Deconvoluting Convolutions

DATA SCIENCE MEETUP

APRIL 2018

Topics

The 2018 Data Science Bowl

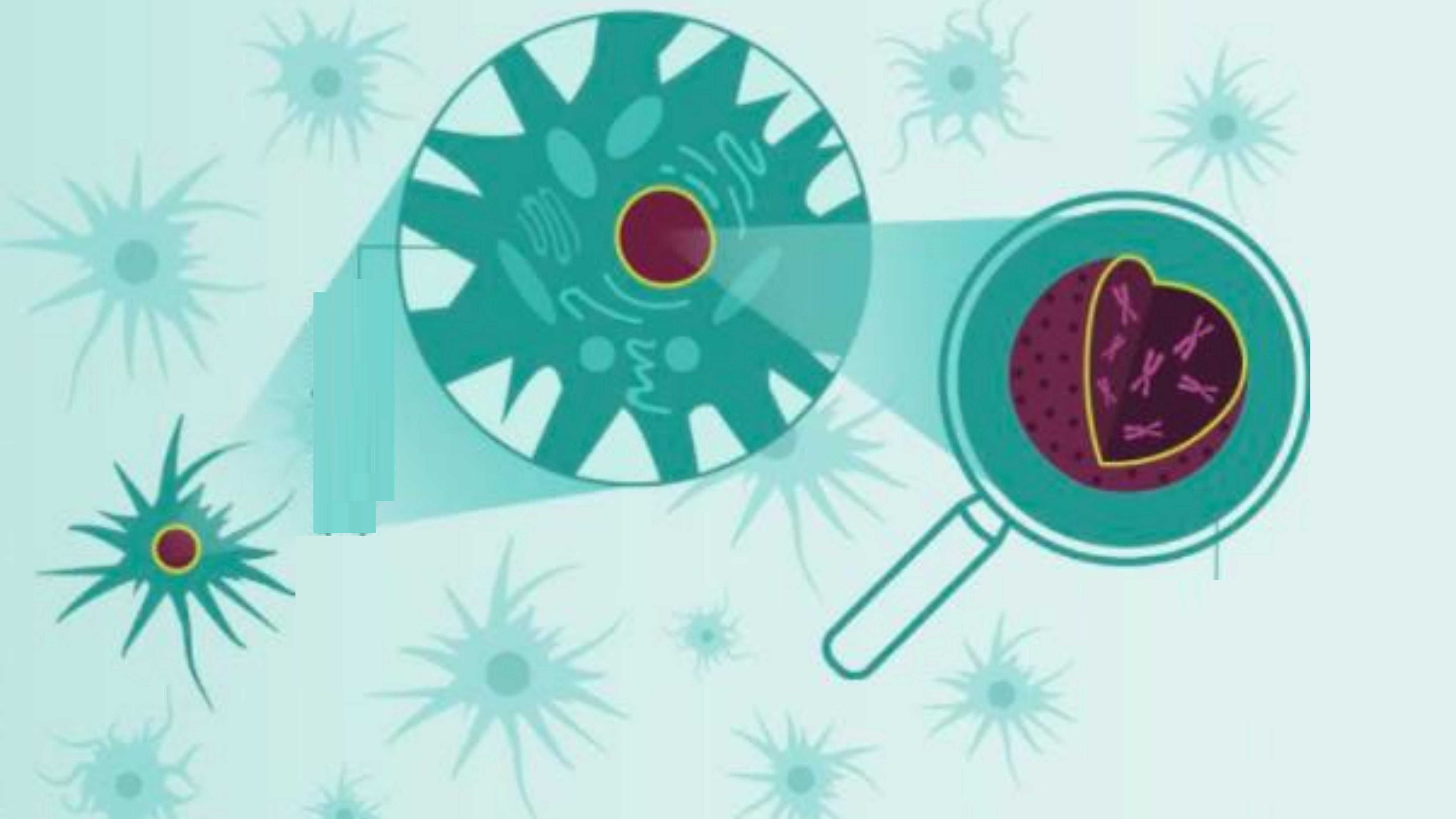
Puppy bowl

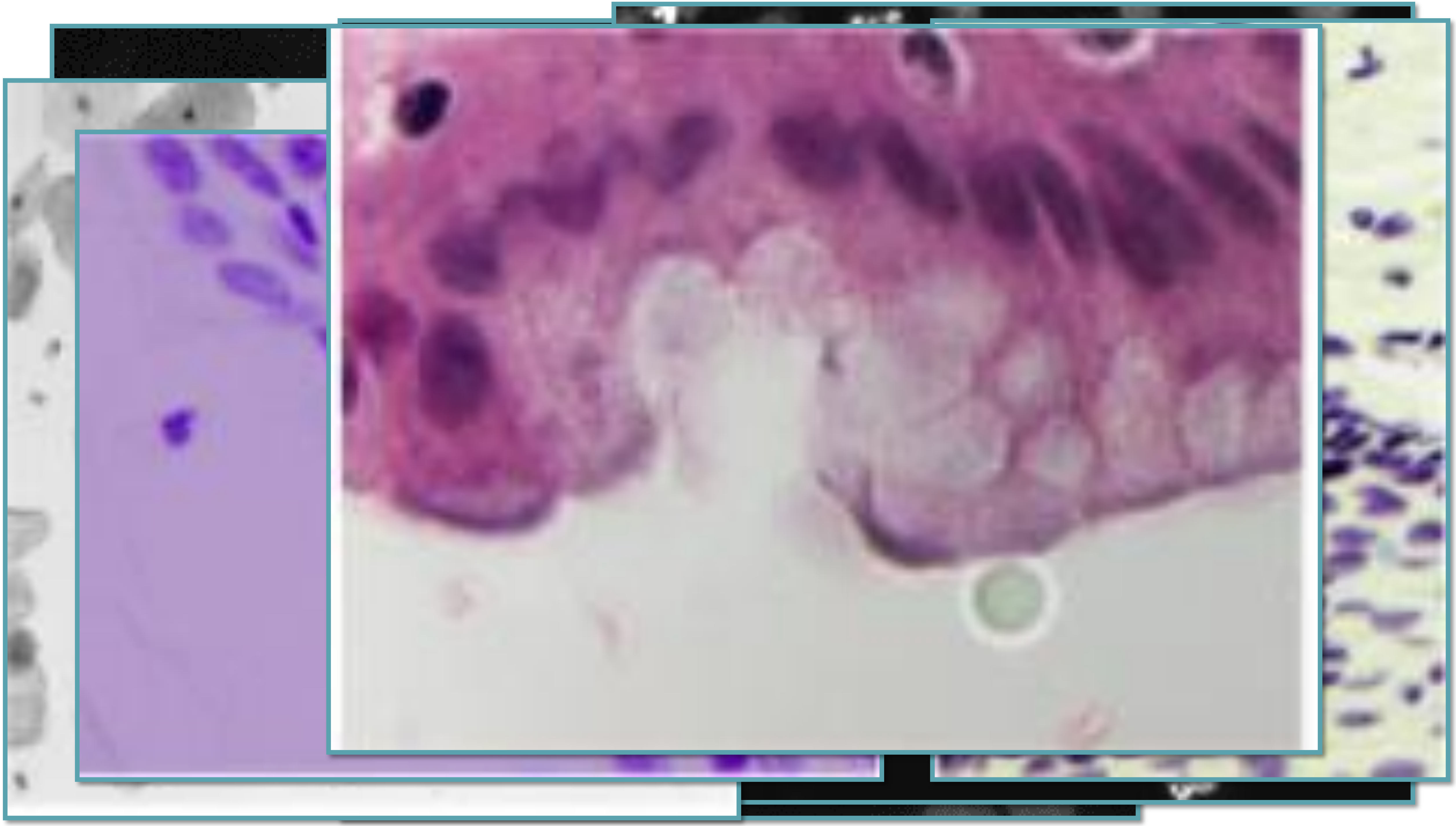
- Image processing basics
- The simple approach

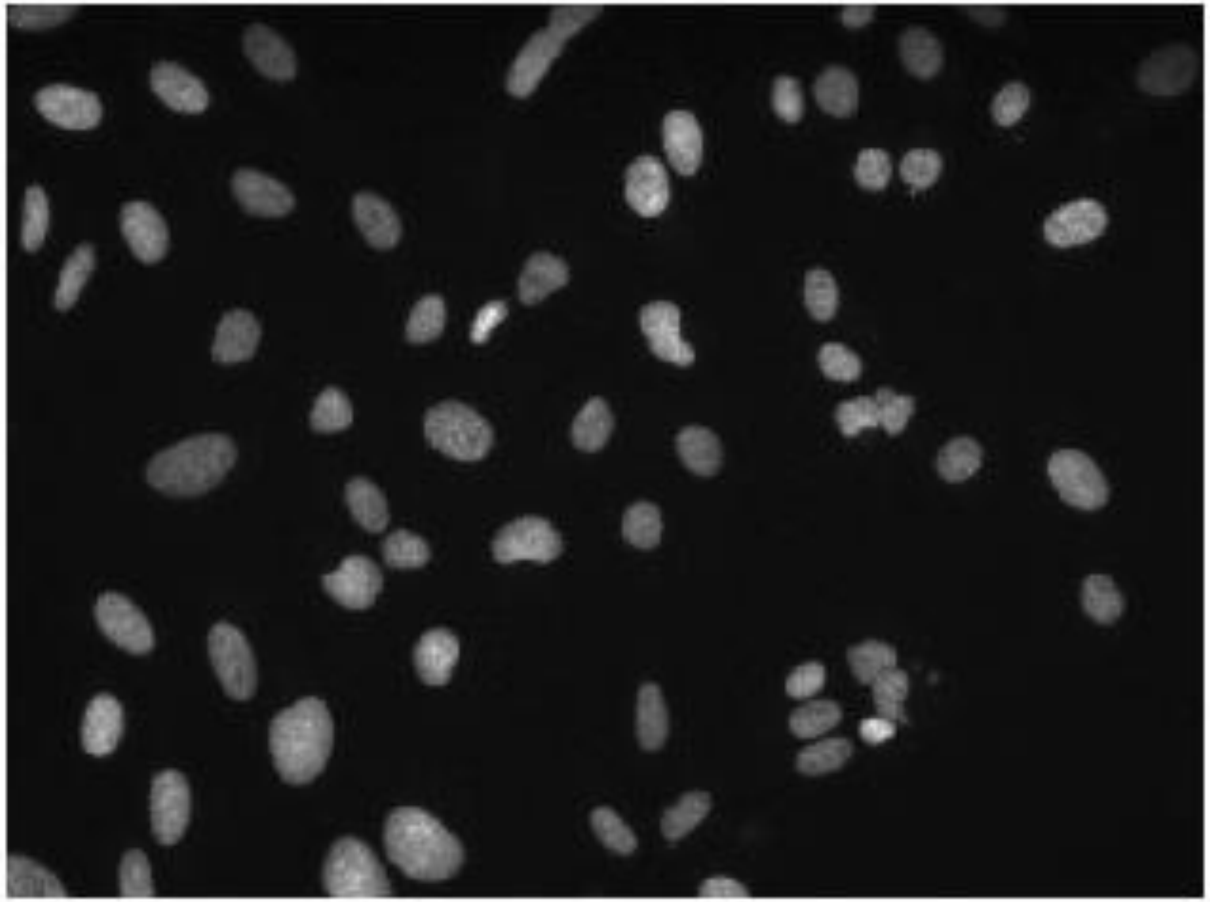
Superbowl

- Feature detection basics
- The U-Net approach

Performance

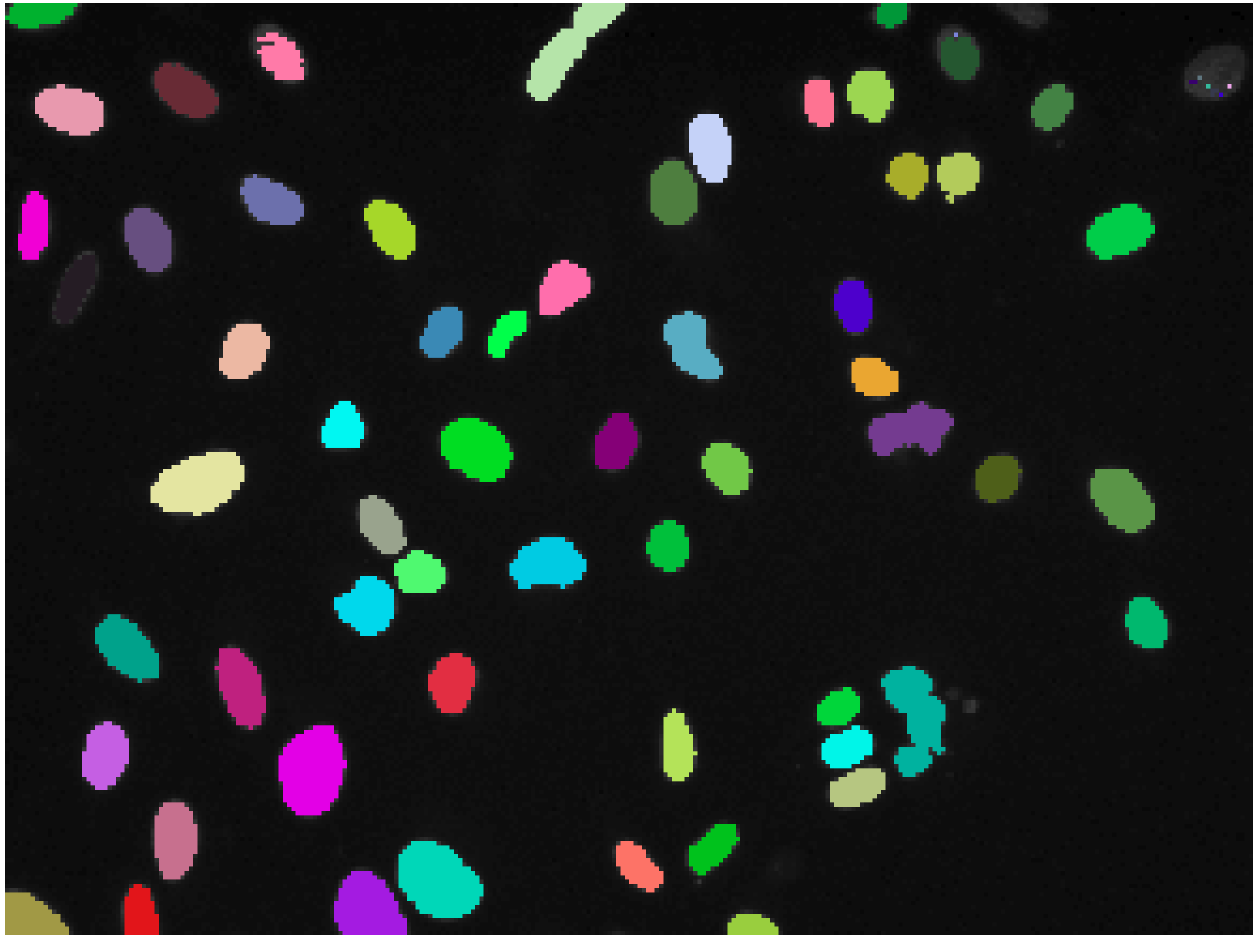






Competition goal:

Separate mask for each nucleus



Competition metric:

Intersection of the Union

Competition challenges

Variety of colors, microscopy types

Variety of sizes and scales

Different background tissue / nuclei types

Overlapping nuclei

Small training set (~700)

Errors in training set

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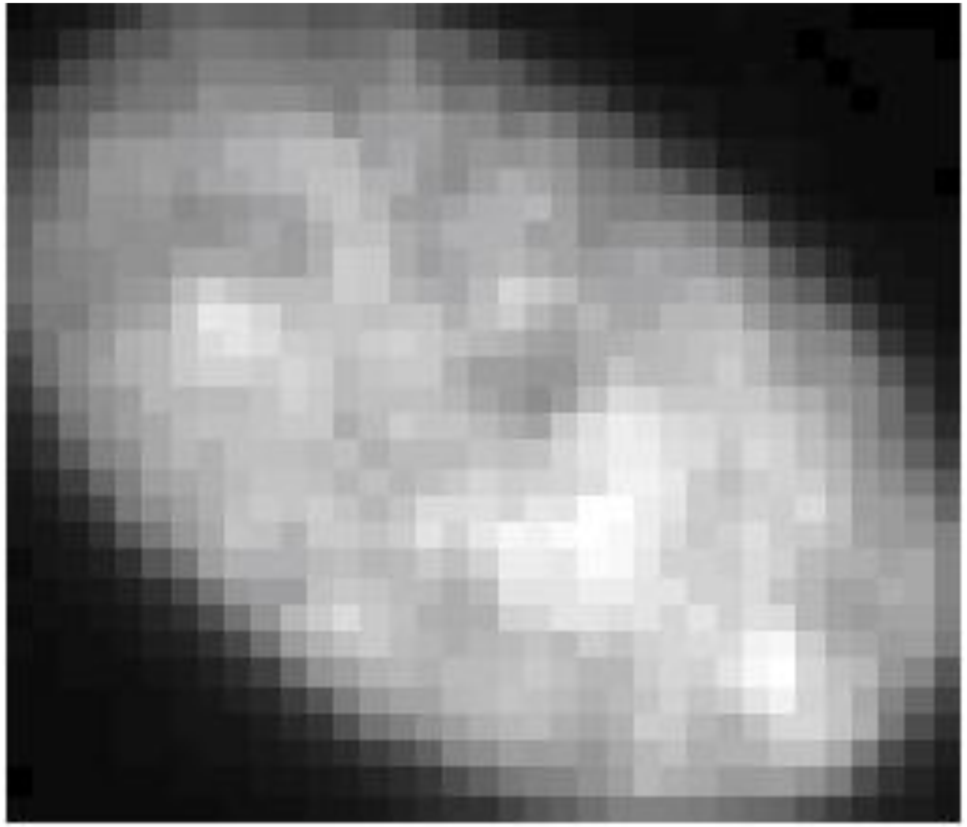
Image:
Intensity data with meaningful order

