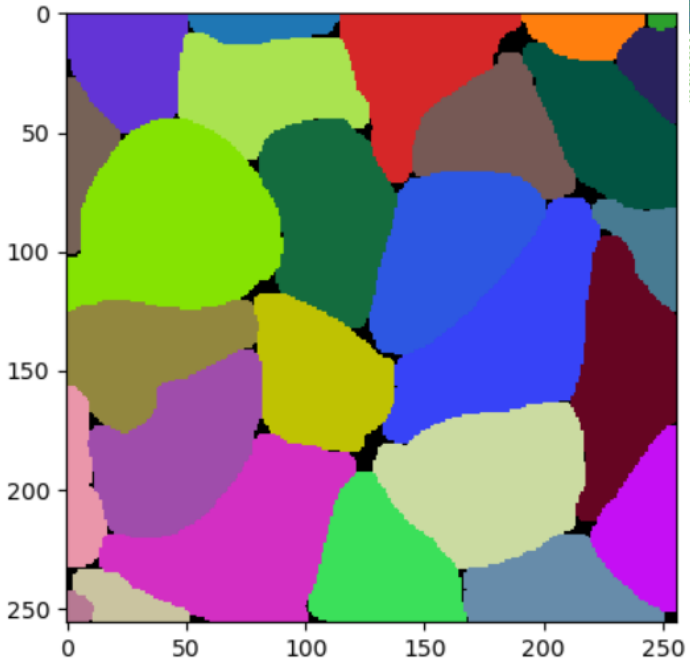
- … similar to morphological operations on binary images



Original



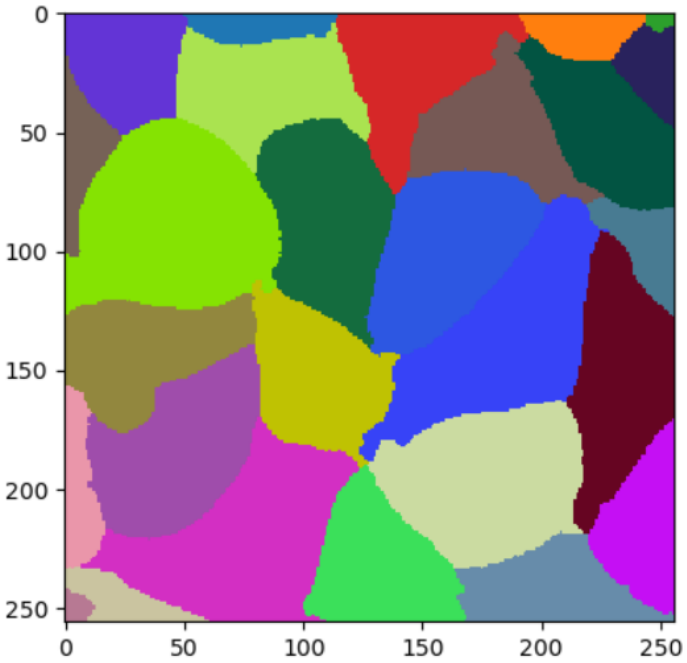
Eroding labels



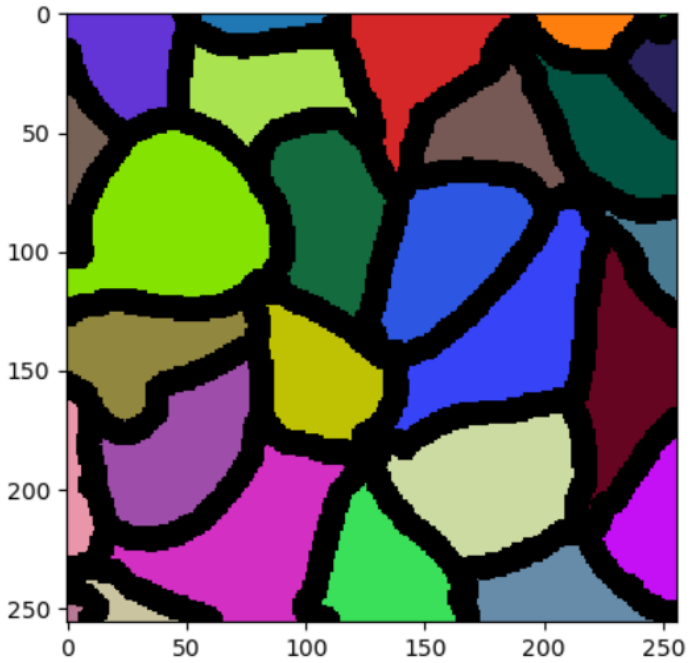
Dilating Labels

Label post-processing / morphological operations

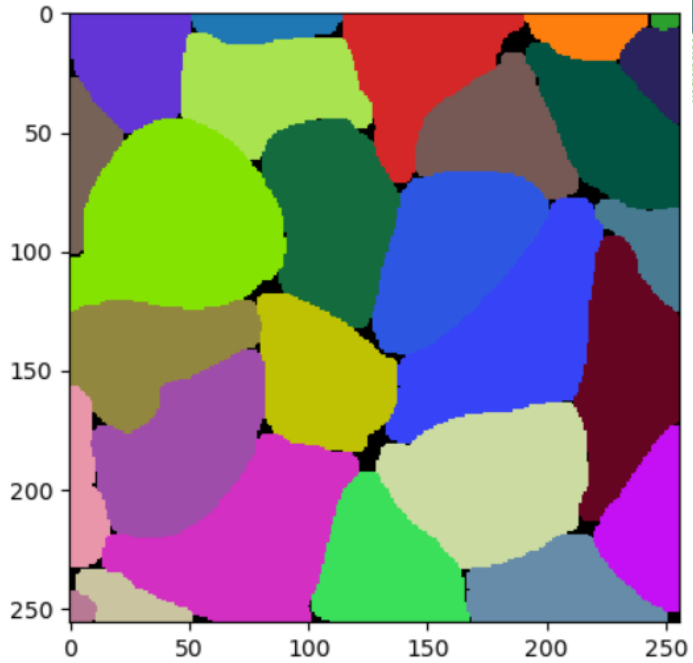
- … similar to morphological operations on binary images



Original



Eroding labels



Dilating Labels

This combination is called …?

Opening

Closing

Epilepsy warning

Label post-processing / morphological operations

- … similar to morphological operations on binary images

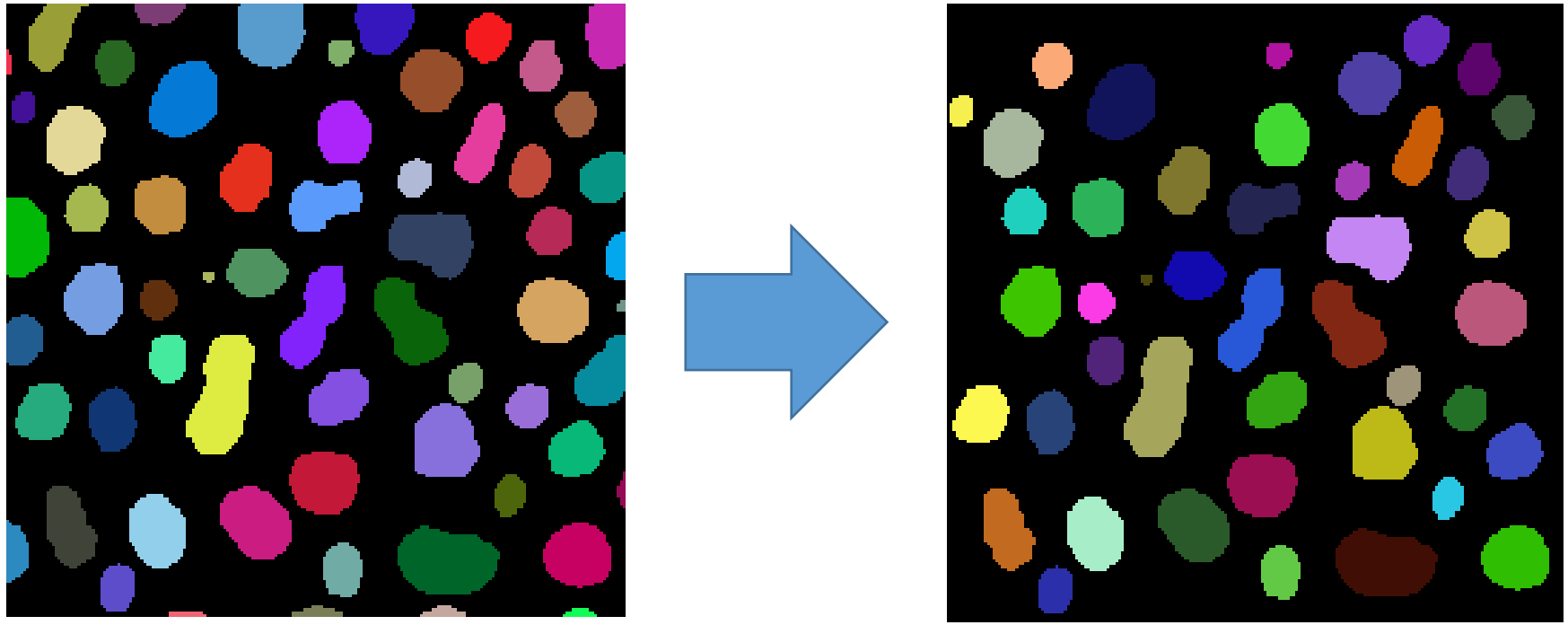
Original

Opening labels

Smoothing Labels

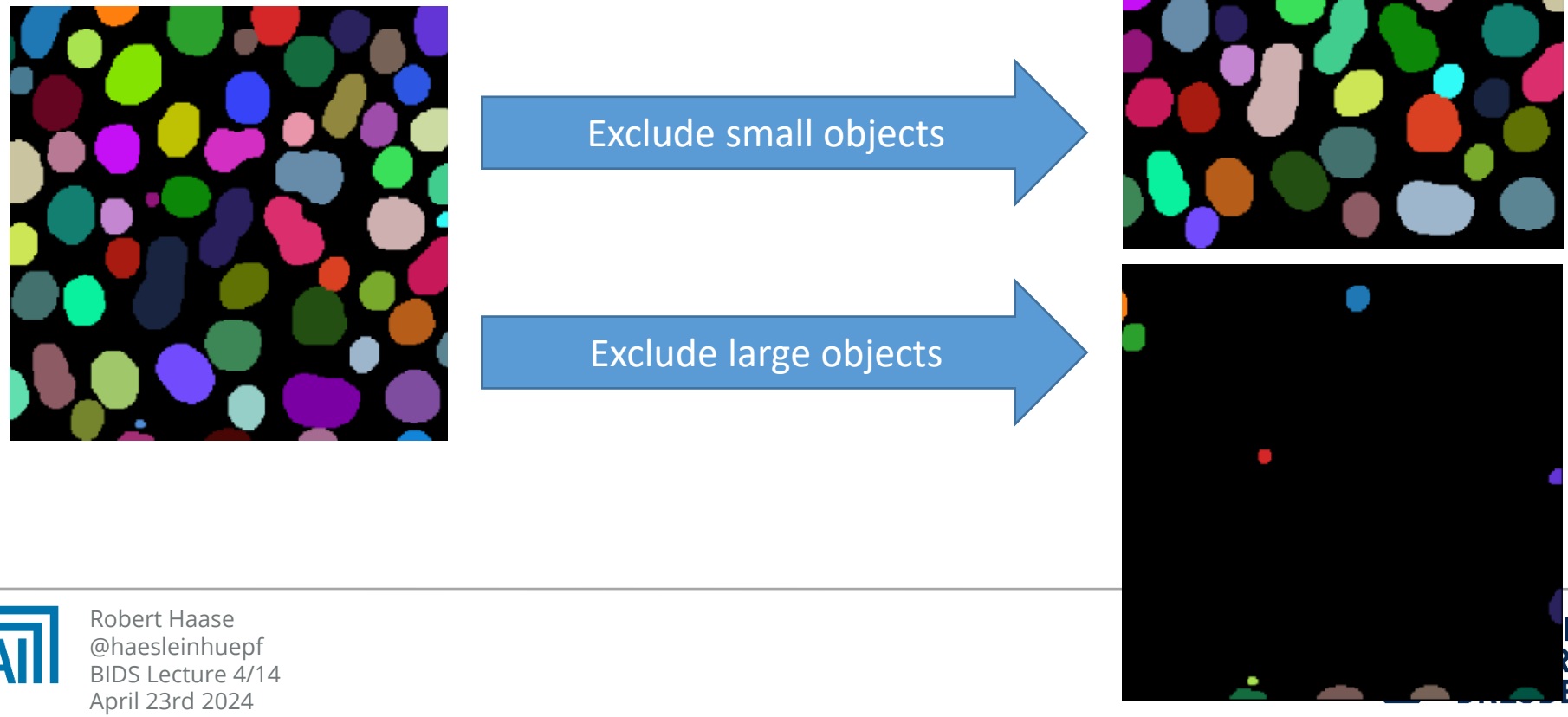
Label post-processing / selections

- Remove objects at the image border
- Their measurements (shape, size) would be misleading anyway



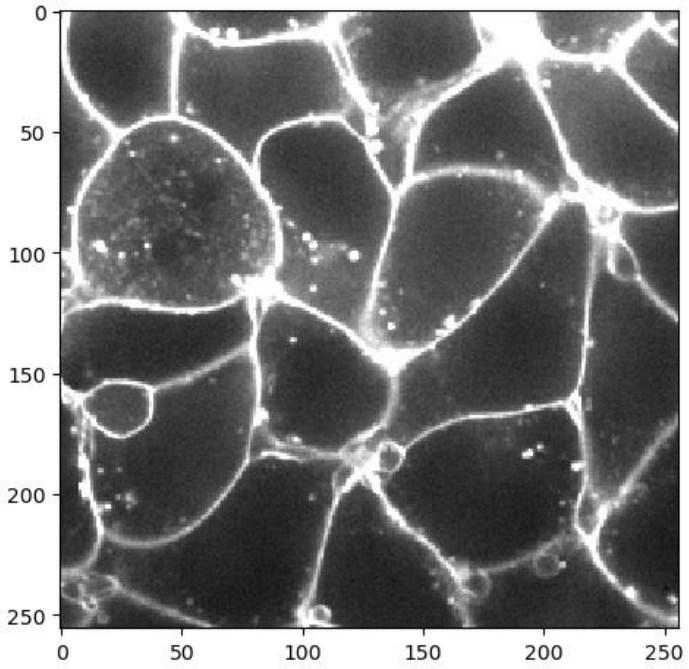
Label post-processing / selections

- Excluding small / large objects
- Common correction-step in case segmentations contain noise-related small particles



Quiz

- What's a reasonable approach to process such an image?



Thresholding

Watershed

Machine-Learning

ScaDS.AI
DRESDEN LEIPZIG

CENTER FOR SCALABLE DATA ANALYTICS AND ARTIFICIAL INTELLIGENCE

Napari

Robert Haase

Funded by

Bundesministerium für Bildung und Forschung

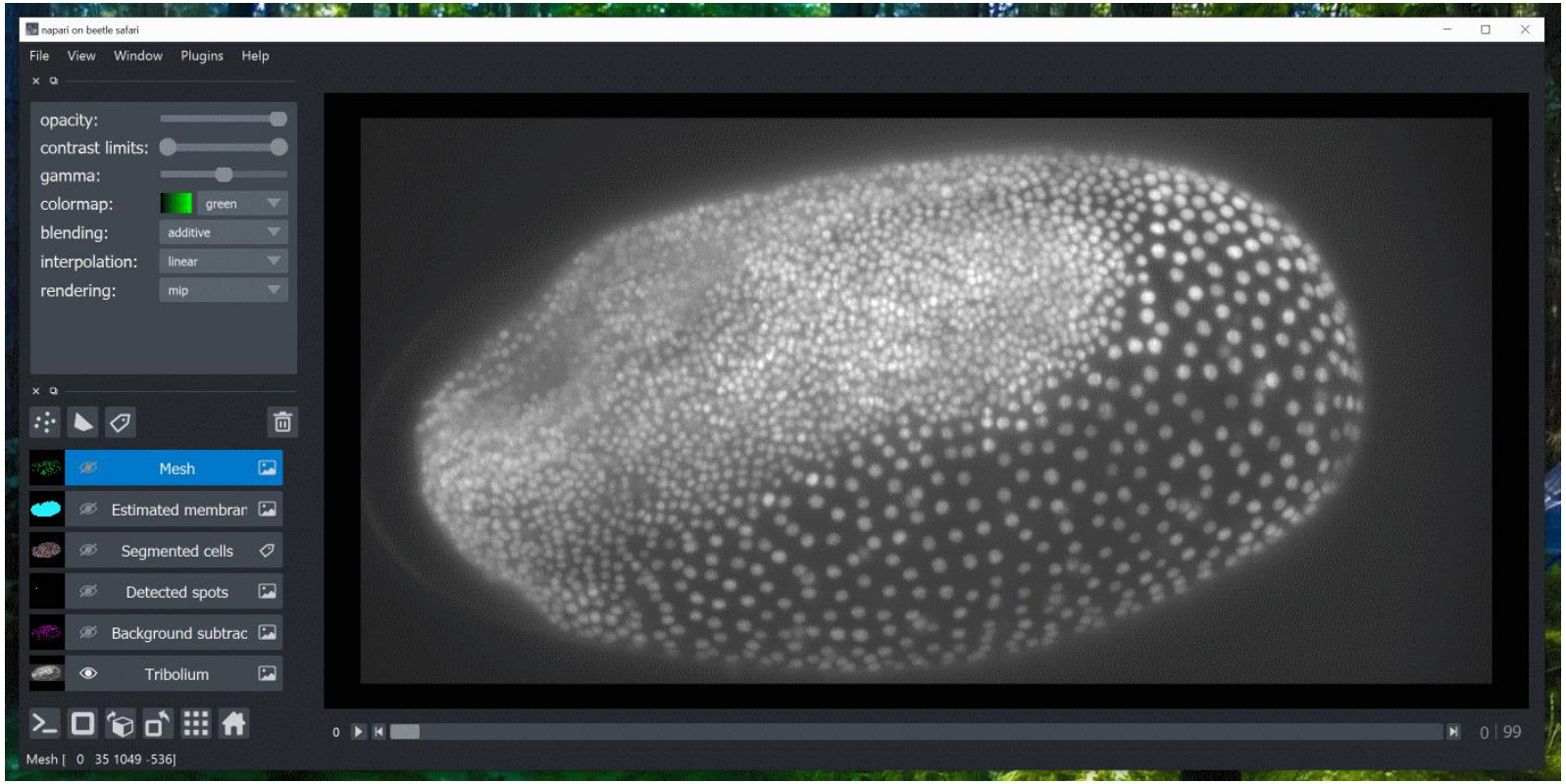
SACHSEN

Diese Maßnahme wird gefördert durch die Bundesregierung aufgrund eines Beschlusses des Deutschen Bundestages. Diese Maßnahme wird mitfinanziert durch Steuermittel auf der Grundlage des von den Abgeordneten des Sächsischen Landtags beschlossenen Haushaltes.

