SSY098 - Image Analysis

Lecture 1 - Introduction and Linear Classifiers

Torsten Sattler
(slides adapted from Olof Enqvist)

Team

Rasmus Kjær Høier
hier@chalmers.se

Carl Toft
carl.toft@chalmers.se

José Pedro Lopes Iglesias
jose.iglesias@chalmers.se

Torsten Sattler torsat@chalmers.se

Course Information

- No exam!
- Exercises (optional, non-graded)
- Four mandatory lab assignments
  - Hand in code and short report
  - Pass or fail
  - Recommended to do labs in pairs or groups of 3
  - Deadlines (23:59): February 2nd, February 12th, February 23nd, March 4th
- Mandatory mini project (four choices):
  - Hand in code, report
  - Graded
  - Has to be done individually
- Deadlines are strict, but you have 8 late days in total
- Revisions of labs possible

Grading

- Grade 3:
  - Pass all 4 labs
  - Pass basic part of the project
- Grade 4:
  - Pass all 4 labs, pass basic part of the project
  - Theoretical questions from project **or** advanced part
- Grade 5:
  - Pass all 4 labs, pass basic part of the project
  - Theoretical questions from project **and** advanced part
- Labs 2-4 have theoretical questions
  - Get 12 out of 18 points to get a better grade (only if pass)
  - Have to be answered individually
- Late days also apply to project (8 in total)
- Theoretical questions from lab cannot be revised
- More details on projects on Canvas page and later in course

Check Canvas Course Page Regularly

SSY098 › Syllabus

lp3 VT20

- Home
- **Syllabus**
- Files
- Assignments
- Discussions
- Grades
- People

Image analysis

Jump to today

Course-PM

SSY098 Image analysis lp3 VT20 (7.5 hp)

Course is offered by the department of Electrical Engineering

Contact details

- examiner, lecturer: Torsten Sattler, torsat@chalmers.se, room 7316, EDIT building
- teaching assistants:
  - Rasmus Kjær Høier, hier@chalmers.se, room 7318, EDIT building
  - José Pedro Lopes Iglesias, jose.iglesias@chalmers.se, room 7412, EDIT building
  - Carl Toft, carl.toft@chalmers.se, room 7314, EDIT building

Course purpose

The main aim of the course is to give a basic introduction to the algorithms and mathematical methods used in image analysis, to an extent that will allow the student to handle industrial image analysis problems. In addition the aim is to help the student

Learning Materials

- Lecture Notes from SSY097
  - Do not cover all material covered in the lecture
  - Cover material not covered in the lecture
- Book: Szeliski, Computer Vision: Algorithms and Applications
  - More detailed than lecture notes, provides pointers to literature
  - Use to read up on technical details
- Book: Goodfellow et al., Deep Learning
  - Very detailed introduction to Deep Learning
  - Covers generative neural networks (not covered in lecture notes)
- Books are freely available, see Canvas for links

Ask Questions

- Feel free to ask questions any time
- Please give us feedback (positive and negative) about the lecture, the labs, …
  - Talk to me before or after the lecture
  - Write me an email
- Happy to adapt based on your suggestions

Today

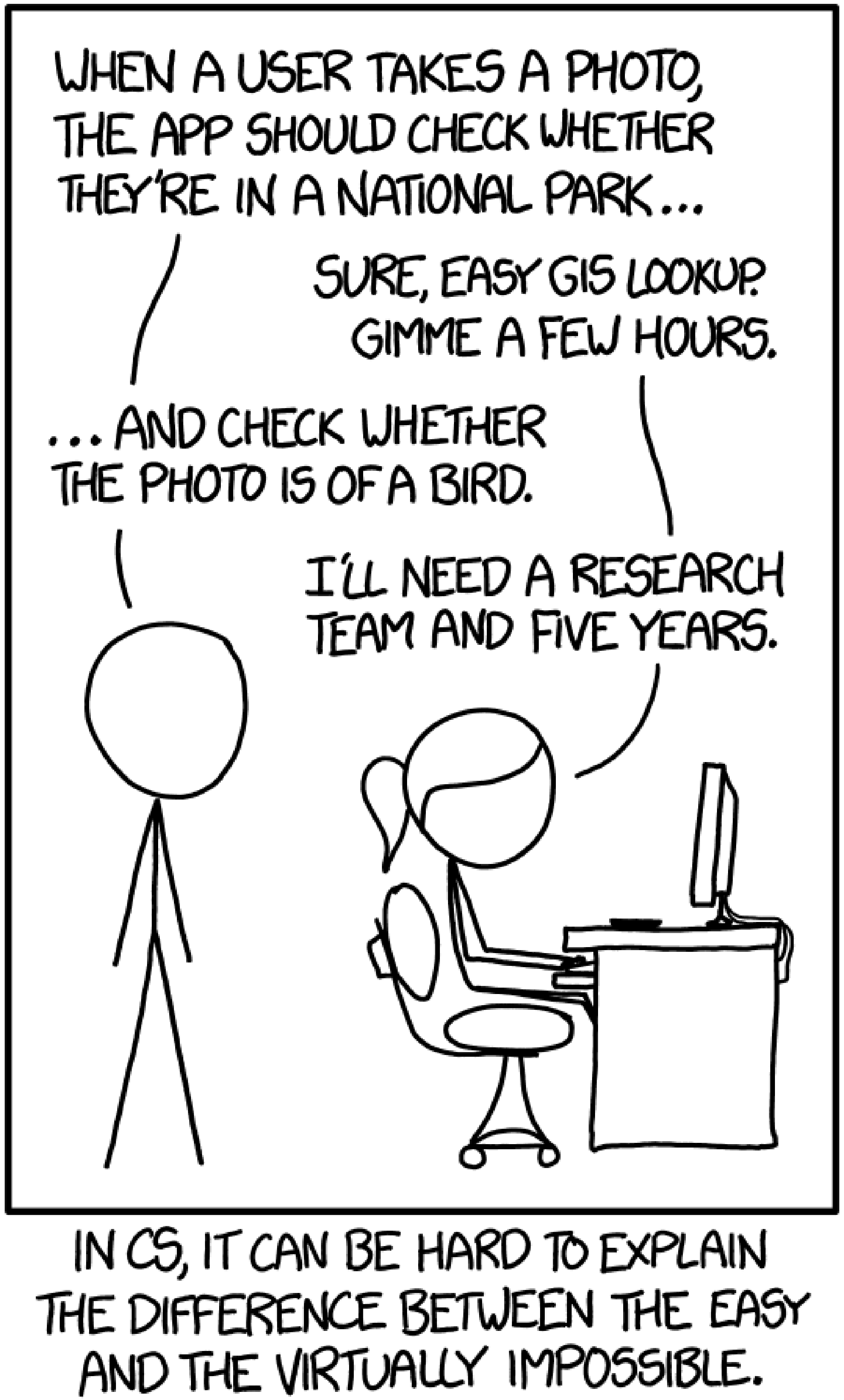
- What is Image Analysis
- Modeling Images
- Filtering and Linear Classifiers

What is Image Analysis?

Image Classification

Is there a robin in this image?

Image Classification



© Randall Munroe (xkcd.com)
https://xkcd.com/1425/

Computer Vision

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROJECT MAC

Artificial Intelligence Group July 7, 1966

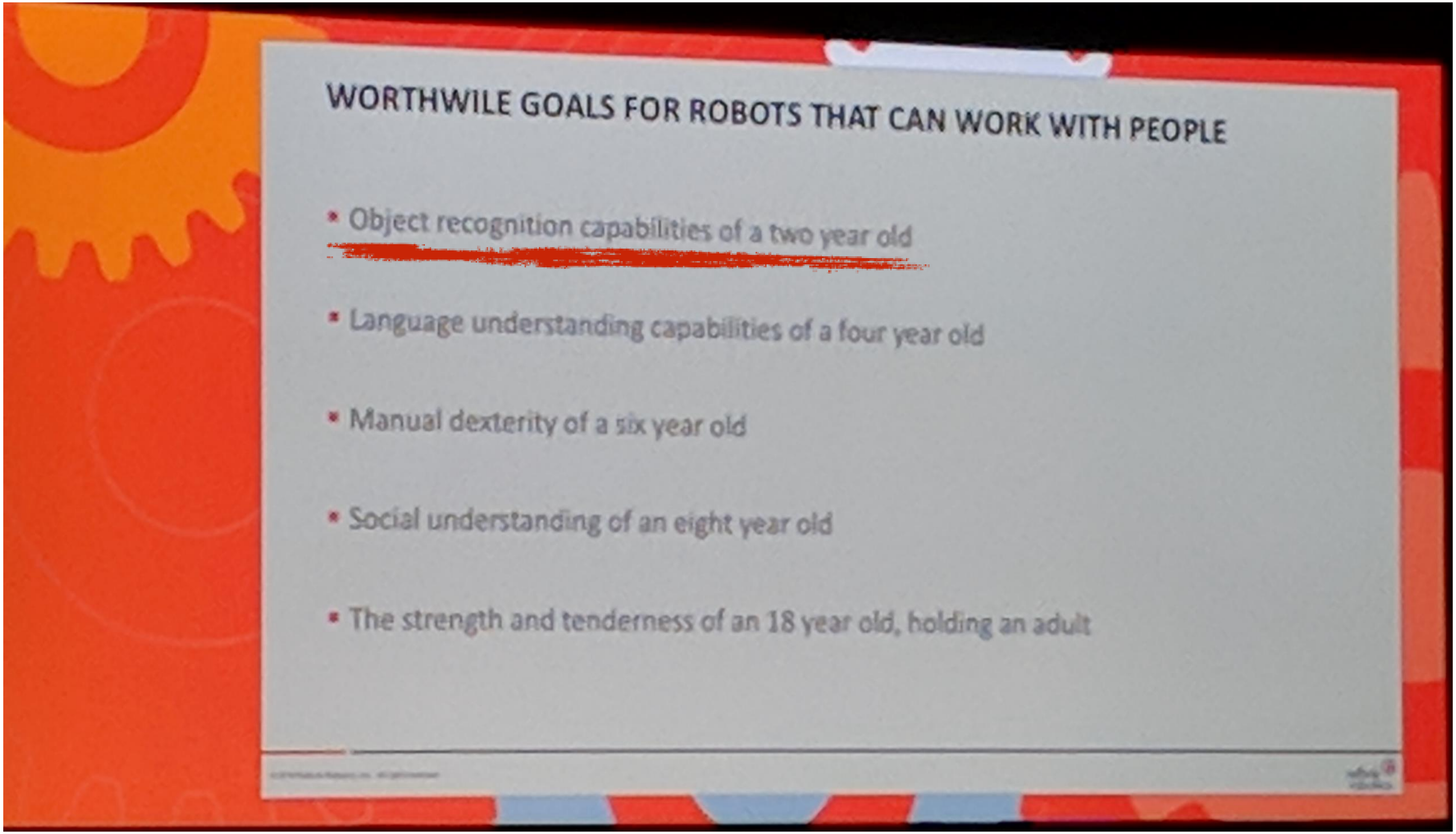
Vision Memo. No. 100.

THE SUMMER VISION PROJECT

Seymour Papert

The summer vision project is an attempt to use our summer workers effectively in the construction of a significant part of a visual system. The particular task was chosen partly because it can be segmented into sub-problems which will allow individuals to work independently and yet participate in the construction of a system complex enough to be a real landmark in the development of "pattern recognition".

Object Detection / Recognition



ICRA 2018 plenary talk by Rodney Brooks

Object Detection

Where is the robin?

Object Detection

[YOLOv3]

Image Segmentation

Full-Resolution Residual Networks for Semantic Segmentation in Street Scenes

Tobias Pohlen, Alexander Hermans,
Markus Mathias, Bastian Leibe

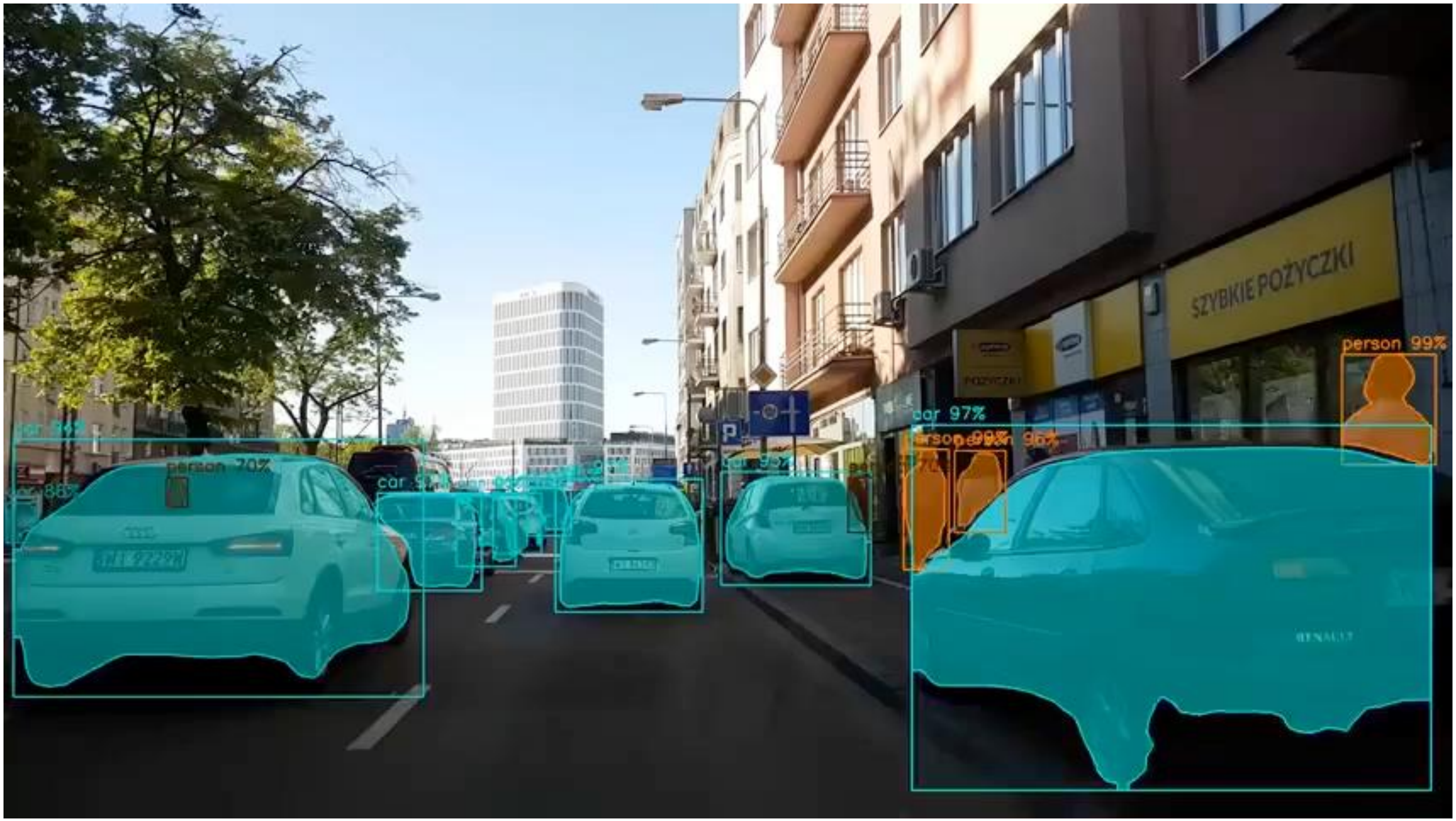
Visual Computing Institute, Computer Vision Group
RWTH Aachen University