One cell from train image



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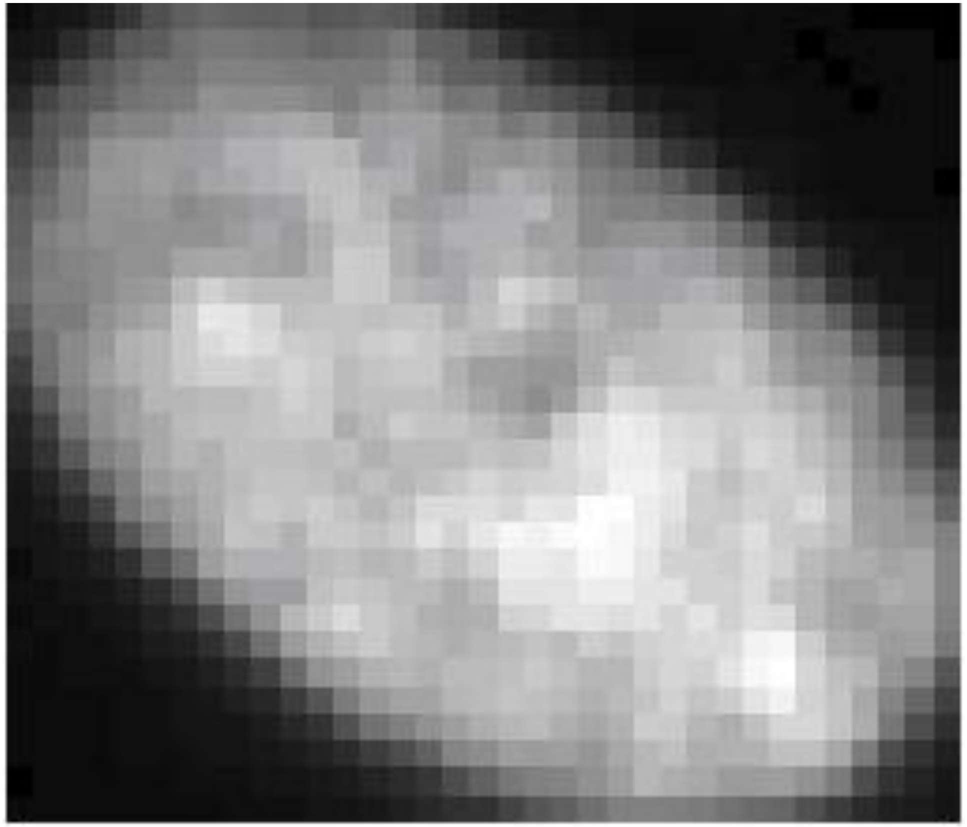


Data with 3 color channels

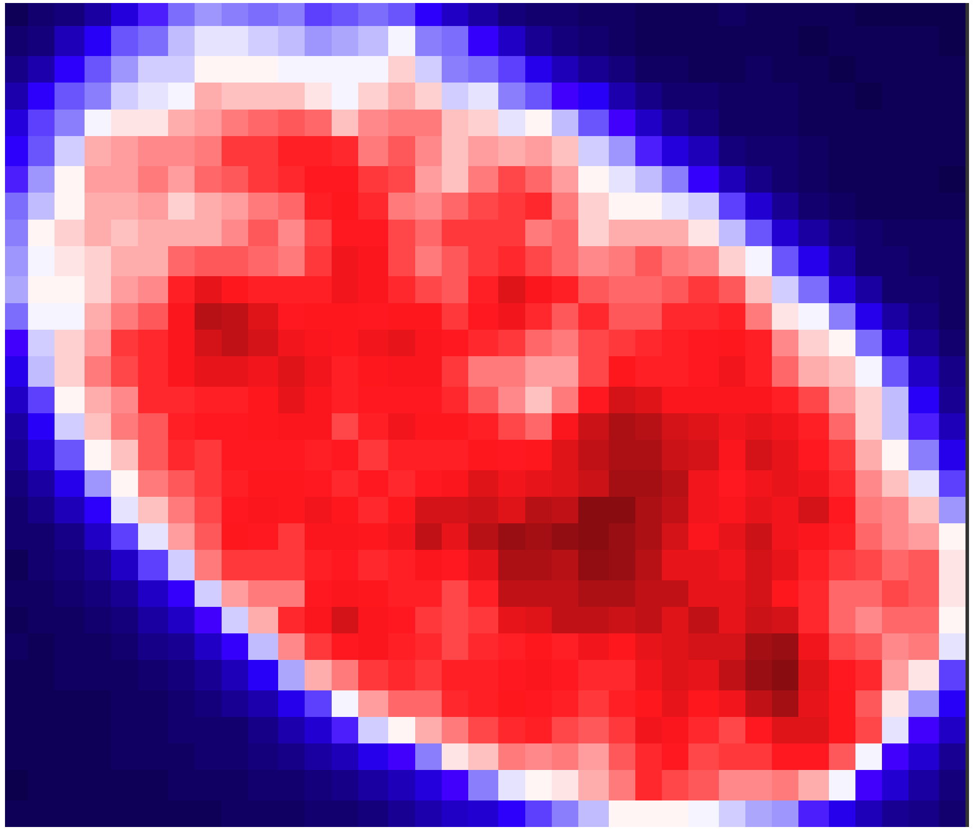
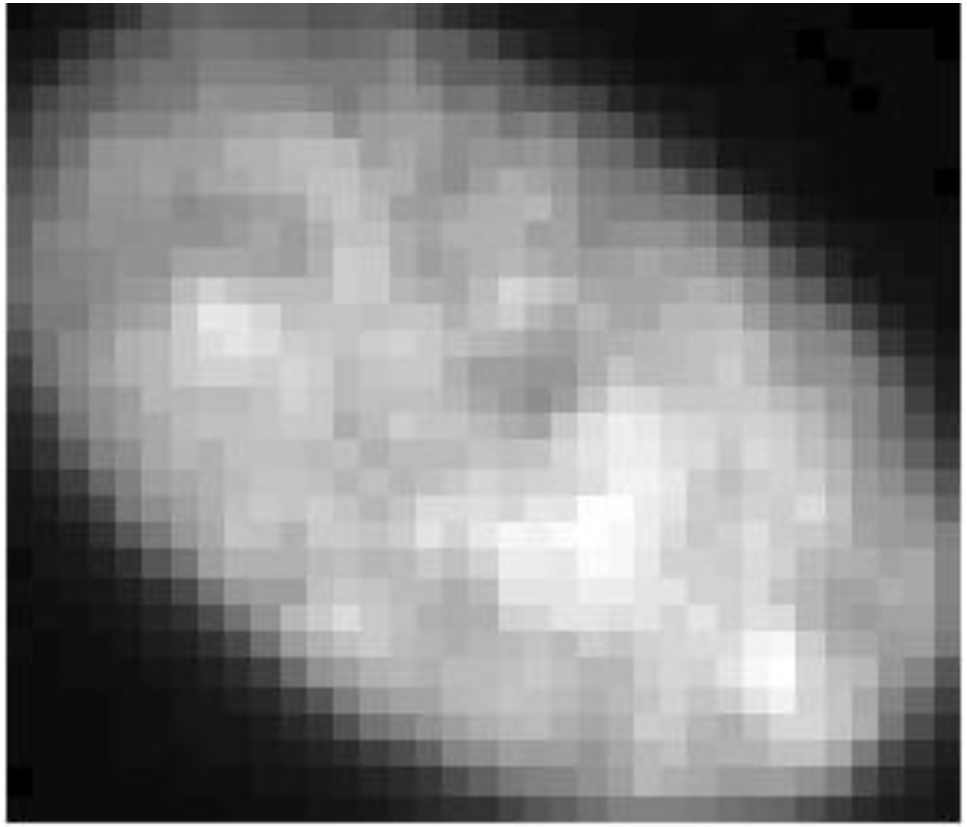
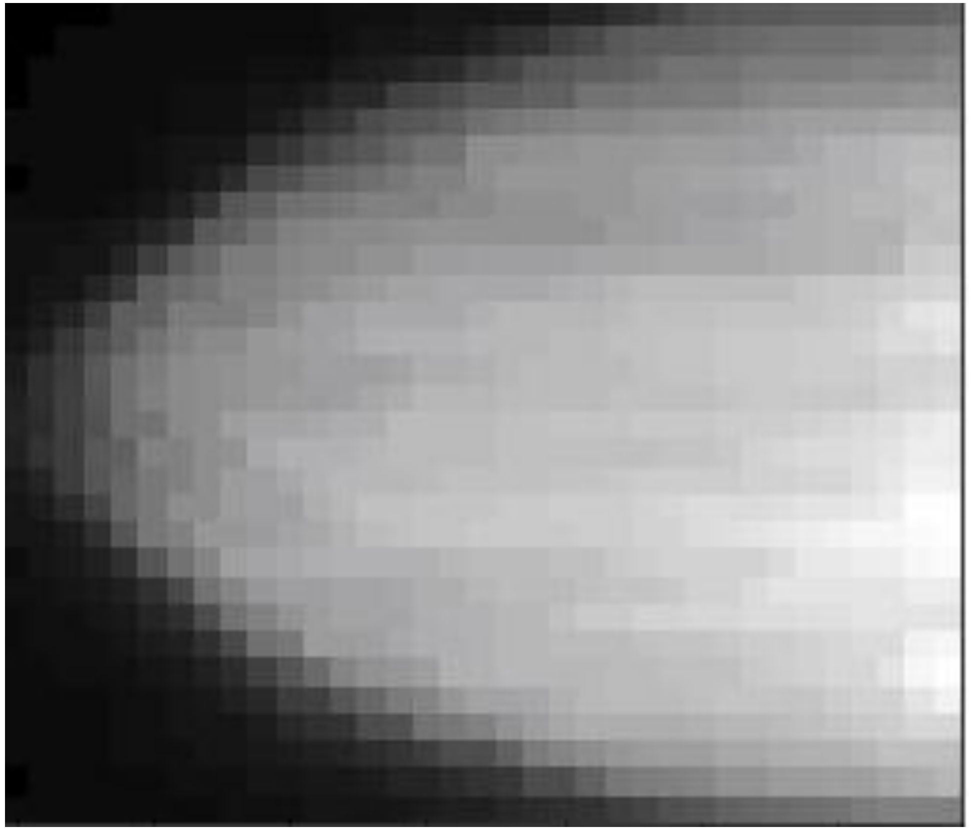


Image:
Intensity data **with meaningful order**

One cell from train image



Data sorted along rows



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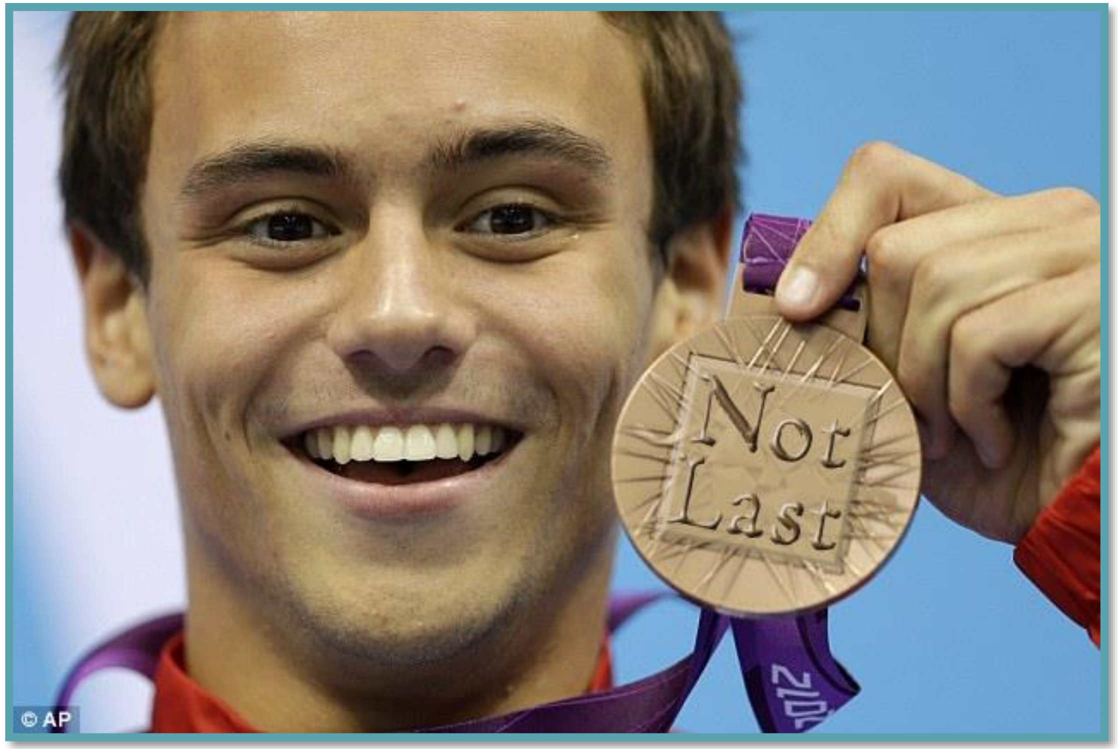

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Stephen Bailey

Teaching notebook for total imaging newbies

352 voters

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Notebook

This kernel will implement classical image techniques and will hopefully serve as a useful primer to people who have never worked with image data before. Ultimately, we will develop a simple pipeline using `scipy` and `numpy` (and a little bit of

Competition challenges

Small training set (~700)

Variety of colors, microscopy types

Variety of sizes and scales

Different background tissue

Overlapping nuclei

Competition challenges

~~Small training set (~700)~~

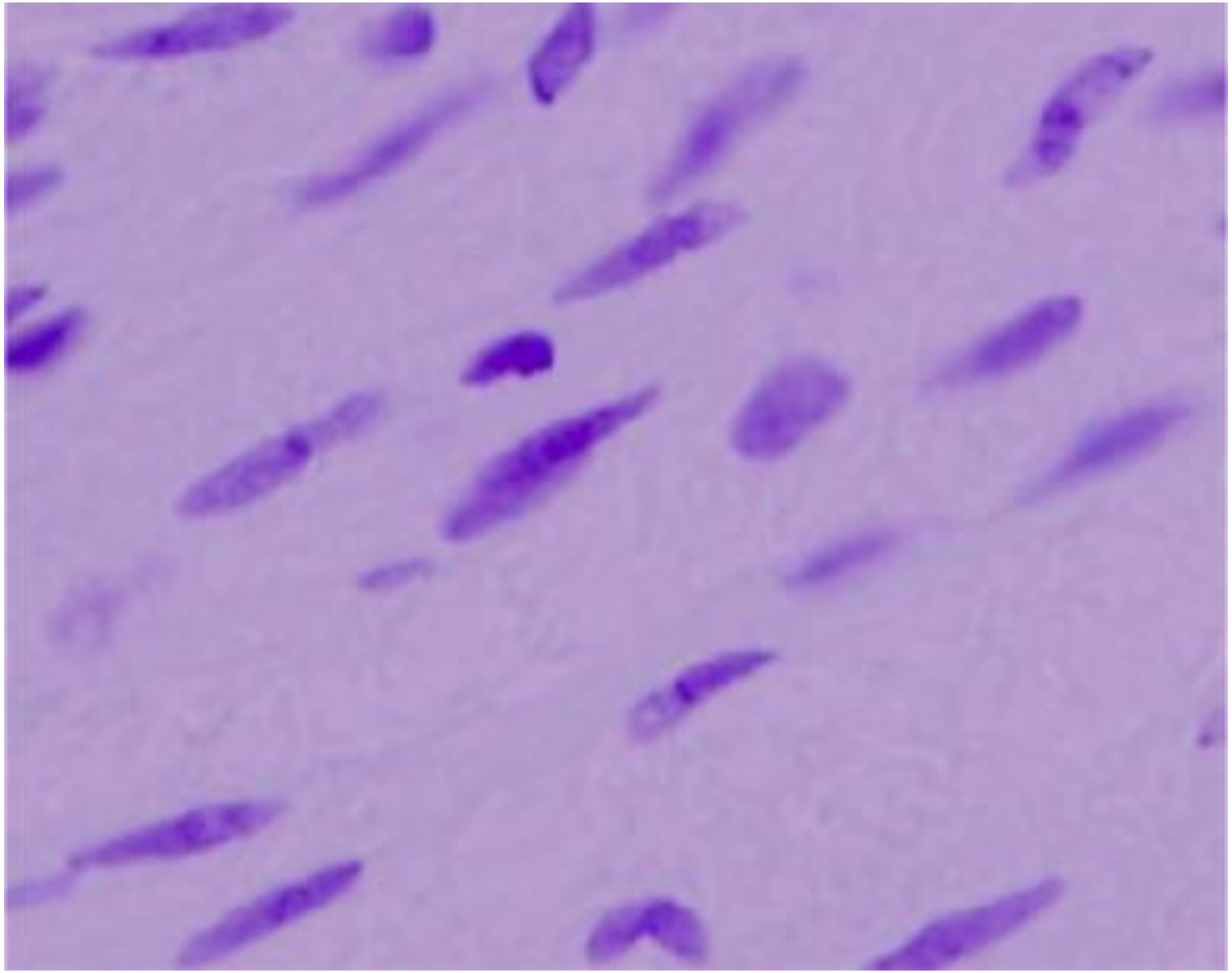
~~Variety of colors, microscopy types~~

~~Variety of sizes and scales~~

~~Different background tissue~~

~~Overlapping nuclei~~

Step one: Convert to grayscale image.