Chan Zuckerberg Initiative

Napari

- A viewer for n-dimensional image data written in Python

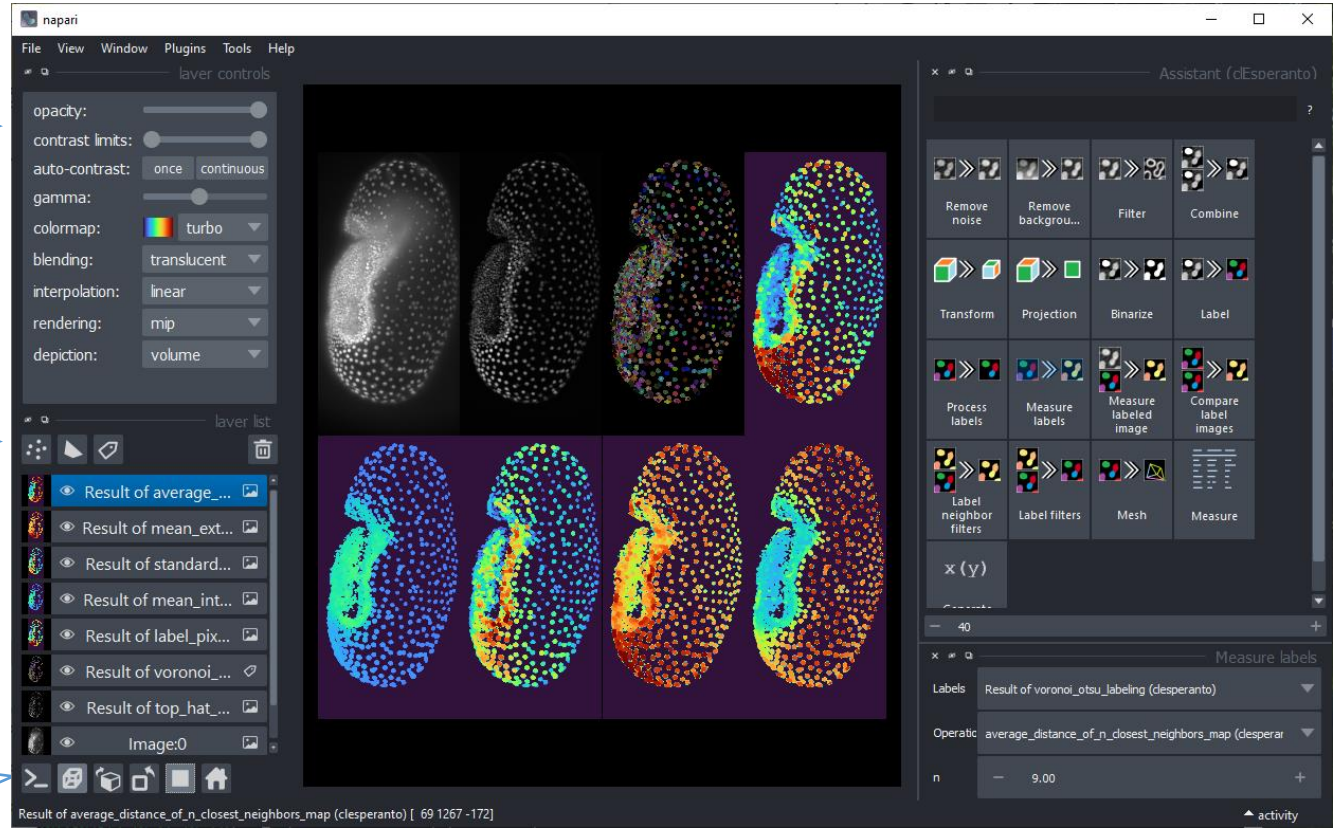


Napari – Graphical User Interface

View configuration / tools

Layers

Viewer controls

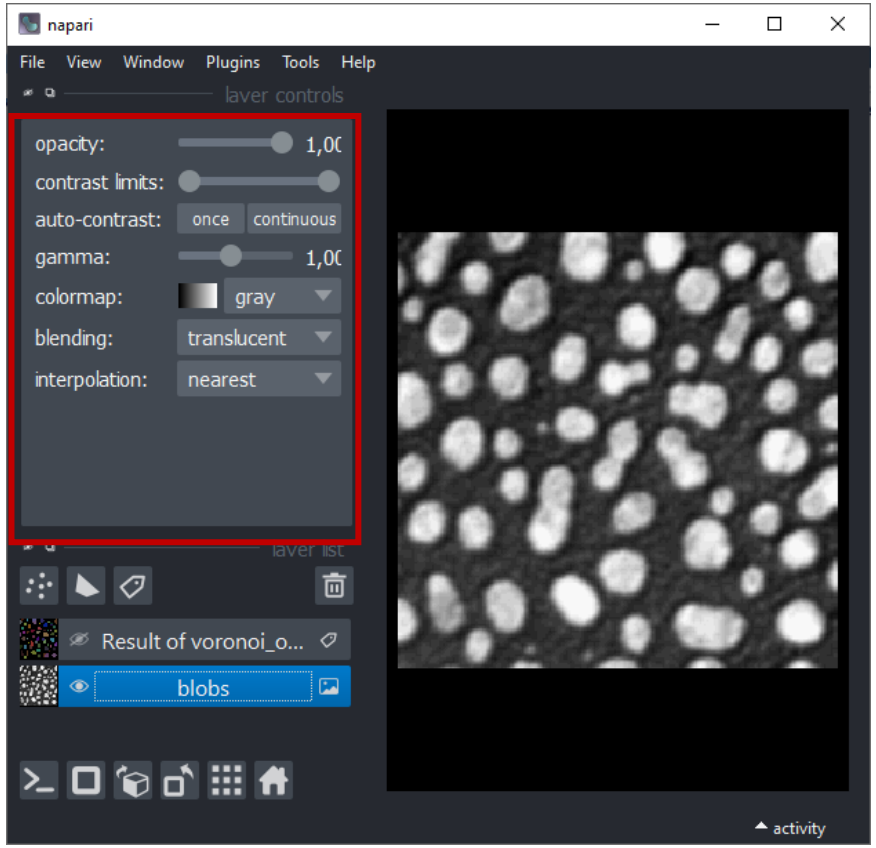


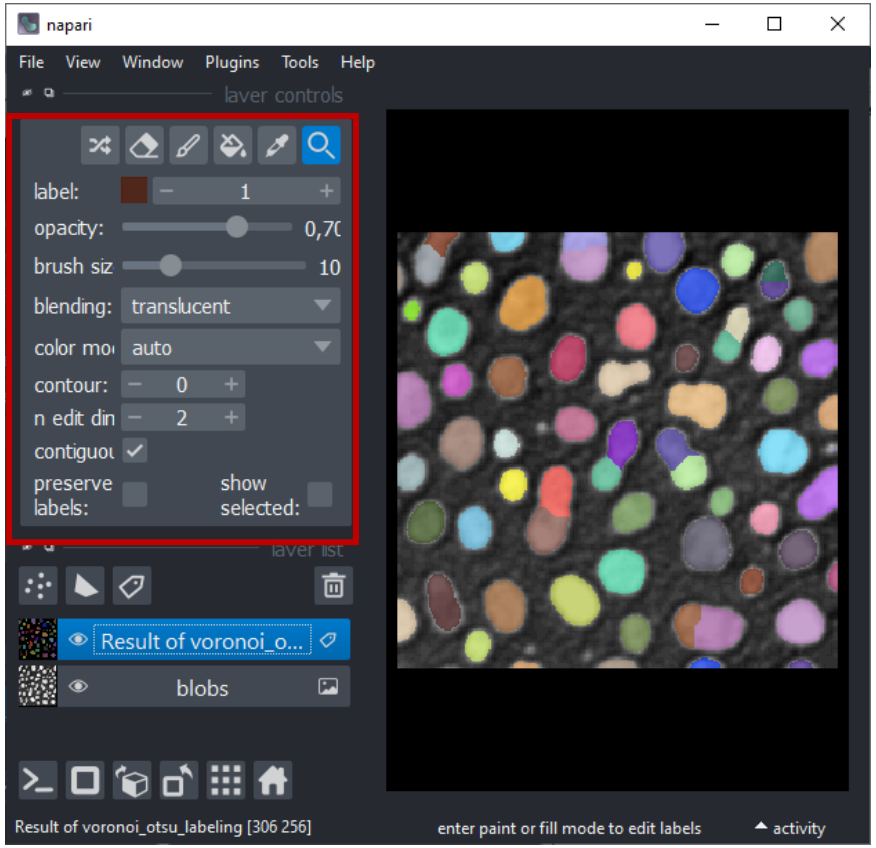
Dock widgets (custom plugins)

Function widgets (custom plugins)

Napari – Graphical User Interface

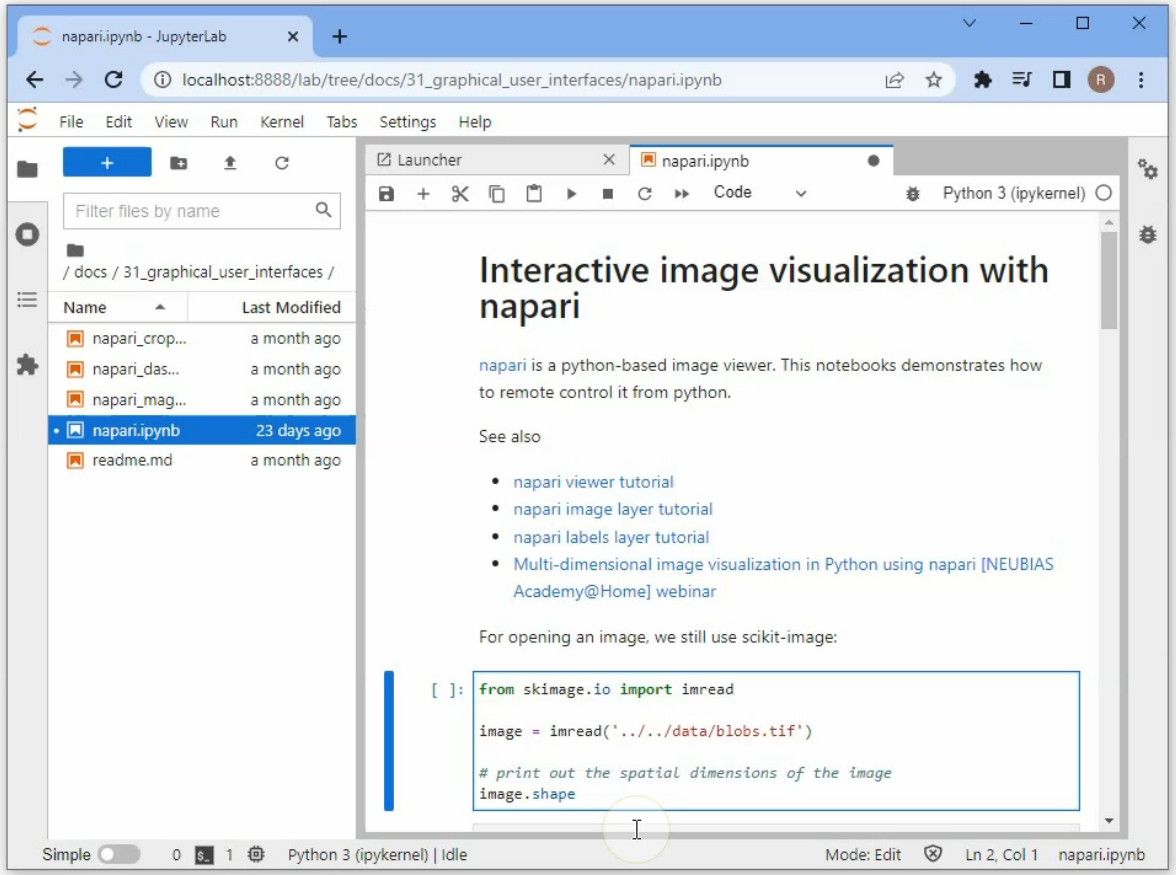
- Context / data type dependent tools





Napari – Python Scripting

- Mixing interactivity and reproducibility



Napari – Python Scripting

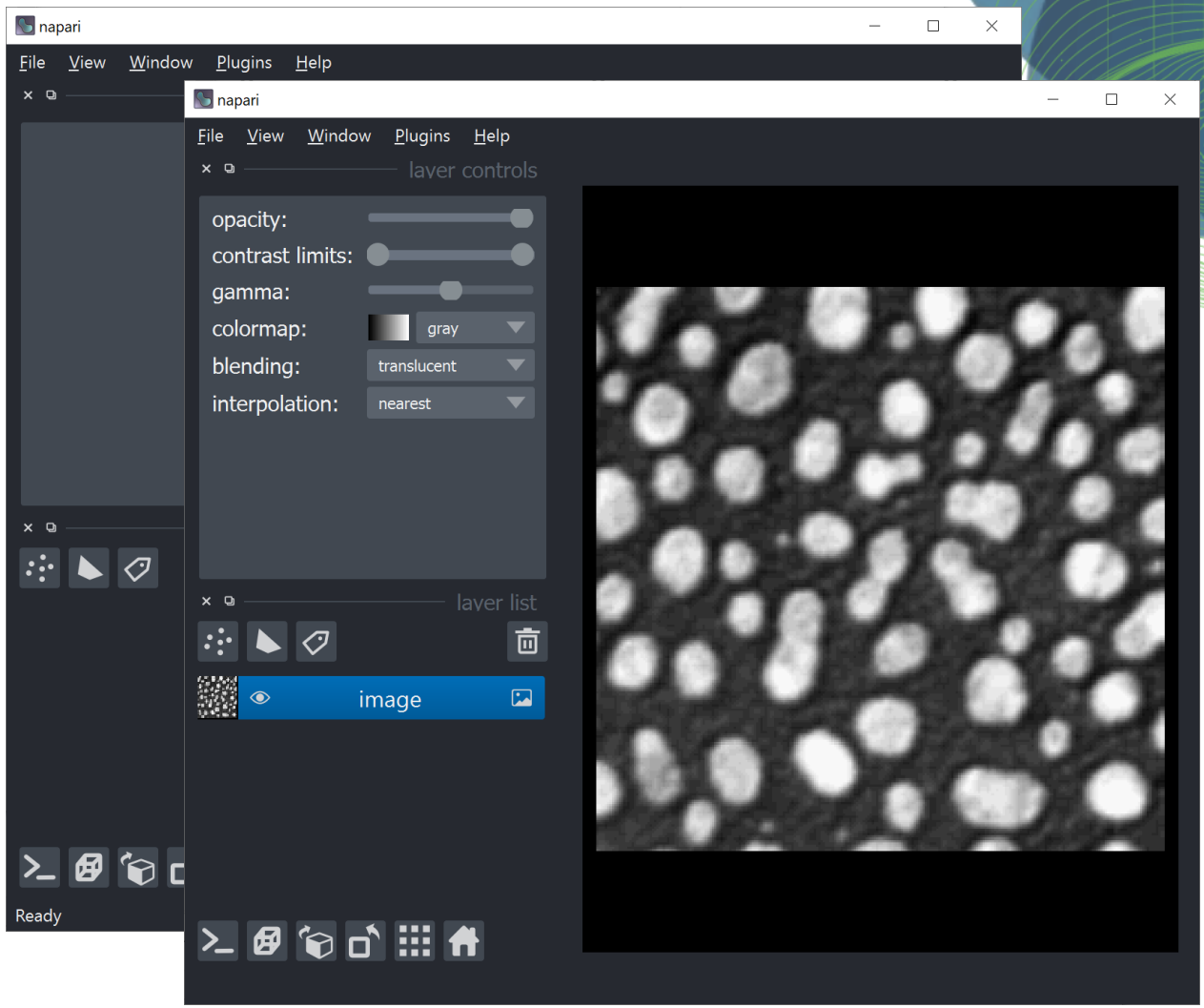
- Initialization

```
import napari

# Create an empty viewer
viewer = napari.Viewer()
```

- Adding images

```
viewer.add_image(image)
```

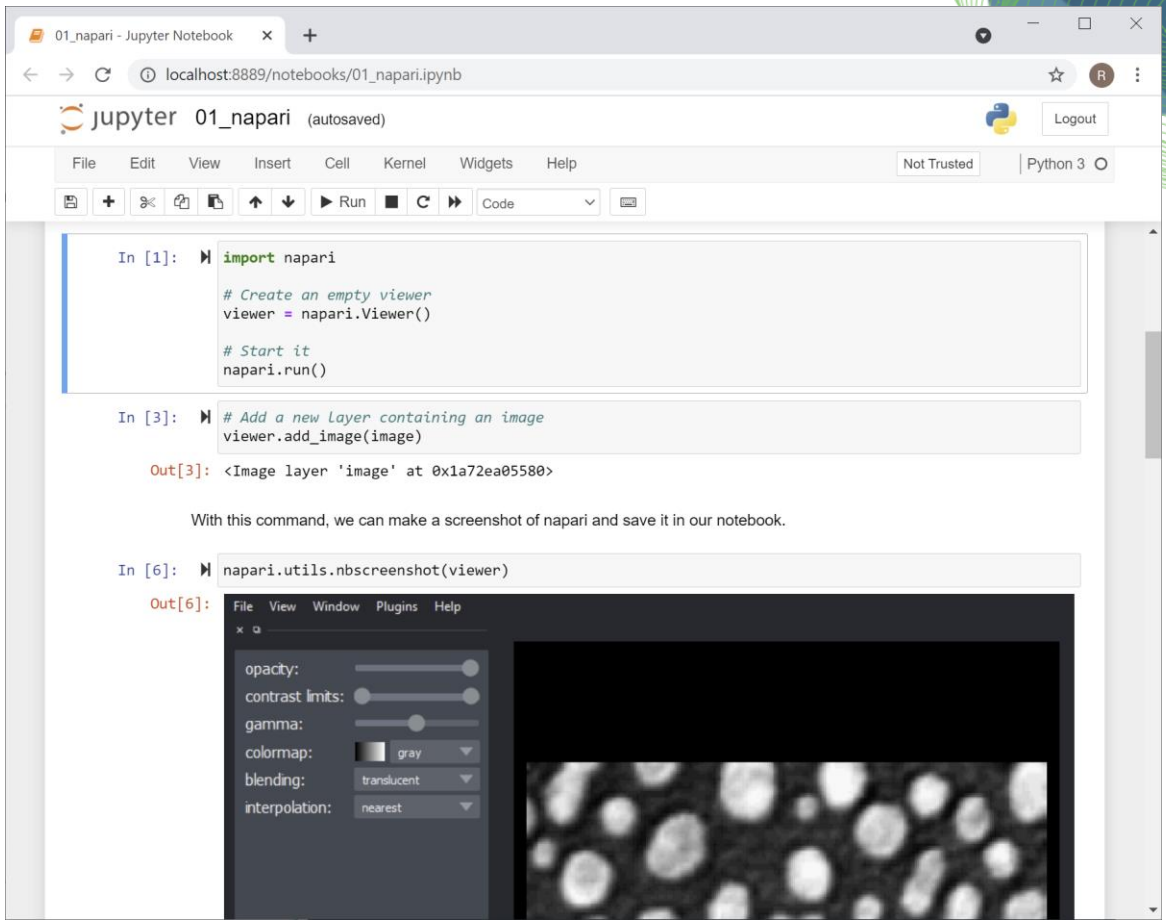


Napari – Python Scripting

- Make screenshots from napari and put them in your jupter notebook

```
napari.utils.nbscreenshot(viewer)
```