Visual Computing Institute
Computer Vision
Prof. Dr. Bastian Leibe

RWTH AACHEN UNIVERSITY

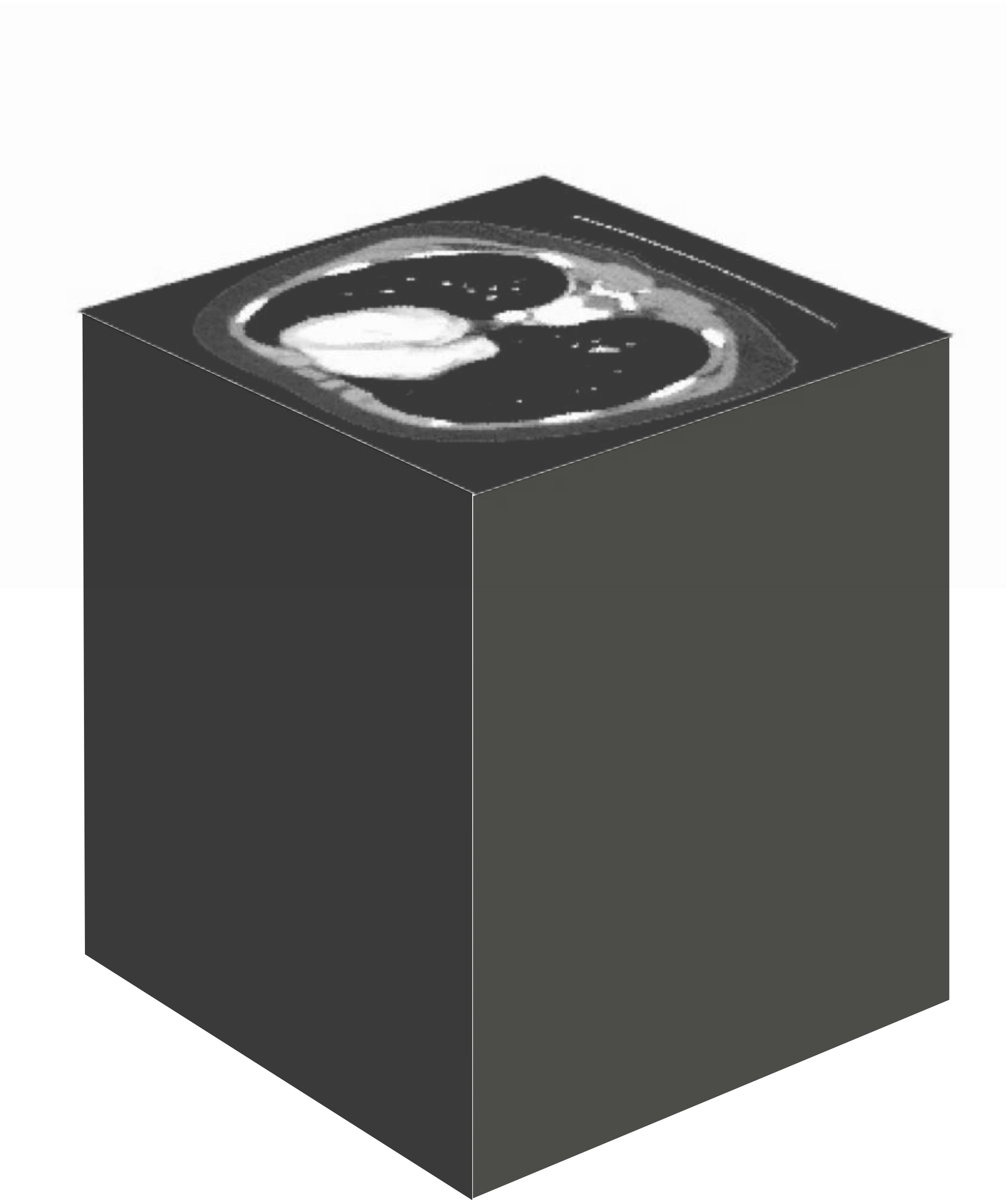
Full-Resolution Residual Networks (FRRNs) for Semantic Image Segmentation in Street Scenes

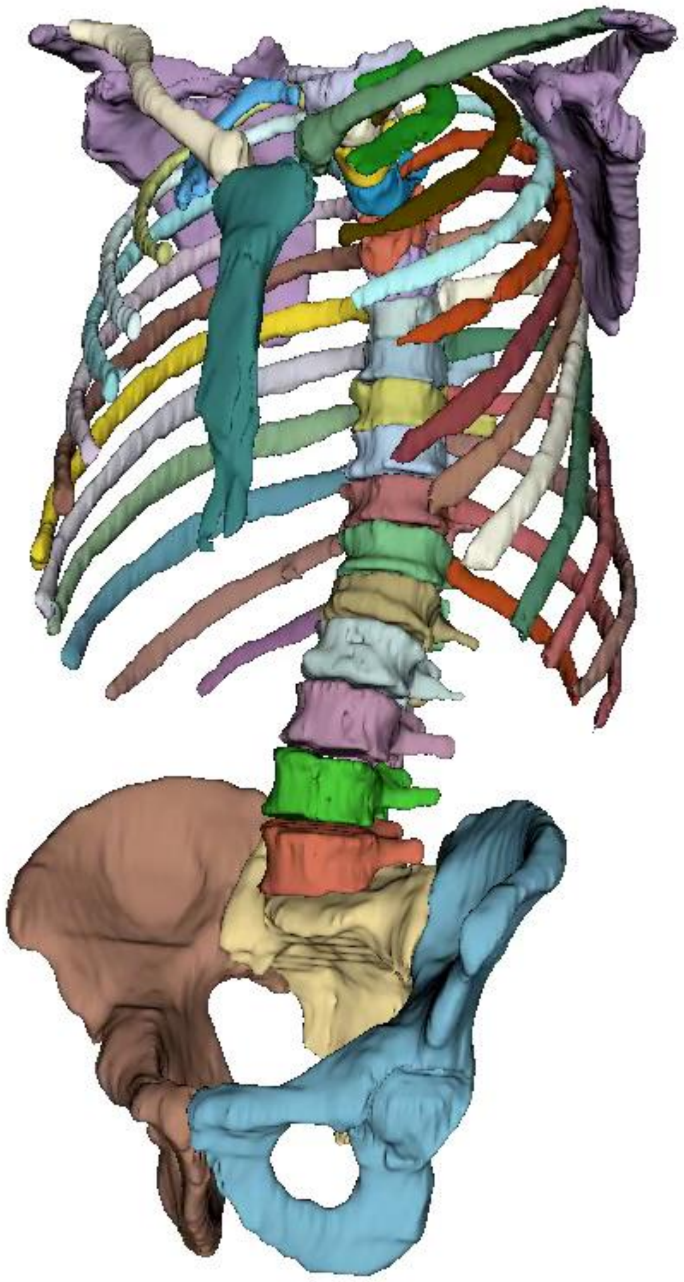
Instance-Level Segmentation



[Masked R-CNN]

3D Segmentation





3D Reconstruction

Dubrovnik

Structure-from-Motion Revisited

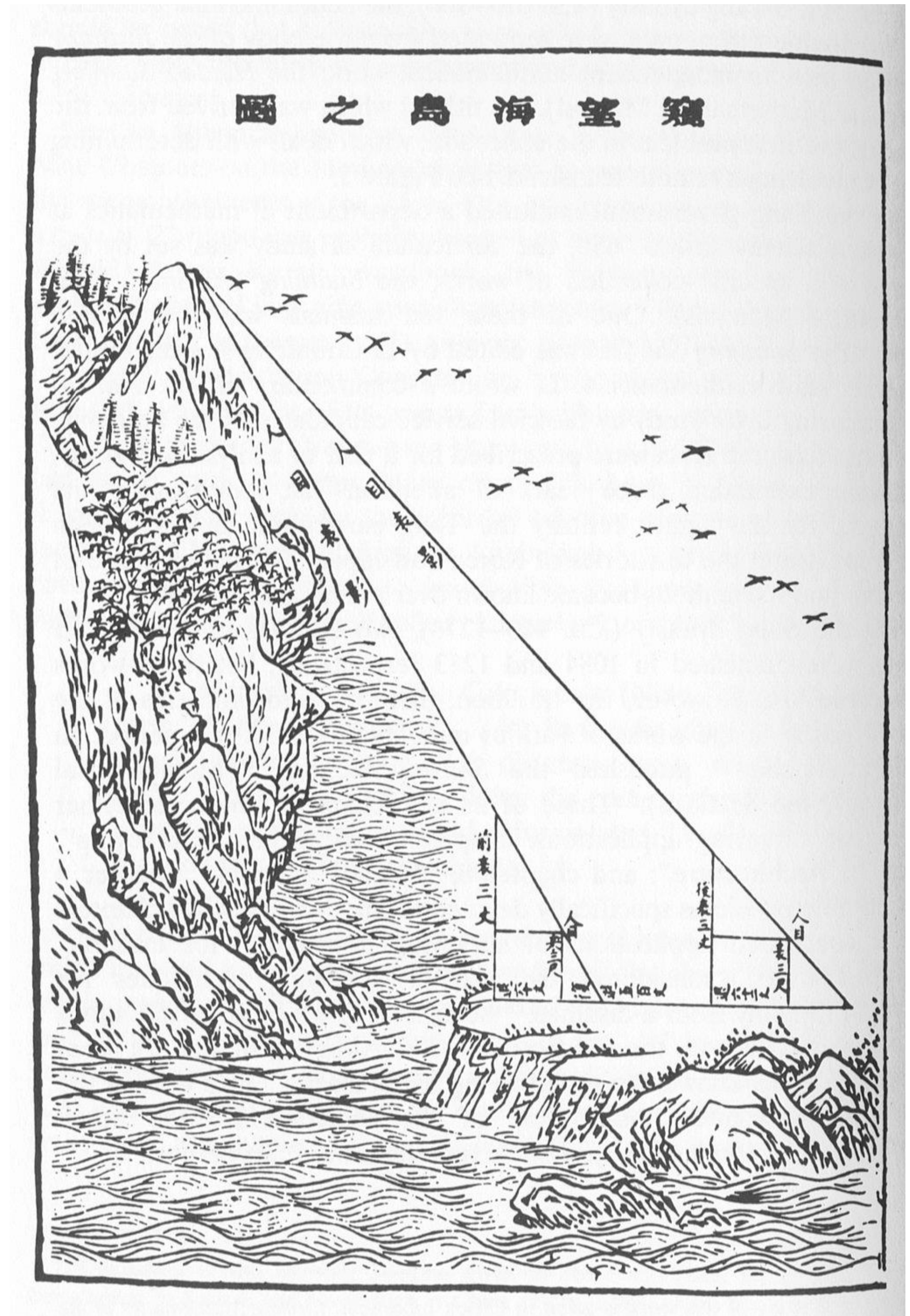
3D Reconstruction

South Building

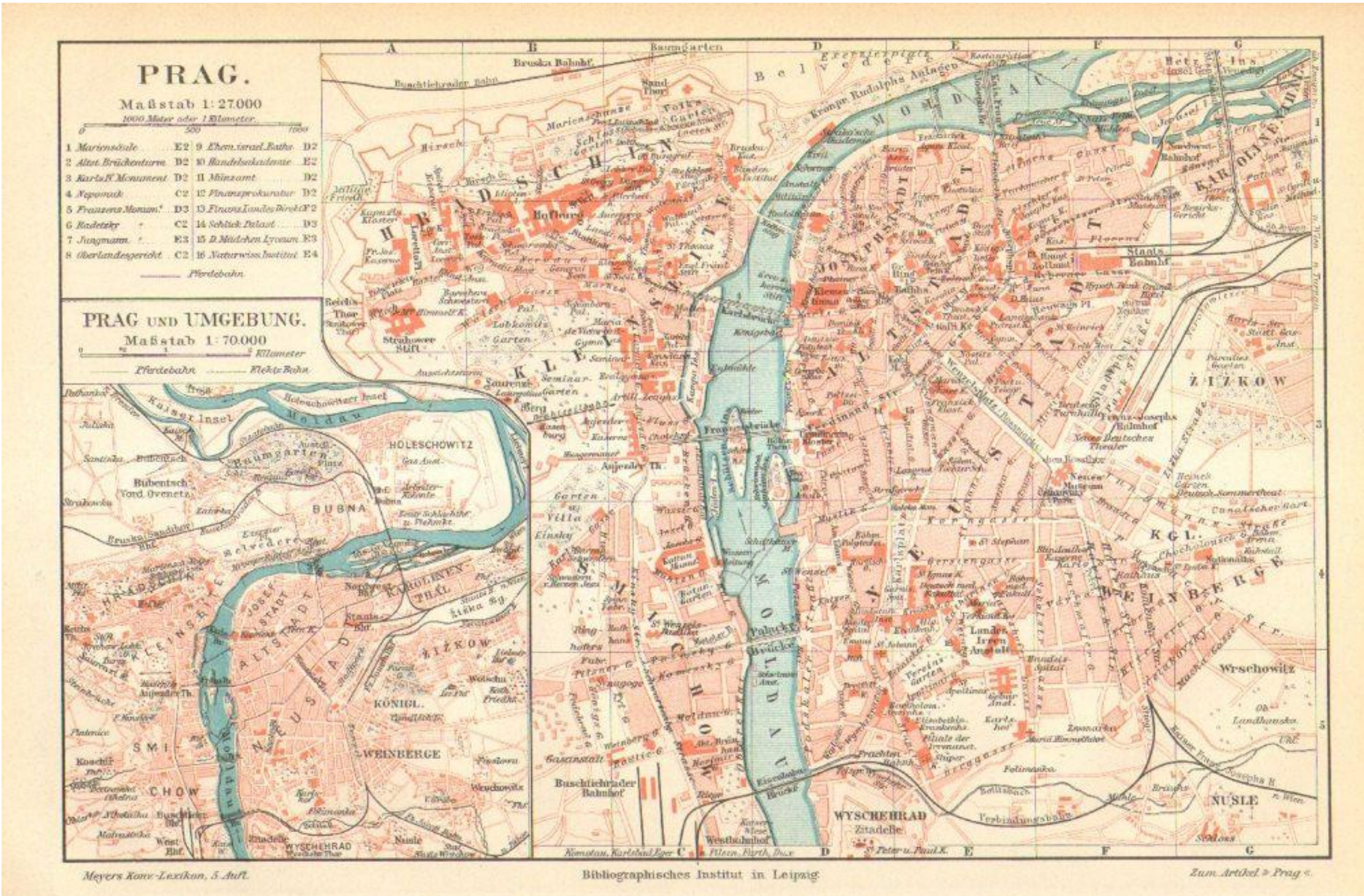
128 images
51 million points

[Pixelwise View Selection for Unstructured Multi-View Stereo]