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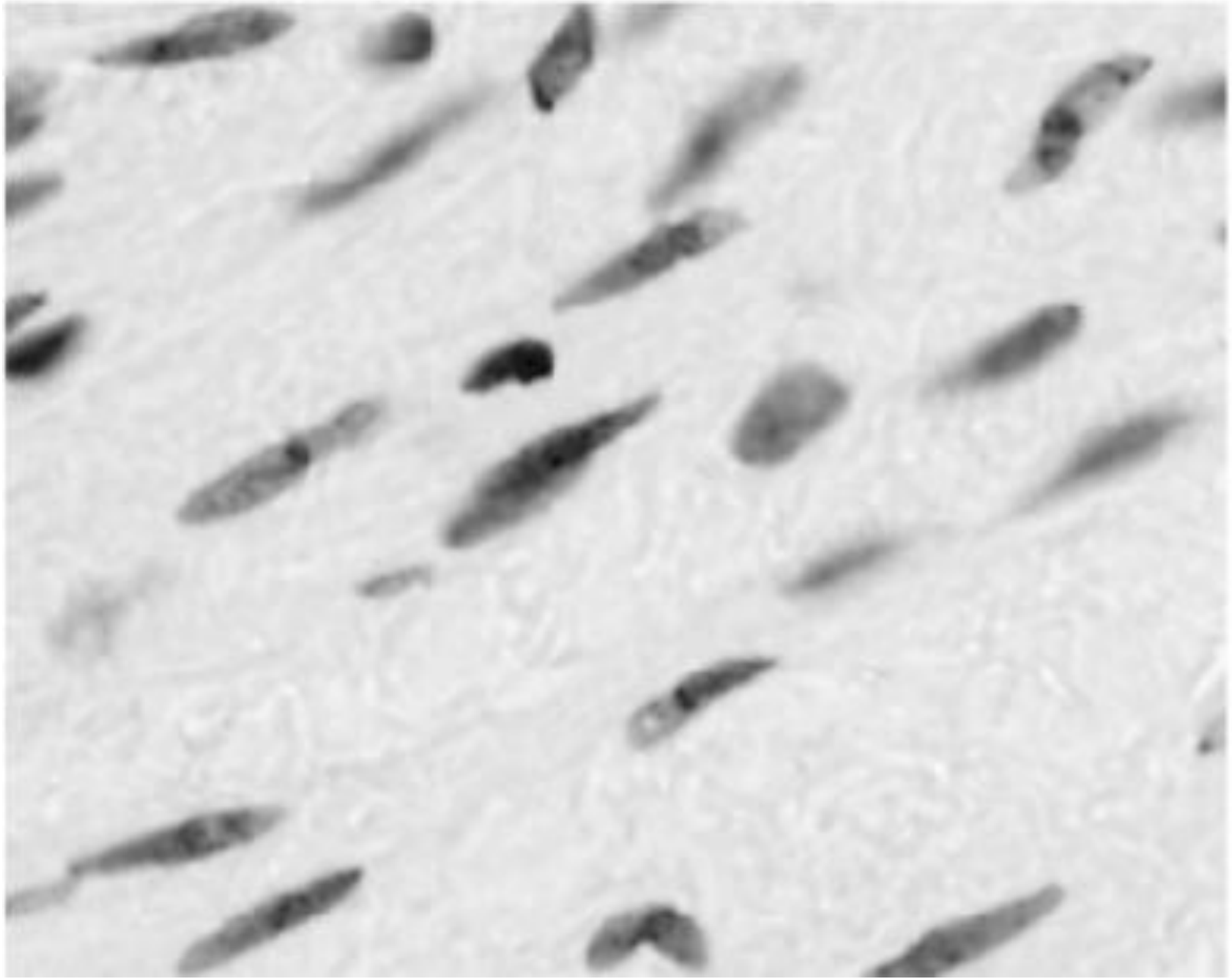
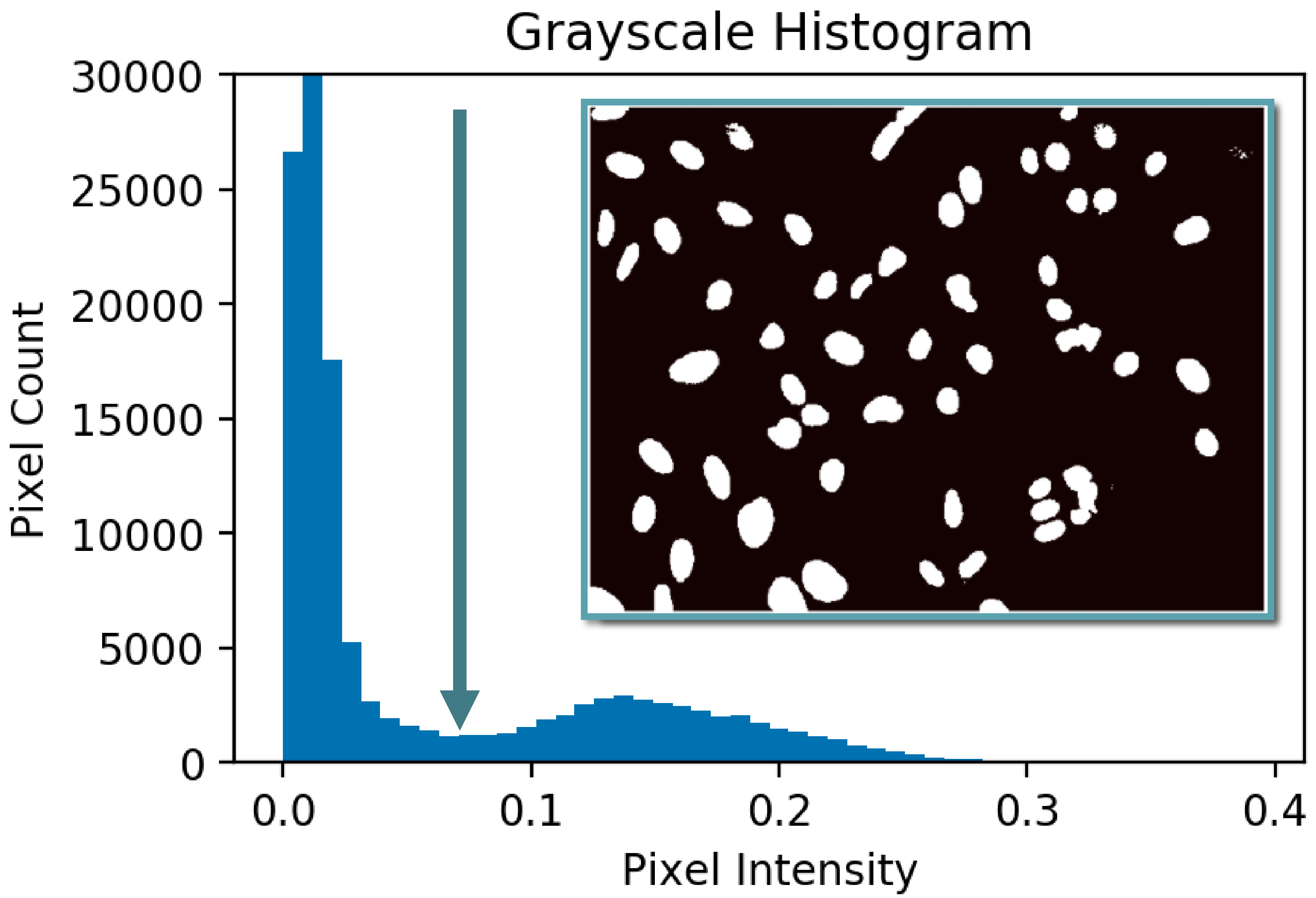


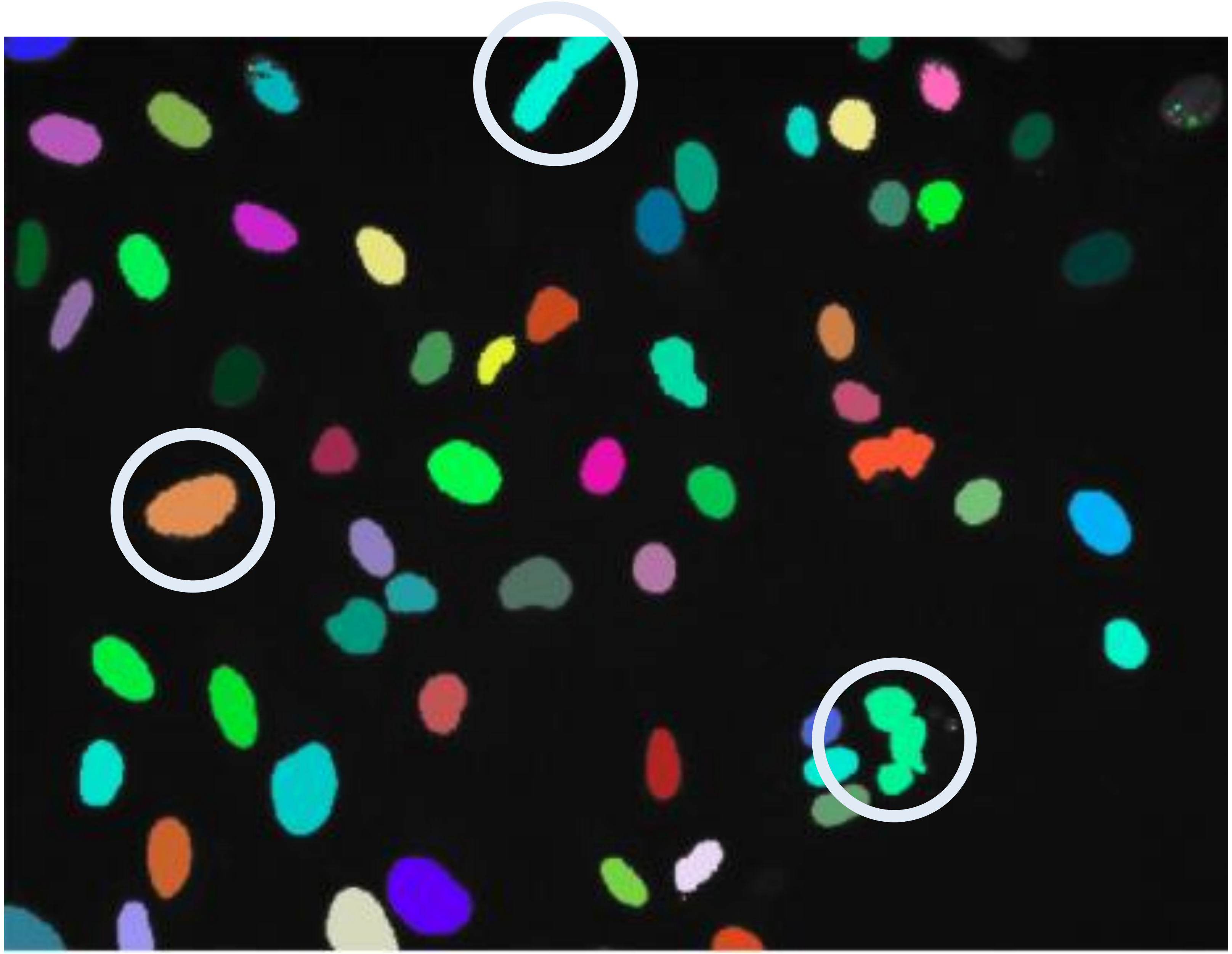
Step two: Threshold background

Assume there are two pixel types in the image:

- Nuclei
- Background.