Place your viewer here



Napari – Python Scripting

- Removing layers

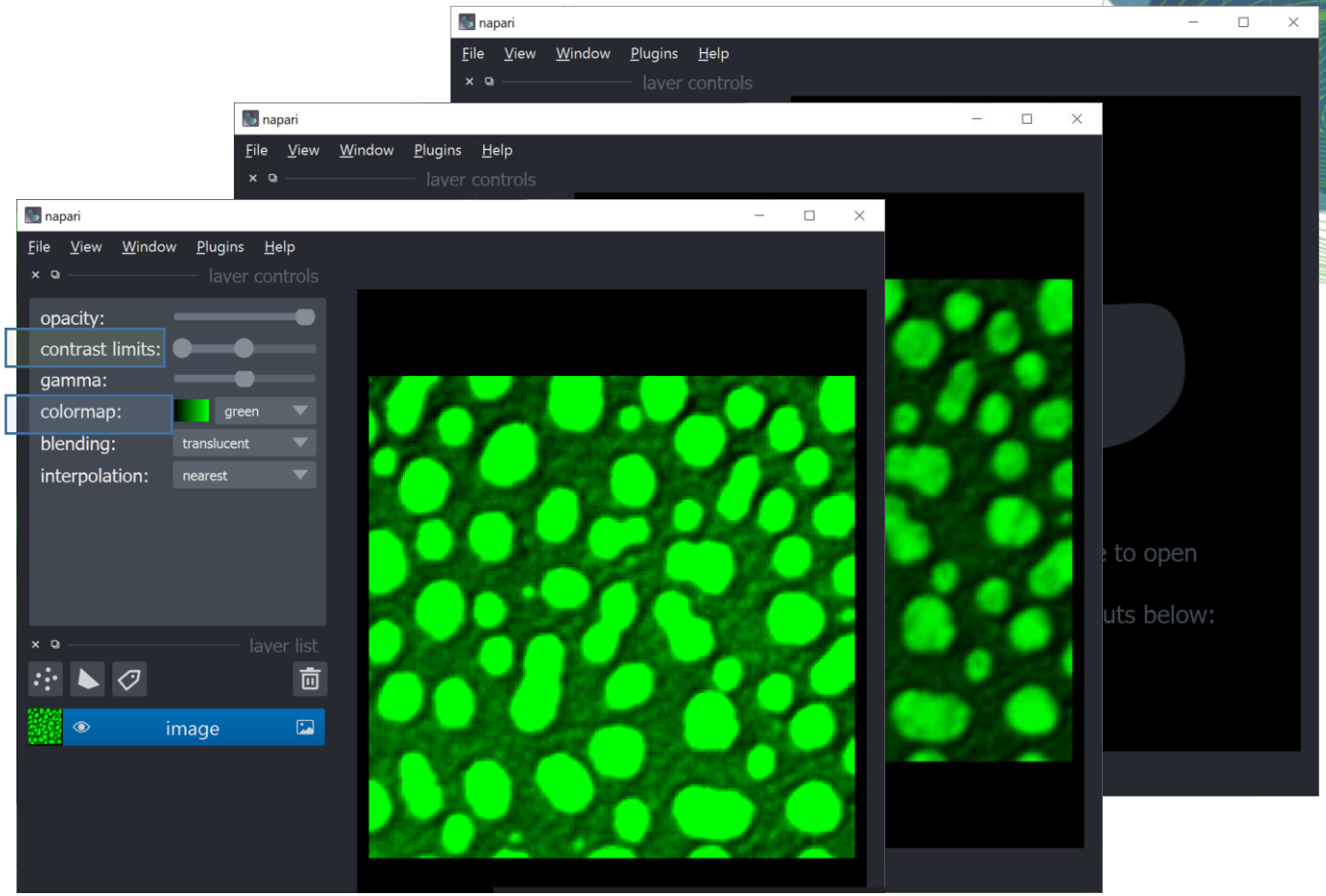
```
for l in viewer.layers:
    viewer.layers.remove(l)
```

- Modify visualization while adding layers

```
viewer.add_image(image,
                 colormap='green')
```

- Modify layers after adding

```
layer = viewer.add_image(image)
layer.colormap = 'green'
layer.contrast_limits = (0, 128)
```

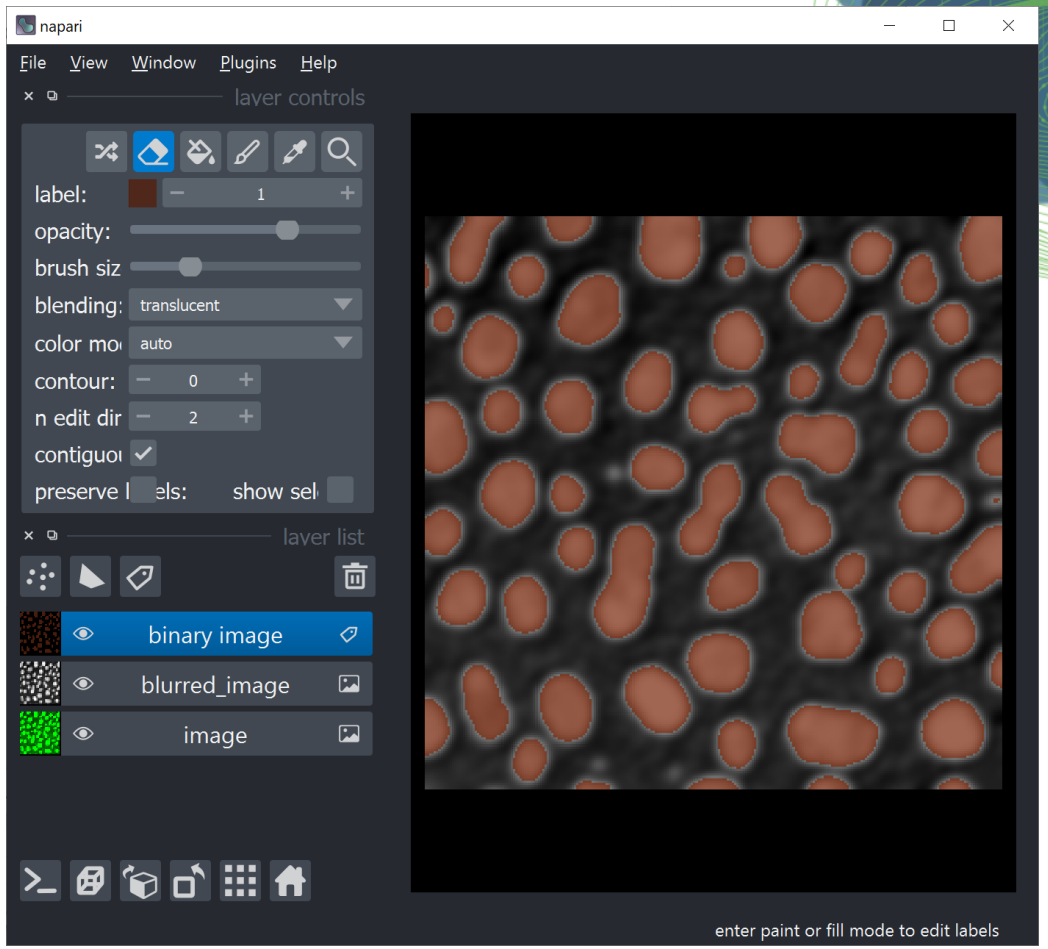


Napari – Python Scripting

- Binary images and label images visualized as label layers

```
from skimage.filters import threshold_otsu
threshold = threshold_otsu(blurred_image)
binary_image = blurred_image > threshold

# Add a new labels layer containing an image
viewer.add_labels(binary_image)
```



The Napari Assistant

- Tools > Utilities > Assistant (na)

Viewer controls

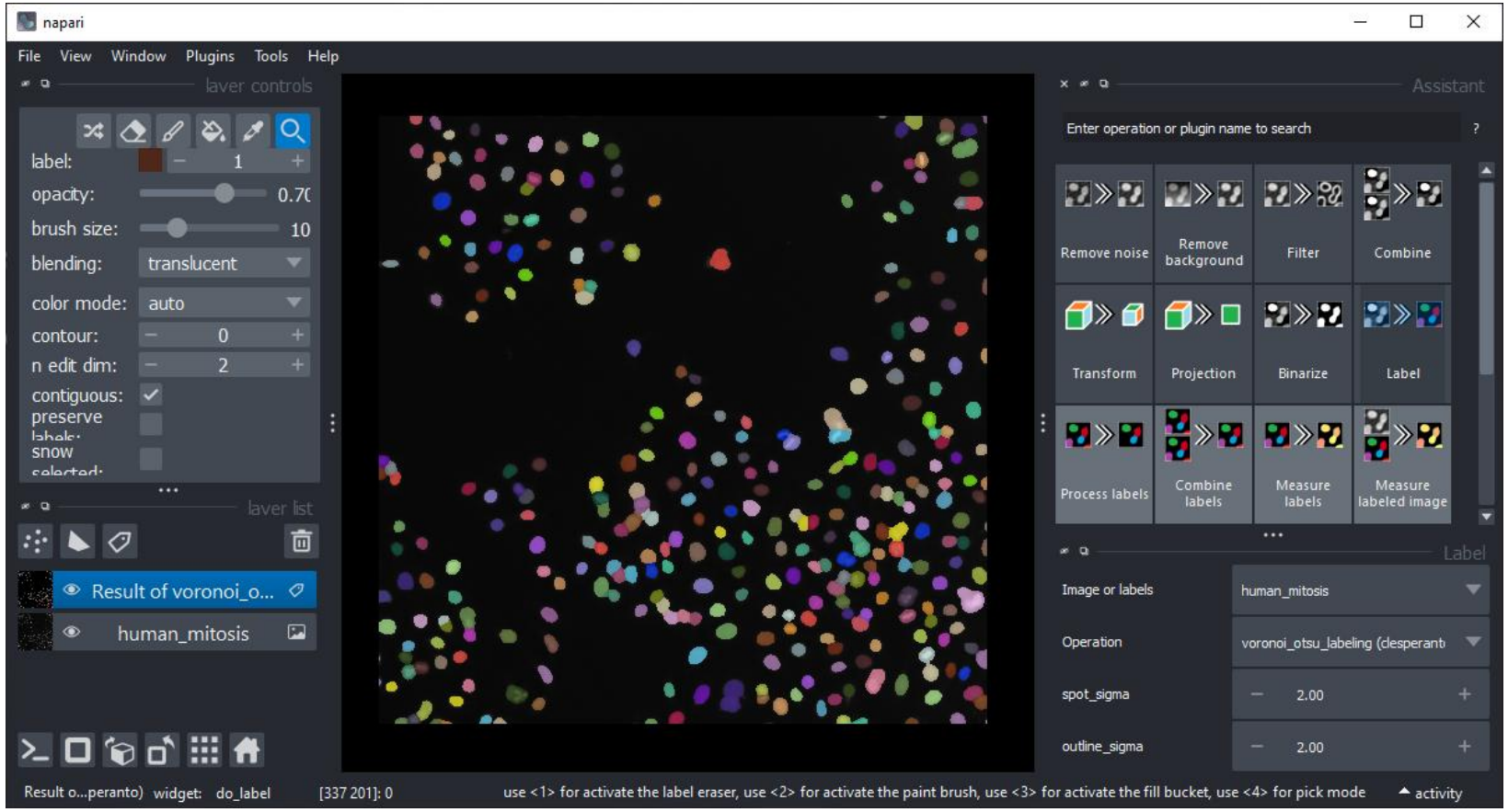
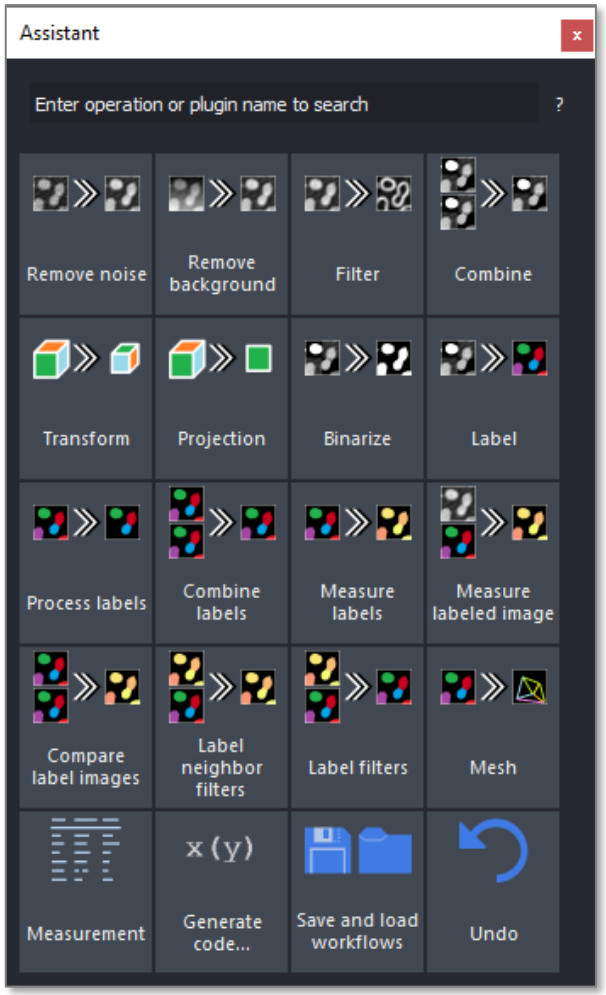
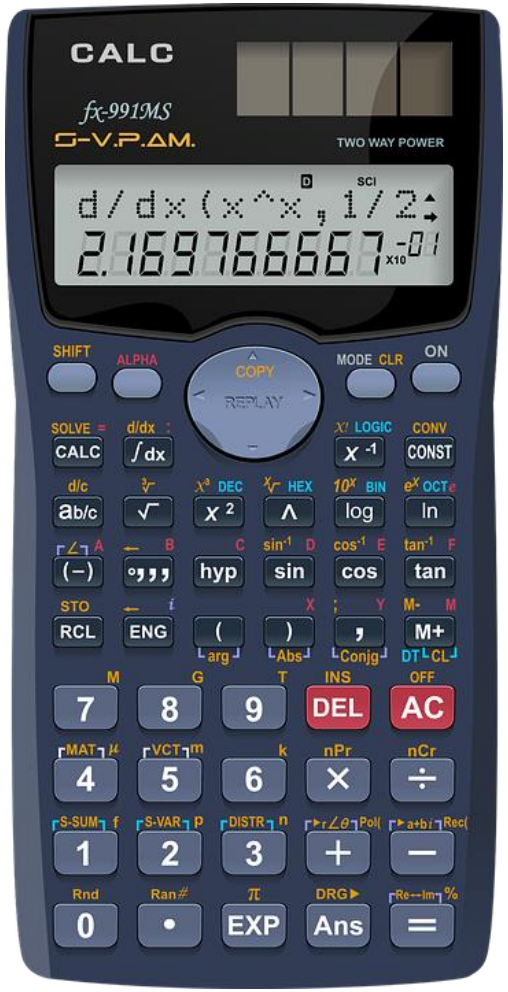