Photogrammetry



Photogrammetry

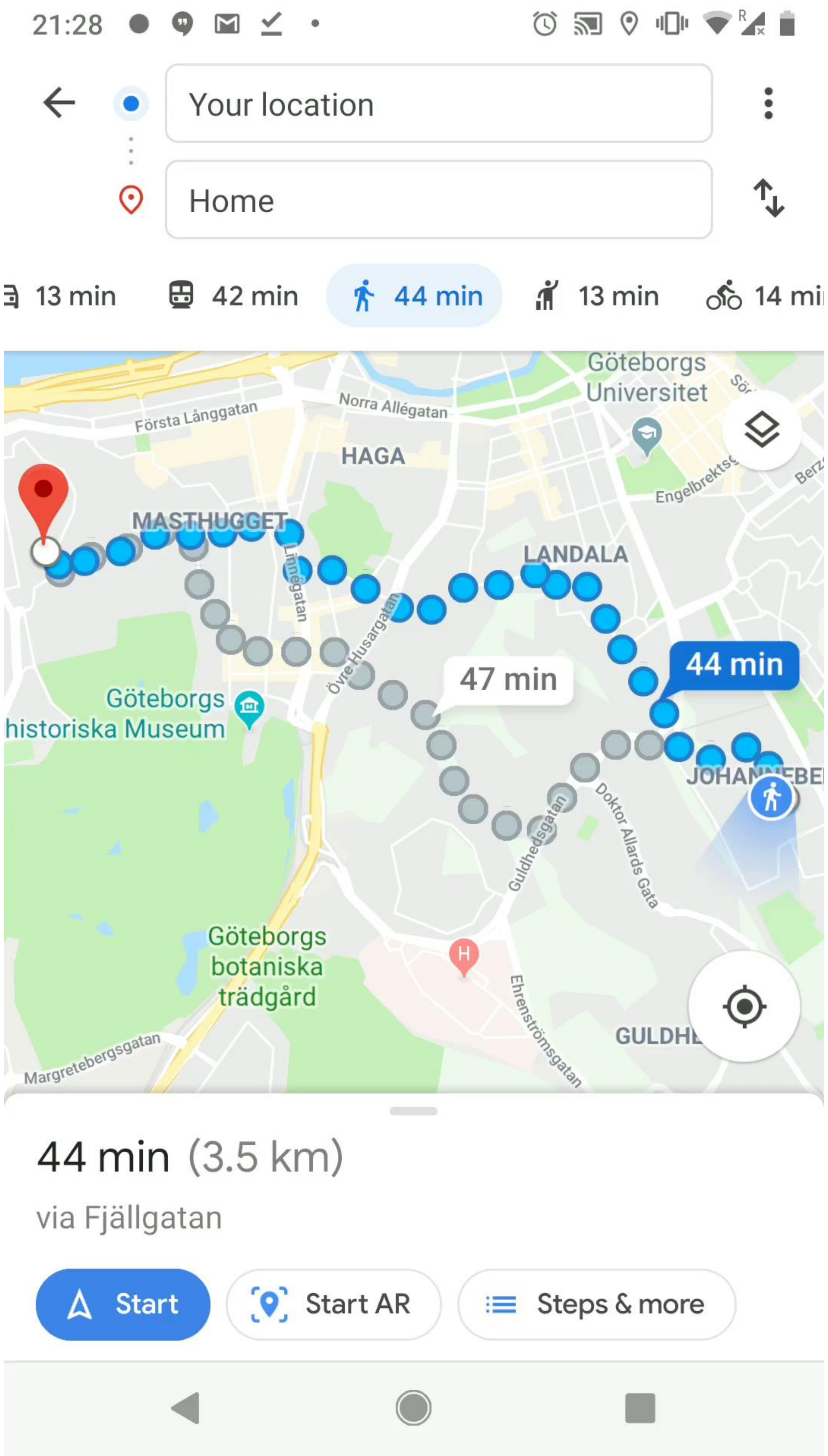


Prague in the 19th century

Mixed Reality

[Microsoft HoloLens]

Mixed Reality

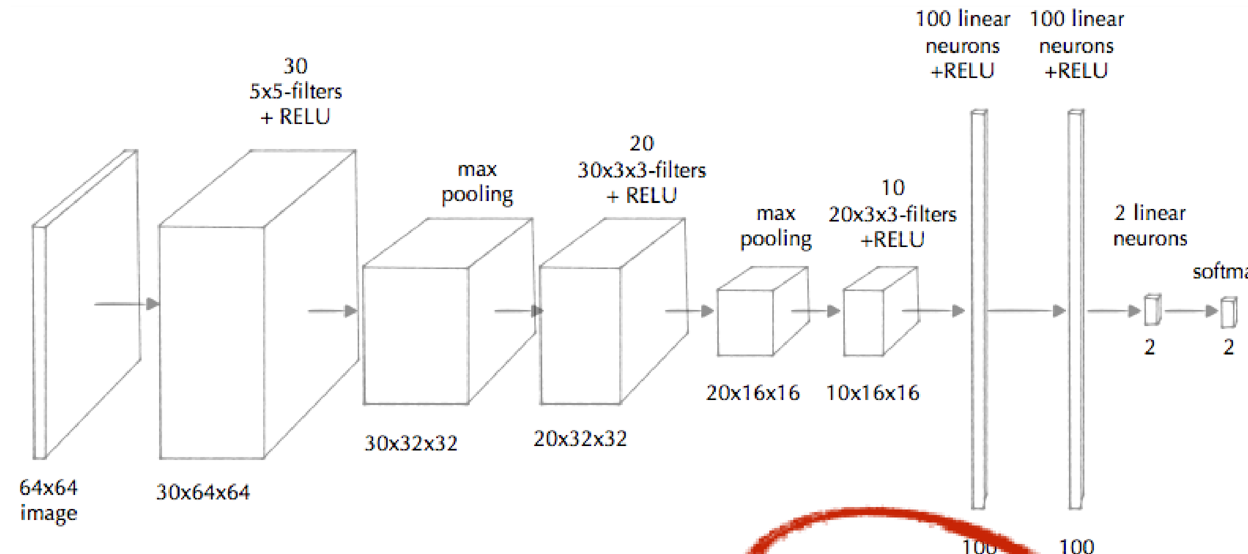


Google Maps

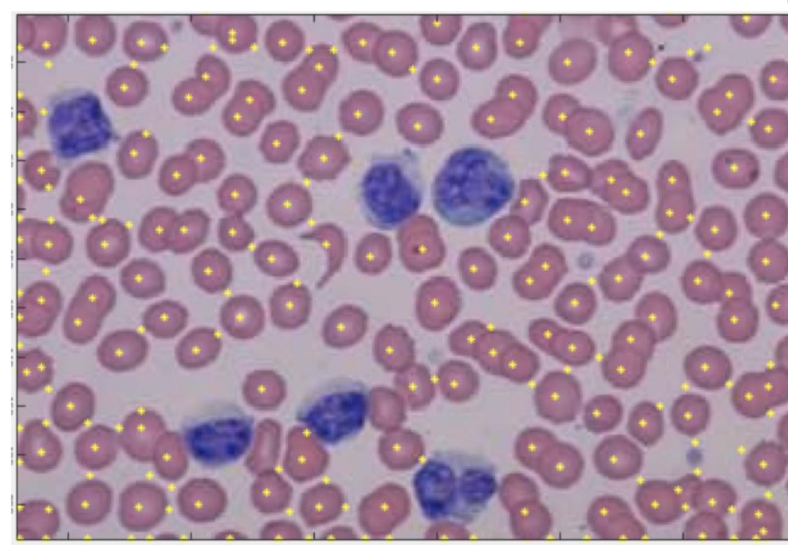
Part 1. Basic image handling and sparse features

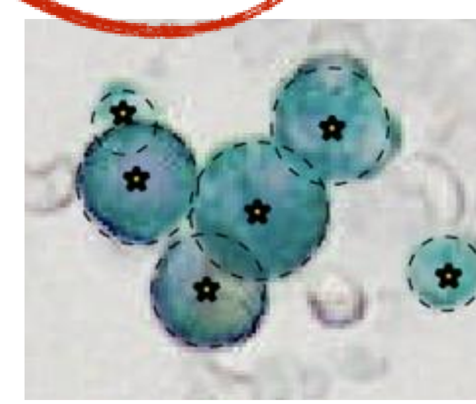
Lab 1

Part 2. Machine learning for classification, detection, and segmentation

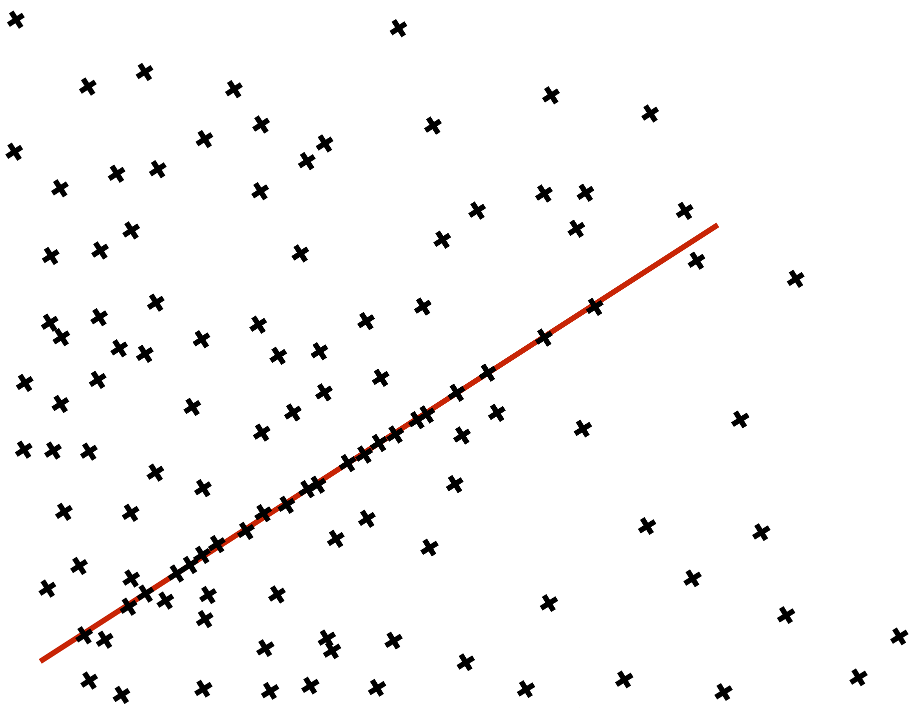


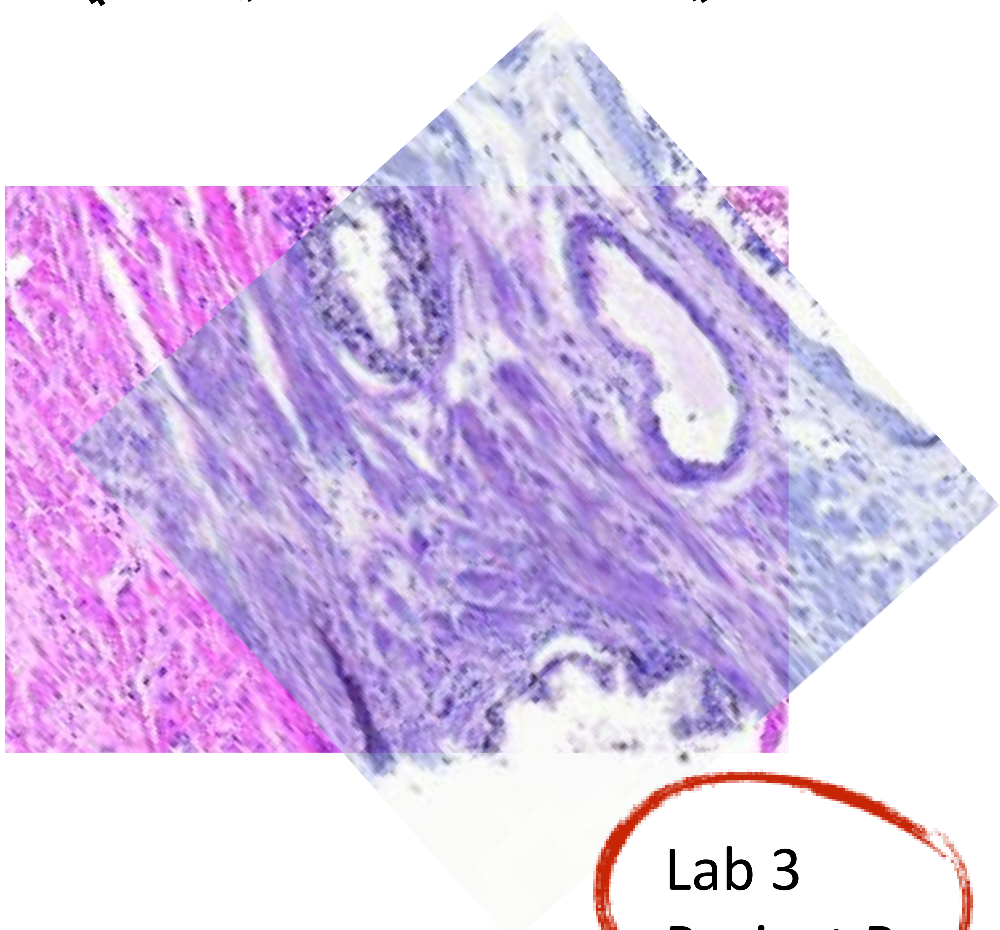
Lab 2
Project A





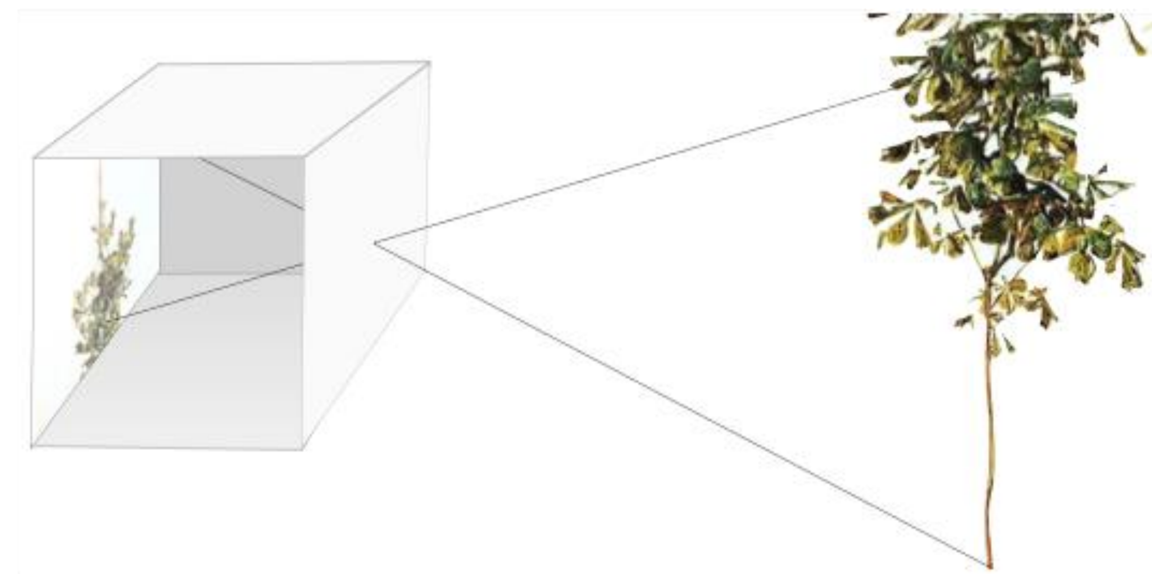
Part 3. Robust model estimation and image registration