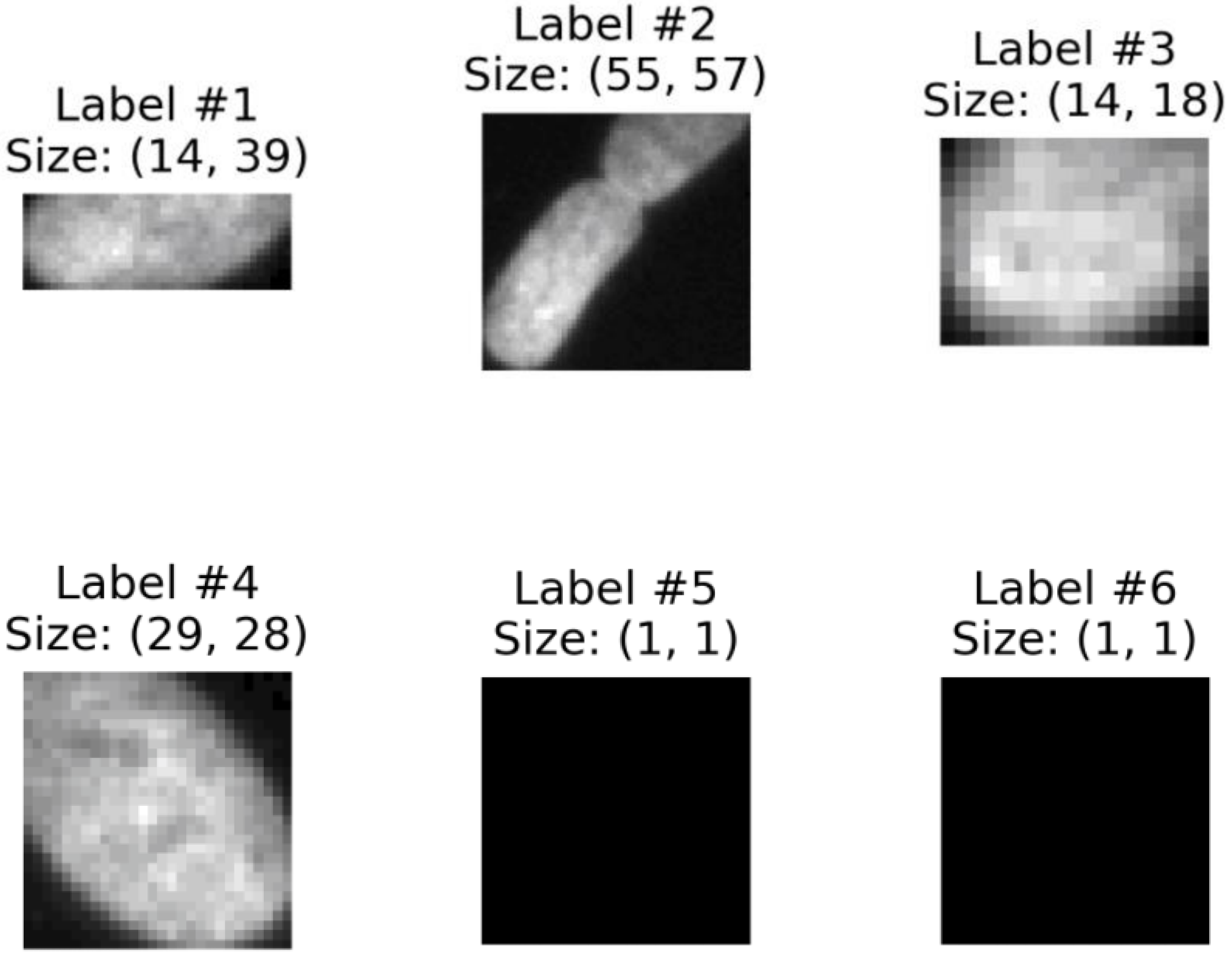


Step three: Separate individual objects



Step four: Post-process individual objects

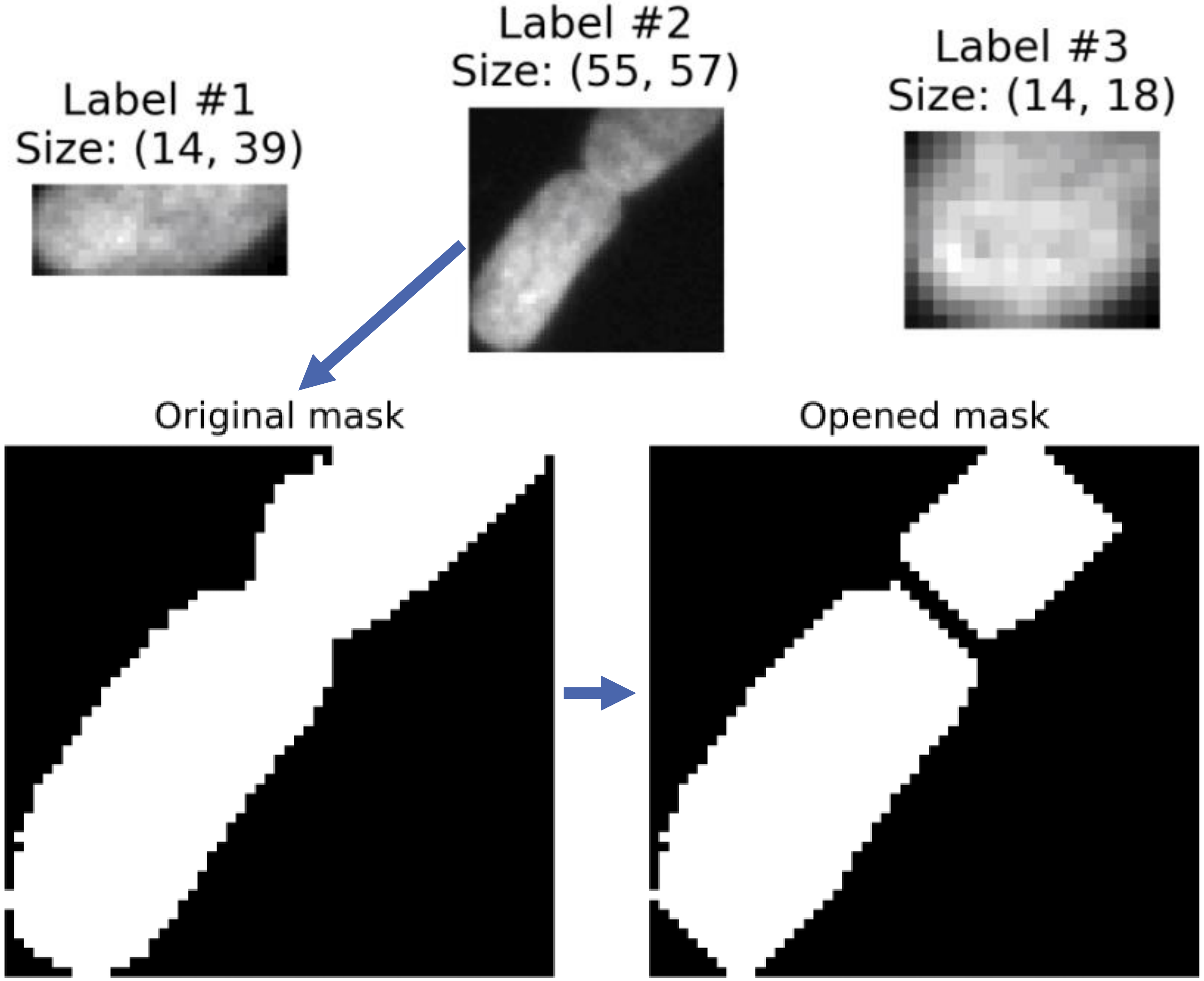
Eliminate tiny objects



Step four: Post-process individual objects

Eliminate tiny objects

Open connected objects




WE NEED TO GO
DEEPER

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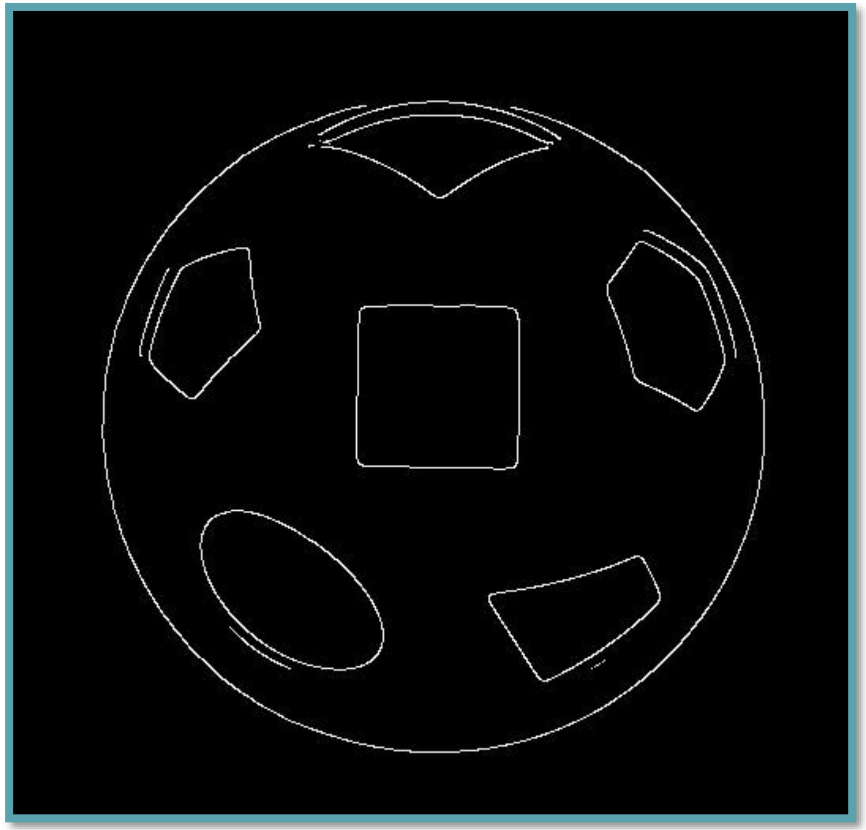
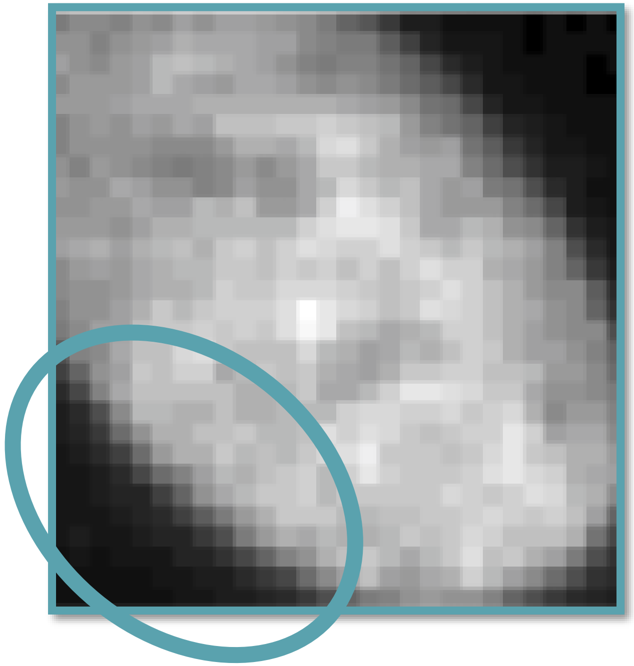
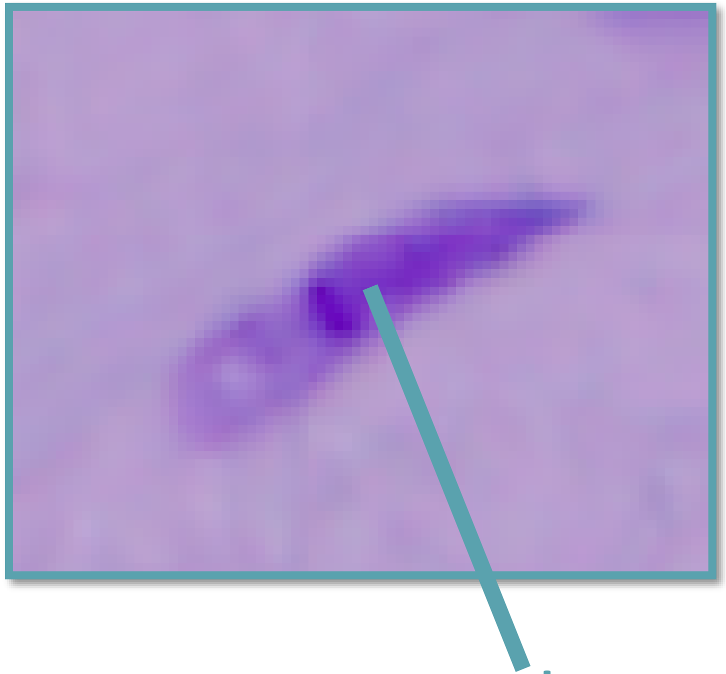


Humans recognize objects from patterns



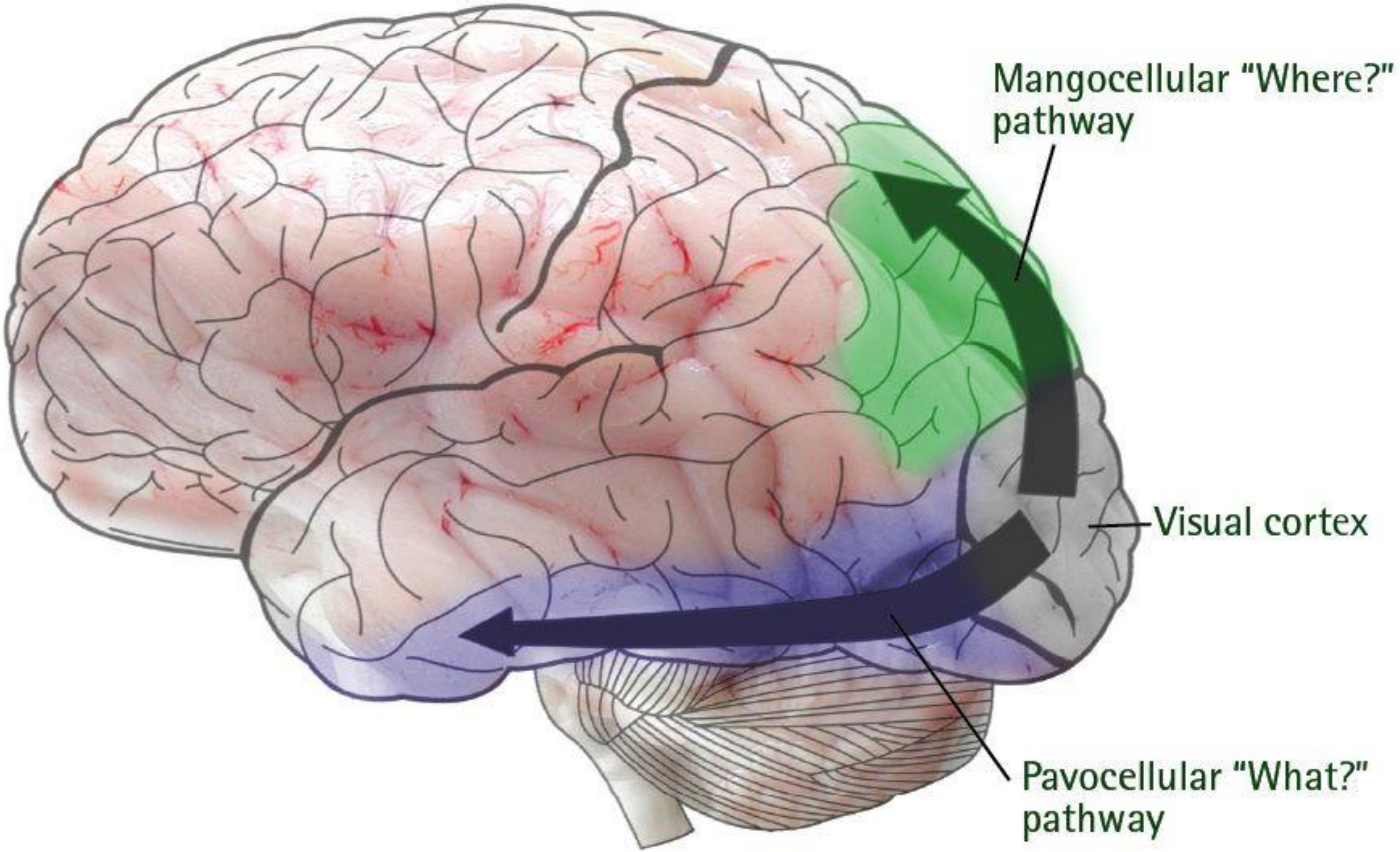
Edges



Color

Ratios

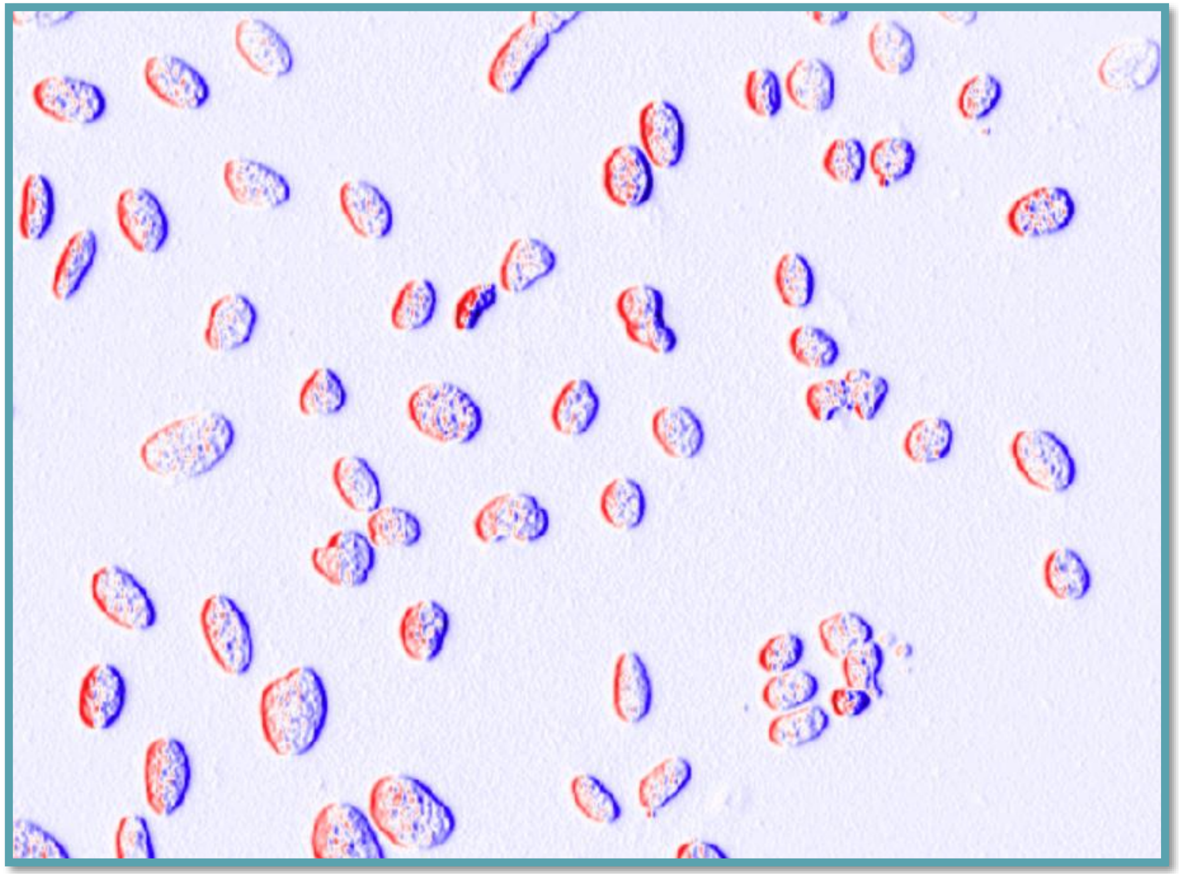
https://www.youtube.com/watch?v=IOHayh06LJ4


Mangocellular "Where?" pathway
Visual cortex
Pavocellular "What?" pathway

Convolution: Weighting an image by a pattern.

Horizontal Edges
3 x 3

1	0	-1
1	0	-1
1	0	-1



Convolution sums the element-wise product of an image window and filter

Image Window

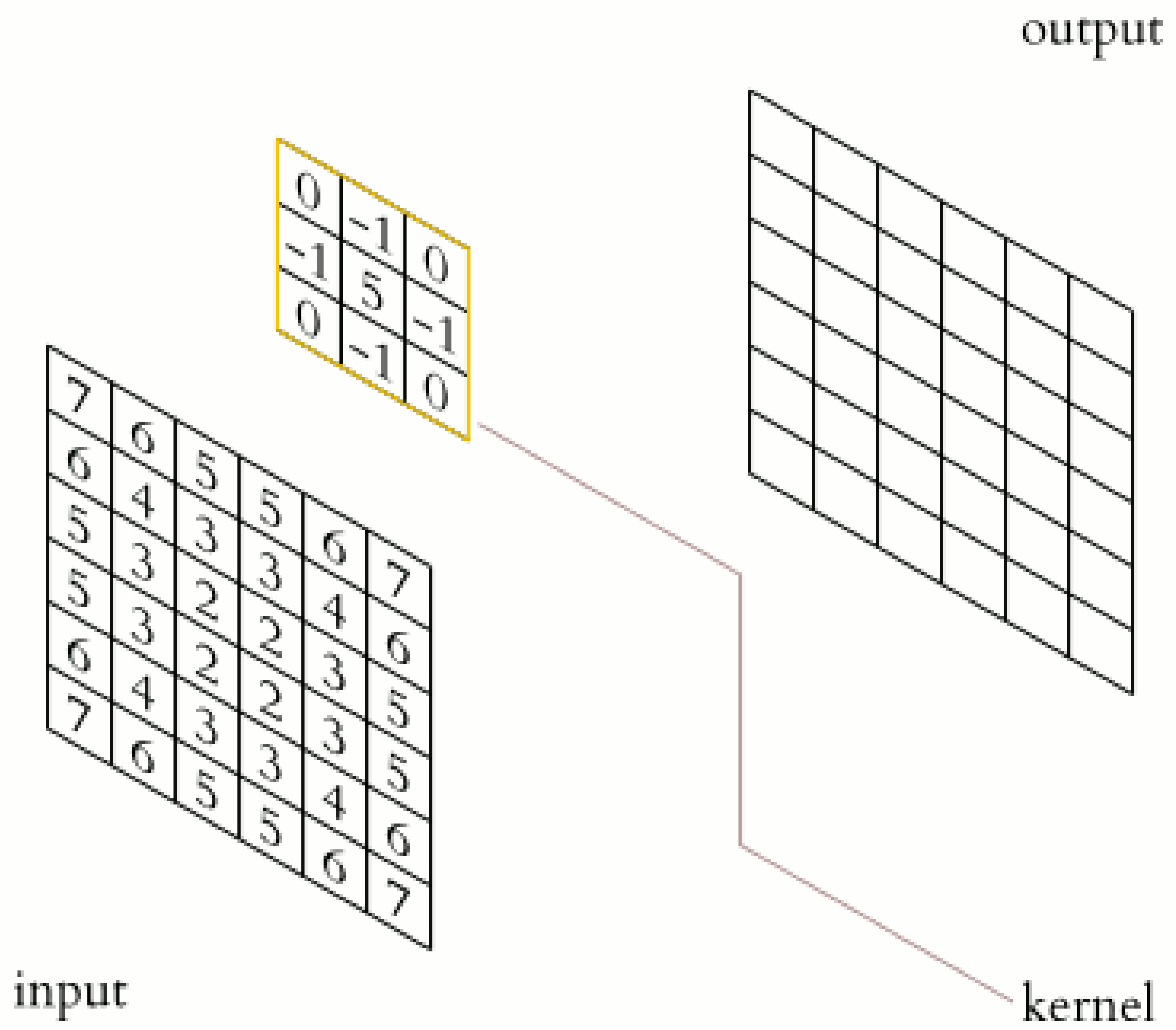
5	4	3
5	4	3
5	4	3

*

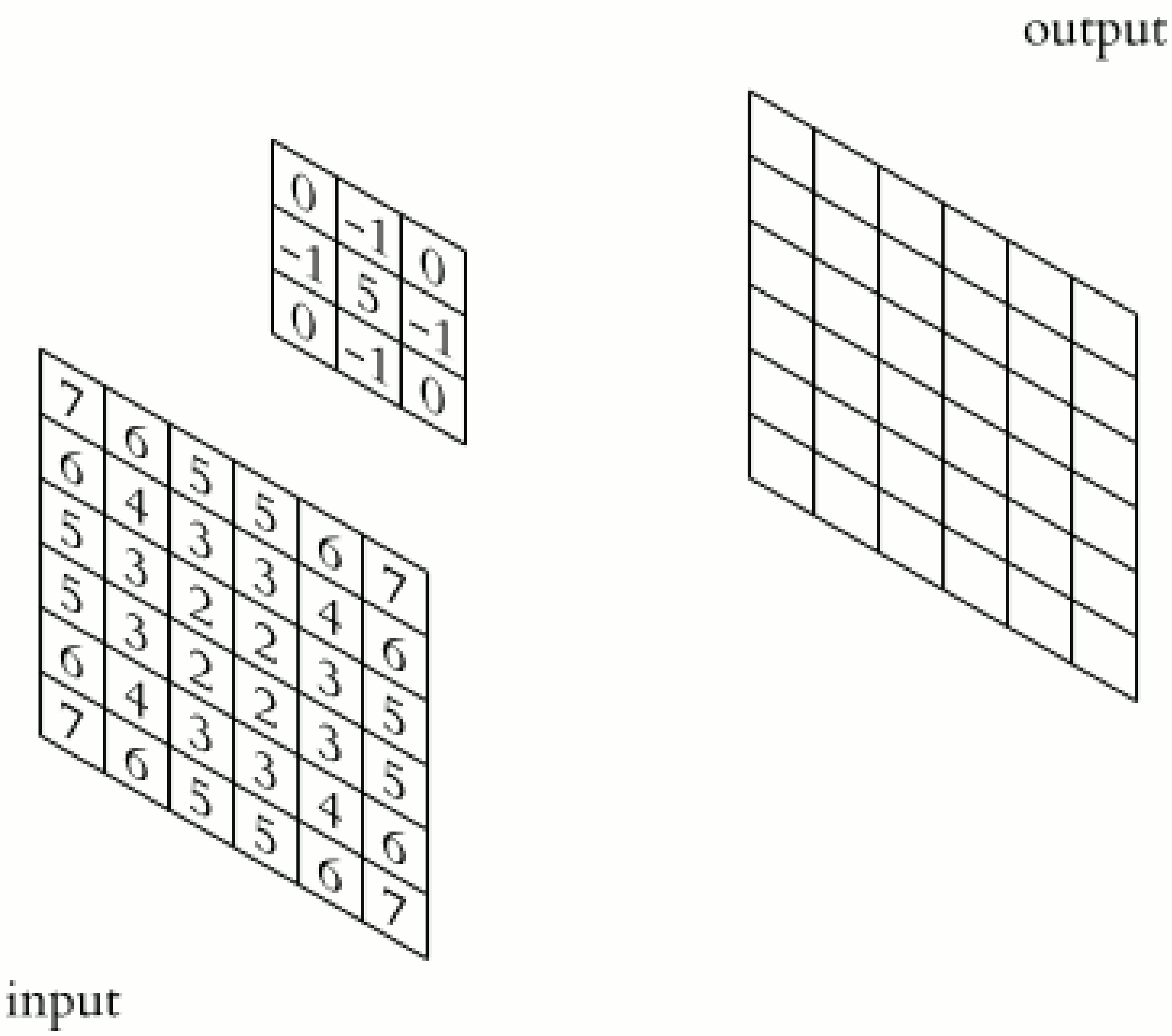
Filter

1	0	-1
1	0	-1
1	0	-1

A separate convolution is performed for each pixel.