Image Processing

The Napari Assistant

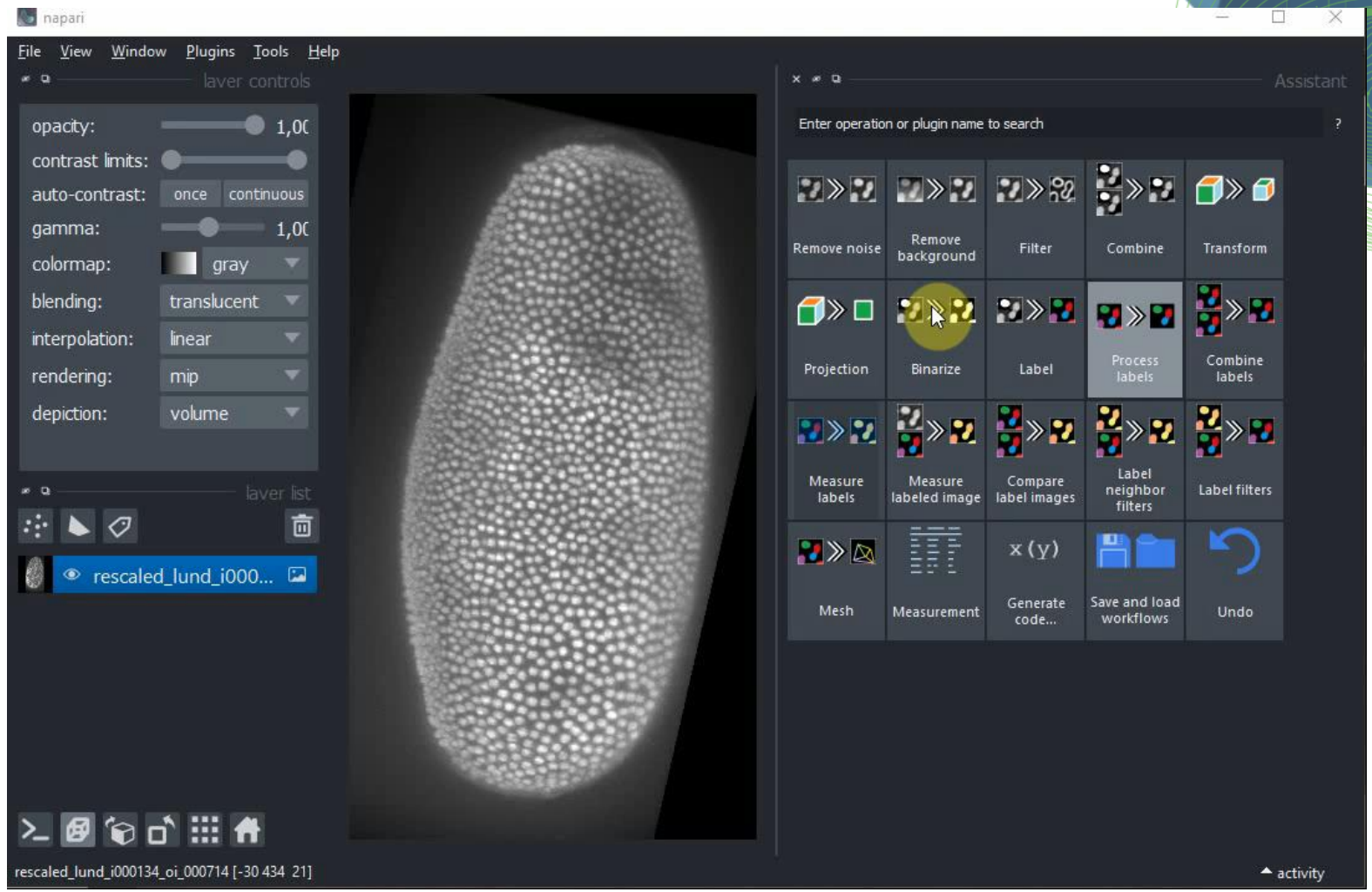
- A pocket-calculator-like interface to build image analysis workflows





The Napari Assistant

- Classical image processing operations + advanced tools
- Saving&loading supported
- Undo [redo]
- Hints for next steps
- …

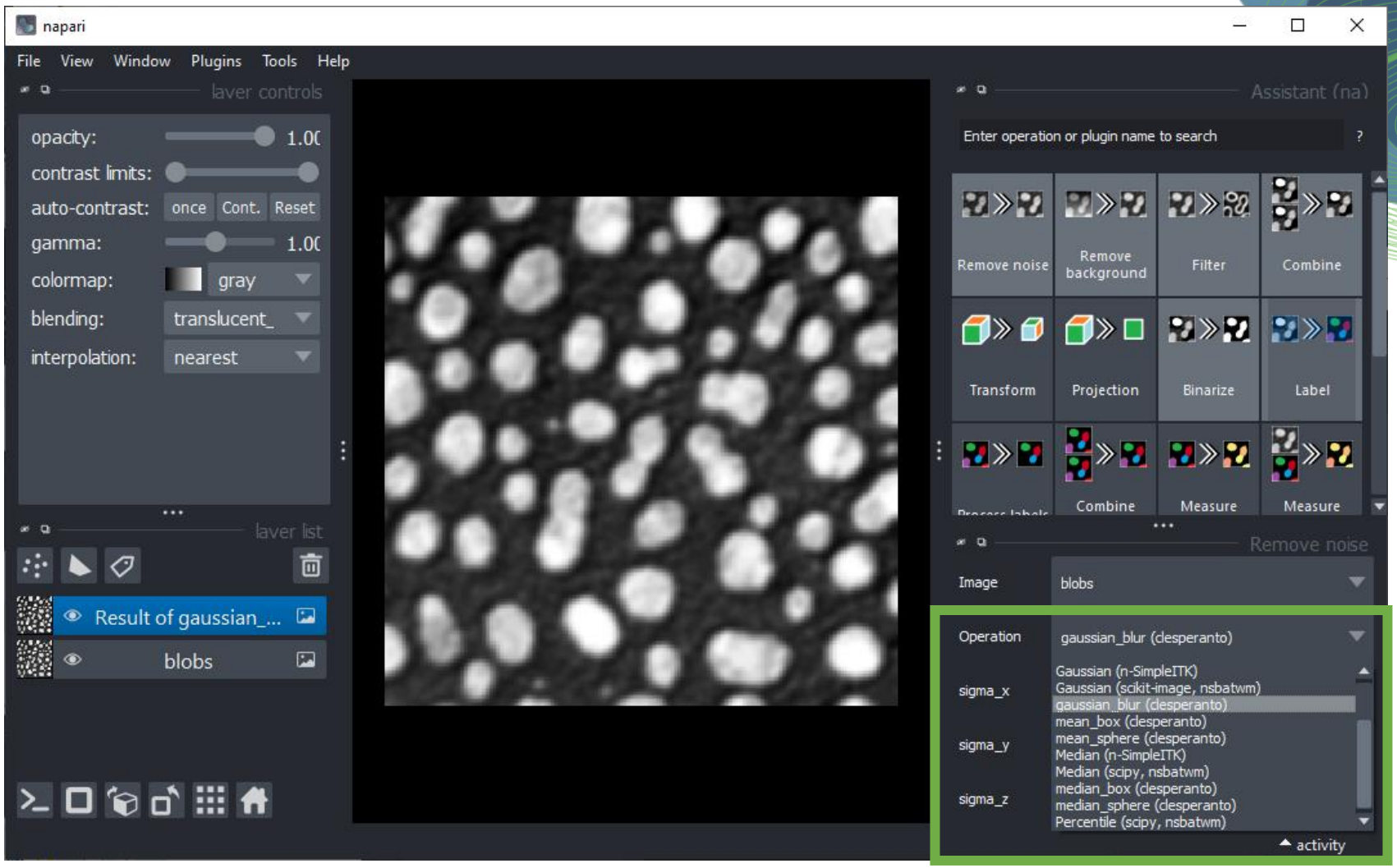


Big thanks to:

Ryan Savill
@RyanSavill4

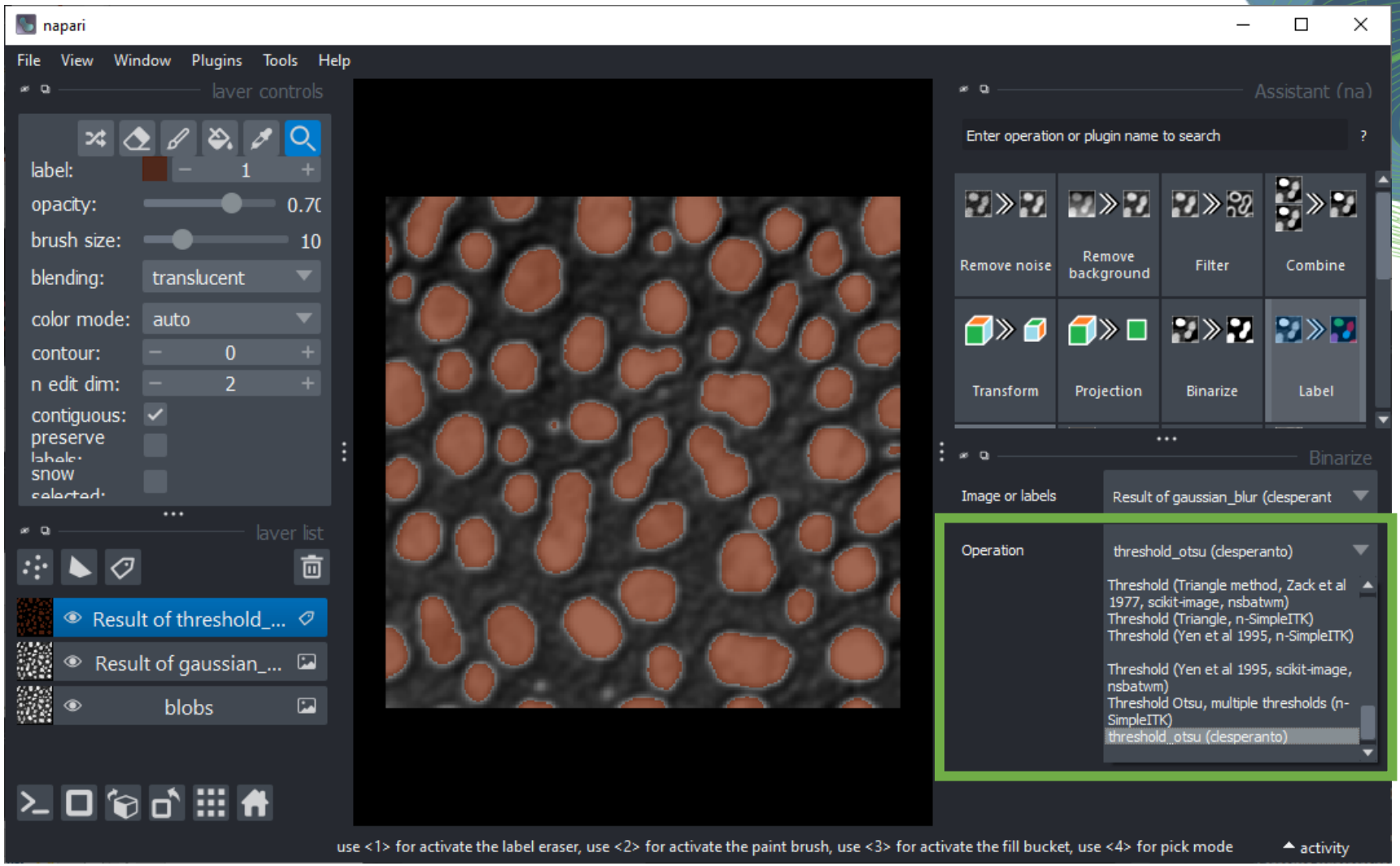
Workflow building

- Try different algorithms, e.g. for removing noise
- Find them in the pulldown



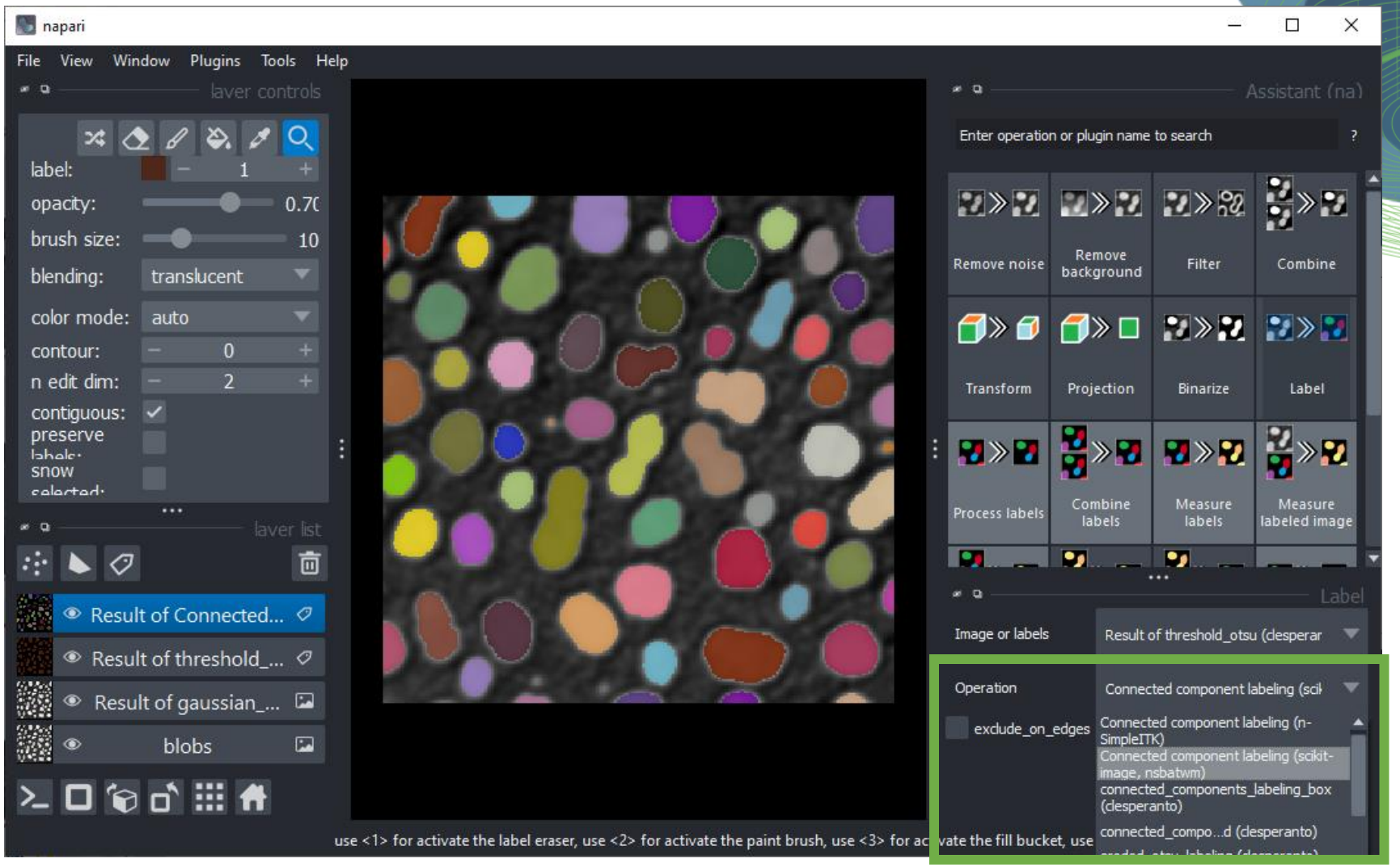
Workflow building

- Try different binarization algorithms



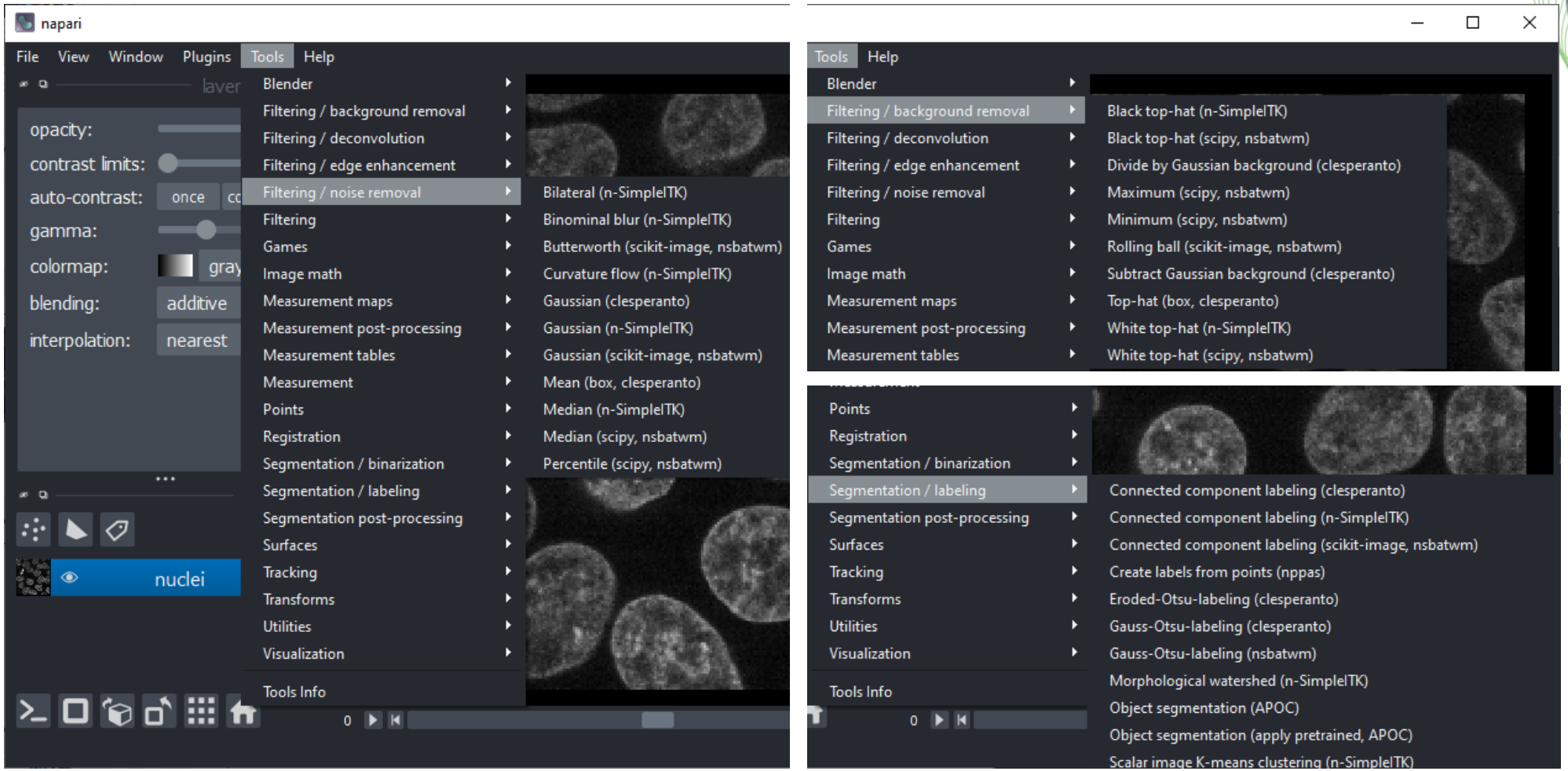
Workflow building

- Try different labeling algorithms



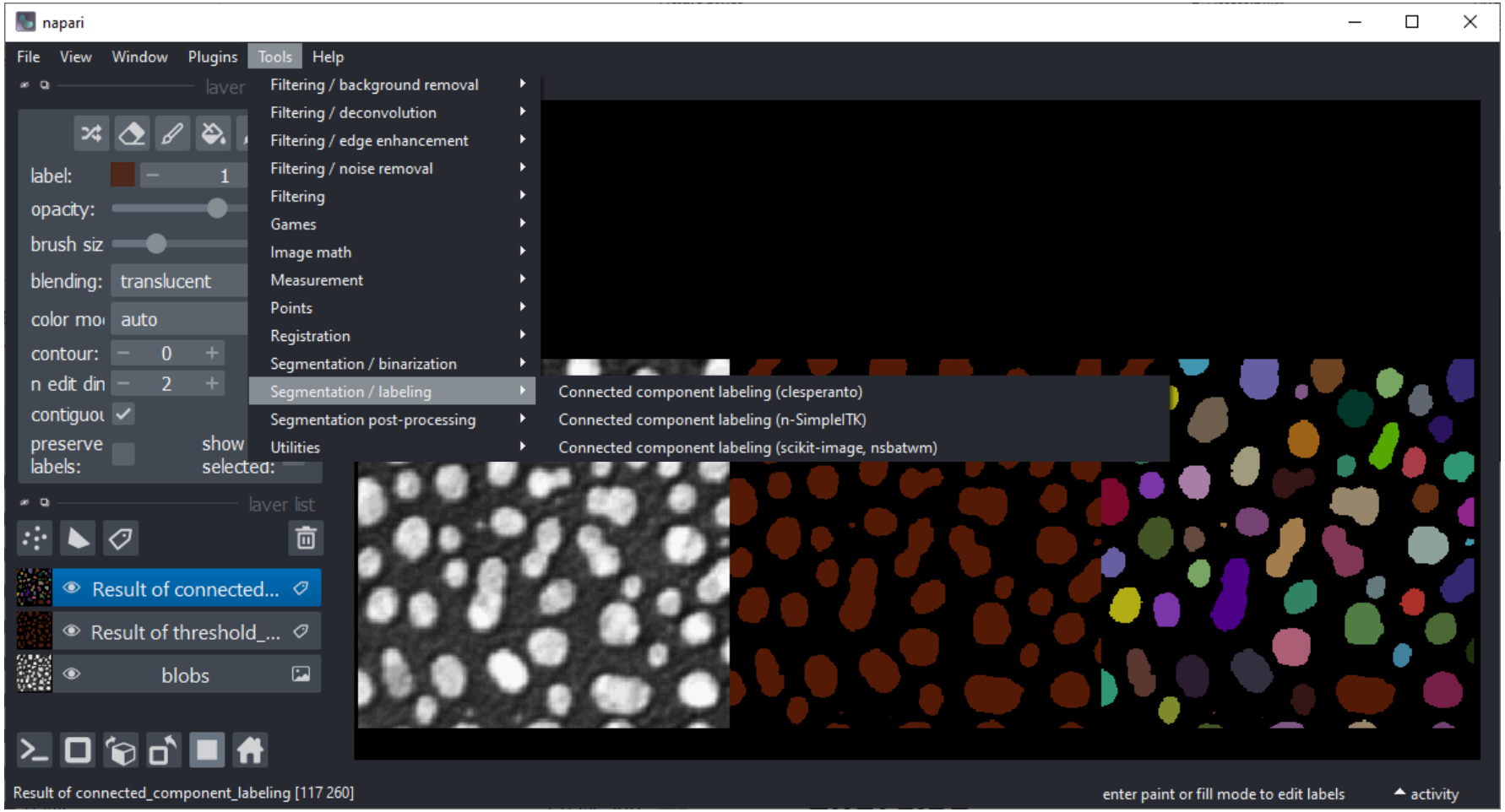
The Tools menu

- Organized in categories



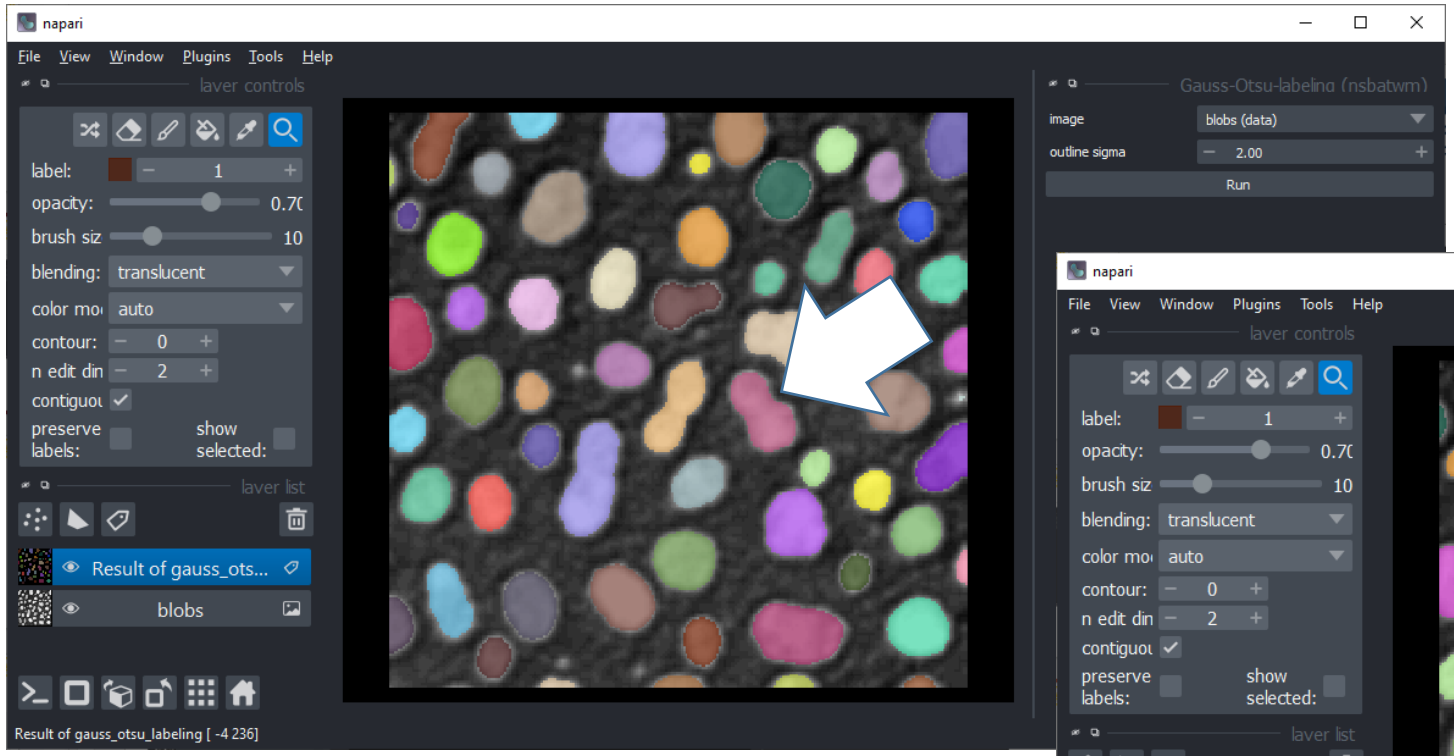
Workflow building

Also check out the Tools > Segmentation / labeling menu



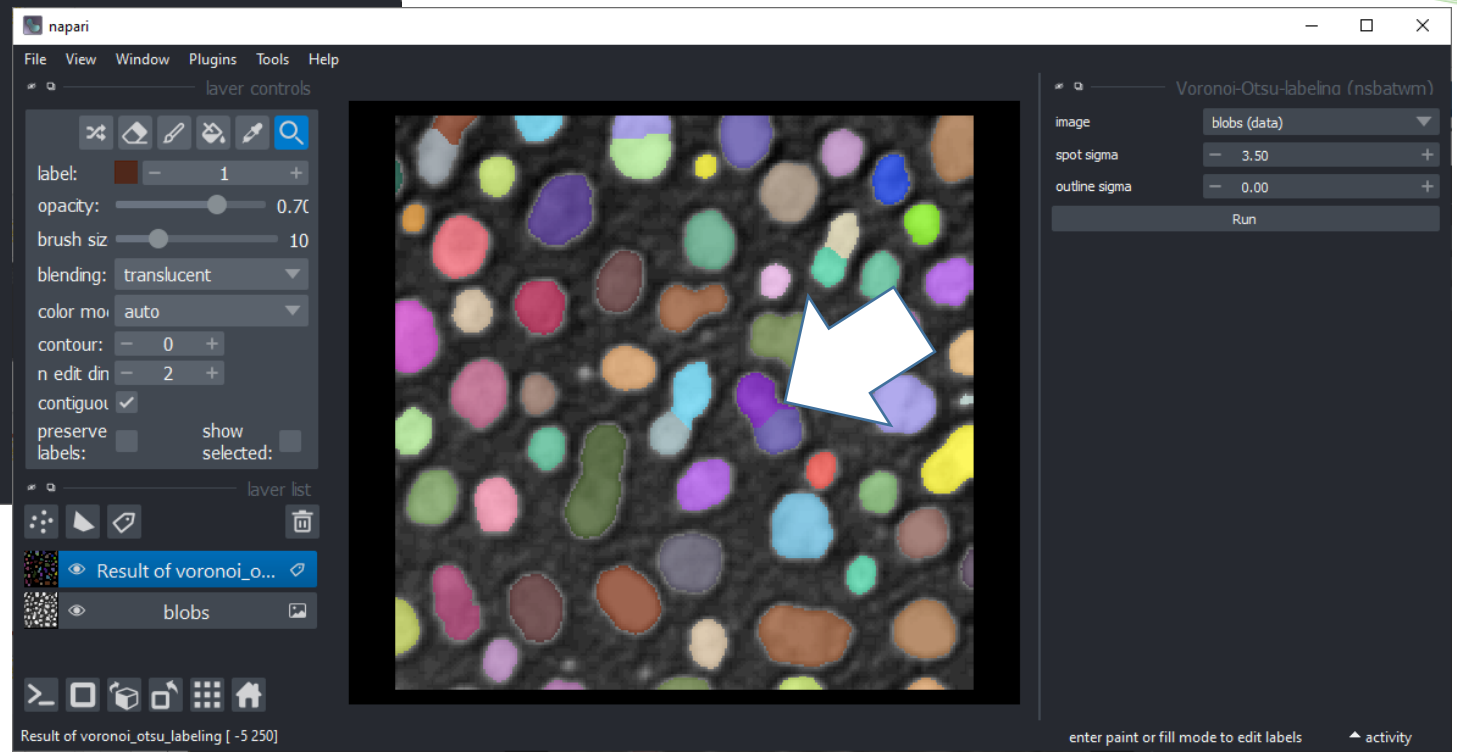
Short-cuts: Voronoi-Otsu-Labeling

Also check out the Tools > Segmentation / labeling menu



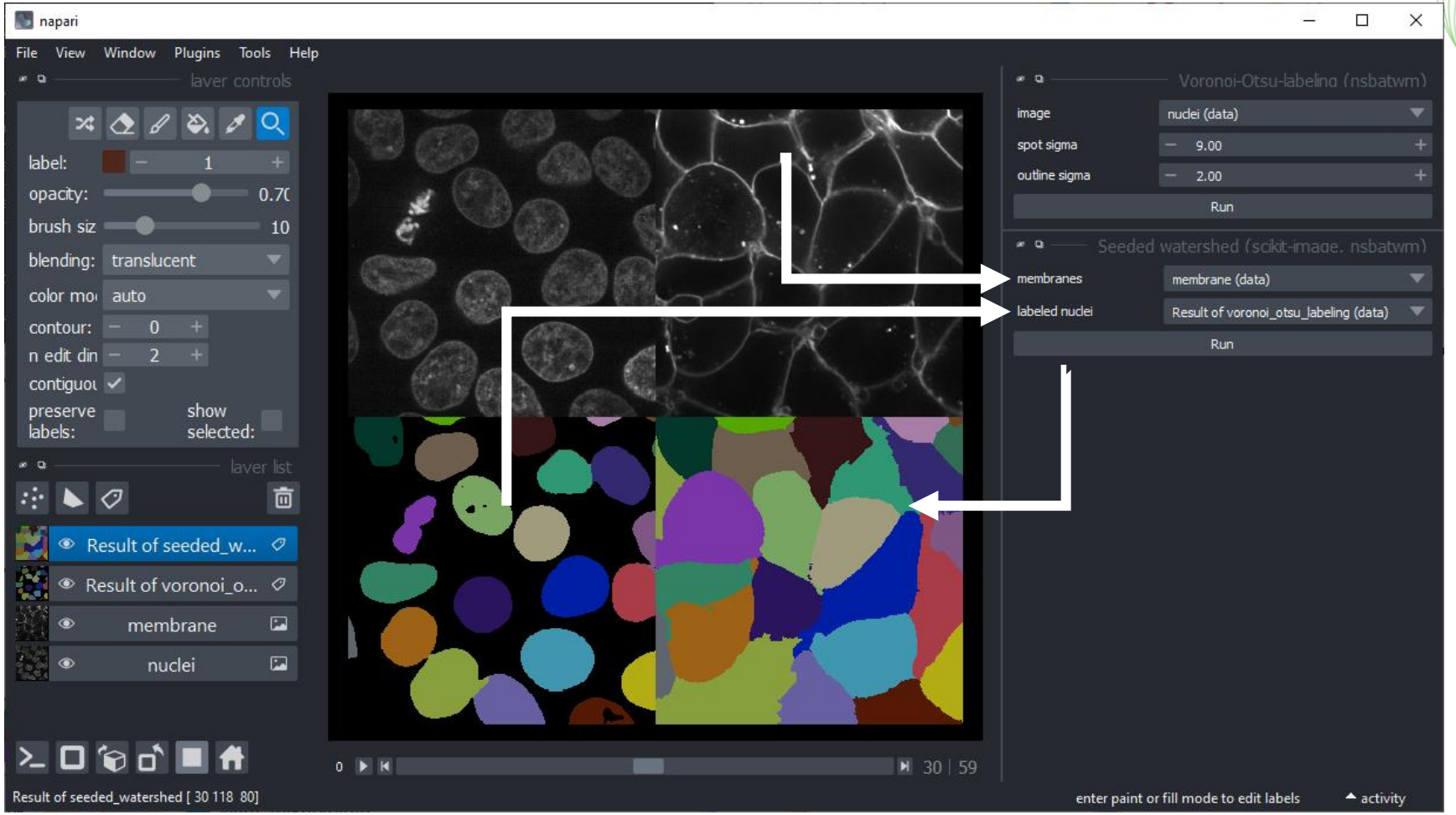
Gauss-Otsu-Labeling

Voronoi-Otsu-Labeling



Watershed

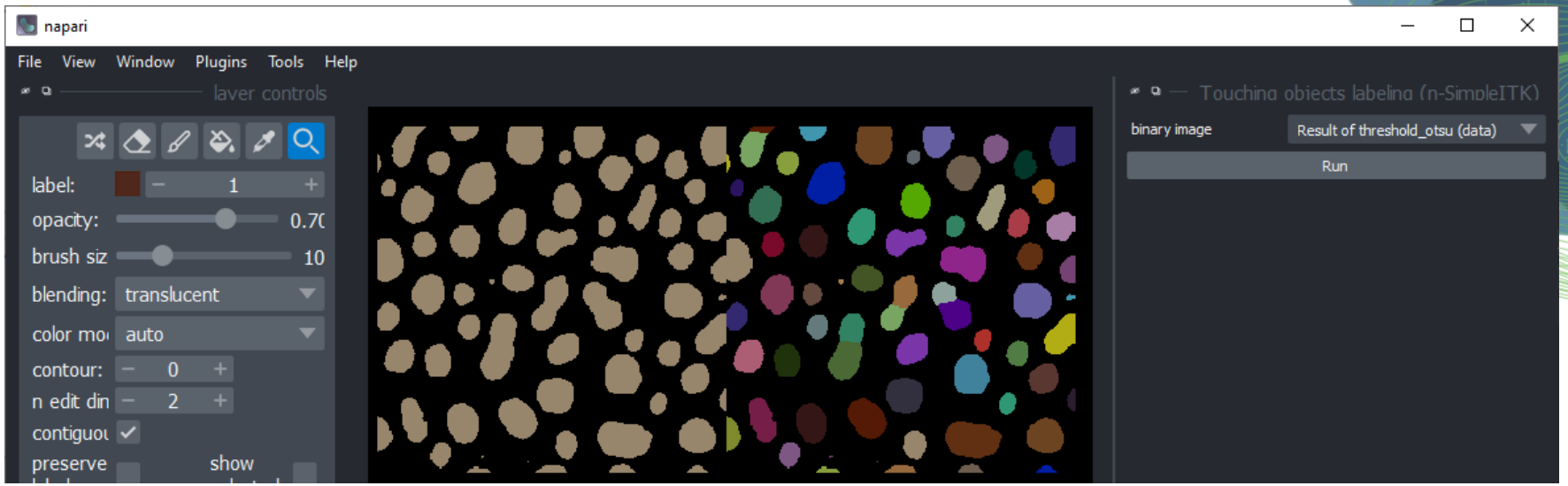
Also check out the Tools > Segmentation / labeling menu