Lab 3
Project B

Part 4. Camera geometry and basic 3D reconstruction



Lab 4
Project C

EEN020 - Computer Vision

Part 5. Generative models for machine learning and machine learning in 3D vision

[Zhu et al., ICCV 2017]

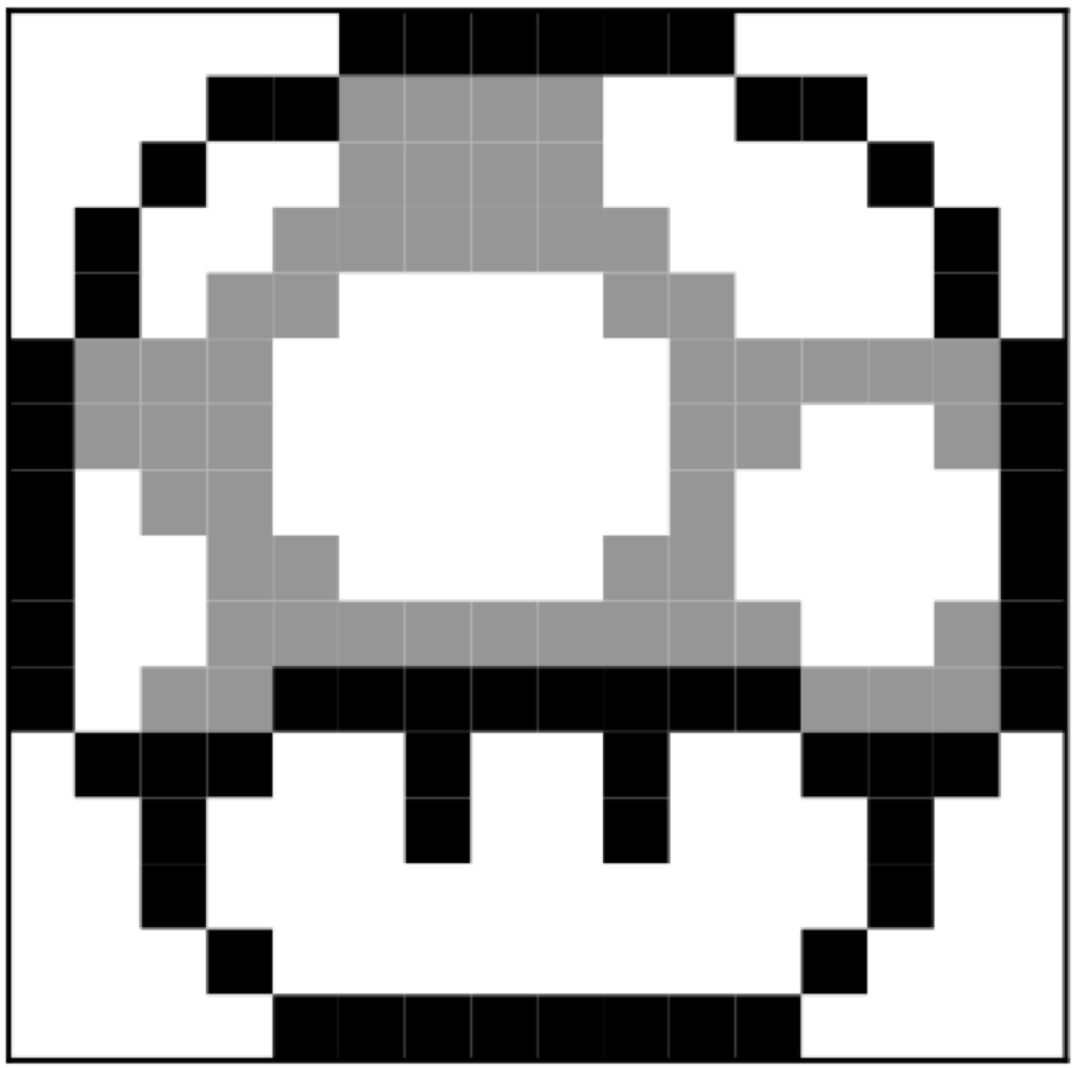
Project D

Course Schedule

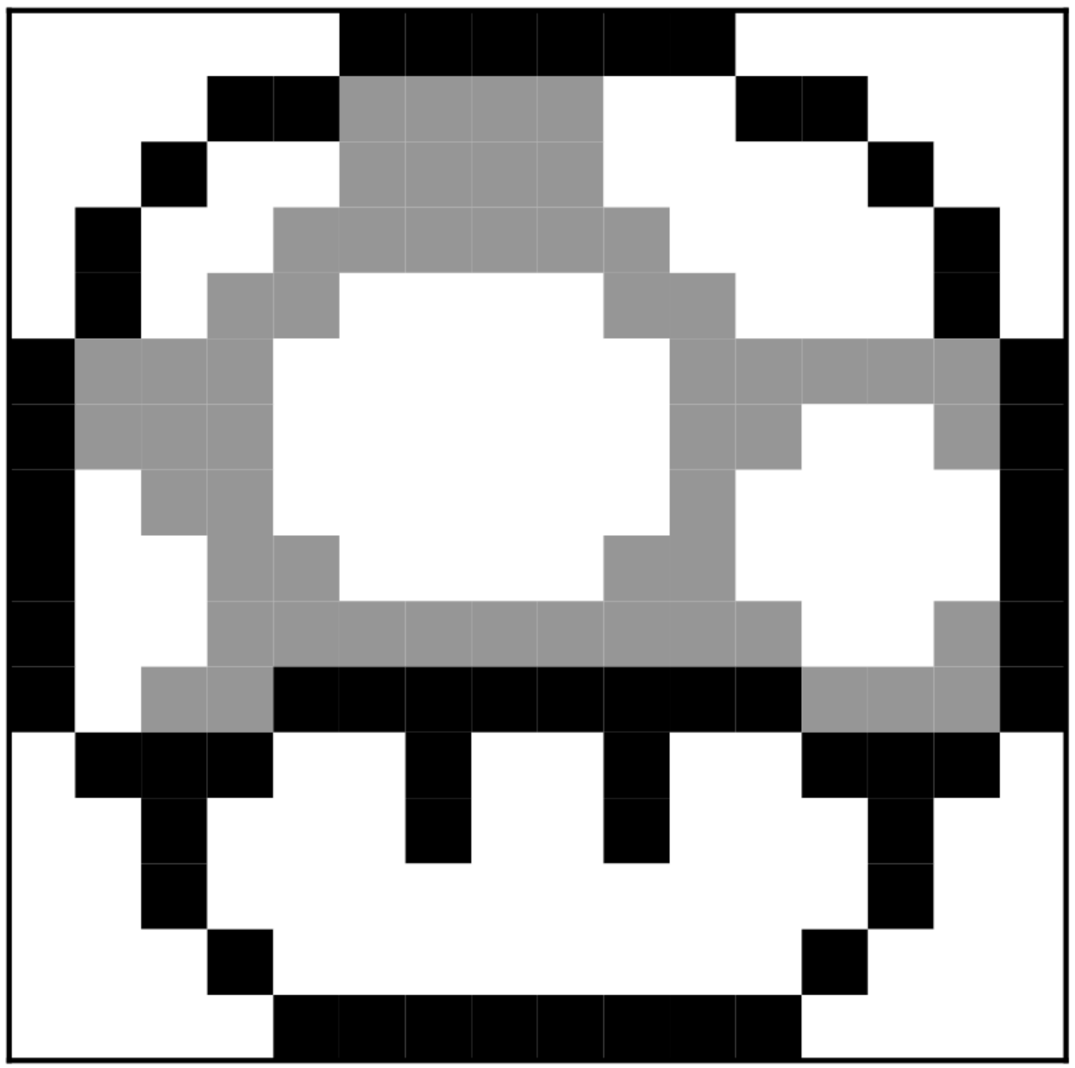
Jan. 20	**Introduction, Linear classifiers and filtering**	
Jan. 23	Filtering, gradients, scale	Lab 1
Jan. 27	Local features	
Jan. 30	Learning a classifier	Lab 2
Feb. 3	Convolutional neural networks	
Feb. 6	More convolutional neural networks	
Feb. 10	Robust model fitting and RANSAC	Lab 3
Feb. 13	Image registration	
Feb. 17	Camera Geometry	Lab 4
Feb. 20	More camera geometry	
Feb. 24	Generative neural networks	
Feb. 27	Generative neural networks	
Mar. 2	TBA	
Mar. 9	TBA	

Modeling Images

What is an Image?



What is an Image?



255	255	255	255	255	0	0	0	0	0	0	255	255	255	255	255
255	255	255	0	0	150	150	150	150	255	255	0	0	255	255	255
255	255	0	255	255	150	150	150	150	255	255	255	255	0	255	255
255	0	255	255	150	150	150	150	150	150	255	255	255	255	0	255
255	0	255	150	150	255	255	255	255	150	150	255	255	255	0	255
0	150	150	150	255	255	255	255	255	255	150	150	150	150	150	0
0	150	150	150	255	255	255	255	255	255	150	150	255	255	150	0
0	255	150	150	255	255	255	255	255	255	150	255	255	255	255	0
0	255	255	150	150	255	255	255	255	150	150	255	255	255	255	0
0	255	255	150	150	150	150	150	150	150	150	150	255	255	150	0
0	255	150	150	0	0	0	0	0	0	0	0	150	150	150	0
255	0	0	0	255	255	0	255	255	0	255	255	0	0	0	255
255	255	0	255	255	255	0	255	255	0	255	255	255	0	255	255
255	255	0	255	255	255	255	255	255	255	255	255	255	0	255	255
255	255	255	0	255	255	255	255	255	255	255	0	255	255	255	255
255	255	255	255	0	0	0	0	0	0	0	0	255	255	255	255

Images are Vectors

Addition, Subtraction

0	0	0	0	0	0	0	0
0	0	150	150	150	150	0	0
0	150	150	150	150	150	150	0
0	150	150	150	150	150	150	0
0	150	150	150	150	150	150	0
0	150	150	150	150	150	150	0
0	0	150	150	150	150	0	0
0	0	0	0	0	0	0	0

+

0	0	0	0	0	0	0	0
0	0	200	200	200	200	0	0
0	50	0	200	200	200	200	0
0	50	50	0	200	200	200	0
0	50	50	50	0	200	200	0
0	50	50	50	50	0	200	0
0	0	50	50	50	50	0	0
0	0	0	0	0	0	0	0

=

0	0	0	0	0	0	0	0
0	0	350	350	350	350	0	0
0	200	150	350	350	350	350	0
0	200	200	150	350	350	350	0
0	200	200	150	150	350	350	0
0	200	200	200	200	150	350	0
0	0	200	200	200	200	0	0
0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0
0	0	150	150	150	150	0	0
0	150	150	150	150	150	150	0
0	150	150	150	150	150	150	0
0	150	150	150	150	150	150	0
0	150	150	150	150	150	150	0
0	0	150	150	150	150	0	0
0	0	0	0	0	0	0	0

-

0	0	0	0	0	0	0	0
0	0	200	0	0	200	0	0
0	200	0	0	0	0	200	0
0	0	0	0	0	0	0	0
0	200	200	0	0	200	200	0
0	200	200	0	0	200	200	0
0	0	200	0	0	200	0	0
0	0	0	0	0	0	0	0

=

0	0	0	0	0	0	0	0
0	0	-50	150	150	-50	0	0
0	-50	150	150	150	150	-50	0
0	150	150	150	150	150	150	0
0	-50	-50	150	150	-50	-50	0
0	-50	-50	150	150	-50	-50	0
0	0	-50	150	150	-50	0	0
0	0	0	0	0	0	0	0

Images are Vectors

Scalar multiplication, dot product

$$2 * \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 150 & 150 & 150 & 150 & 0 & 0 \\ 0 & 150 & 150 & 150 & 150 & 150 & 150 & 0 \\ 0 & 150 & 150 & 150 & 150 & 150 & 150 & 0 \\ 0 & 150 & 150 & 150 & 150 & 150 & 150 & 0 \\ 0 & 150 & 150 & 150 & 150 & 150 & 150 & 0 \\ 0 & 0 & 150 & 150 & 150 & 150 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 300 & 300 & 300 & 300 & 0 & 0 \\ 0 & 300 & 300 & 300 & 300 & 300 & 300 & 0 \\ 0 & 300 & 300 & 300 & 300 & 300 & 300 & 0 \\ 0 & 300 & 300 & 300 & 300 & 300 & 300 & 0 \\ 0 & 300 & 300 & 300 & 300 & 300 & 300 & 0 \\ 0 & 0 & 300 & 300 & 300 & 300 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 255 & 0 \\ 255 & 255 & 255 \\ 0 & 255 & 0 \end{bmatrix} * \begin{bmatrix} 0 & 255 & 0 \\ 0 & 255 & 0 \\ 0 & 0 & 0 \end{bmatrix} = 2 * 255^2$$

Images are Vectors

Average
speed limit sign

Images are Vectors

image source: [pinterest]