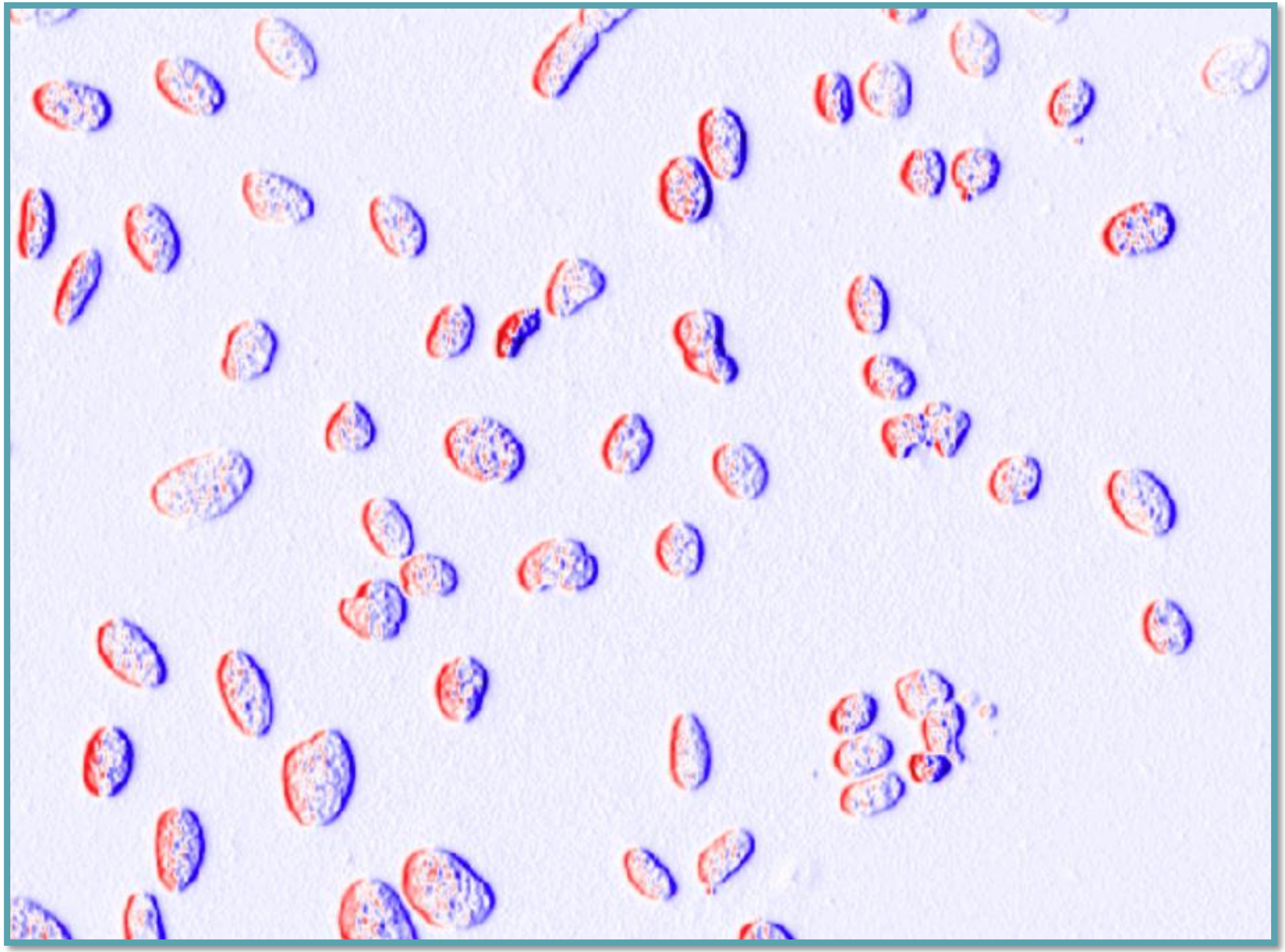


A separate convolution is performed for each pixel.



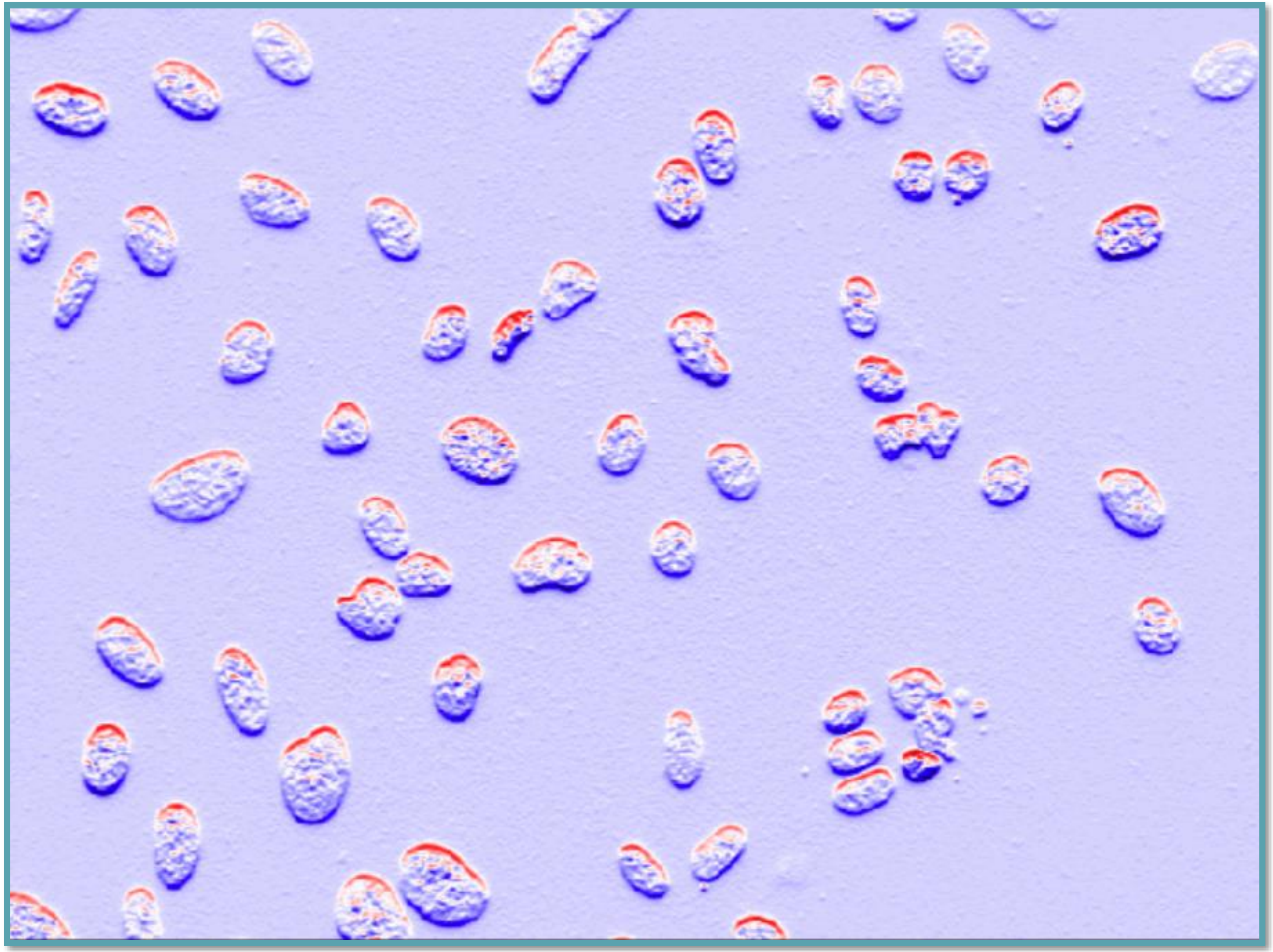
Results: Horizontal Edges

1	0	-1
1	0	-1
1	0	-1



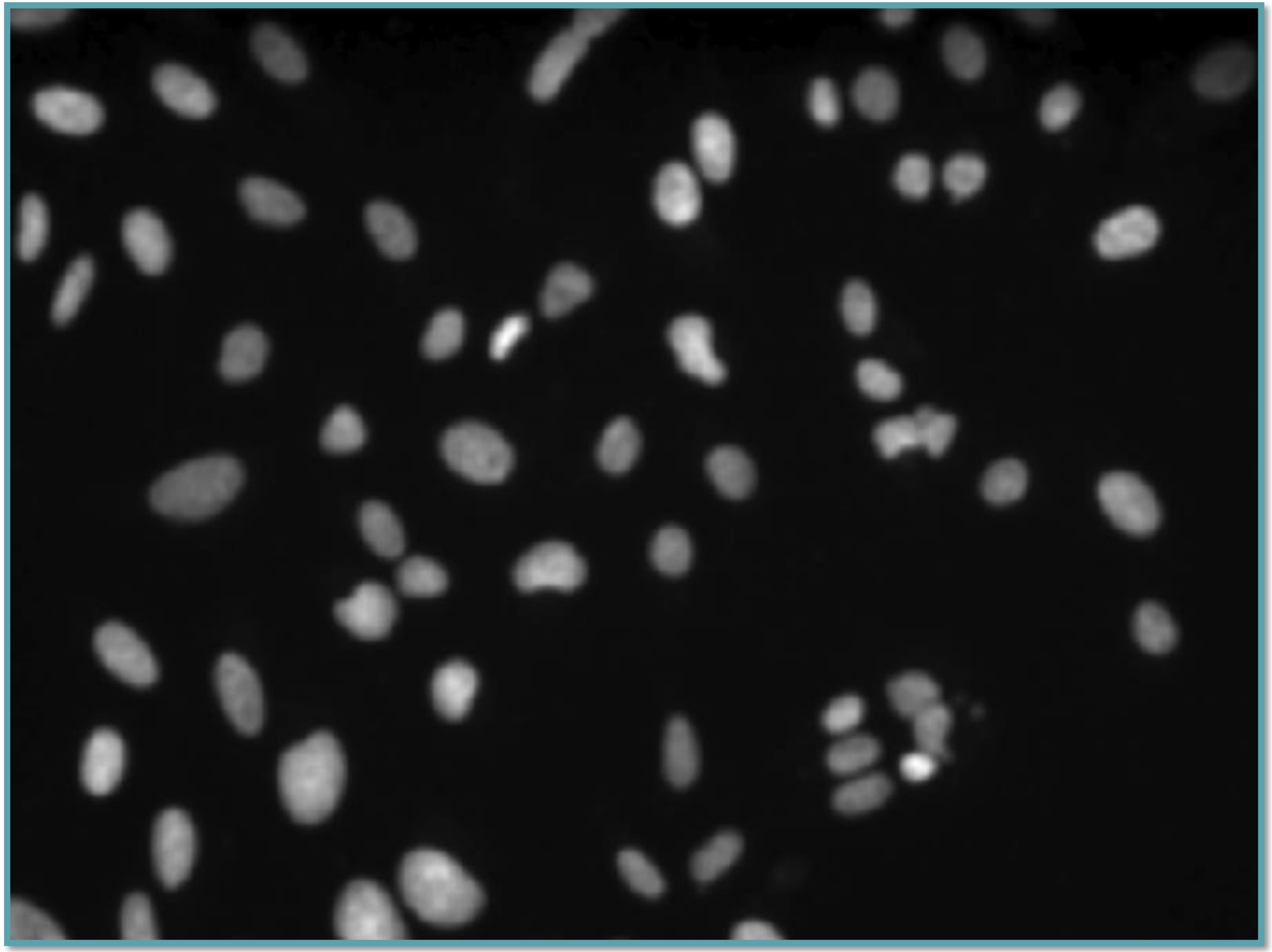
Results: Vertical Edges

1	1	1
0	0	0
-1	-1	-1



Results: Mean Filter

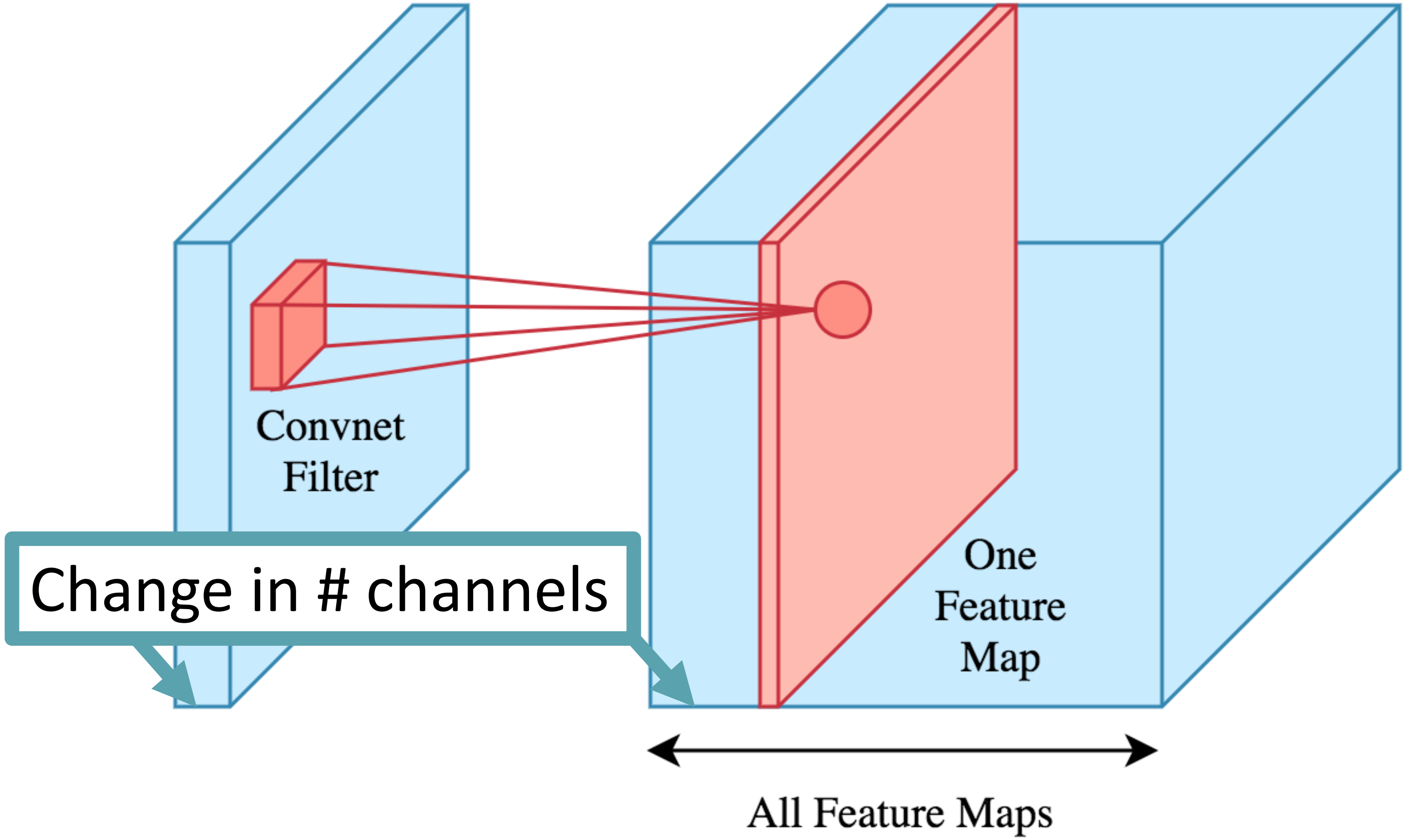
1	1	1
1	1	1
1	1	1



Convolve image with multiple filters

Input

Convolve image with many filters



- Horiz. edges
- Vert. edges
- Diag. edges
- Flat areas
- Smooth areas
- High color
- …

Convolutional neural networks

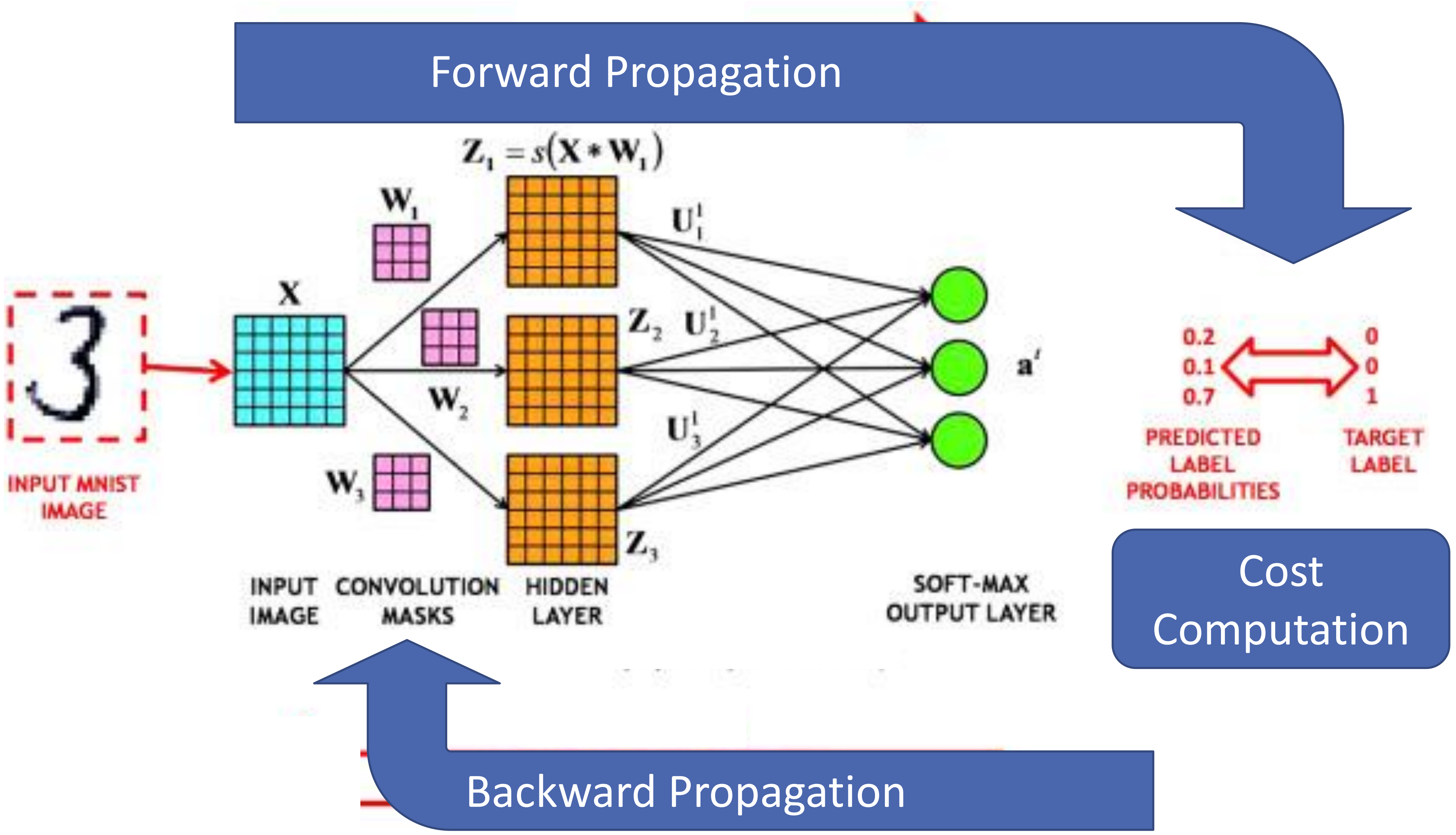
Don't impose filter weights… learn them!