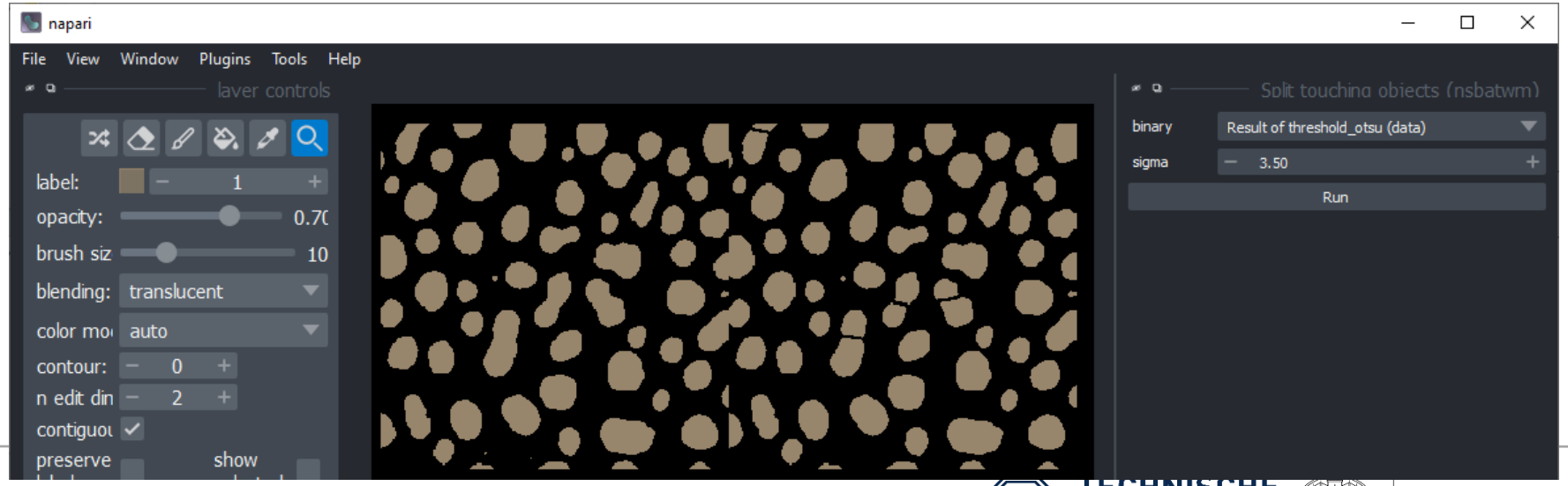
Watershed

- From binary images

Tools > Segmentation / labeling >
Label touching objects

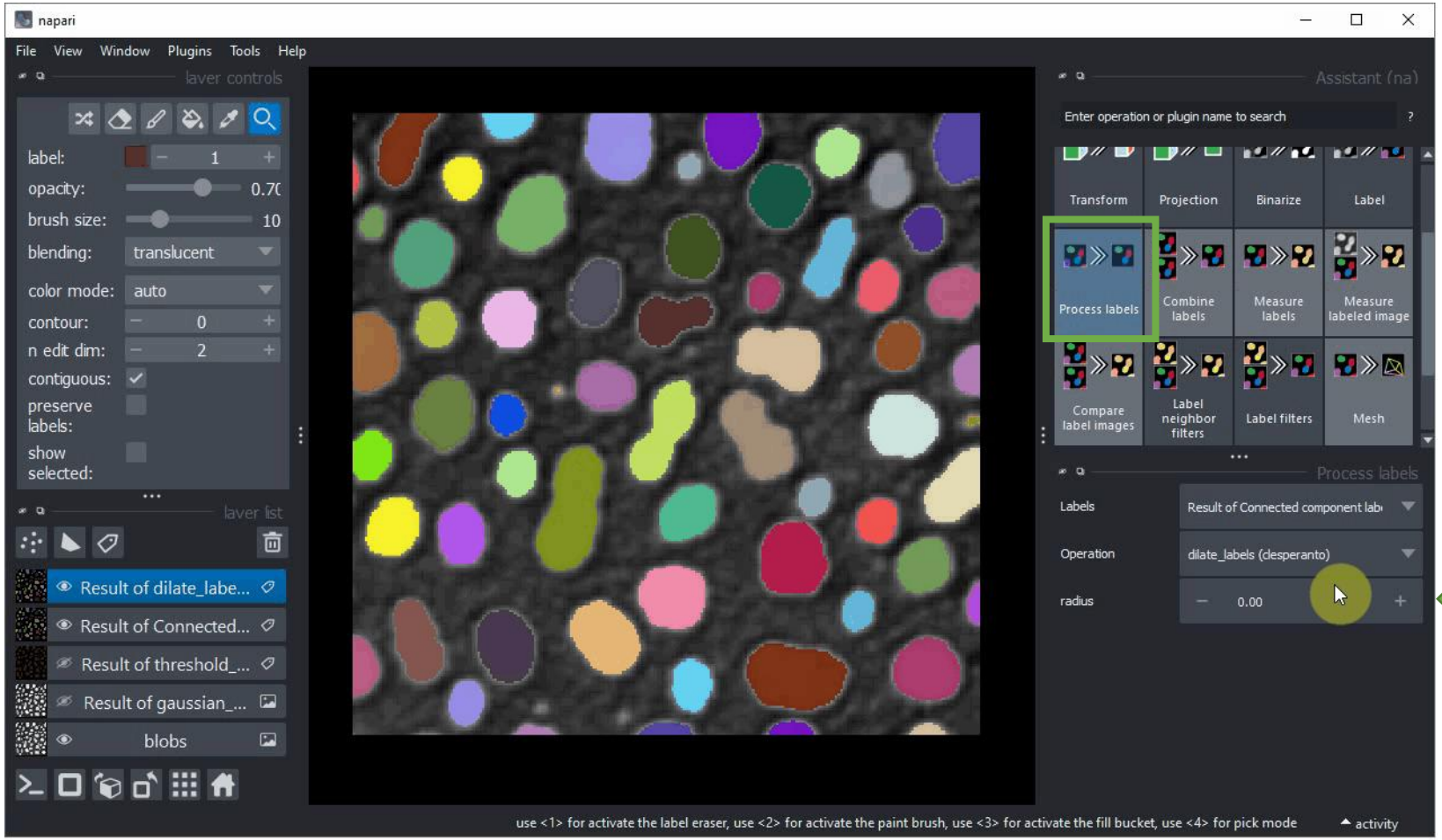


Tools > Segmentation post-processing >
Split touching objects
(Similar to ImageJ's Watershed)



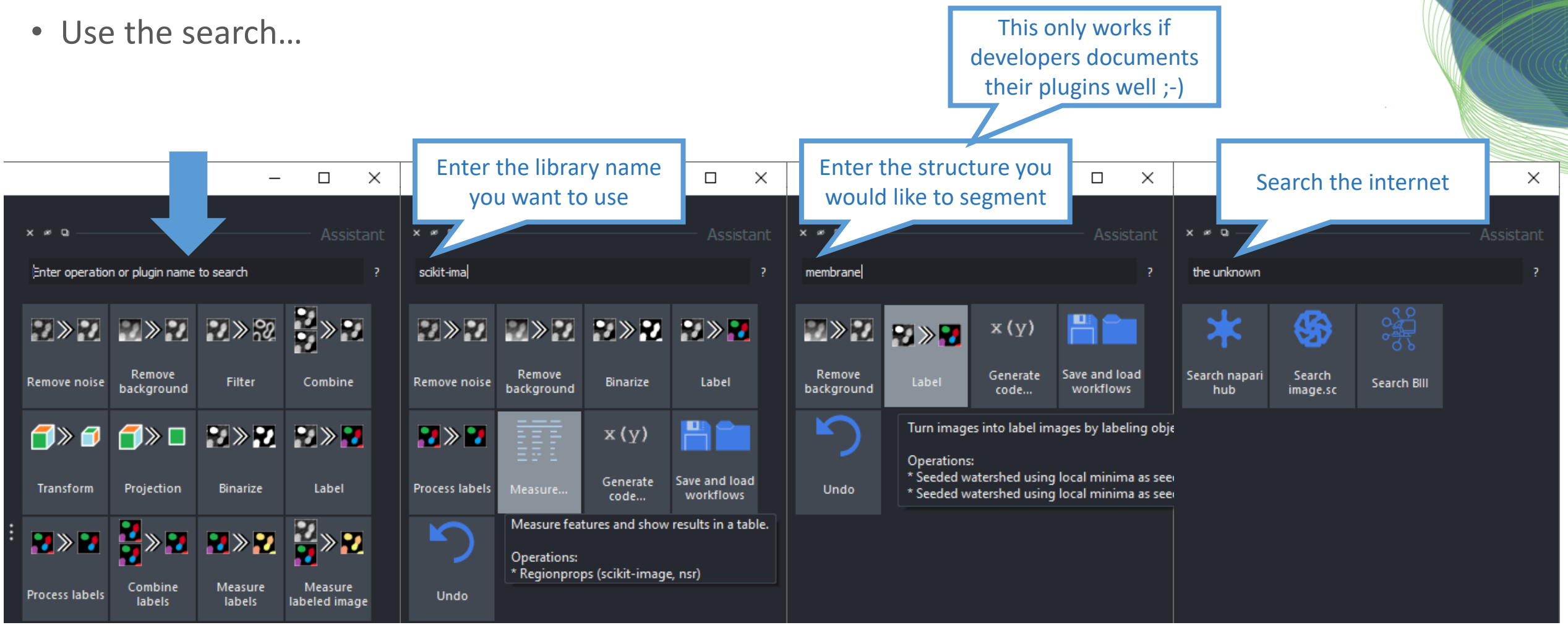
Label erosion, dilation, opening, closing, …

- In Napari Assistant: Process labels



Browse operations

- Use the search…



Export code to Jupyter Notebooks

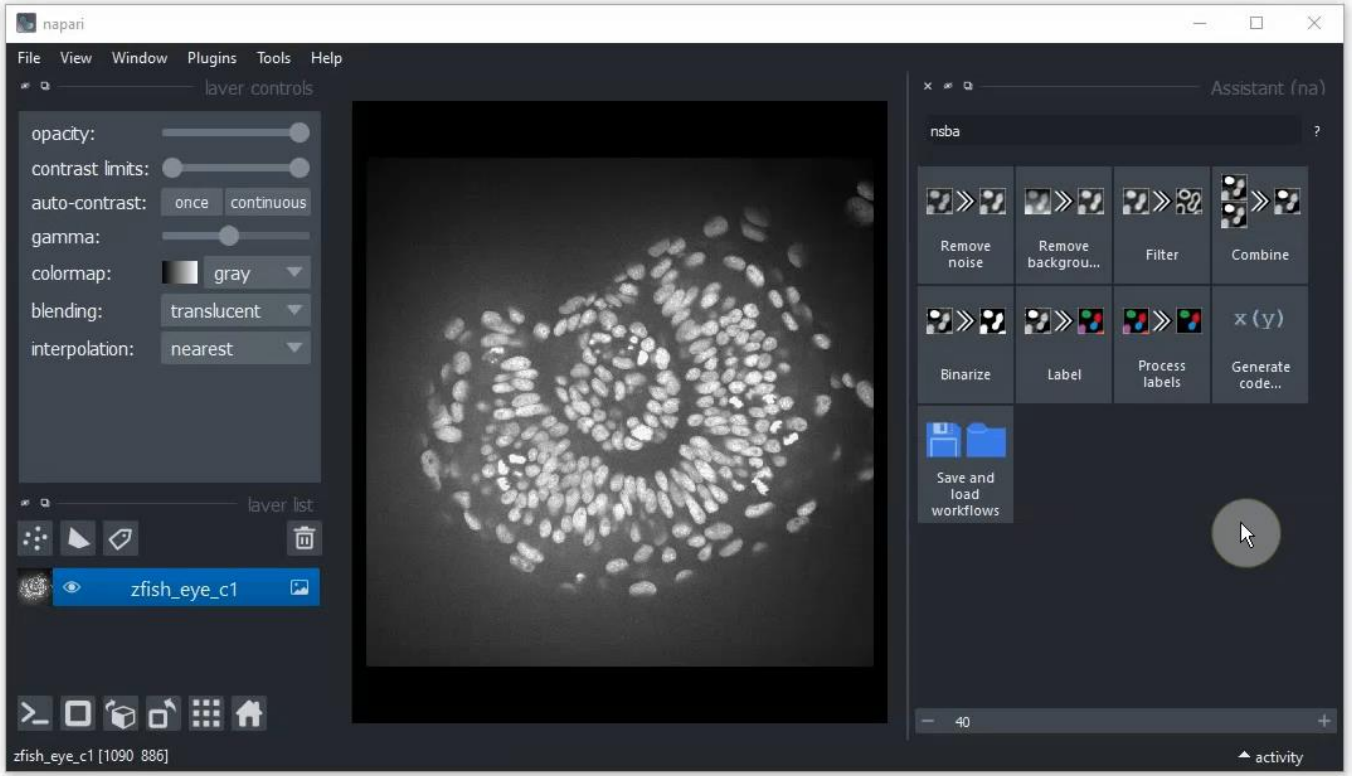
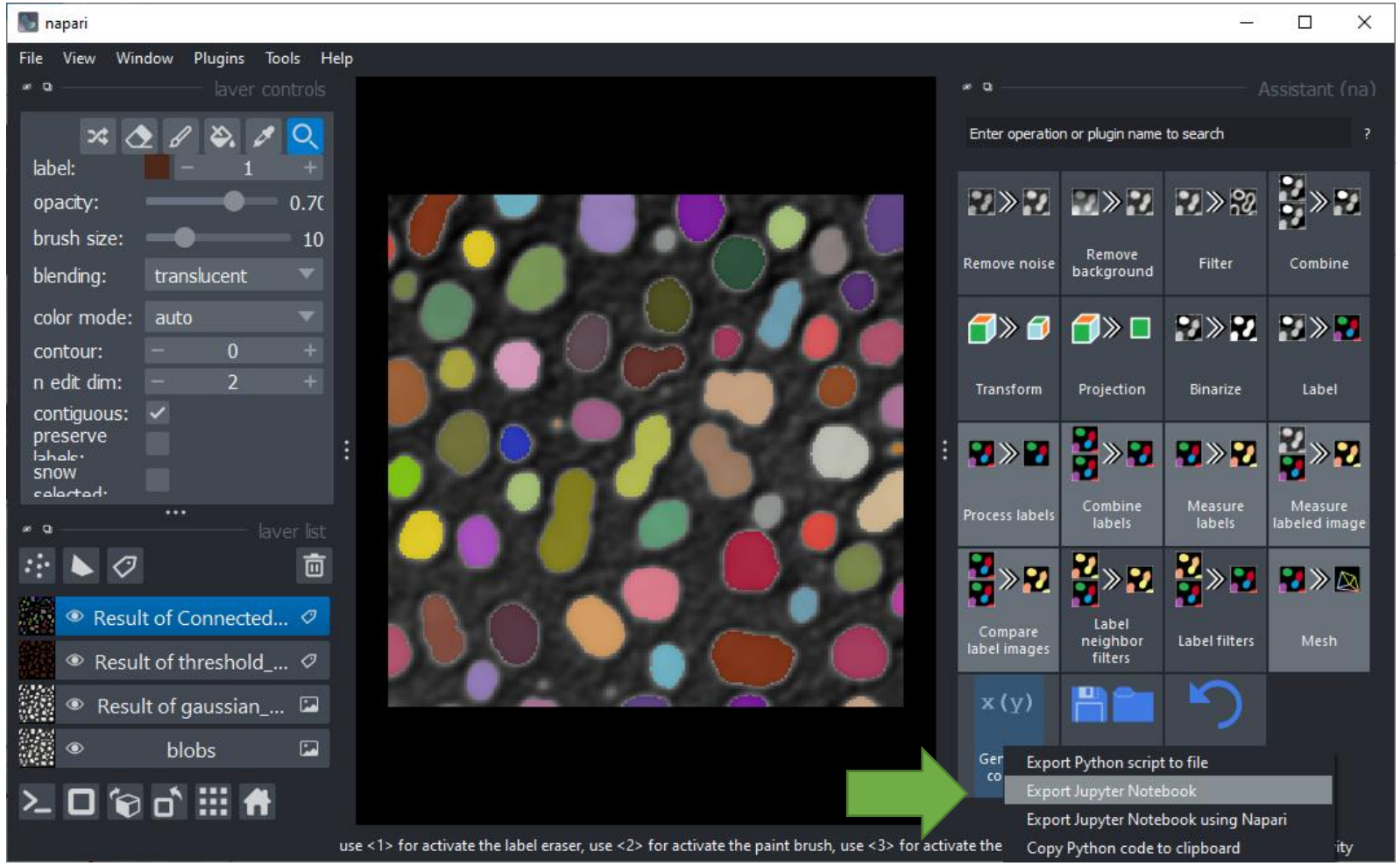
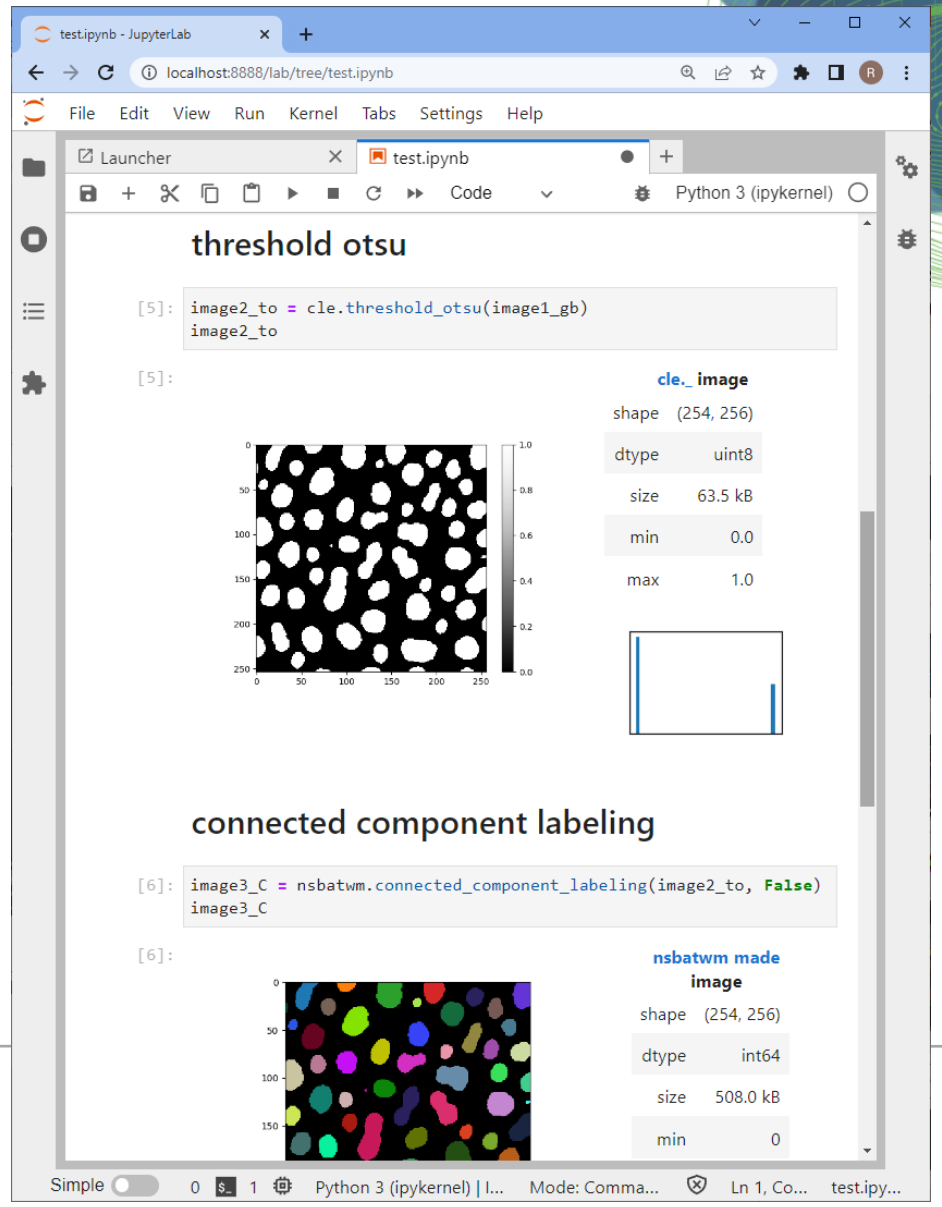