Average
speed limit sign

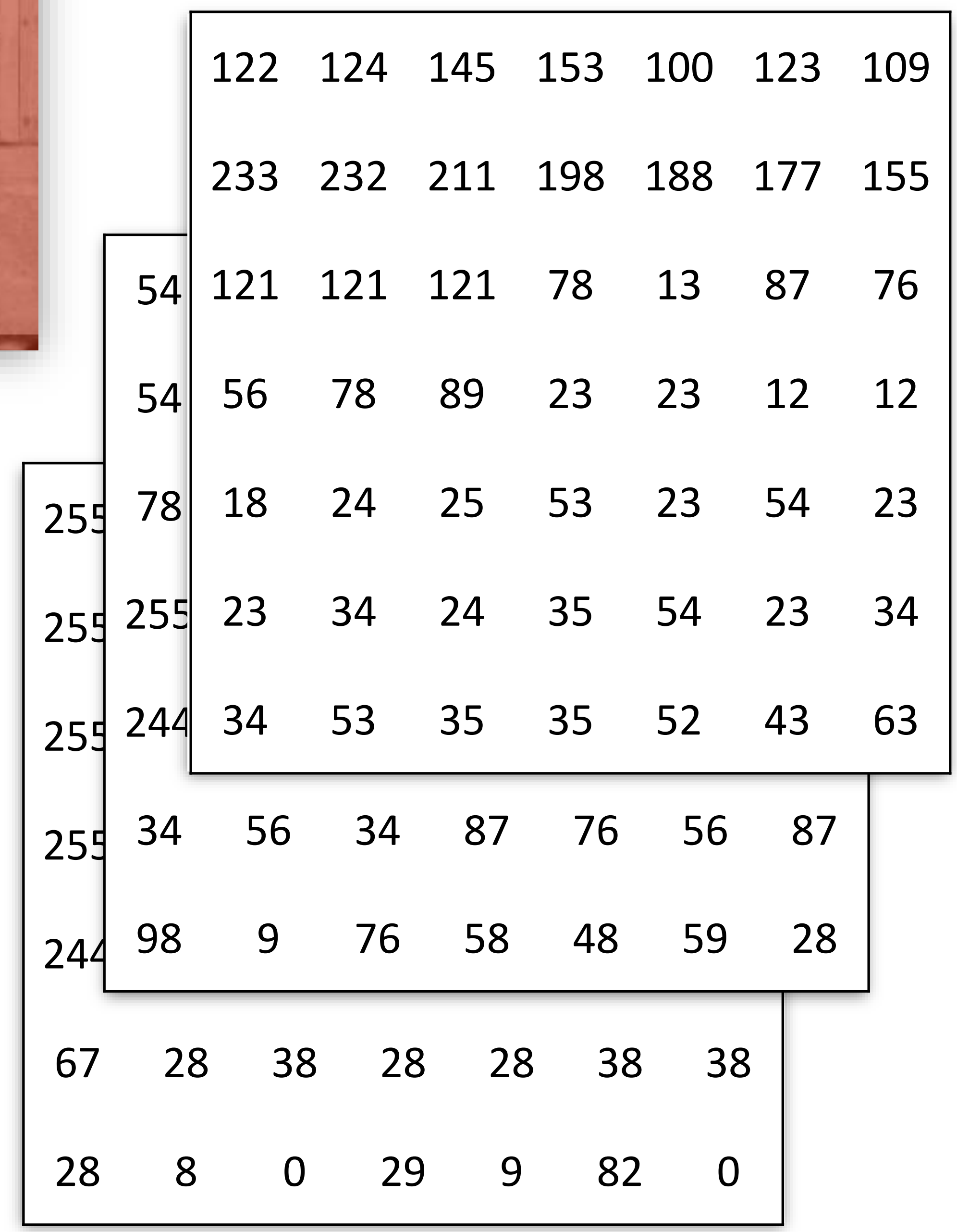
Average
president

Color

Color

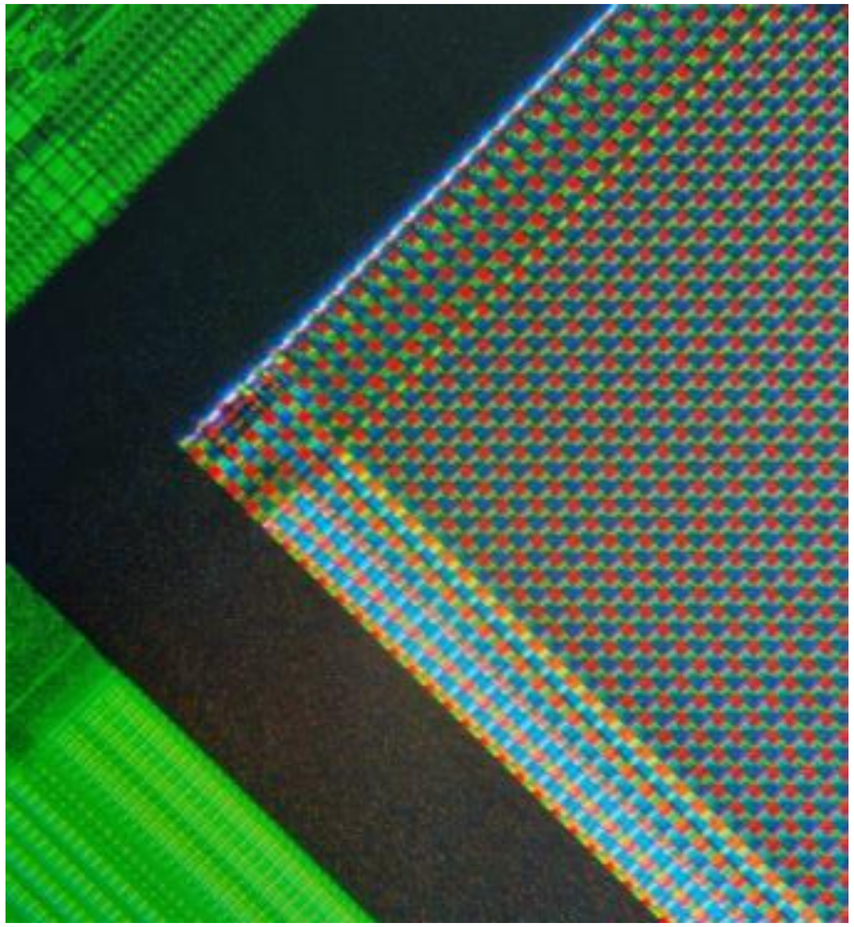
Color

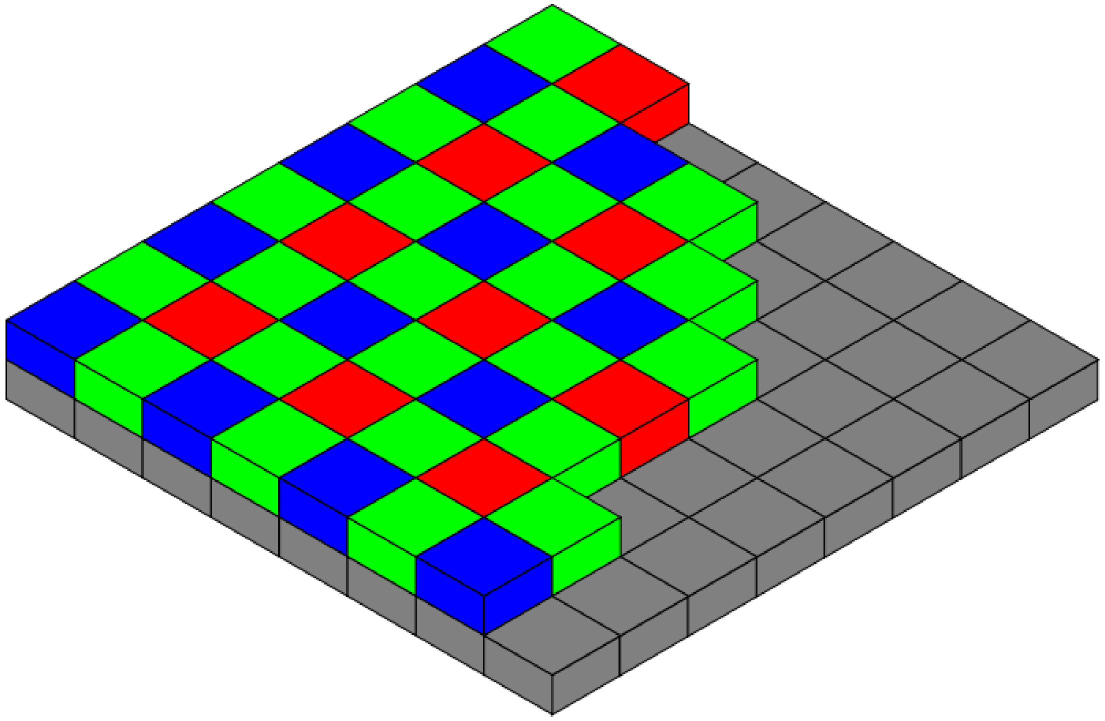
RGB



Channel-wise operations

Digital Cameras

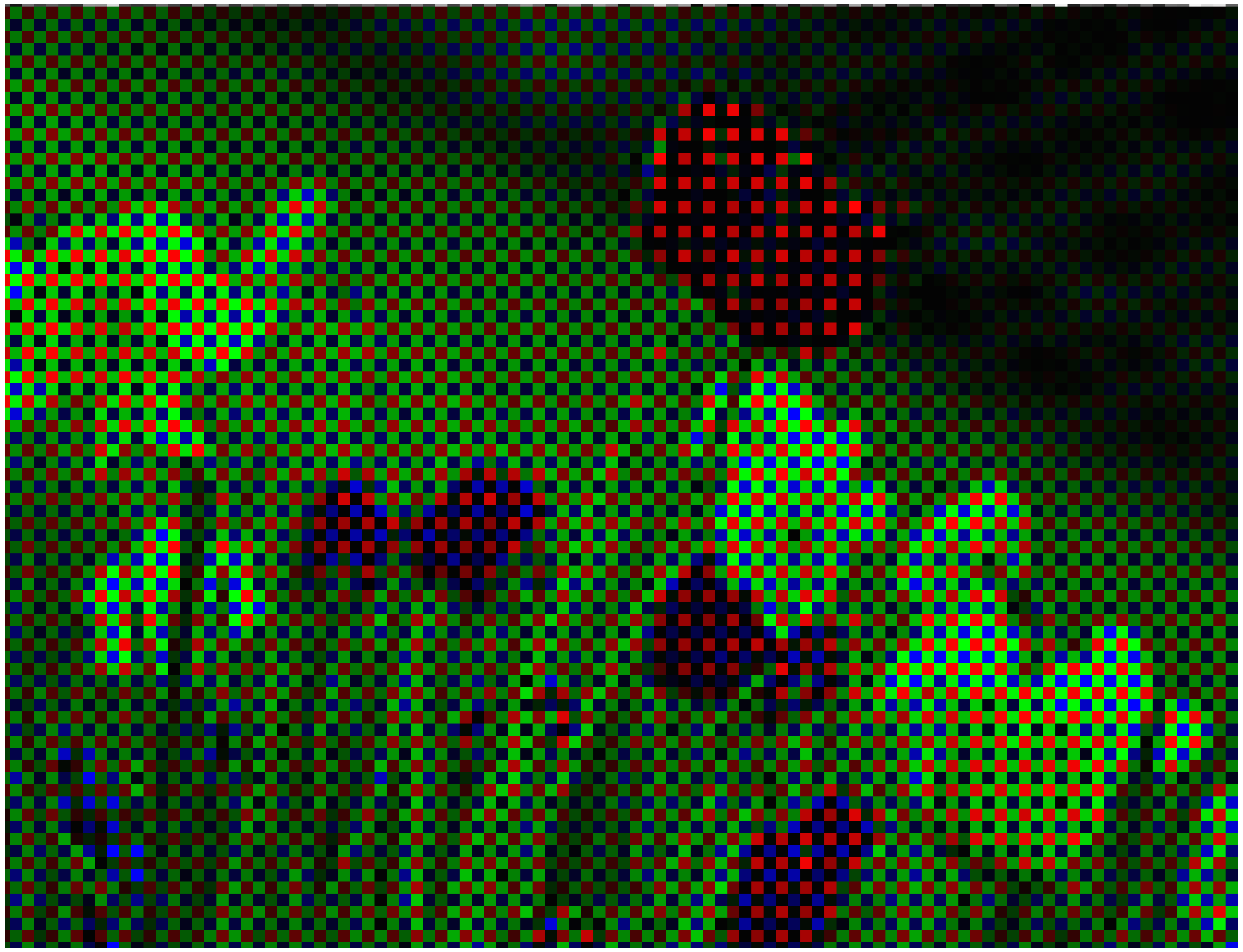




Bayer filter

Digital Cameras

Digital Cameras



Digital Cameras

Demosaicing

Lighting and White Balance

RGB-D Images

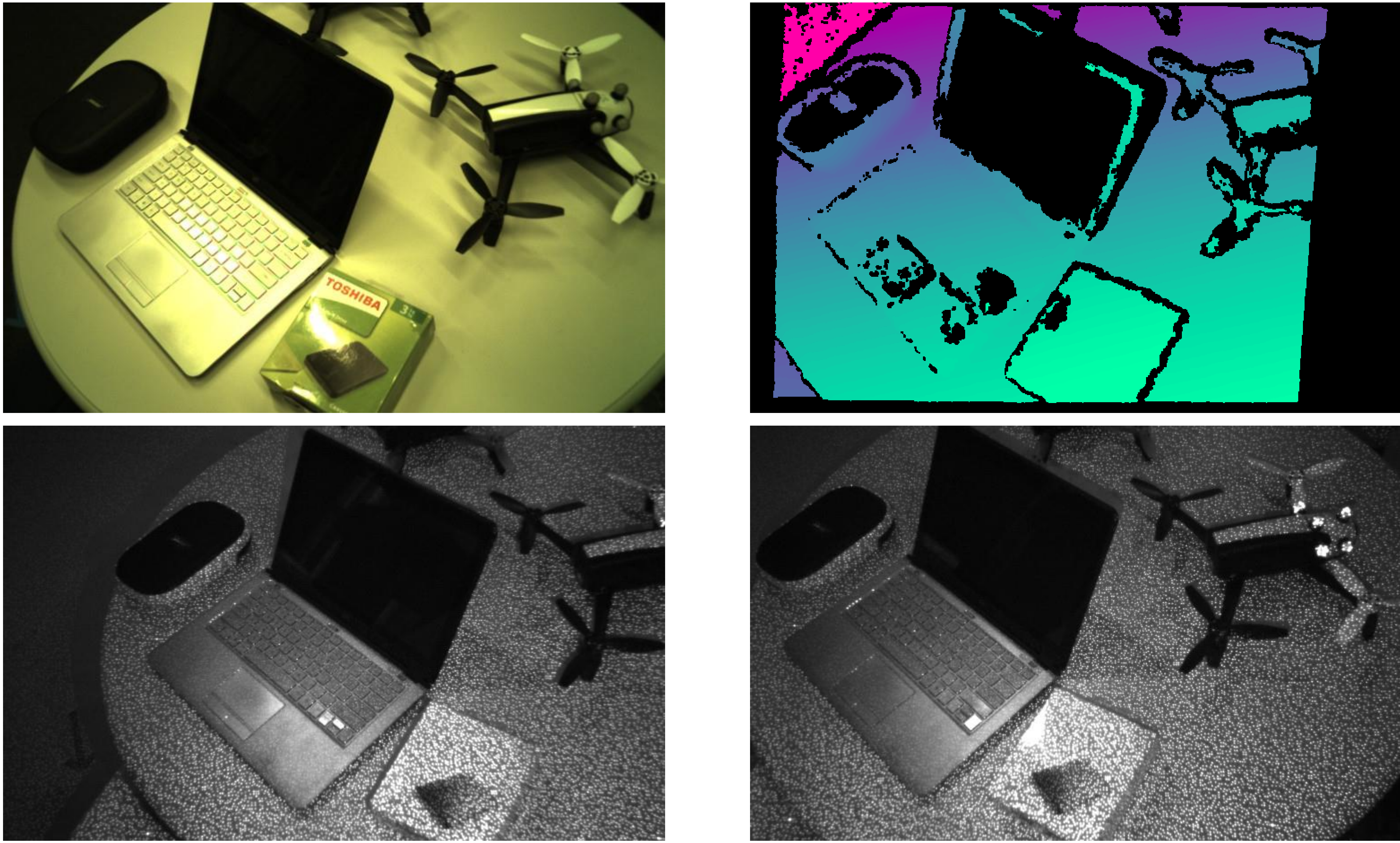
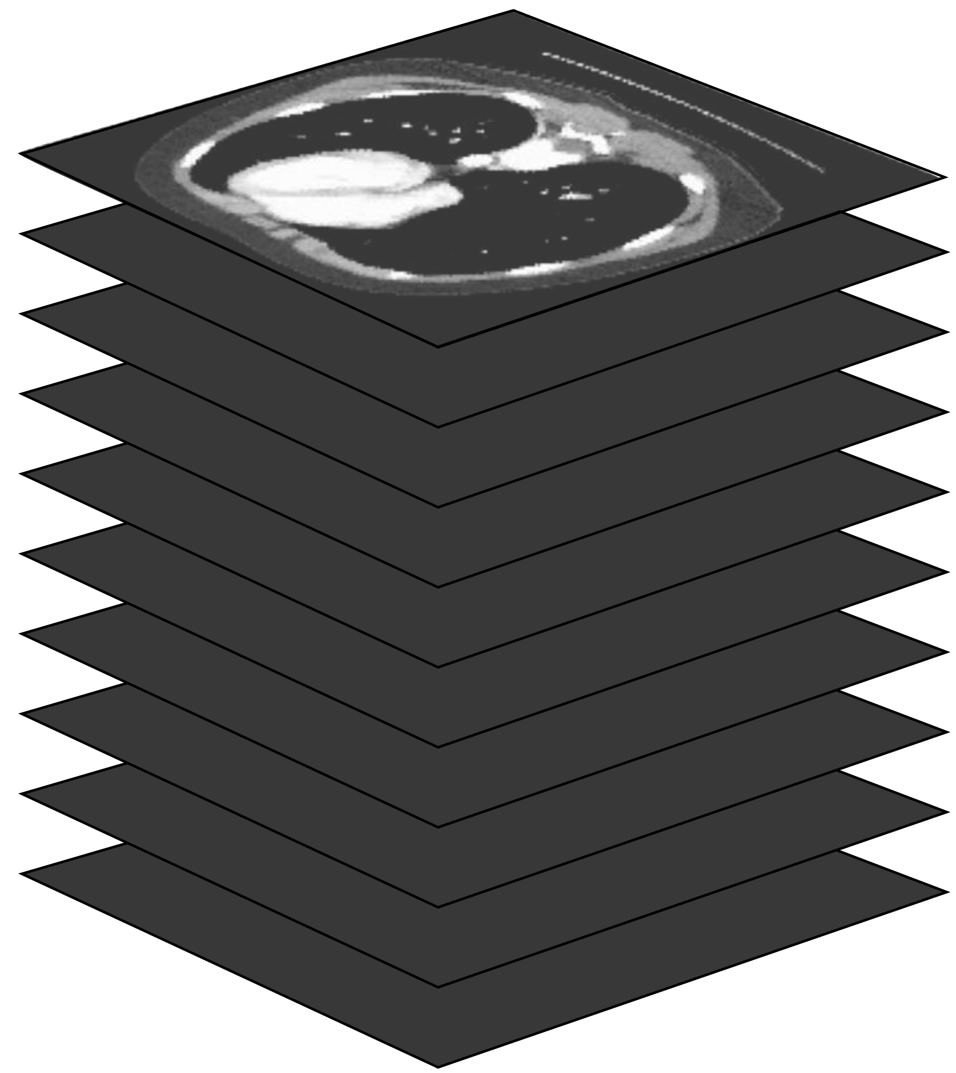