Horizontal Edges
3 x 3

1	0	-1
1	0	-1
1	0	-1

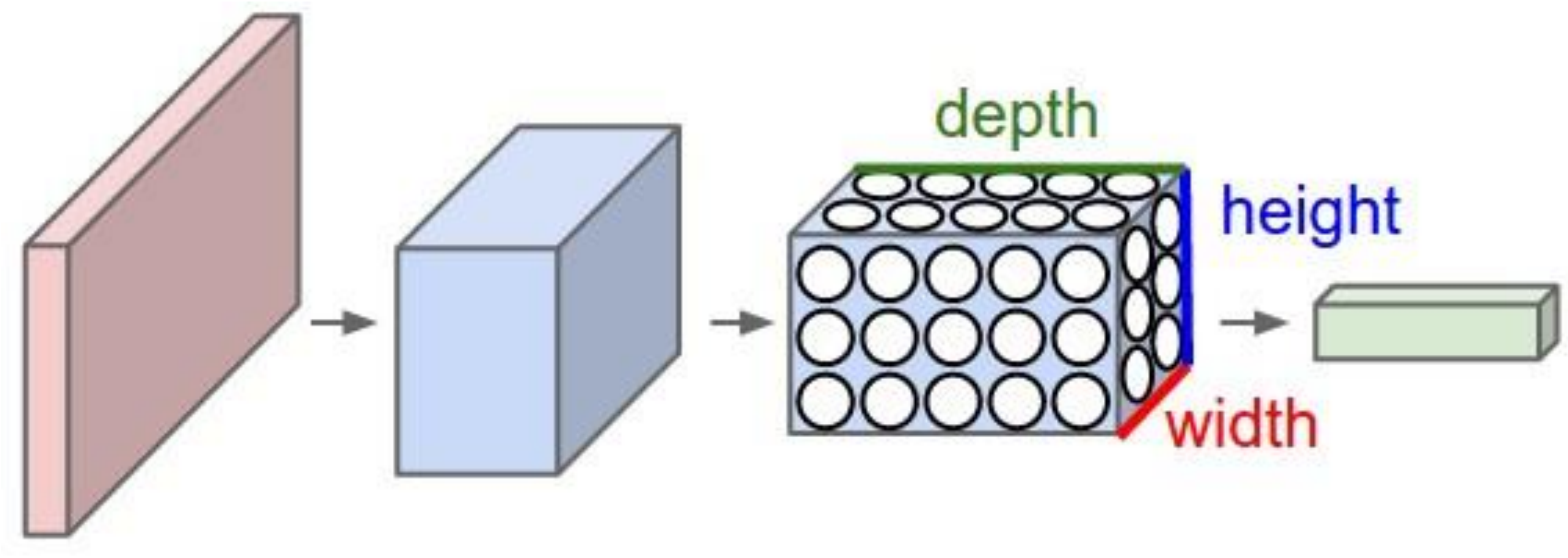
Conv2D Weights [0]
3 x 3

1.2	-0.3	-1.3
1.8	0.1	-1.6
1.1	0.2	-0.4

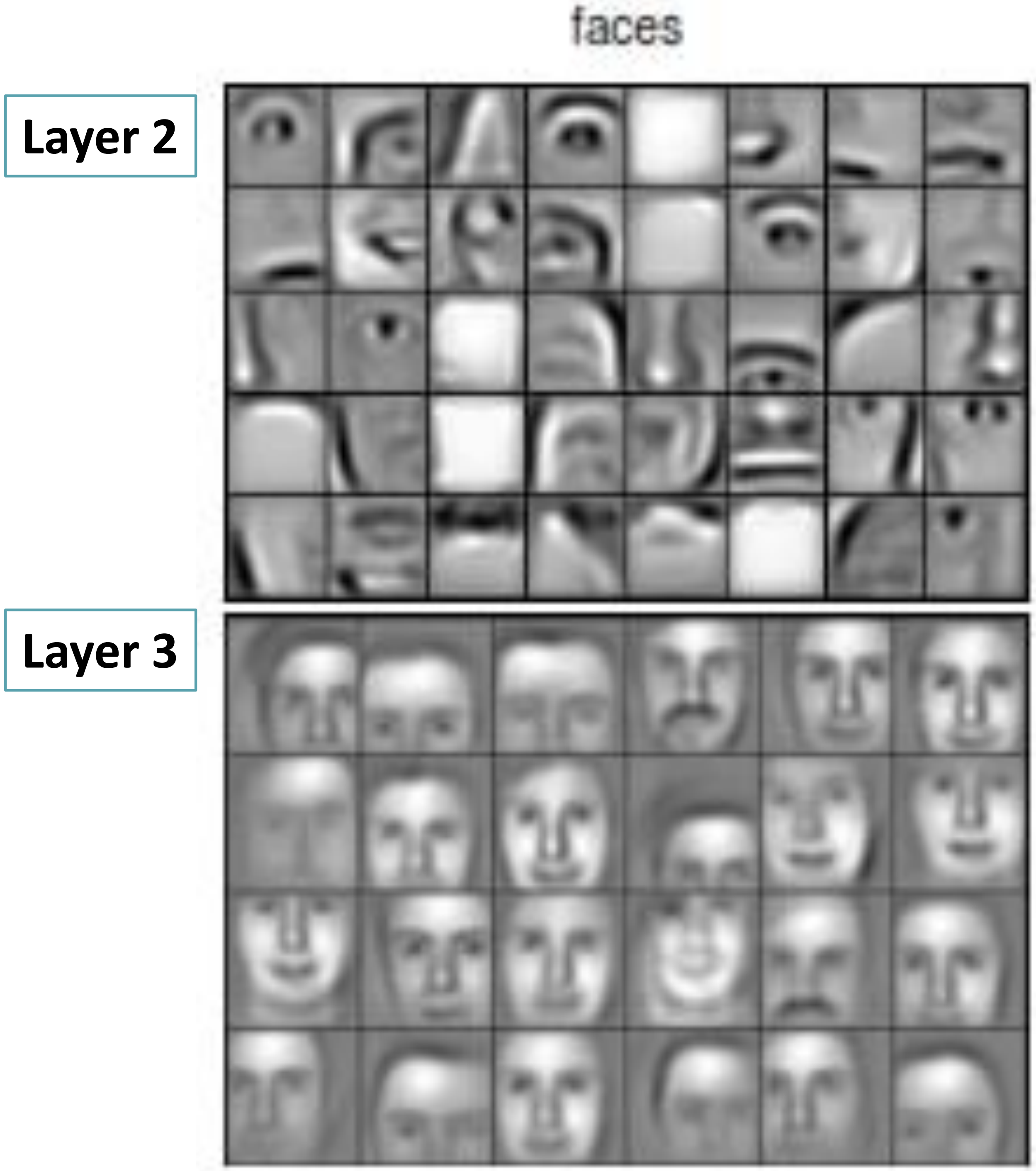


Forward Propagation
$Z_1 = s(X * W_1)$
W_1
U_1^1
X
Z_2
U_2^1
W_2
U_3^1
W_3
Z_3
a^l
3
INPUT MNIST IMAGE
INPUT IMAGE
CONVOLUTION MASKS
HIDDEN LAYER
SOFT-MAX OUTPUT LAYER
0.2
0.1
0.7
0
0
1
PREDICTED LABEL PROBABILITIES
TARGET LABEL
Cost Computation
Backward Propagation

Rule of thumb:
Layers get more compact but deeper.

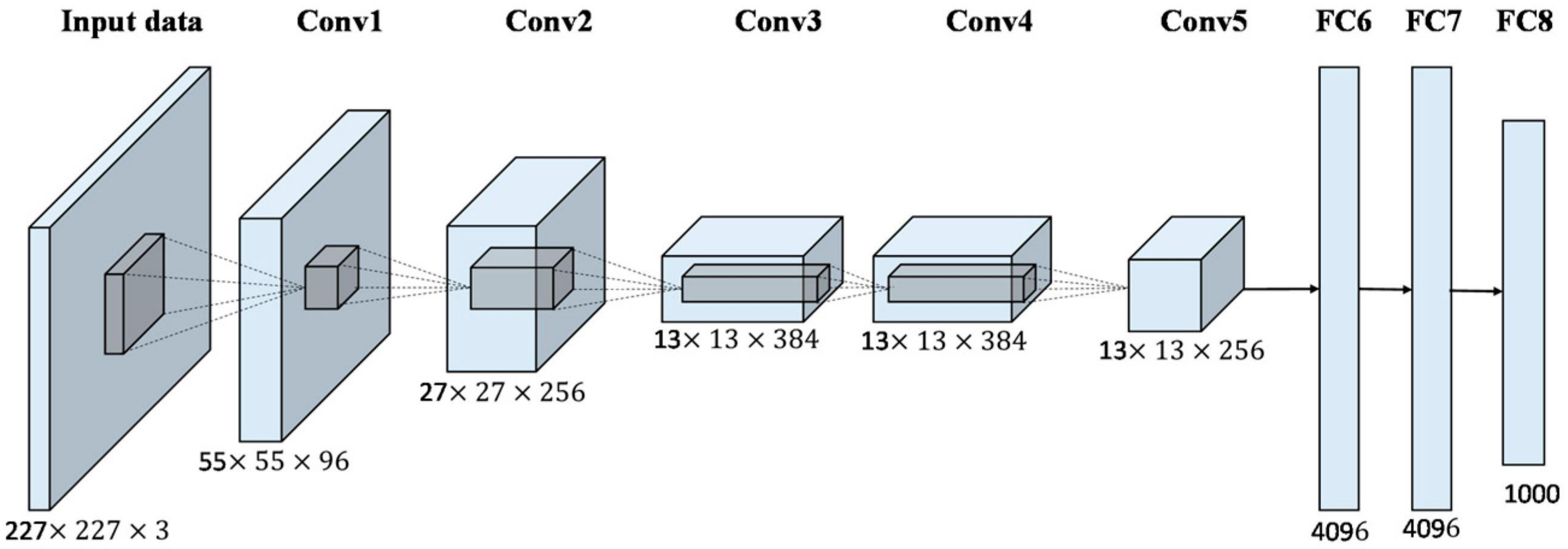


Rule of thumb: Filters become sensitive to higher level features in deeper layers



www.chioka.in

Rule of thumb: Use a pre-built architecture



https://medium.com/

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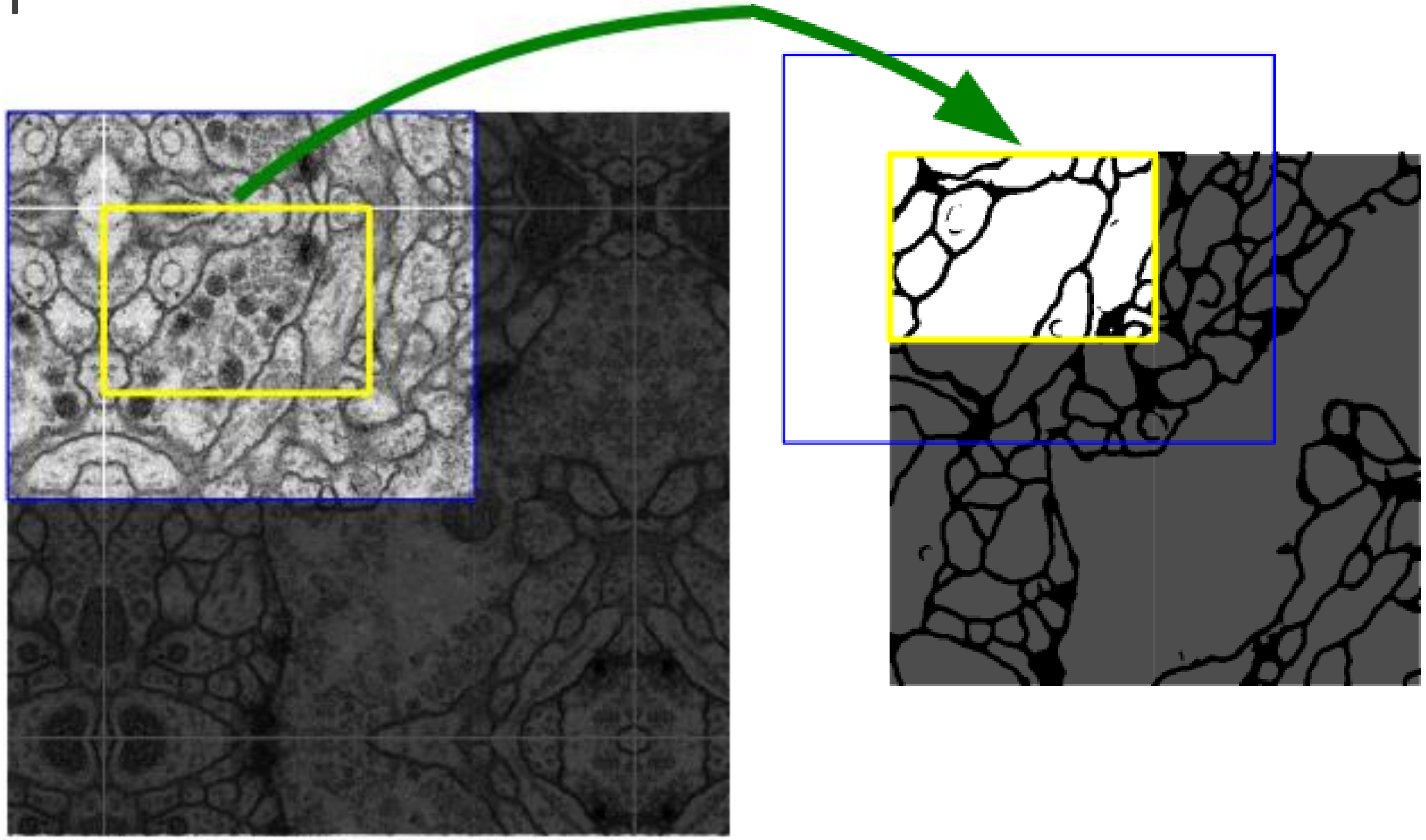
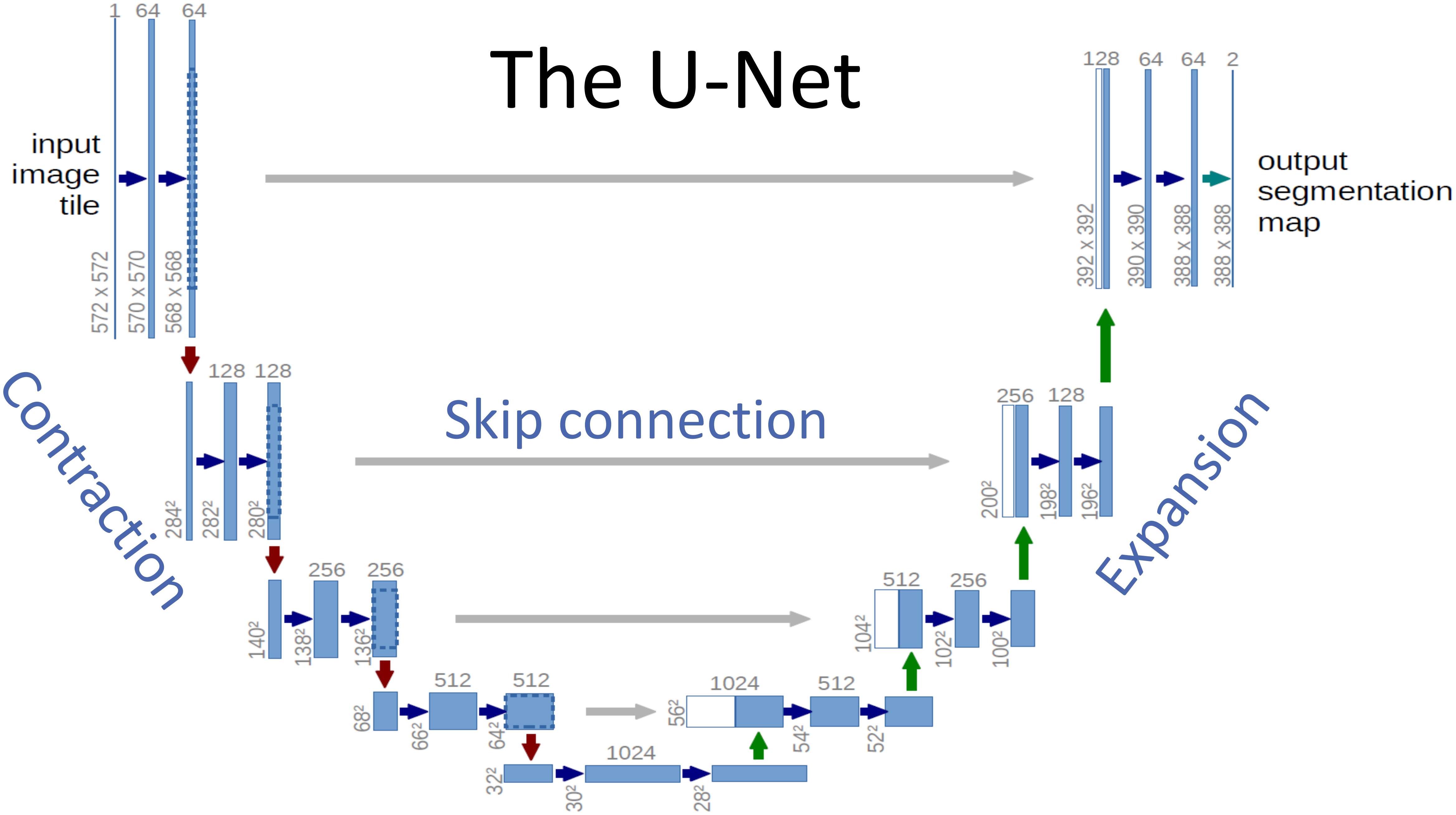