Image data source: Mauricio Rocha Martins, Norden lab, MPI CBG (now at IGC Oeiras)

Export code to Jupyter Notebooks





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BIDS Lecture 4/14
April 23rd 2024

https://github.com/haesleinhuepf/napari-assistant#code-generation

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Image segmentation in Python

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Diese Maßnahme wird gefördert durch die Bundesregierung aufgrund eines Beschlusses des Deutschen Bundestages.
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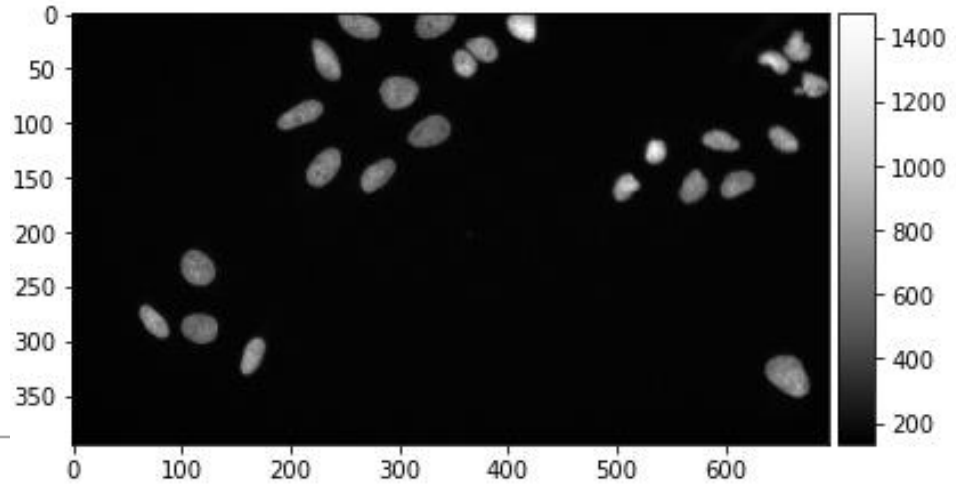
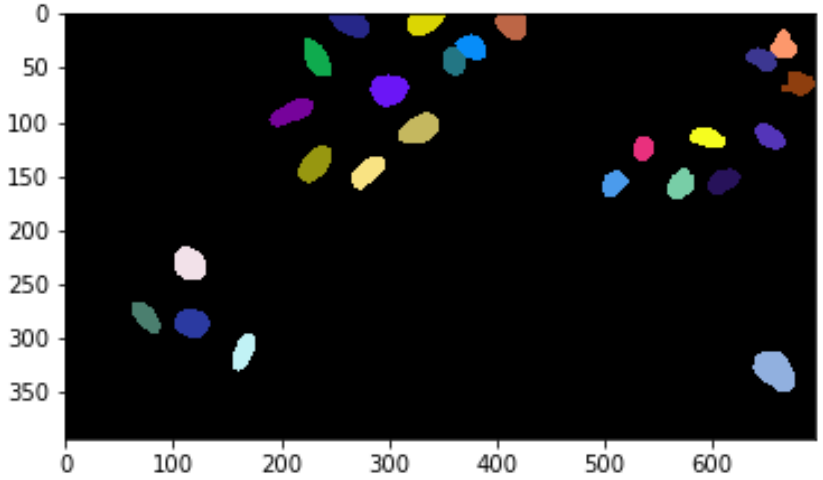
Voronoi-Otsu-Labeling

- Gaussian-Blur
- Otsu-Thresholding
- Spot-detection
- Watershed on the binary image

… in a single line of code:

```
segmented = nsbatwm.voronoi_otsu_labeling(input_image,
                                          spot_sigma=5,
                                          outline_sigma=1
                                         )
segmented
```





nsbatwm made image

shape	(395, 695)
dtype	int32
size	1.0 MB
min	0
max	25

https://haesleinhuepf.github.io/BioImageAnalysisNotebooks/20_image_segmentation/11_voronoi_otsu_labeling.html
https://www.youtube.com/watch?v=evgRgDfVuEc

Anisotropy

- Some [segmentation] algorithms have prerequisites…

```
[1]: import pyclesperanto_prototype as cle

[ ]: cle.voronoi_otsu_labeling(

[ ]:
```

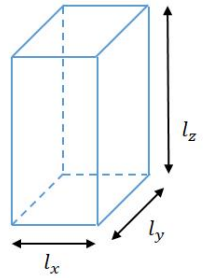
```
Docstring:
Labels objects directly from grey-value images.

The two sigma parameters allow tuning the segmentation result. Under the hood,
this filter applies two Gaussian blurs, spot detection, Otsu-thresholding [2] and Voronoi-labeling
[3]. The
thresholded binary image is flooded using the Voronoi tesselation approach starting from the found
local maxima.

Notes
-----
* This operation assumes input images are isotropic.

Parameters
----------
source : Image
    Input grey-value image
label_image_destination : Image, optional
    Output image
spot_sigma : float, optional
```

Anisotropy

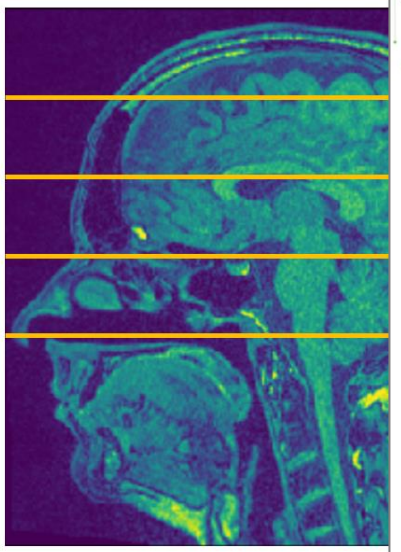
- Reminder: Anisotropic images might be tricky to process properly

Image stacks and voxels

- 3-dimensional images consisting of voxels
- "Image stack"
- Often *anisotropic* (not equally large in all directions)

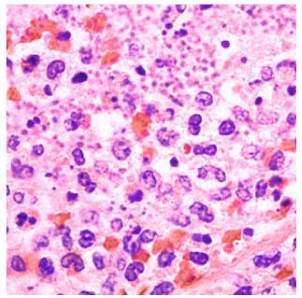


$l_x = l_y \neq l_z$

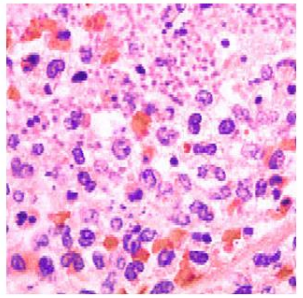


Anisotropy

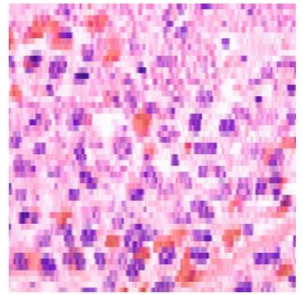
- Voxel size has immediate impact on image quality and thus, on processing / analysis results.



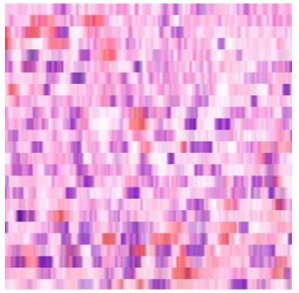
1:1
250 x 250 px



1:2
250 x 125 px



1:5
250 x 50 px



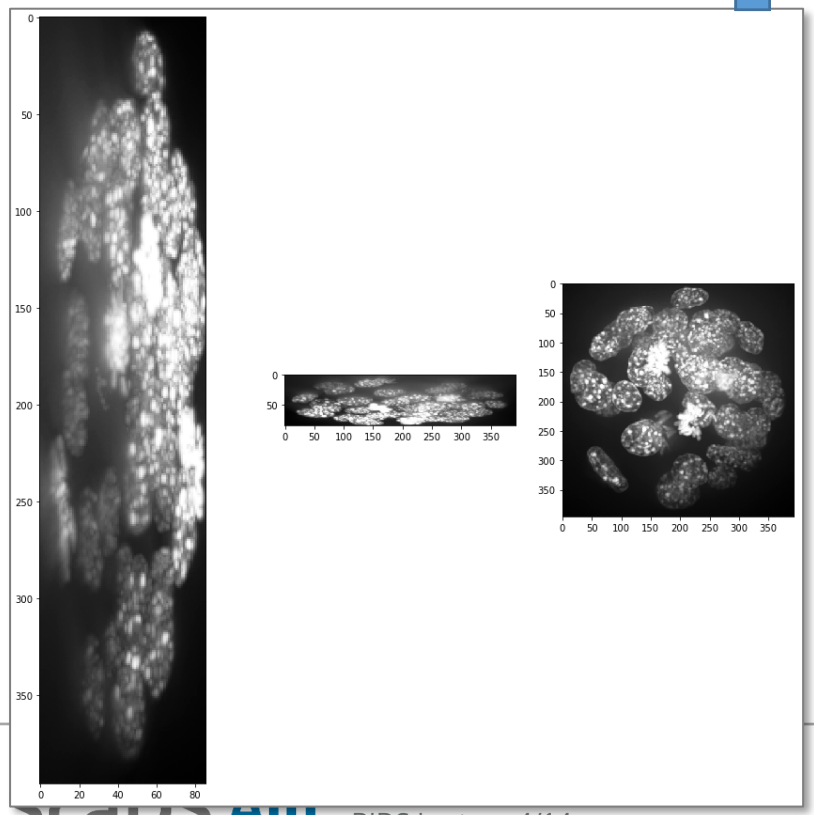
1:10
250 x 25 px

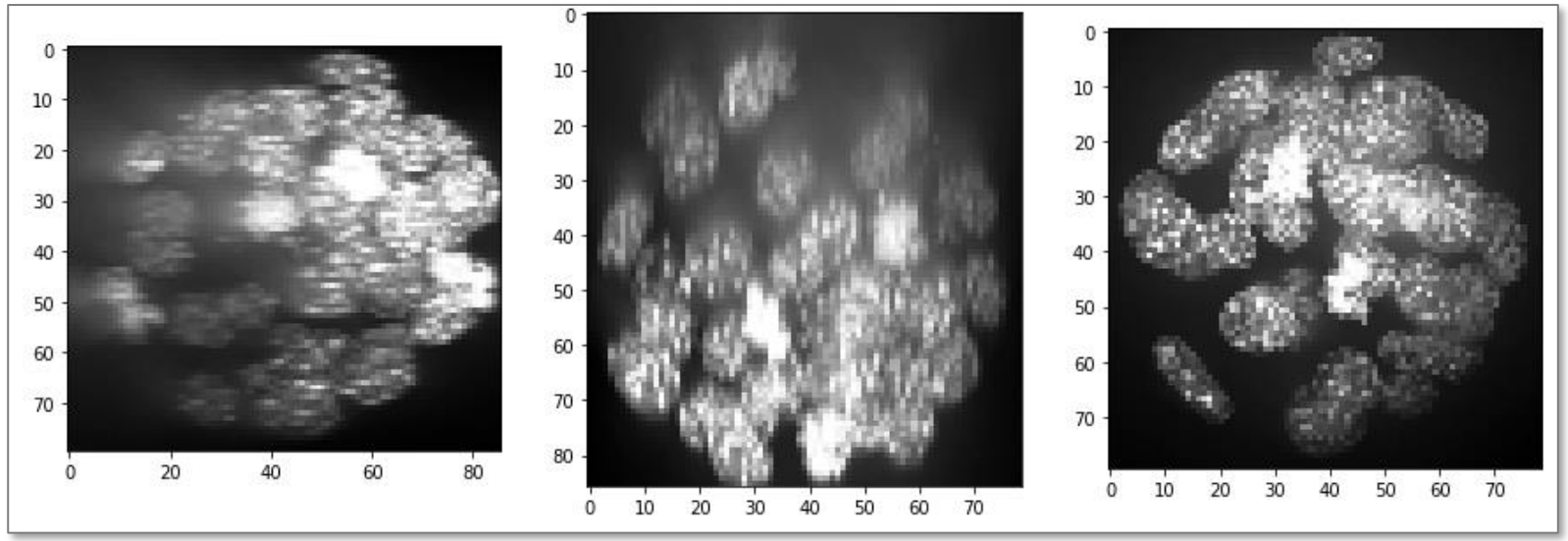
Image source: cropped from
https://de.m.wikipedia.org/wiki/Datei:Histo_Lungenpest.jpg

Reslicing / scaling / sampling

- Resample image data to a specific voxel size

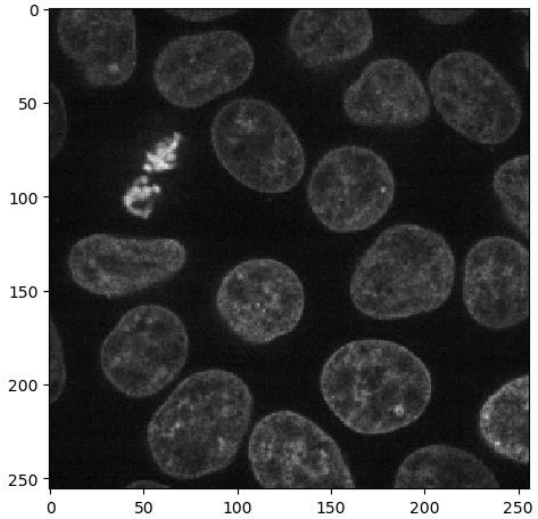
```
resampled = cle.scale(input_image, factor_x=voxel_size_x, factor_y=voxel_size_y, factor_z=voxel_size_z, auto_size=True)

show(resampled)
```

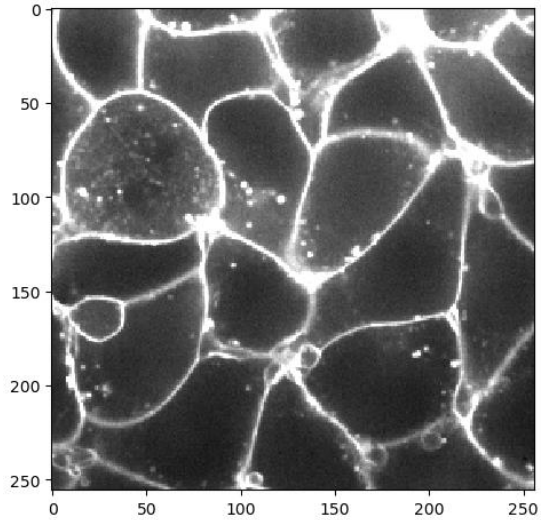


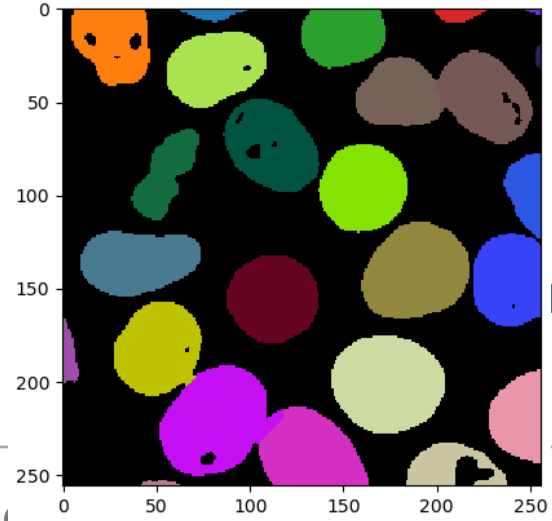


Watershed

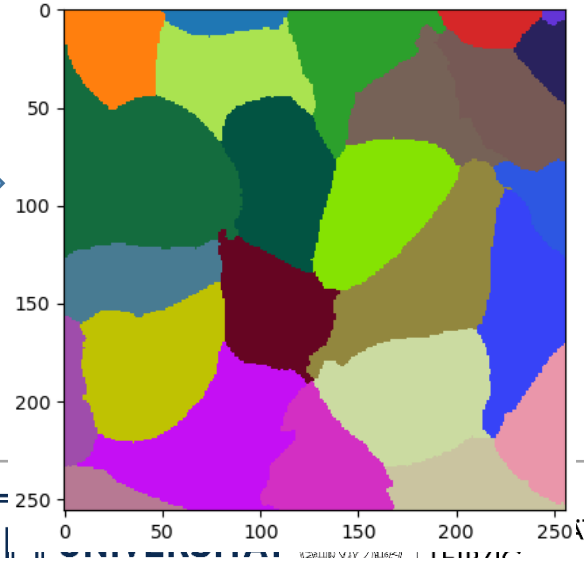
- … in Python practice








```
labeled_cells = seeded_watershed(membrane_channel, labeled_nuclei)

labeled_cells
```



https://www.napari-hub.org/plugins/napari-segment-blobs-and-things-with-membranes#seeded-watershed

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Exercises

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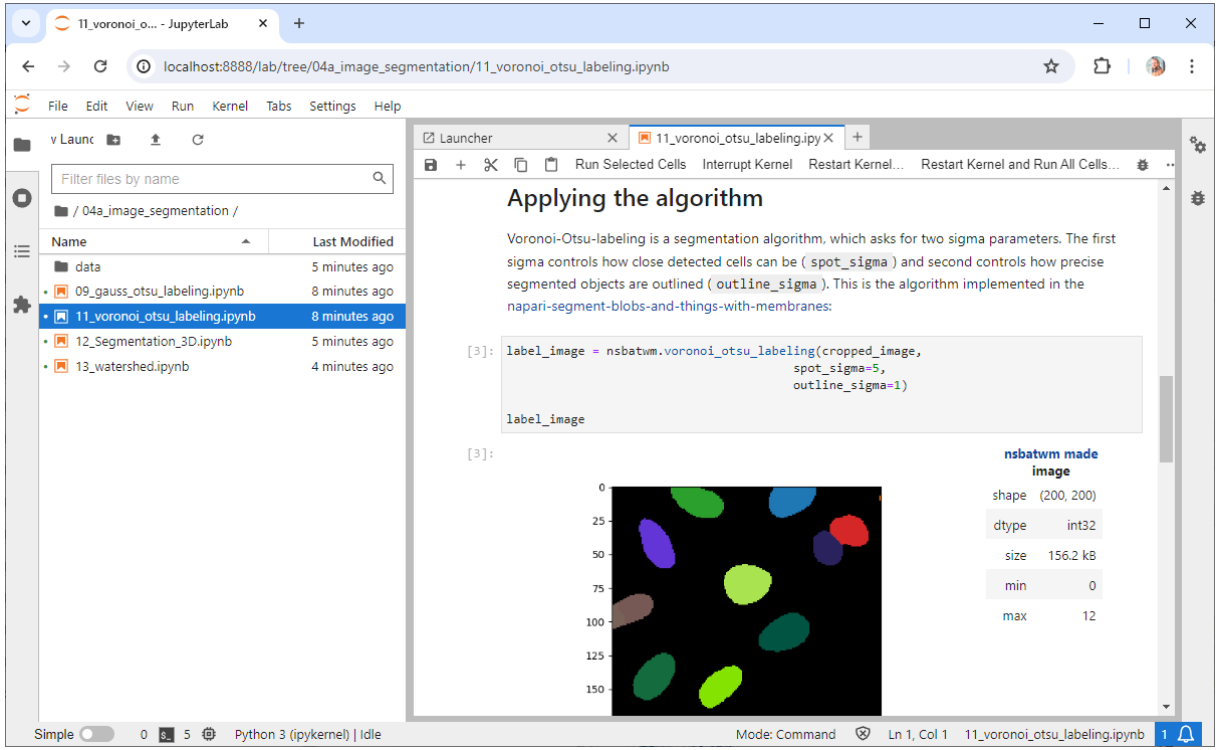
Image segmentation exercises