image credit: Thomas Schöps

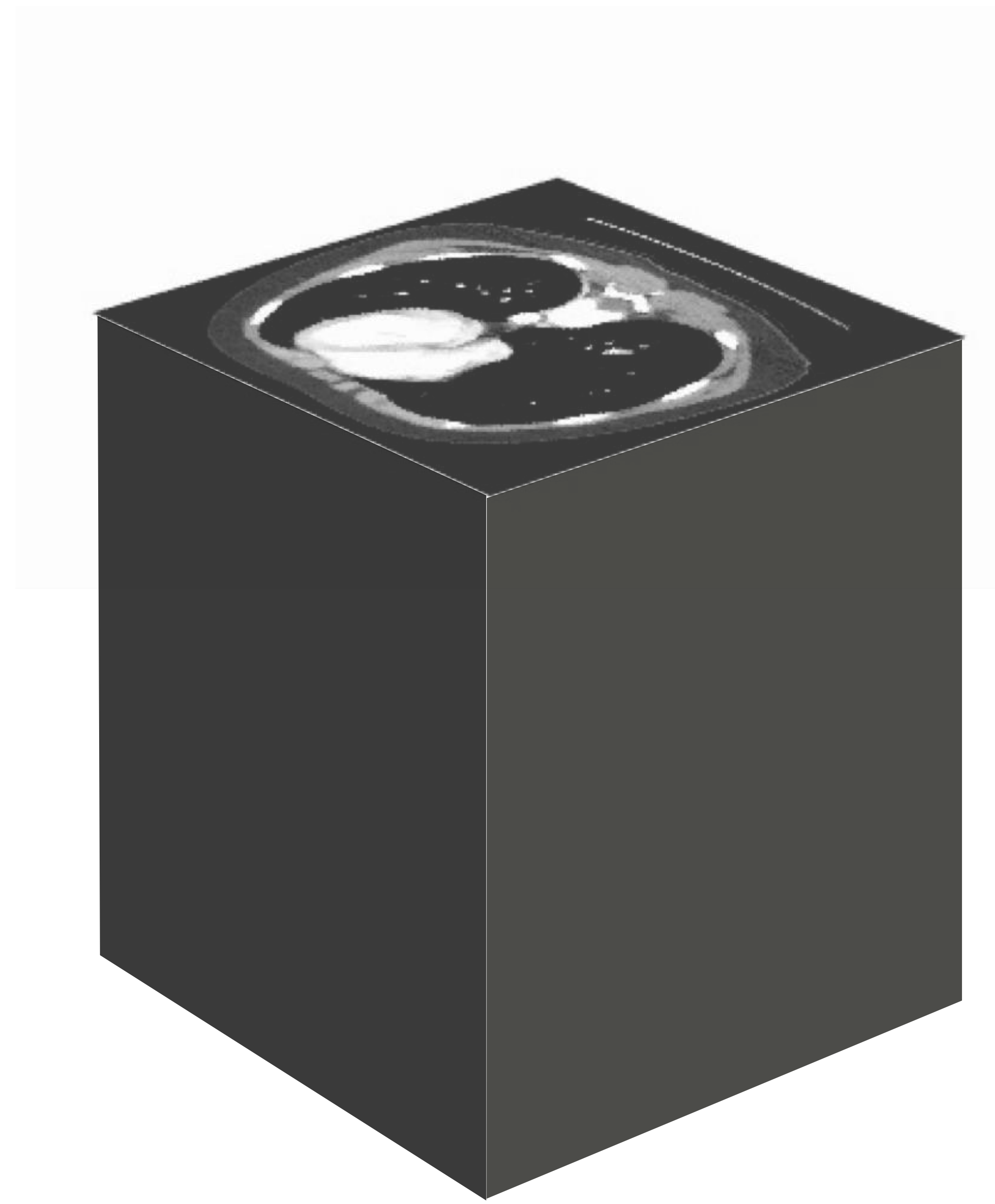
3D Images

Computed tomography



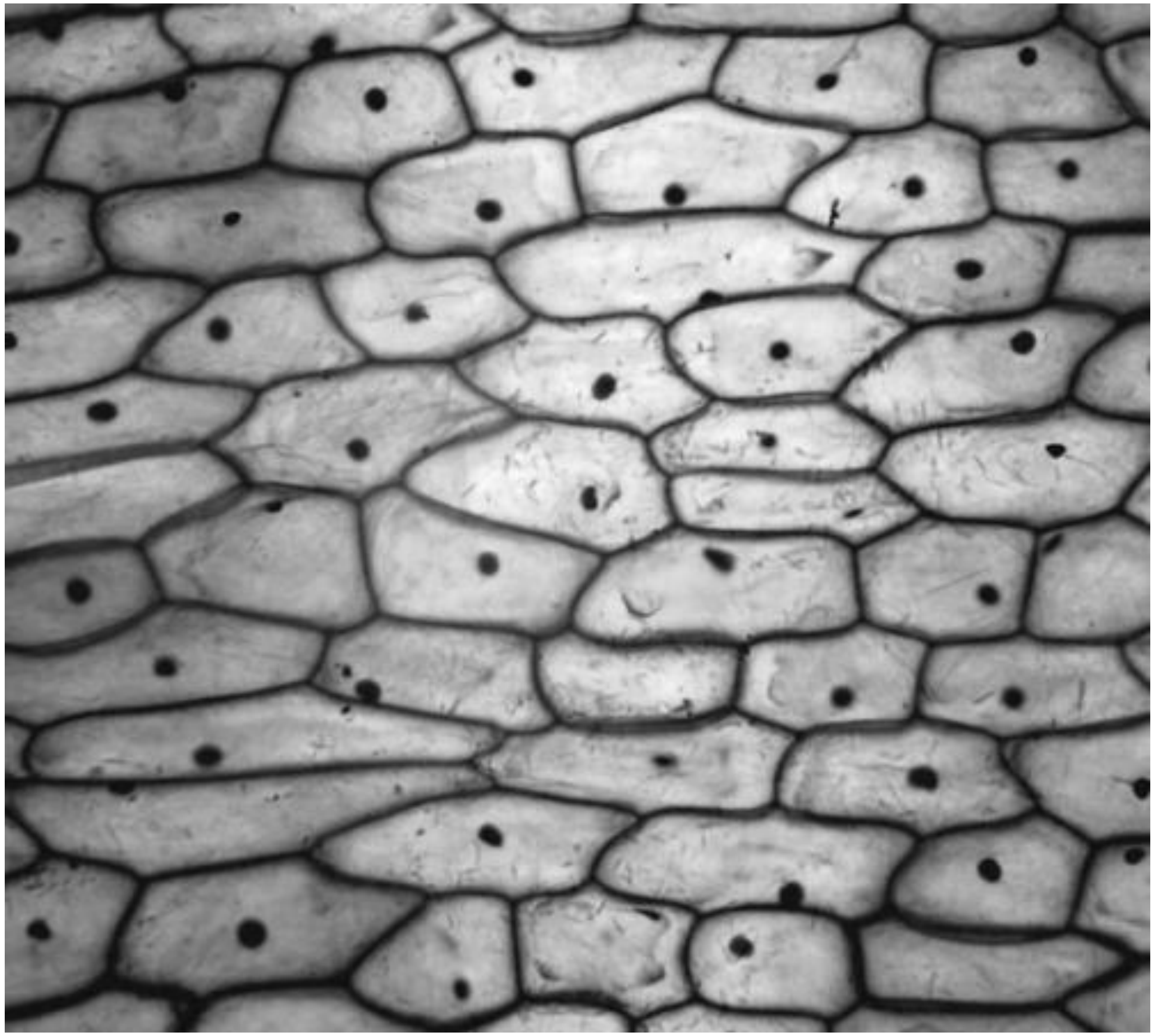
3D Images

Computed tomography



Filtering and Linear Classifiers

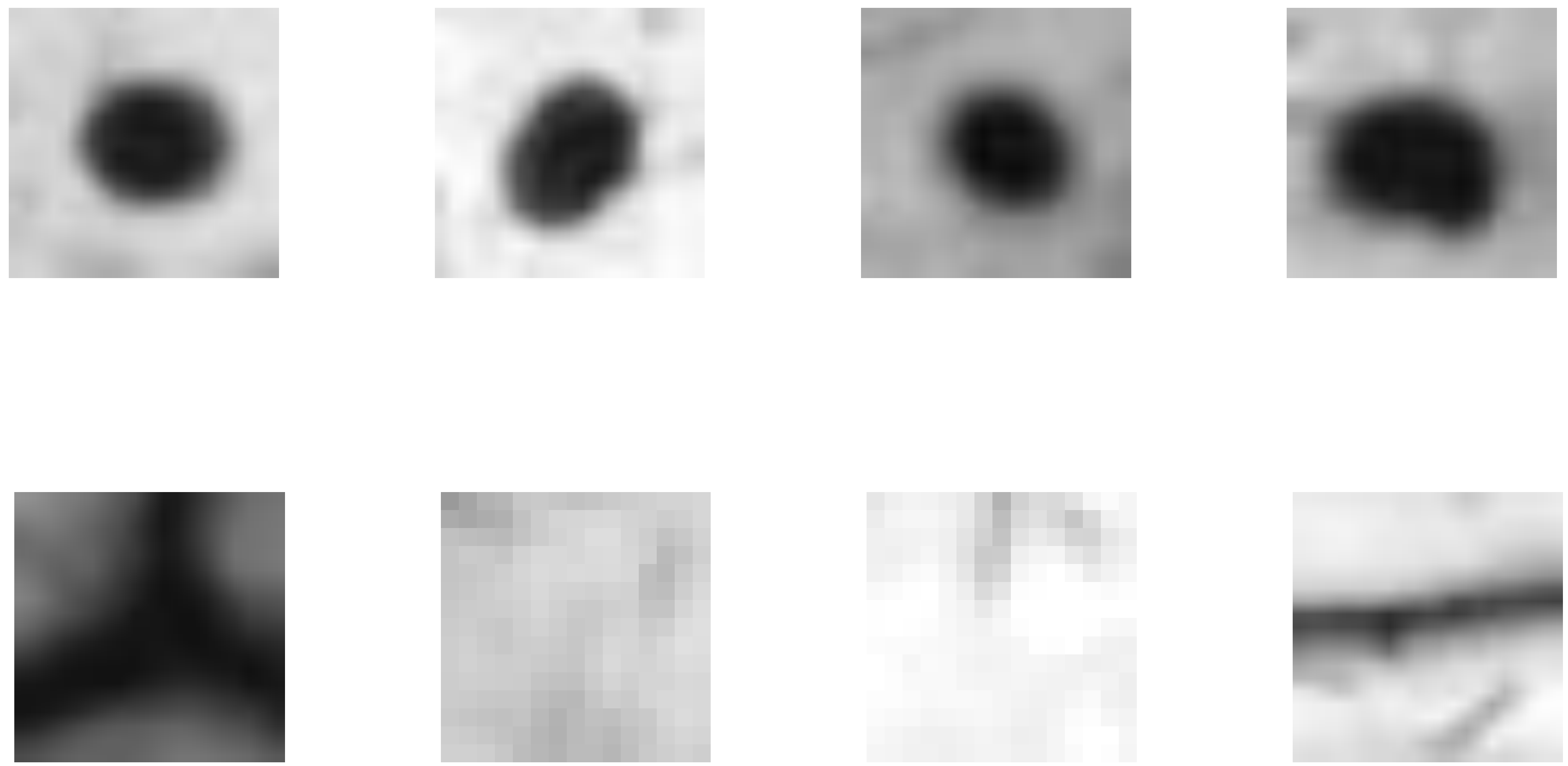
Count the Nuclei



Classification

nuclei

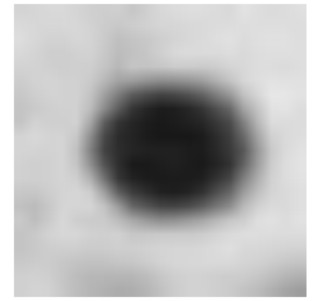
other



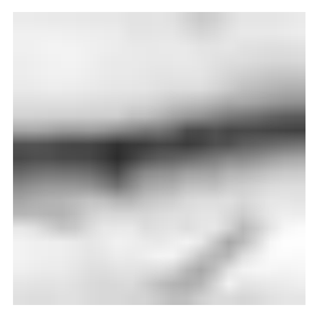
21 x 21 patches

A Linear Classifier

Target / template

$w \cdot$  $> \tau$

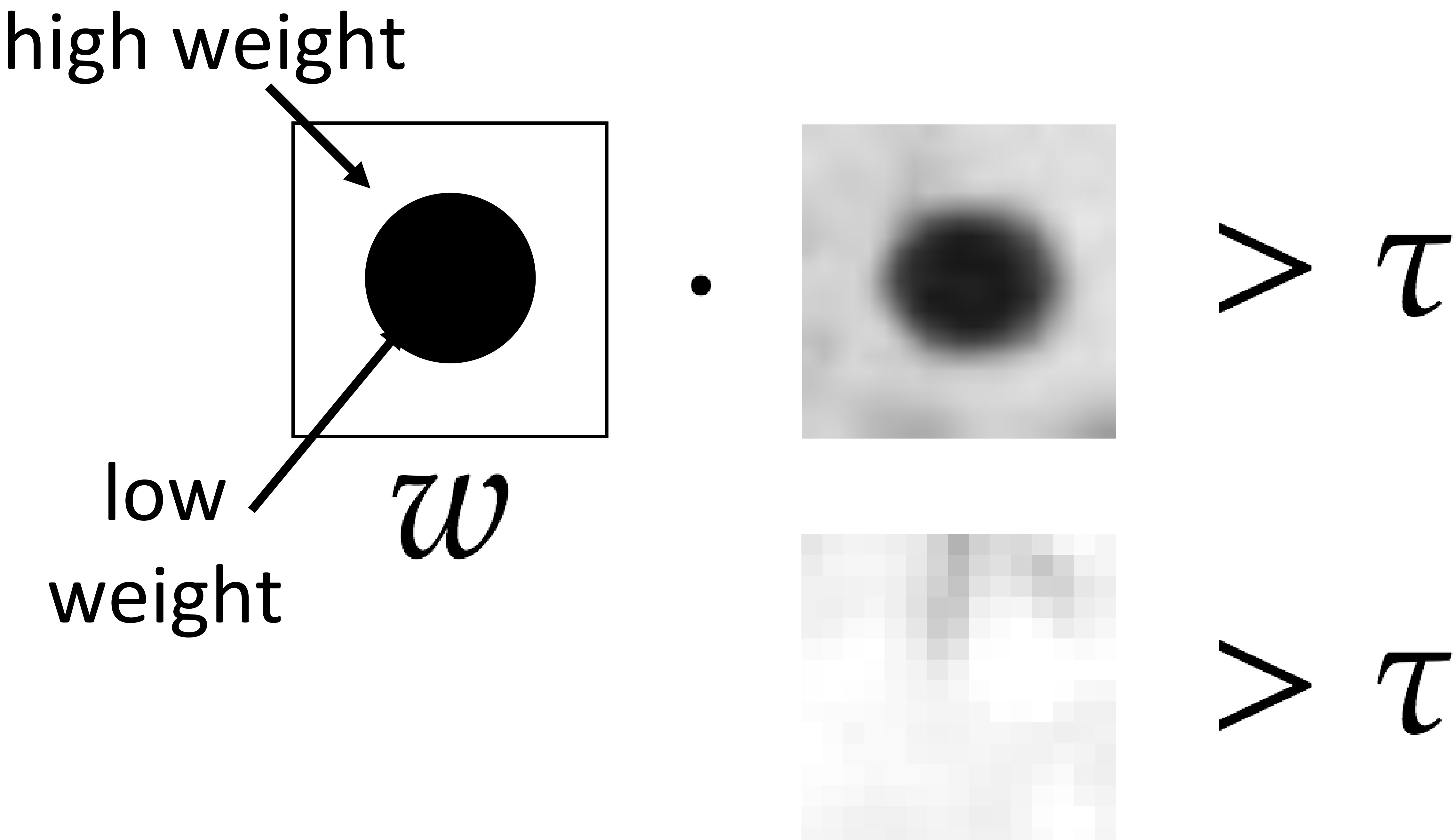
$w \cdot$  $> \tau$

$w \cdot$  $< \tau$

$w \cdot$  $< \tau$

Decision threshold

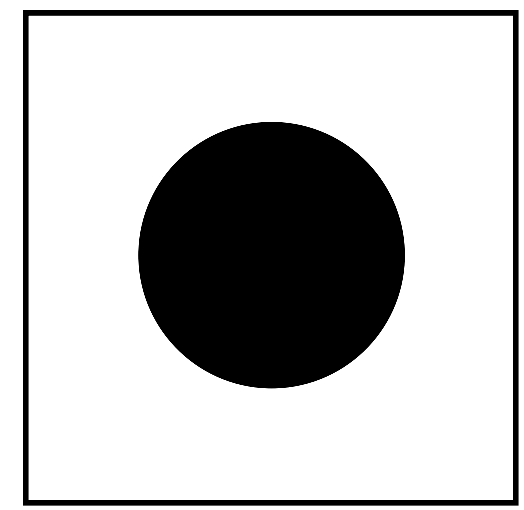
Designing a Classifier



Not a good classifier!

Designing a Better Classifier

$$w = \frac{1}{N}\left(w' - \mu_{w'}\mathbb{1}\right)$$



w'

Motivation: uniform patches should have response ~0

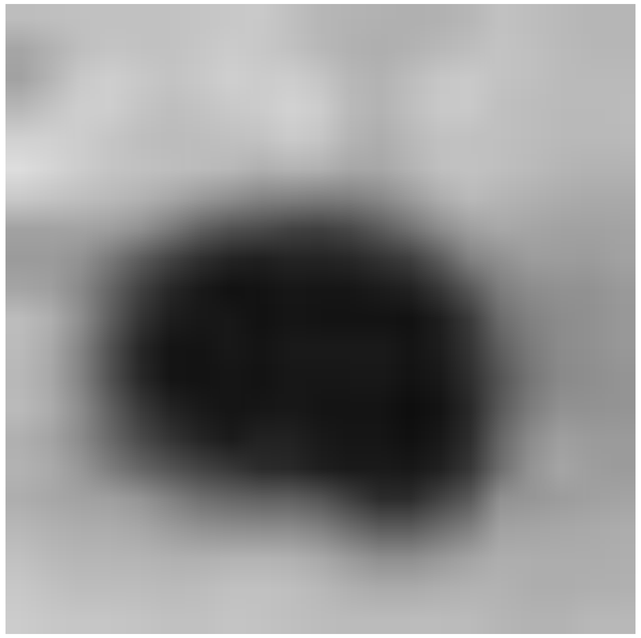
Designing a Better Classifier

Example:

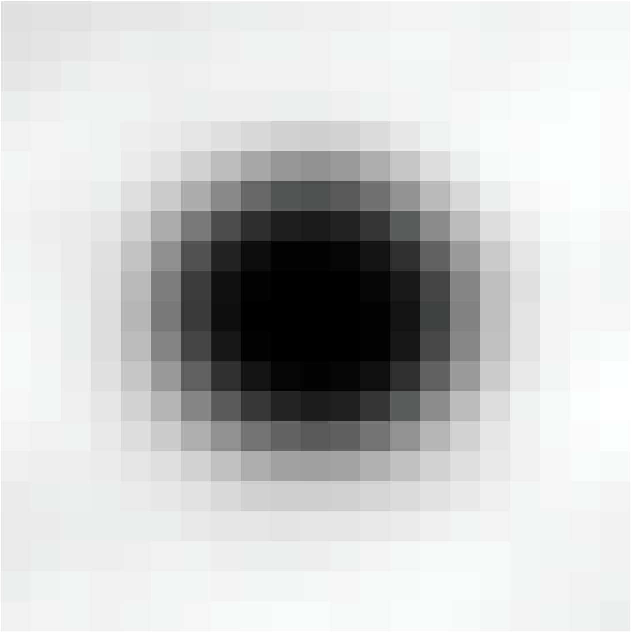
$$w = 1/9 * \left(\begin{bmatrix} 252 & 252 & 252 \\ 252 & 0 & 252 \\ 252 & 252 & 252 \end{bmatrix} - 224* \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \right)$$

$$w* \begin{bmatrix} 200 & 200 & 200 \\ 200 & 15 & 200 \\ 200 & 200 & 200 \end{bmatrix} =4604.44 \qquad w* \begin{bmatrix} 200 & 200 & 200 \\ 200 & 200 & 200 \\ 200 & 200 & 200 \end{bmatrix} =0$$