Ronneberger et al., 2015

The U-Net



Ronneberger et al., 2015

Layer Types

Convolutions

- 3 x 3 Filter Size
- “Valid” padding

Max Pooling

Up-convolutions

Skip Connections

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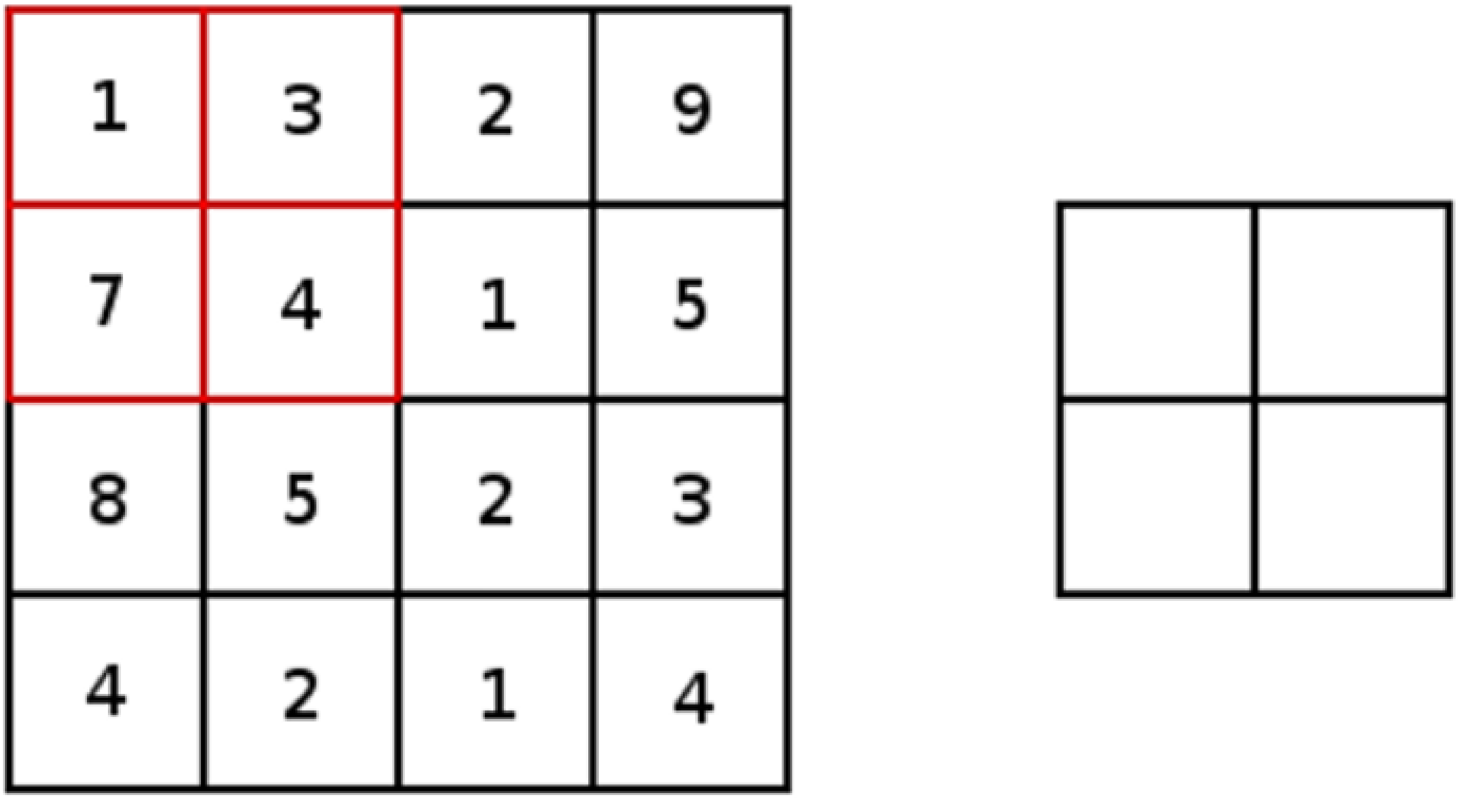


Layer Types

Convolutions
- 3 x 3 Filter Size
- “Valid” padding

Max Pooling

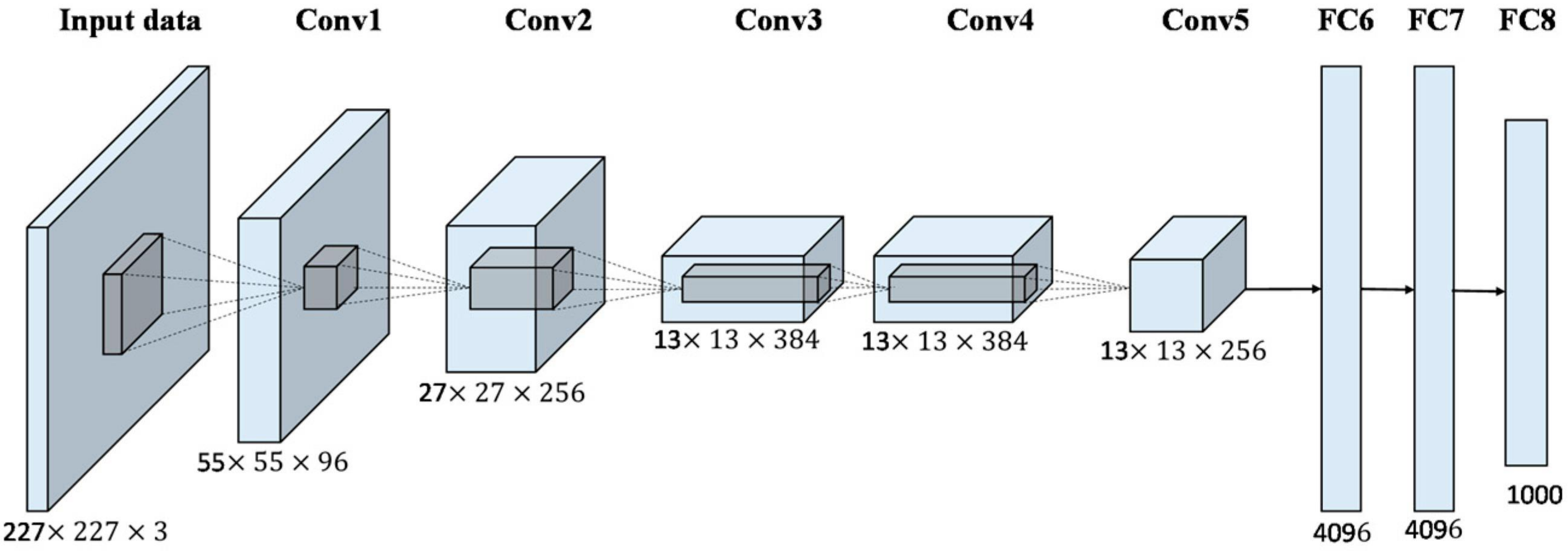
Up-convolutions

Skip Connections

1	3	2	9
7	4	1	5
8	5	2	3
4	2	1	4

7	9
8	

Convolutions change depth, Pooling changes height / width



https://medium.com/

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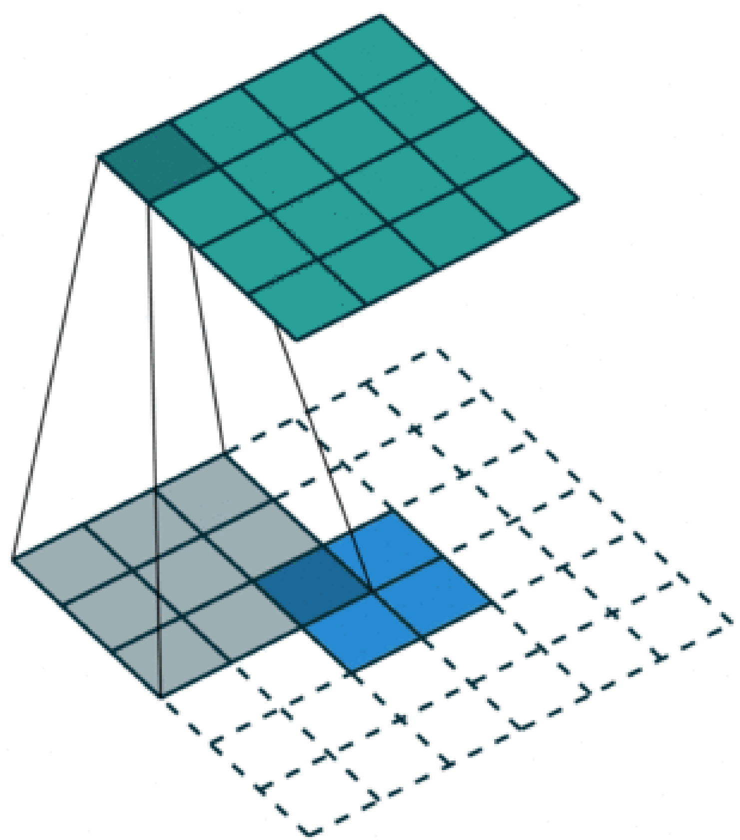
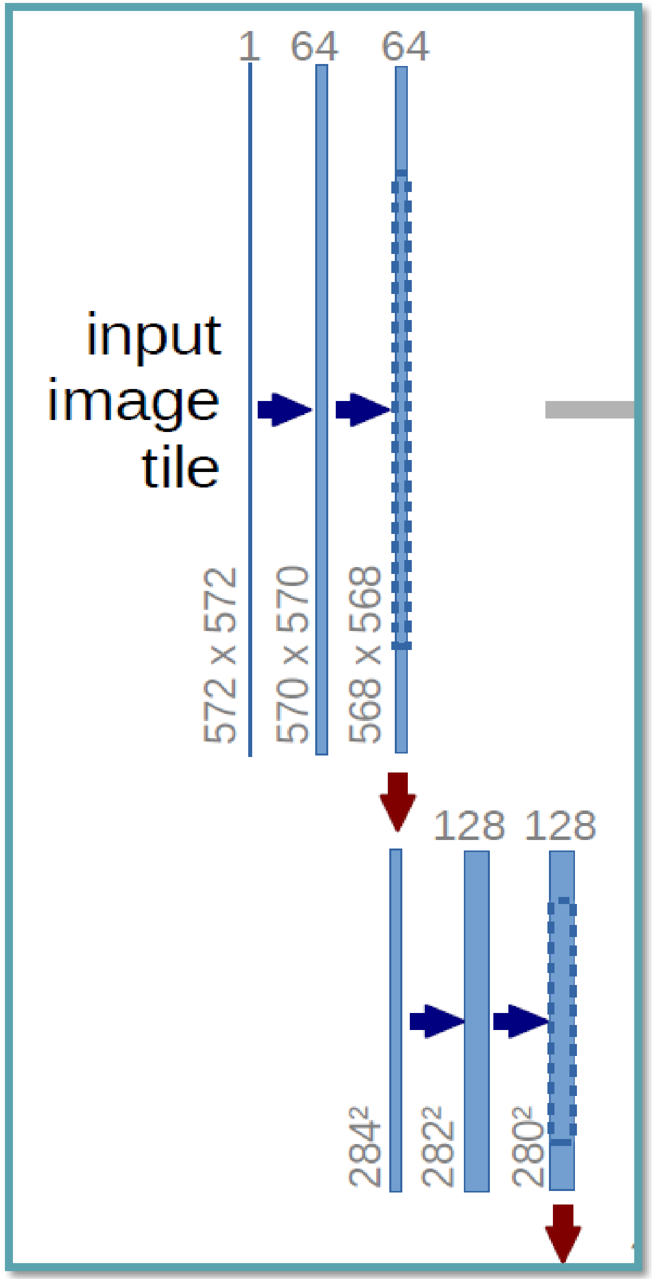


https://github.com/vdumoulin/conv_arithmetic

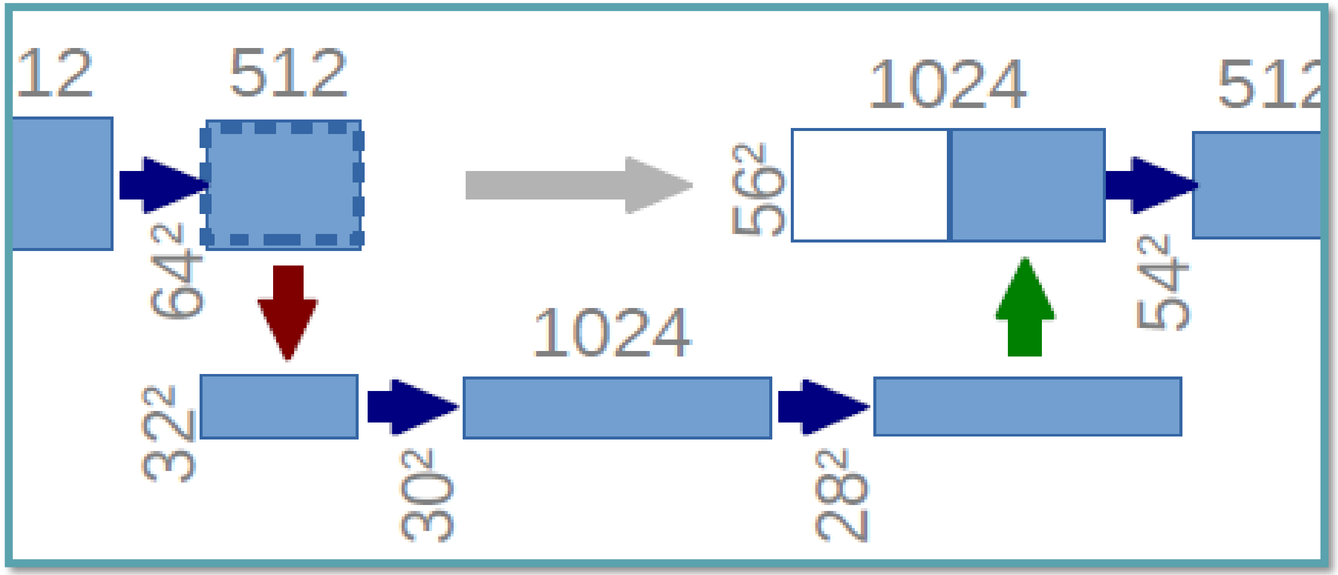
Contraction Path

Layer	Area	Depth
Input	572^2	1
Conv1	570^2	64
Conv2	568^2	64
MaxPool1	284^2	64
Conv3	282^2	128
Conv4	280^2	128
MaxPool2	140^2	128



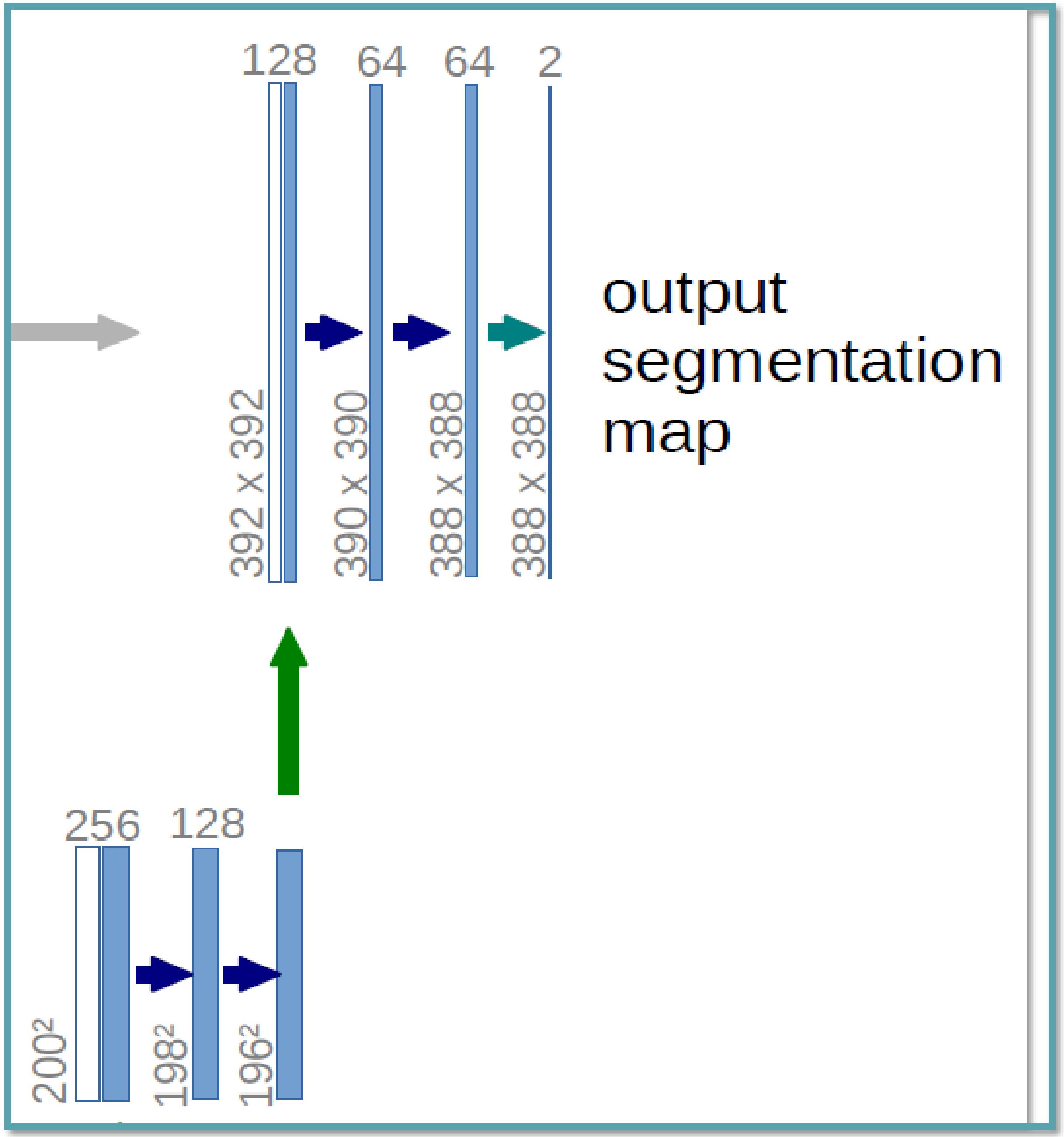
Basin

Layer	Area	Depth
MaxPool4	32^2	512
Conv9	30^2	1024
Conv10	28^2	1024
UpConv1	56^2	512