- Try out segmentation algorithms and apply them to other datasets



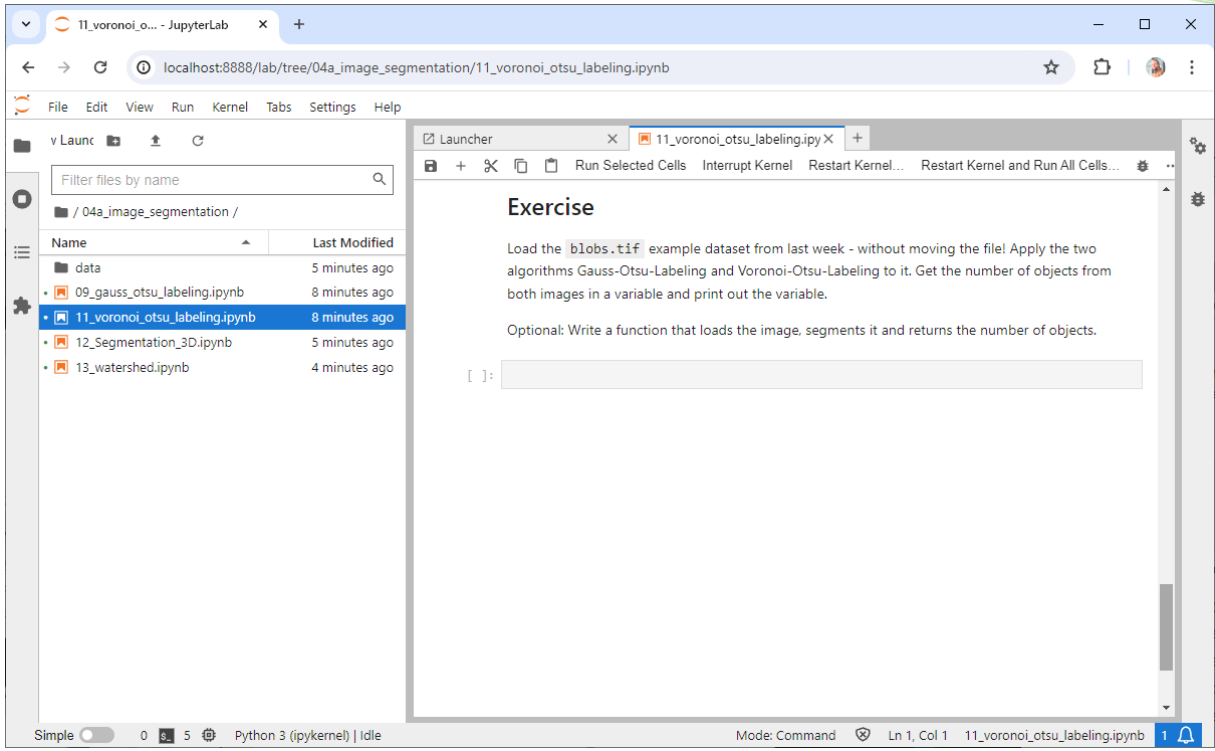
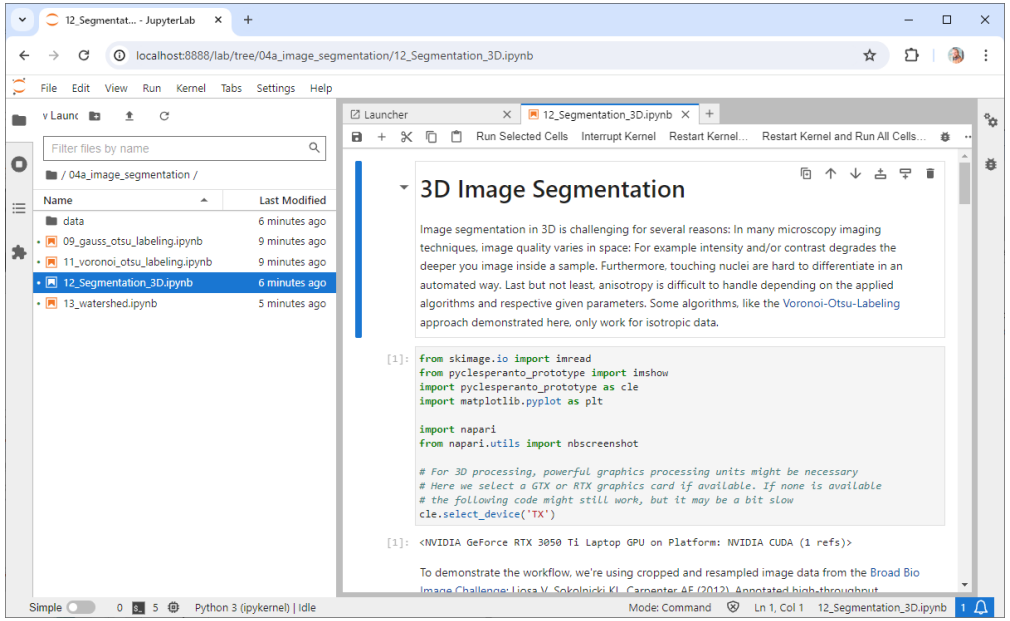
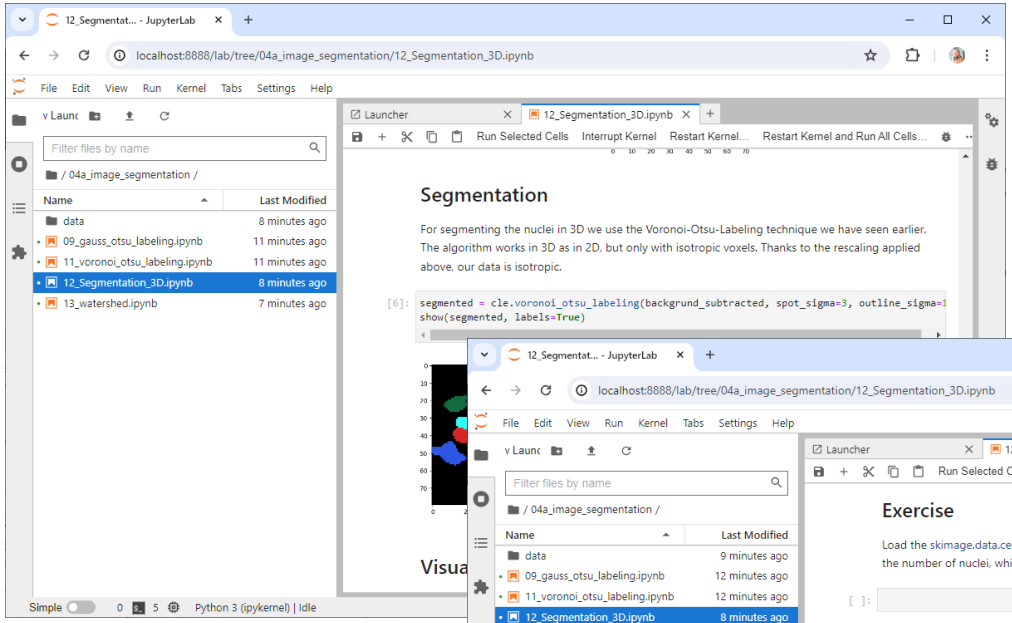
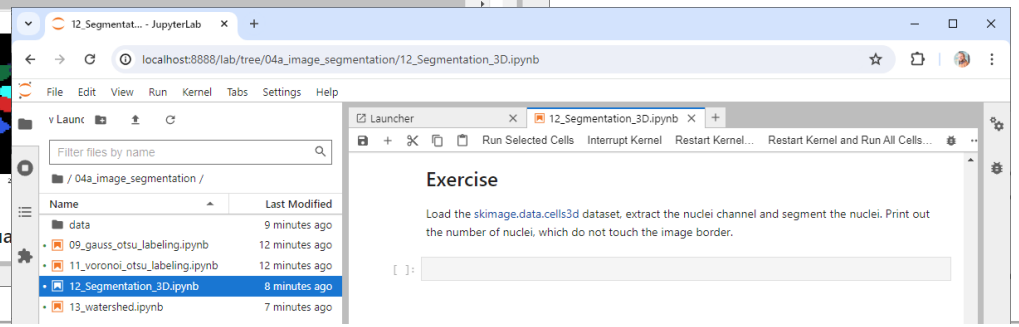


Image segmentation exercises

- 3D image processing may require GPU-acceleration
- In case there are errors:
  https://github.com/clEsperanto/pyclesperanto_prototype/?tab=readme-ov-file#troubleshooting-graphics-cards-drivers

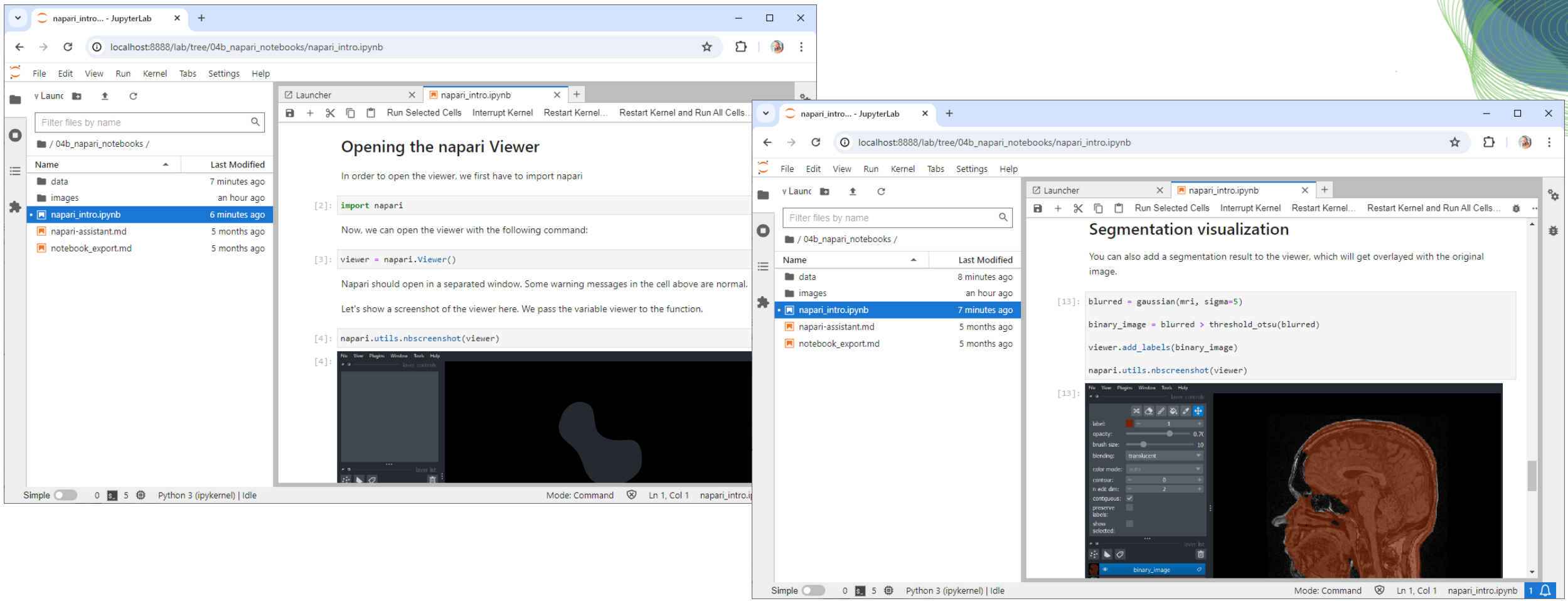






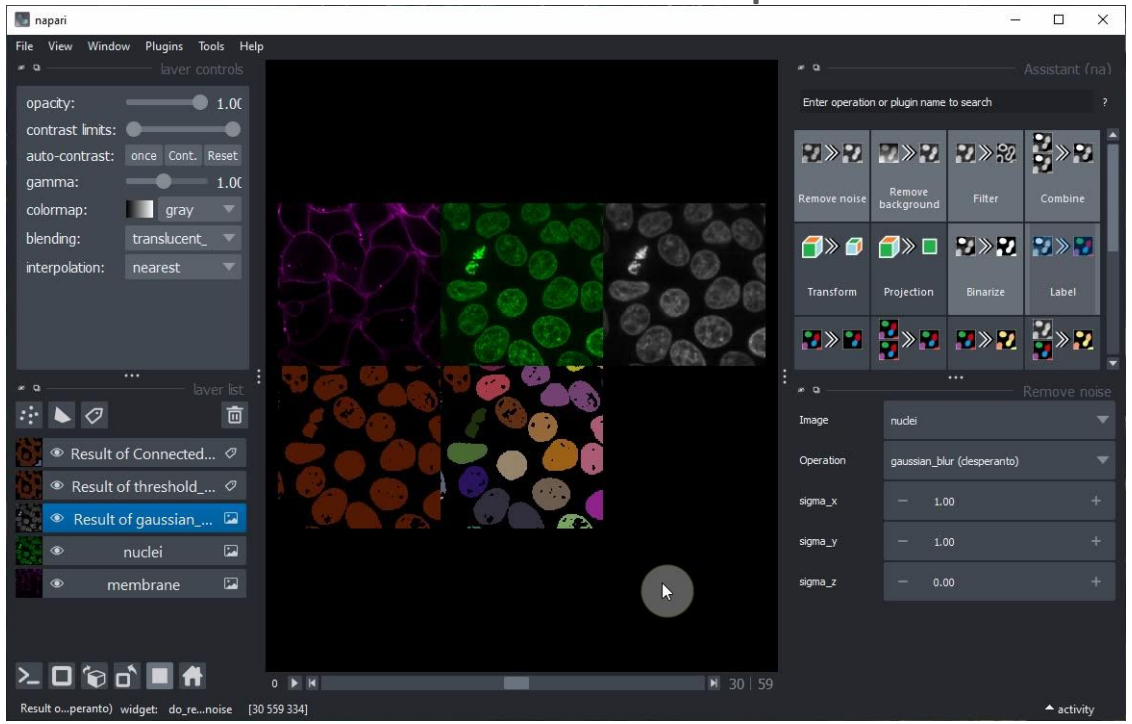
Napari - Exercises

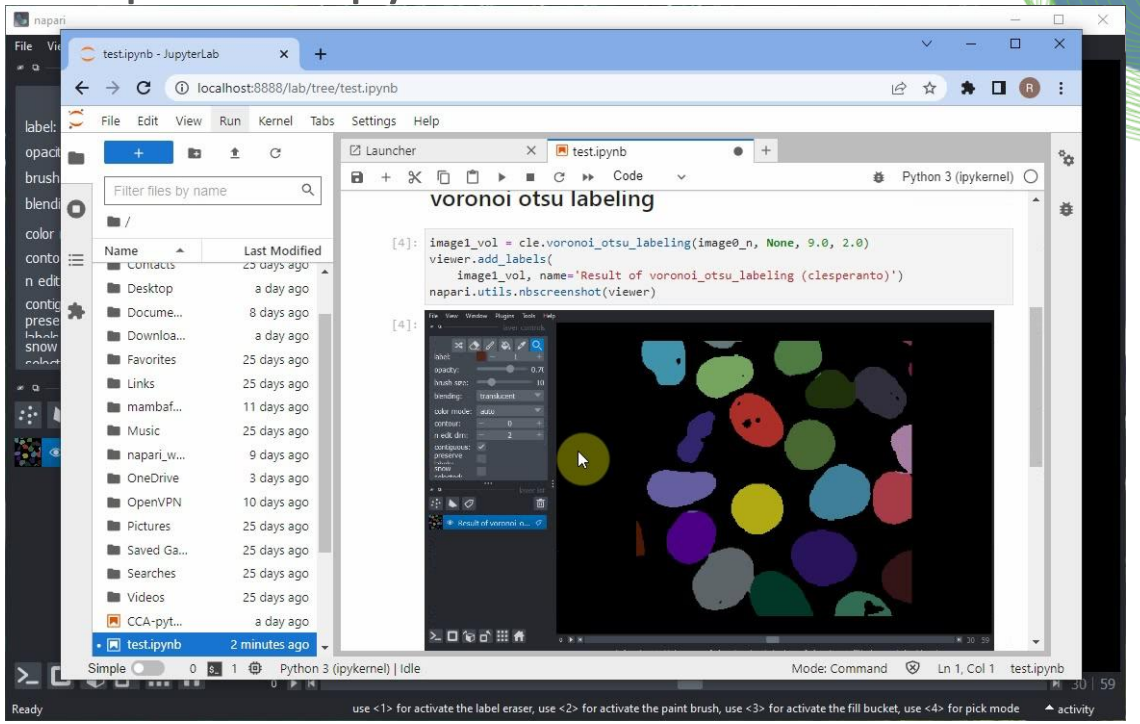
- Start using napari from Python



Napari - Exercises

- Start napari from the terminal!
- Follow the instructions to set up a workflow and export a Jupyter notebook





https://github.com/ScaDS/BIDS-lecture-2024/blob/main/04b_napari_notebooks/napari-assistant.md

https://github.com/ScaDS/BIDS-lecture-2024/blob/main/04b_napari_notebooks/notebook_export.md