Choosing A Template

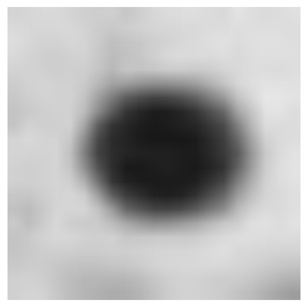
$w =$ 

some nucleus

$w =$ 

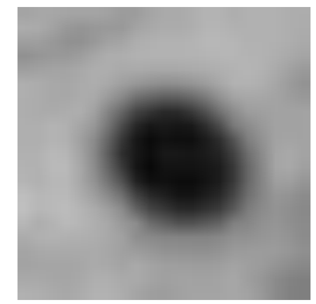
mean nucleus

Choosing a Threshold

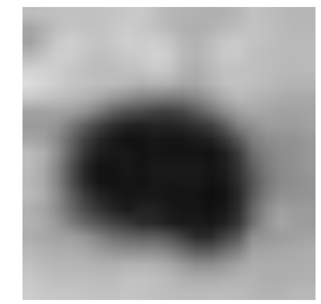


1.72

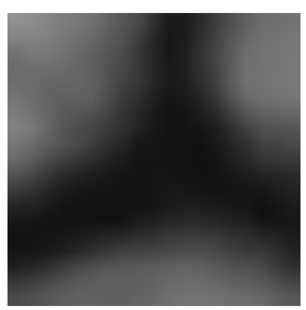
1.88



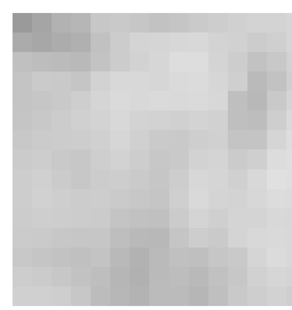
1.26



1.45



0.56

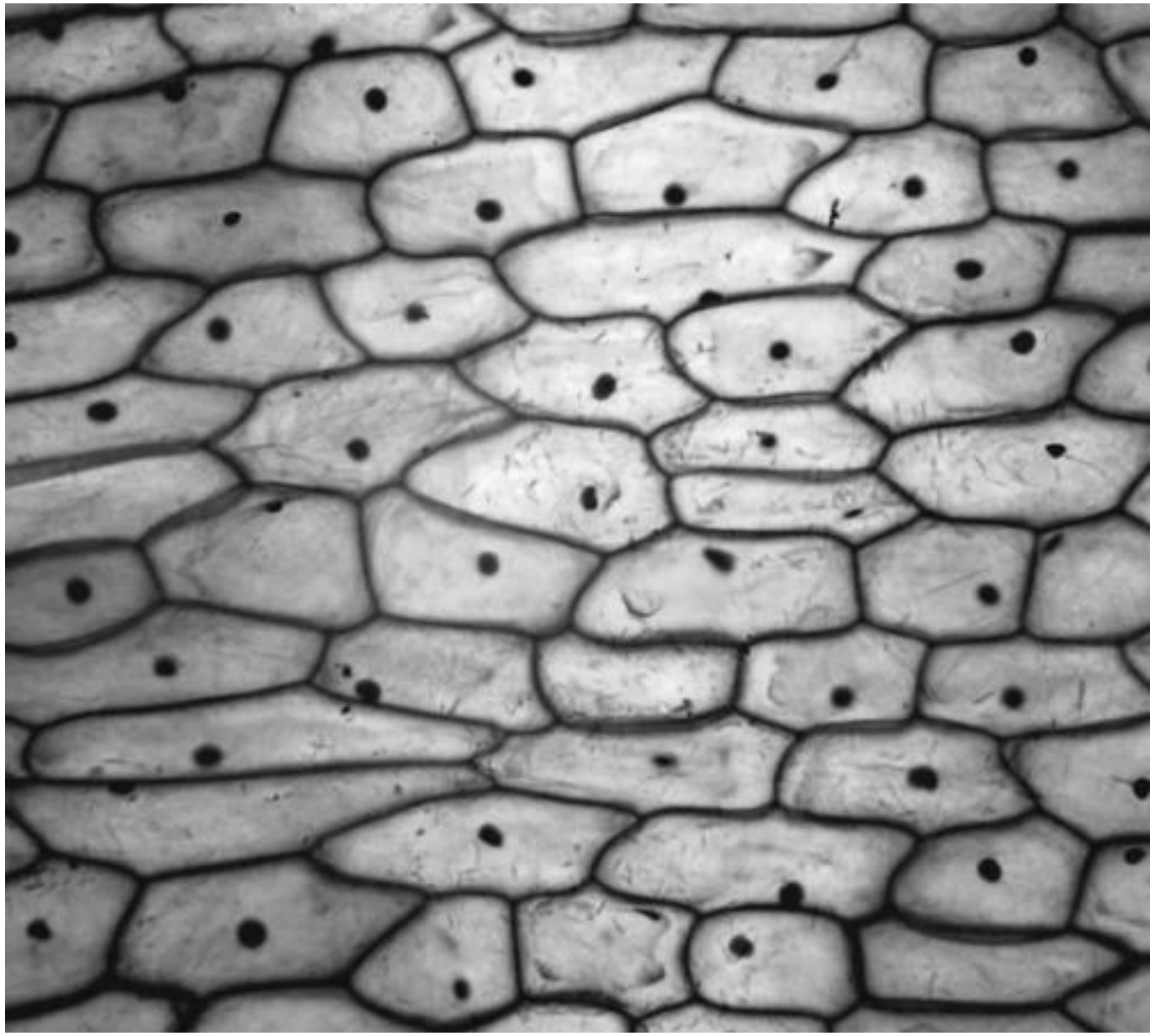


-0.07

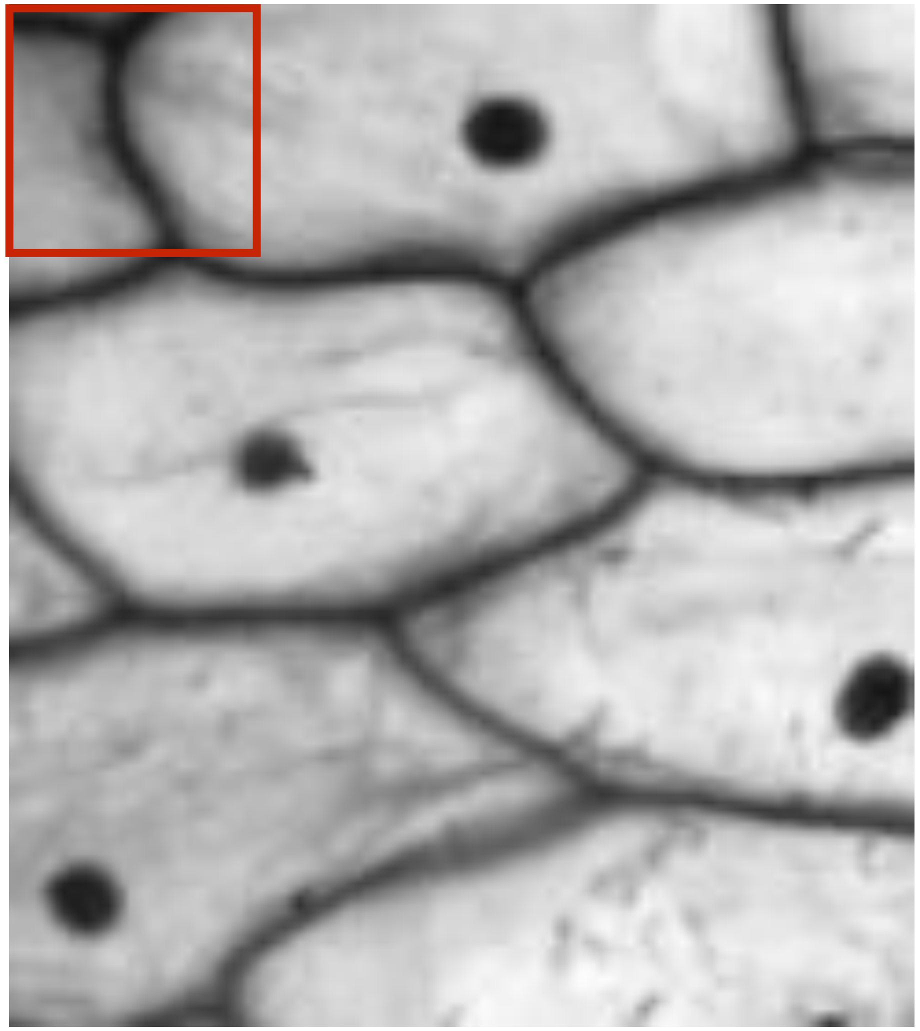