Expansion Path

Layer	Area	Depth
UpConv3	200^2	256
Conv15	198^2	128
Conv16	196^2	128
UpConv4	392^2	128
Conv17	390^2	64
Conv18	388^2	64
Output	388^2	2



Skip Connections

Crops and copies information from earlier in the network to deeper layers

Allows final resolution to remain high

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Kjetil Åmdal-Sævik

Keras U-Net starter - LB 0.277

747 voters

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Tags tutorial

Notebook

```python
# Build U-Net model
inputs = Input((IMG_HEIGHT, IMG_WIDTH, IMG_CHANNELS))
s = Lambda(lambda x: x / 255) (inputs)

c1 = Conv2D(8, (3, 3), activation='relu', padding='same') (s)
c1 = Conv2D(8, (3, 3), activation='relu', padding='same') (c1)
p1 = MaxPooling2D((2, 2)) (c1)

c2 = Conv2D(16, (3, 3), activation='relu', padding='same') (p1)
c2 = Conv2D(16, (3, 3), activation='relu', padding='same') (c2)
p2 = MaxPooling2D((2, 2)) (c2)
```

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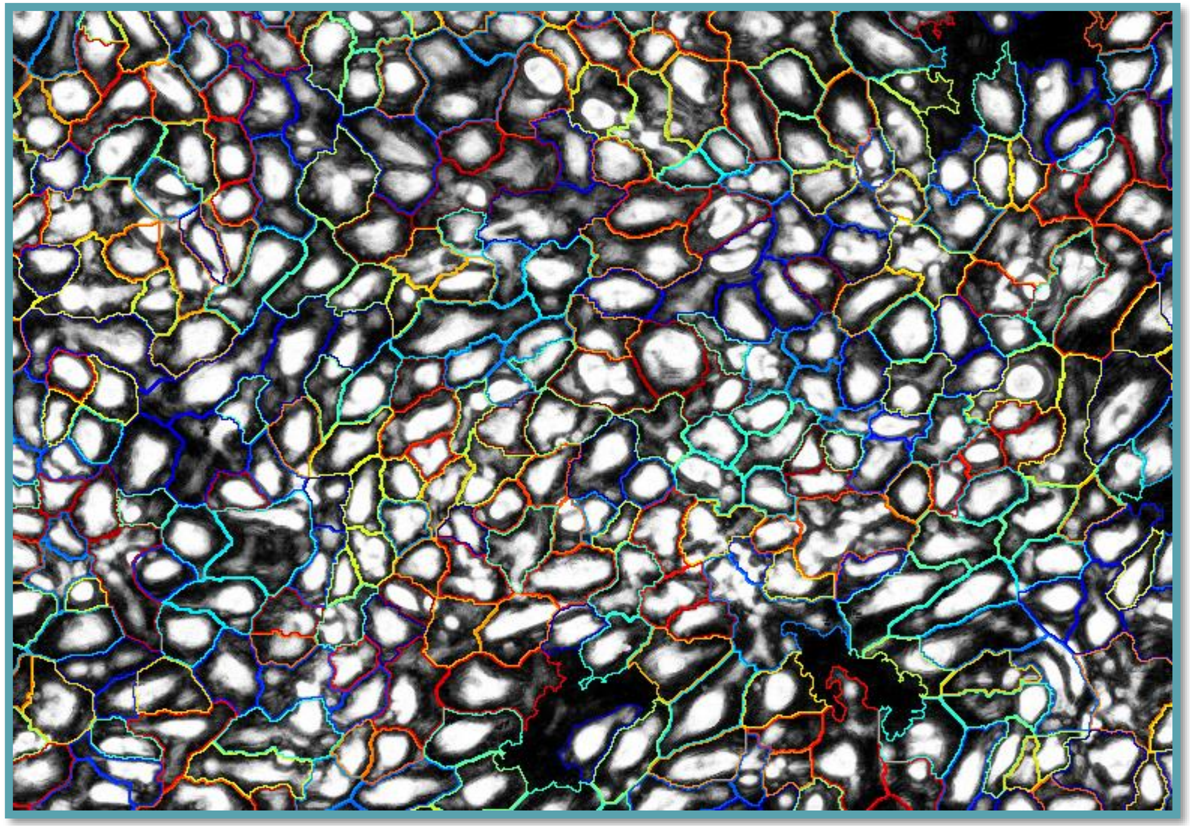


Model performance (0.0 – 0.6)

Approach	Mean Average Precision
1. Vanilla image processing	0.20 – 0.28
2. Vanilla U-Net	0.25 – 0.42
3. Vanilla Mask R-CNN	0.37 – 0.50
4. U-Net + Deep Watershed	0.45 – 0.55
5. Winning model	~ 0.65

Insight 1:
Data augmentation is critical.

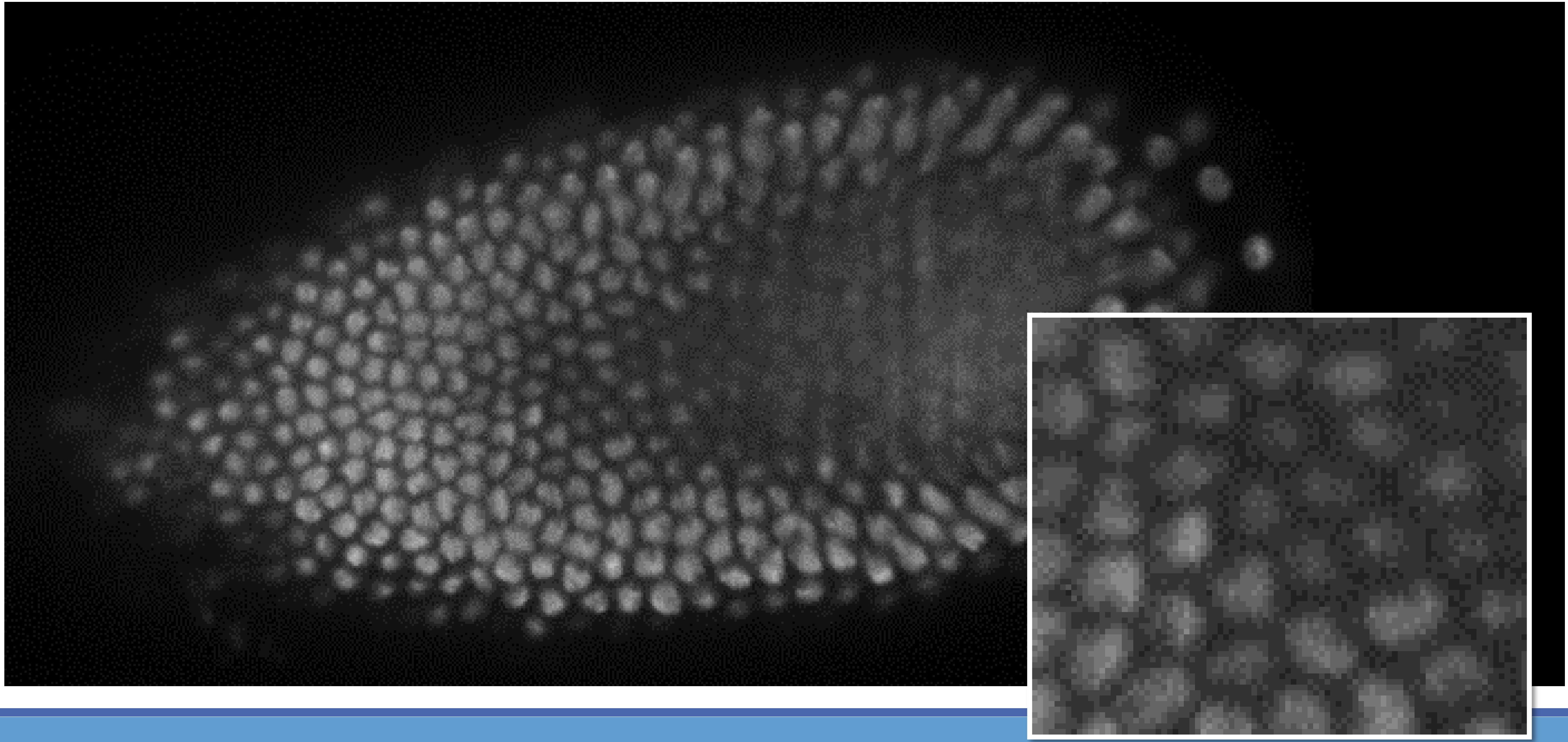
1. Add gaussian noise
2. Color to gray
3. Contrast and brightness
4. Random crop
5. Mosaics
6. Random rotate

Insight 2:
Neural networks don’t do it all.

Output of models was treated as “candidate nuclei”… still need to post-process data!

- e.g., Use morphological features such as solidity, circularity, convexity, area, neighbors median, count, etc. to calculate “predicted IOU” for each mask.

Insight 3: Pick the right target…



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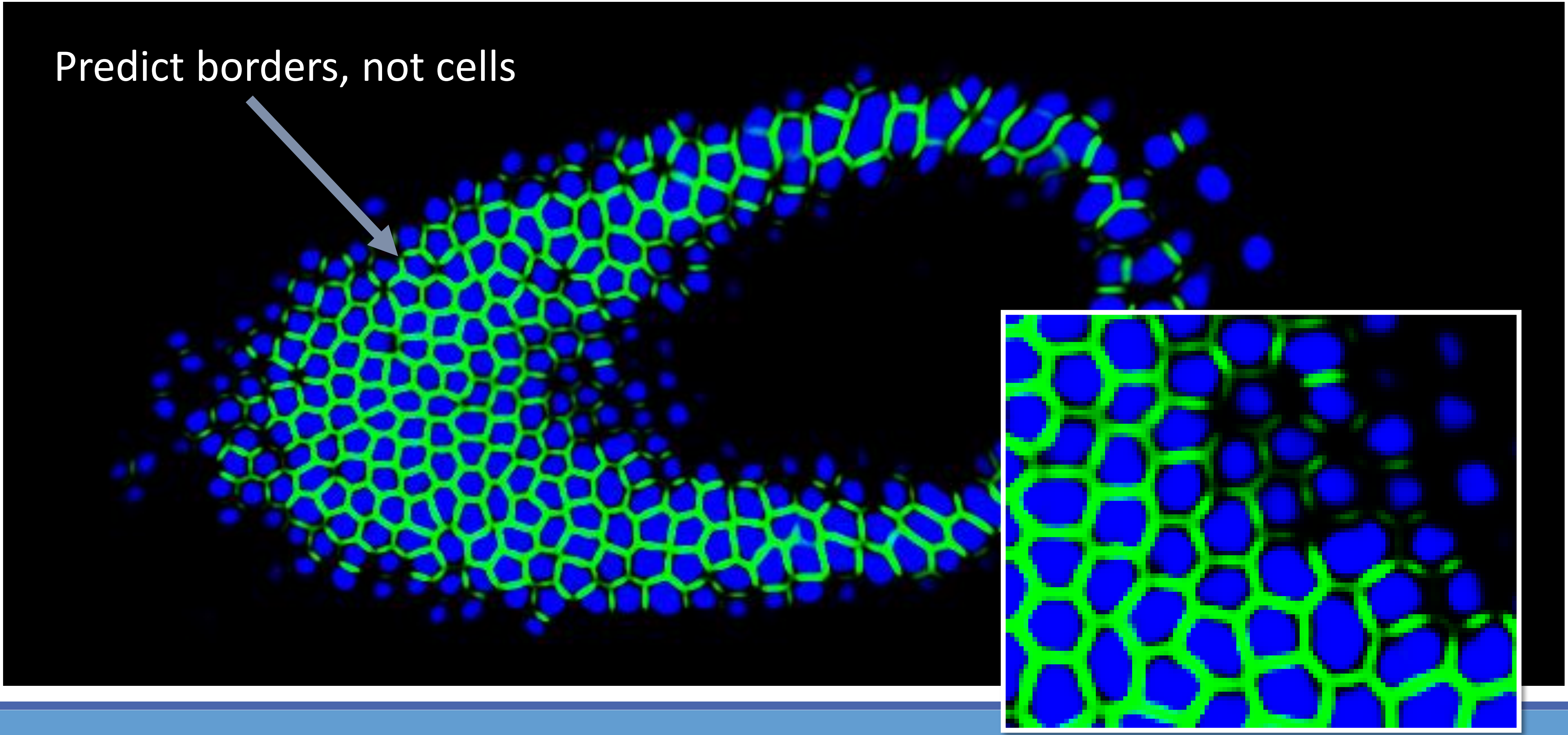

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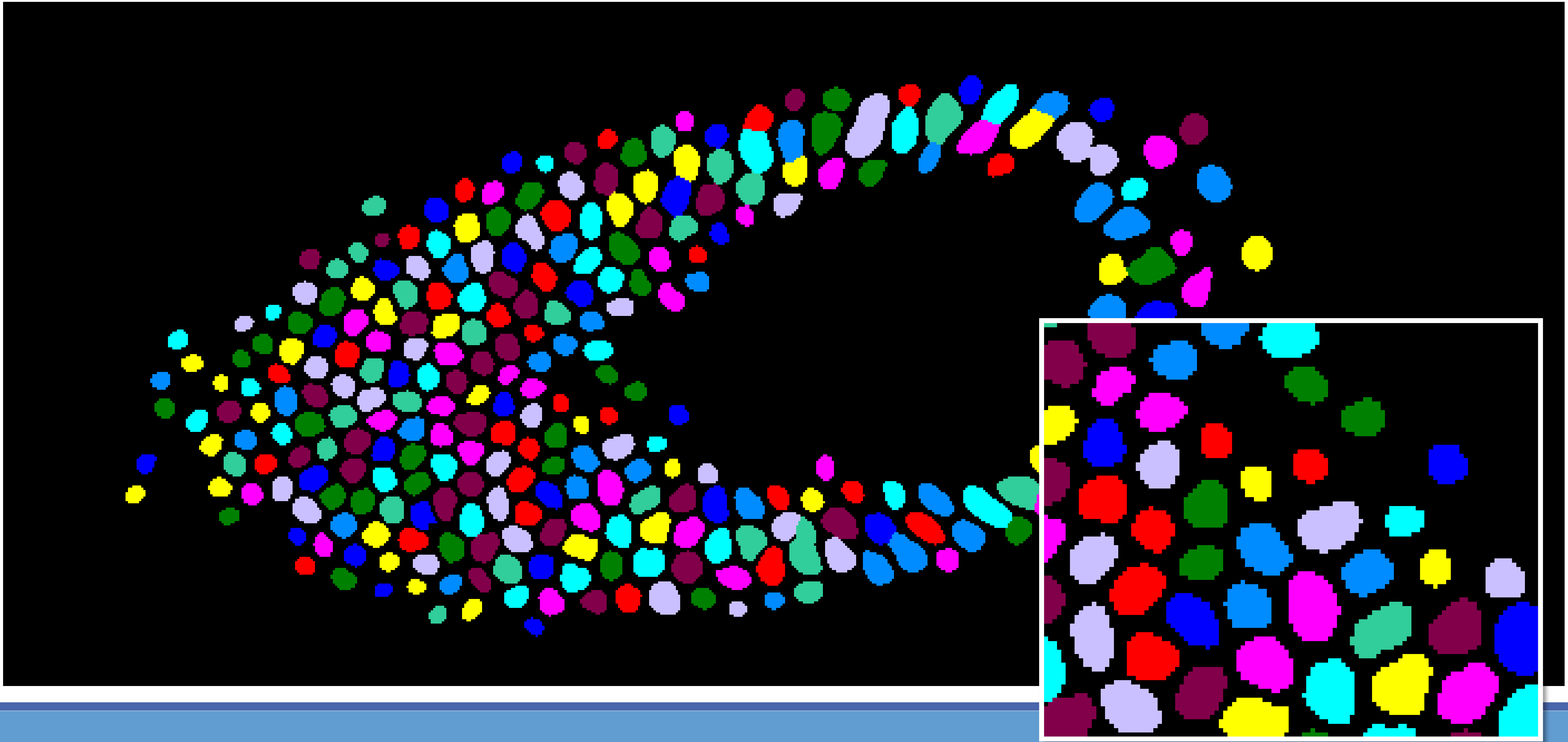

For further reference…

1. Coursera's Deep learning specialization
2. "U-Net: Convolutional Networks for Biomedical Image Segmentation" by Ronneberger, Fischer and Brox
3. Kaggle's Data Science Bowl 2018
   1. 1st Place Solution from *ods.ai*
   2. 4th Place U-Net + Watershed from *Nuclear Vision*
   3. 11th Place Open Solution from Zheng Li