-0.06

0.75

Count the Nuclei

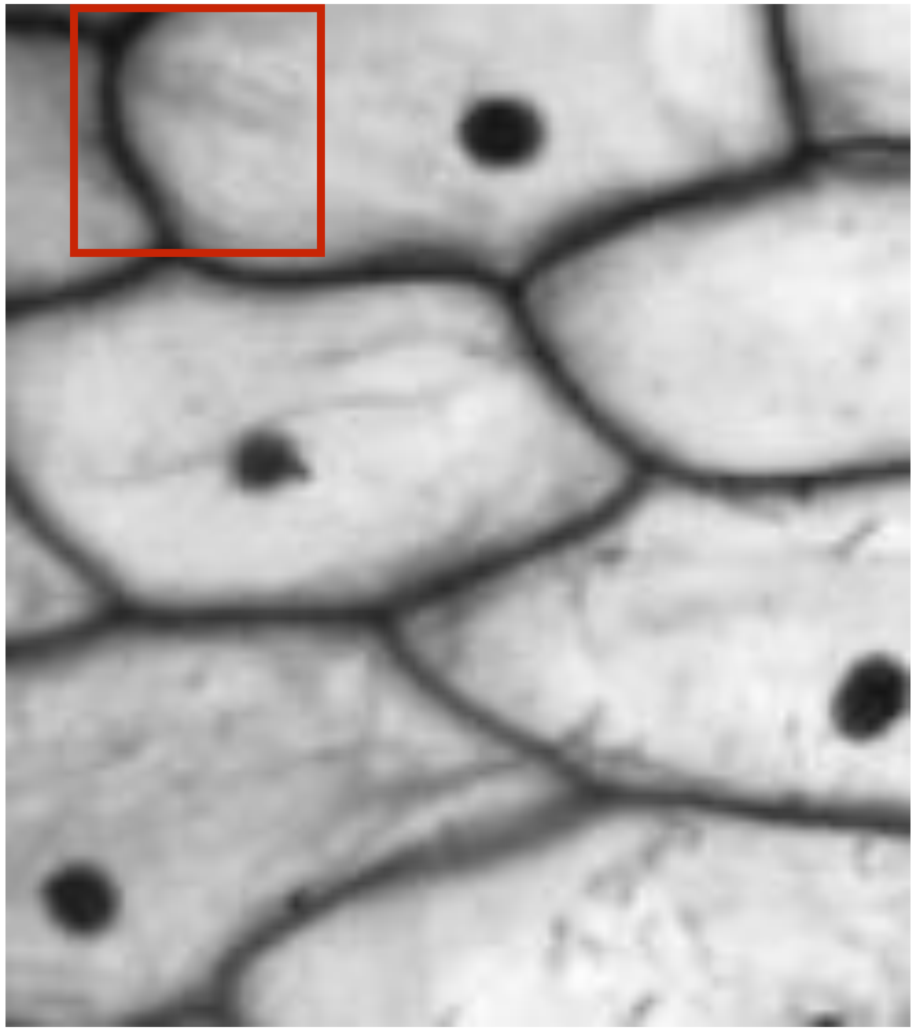


Sliding Window Classification



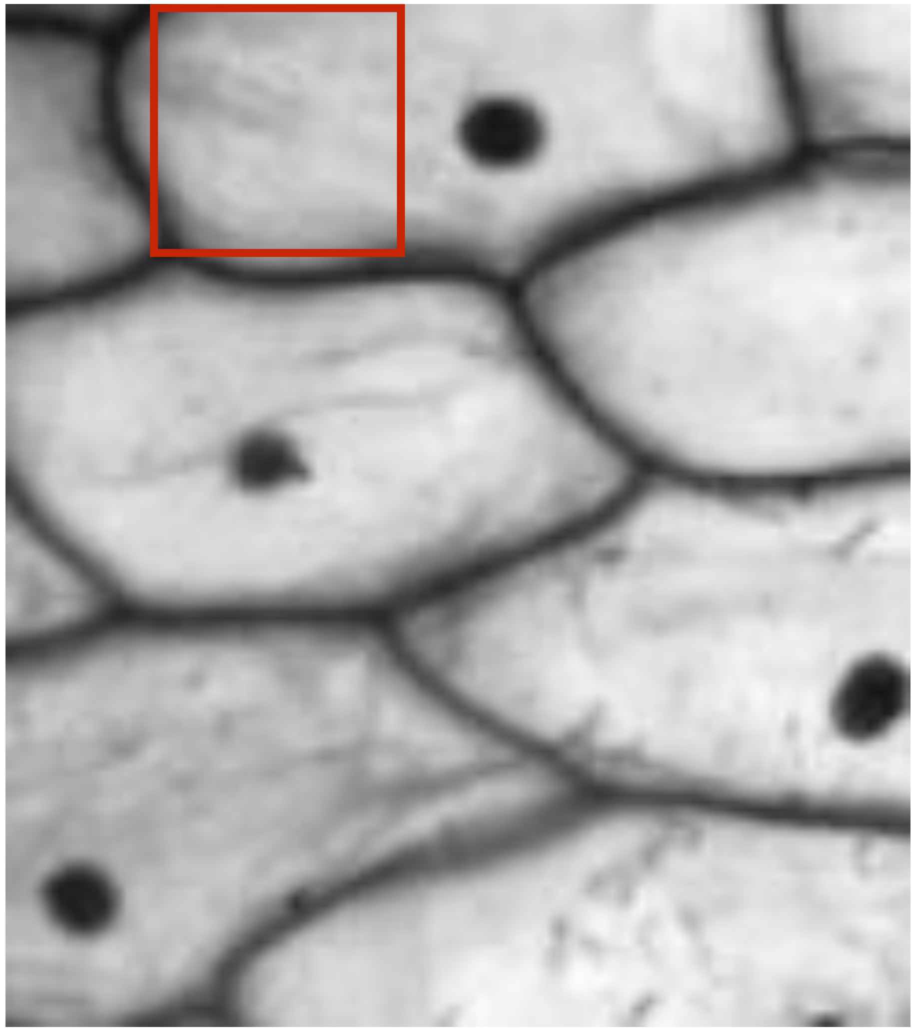
$\cdot\, w < \tau$

Sliding Window Classification



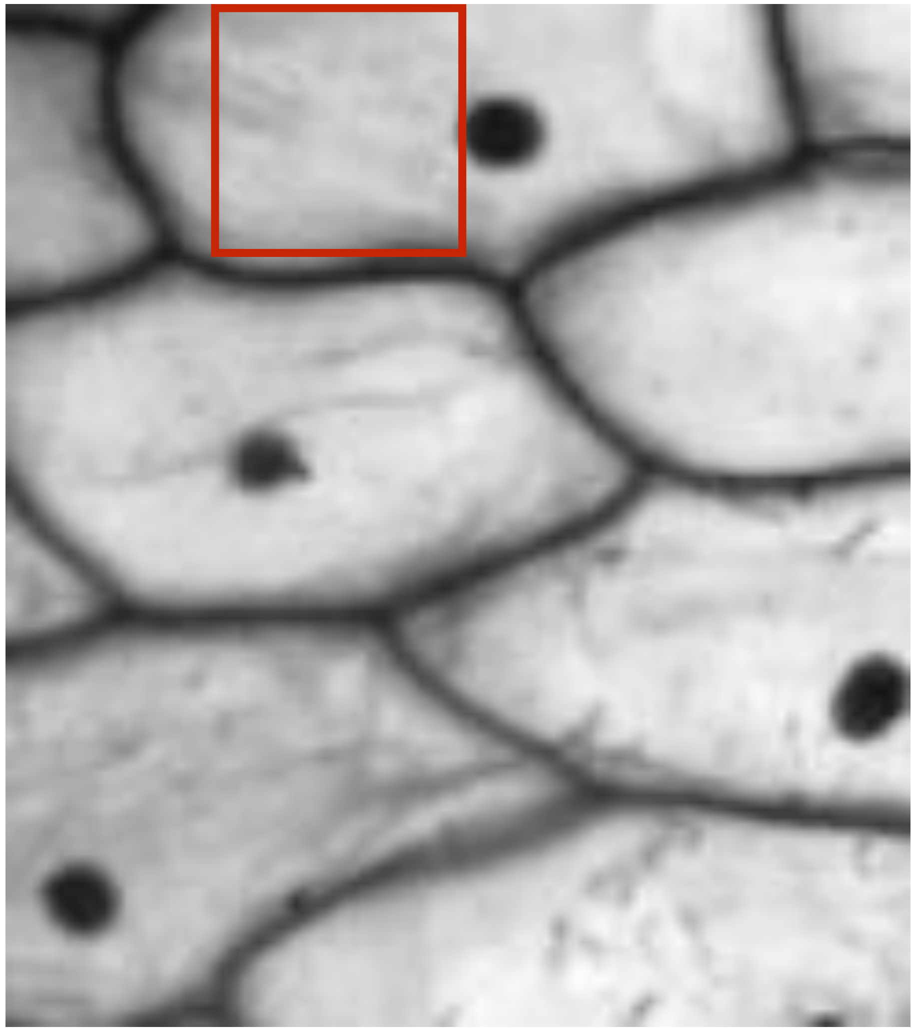
$$\cdot\, w < \tau$$

Sliding Window Classification



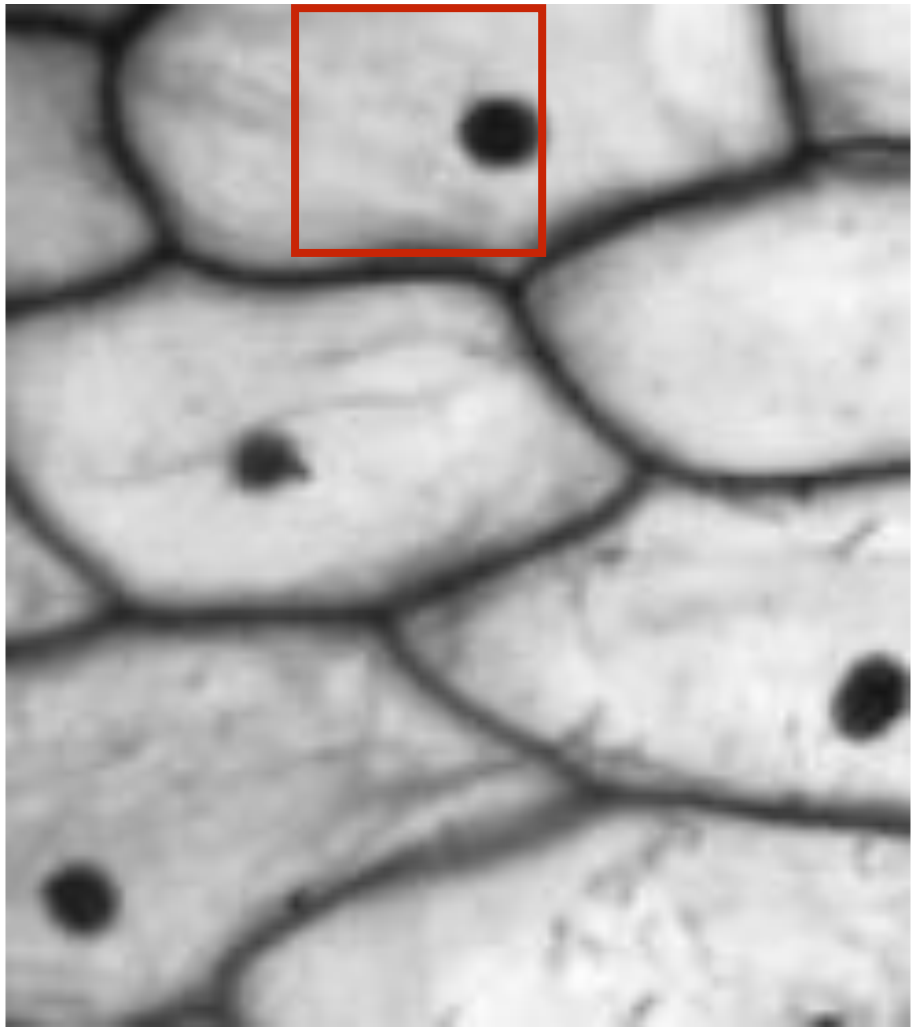
$$\cdot\, w < \tau$$

Sliding Window Classification



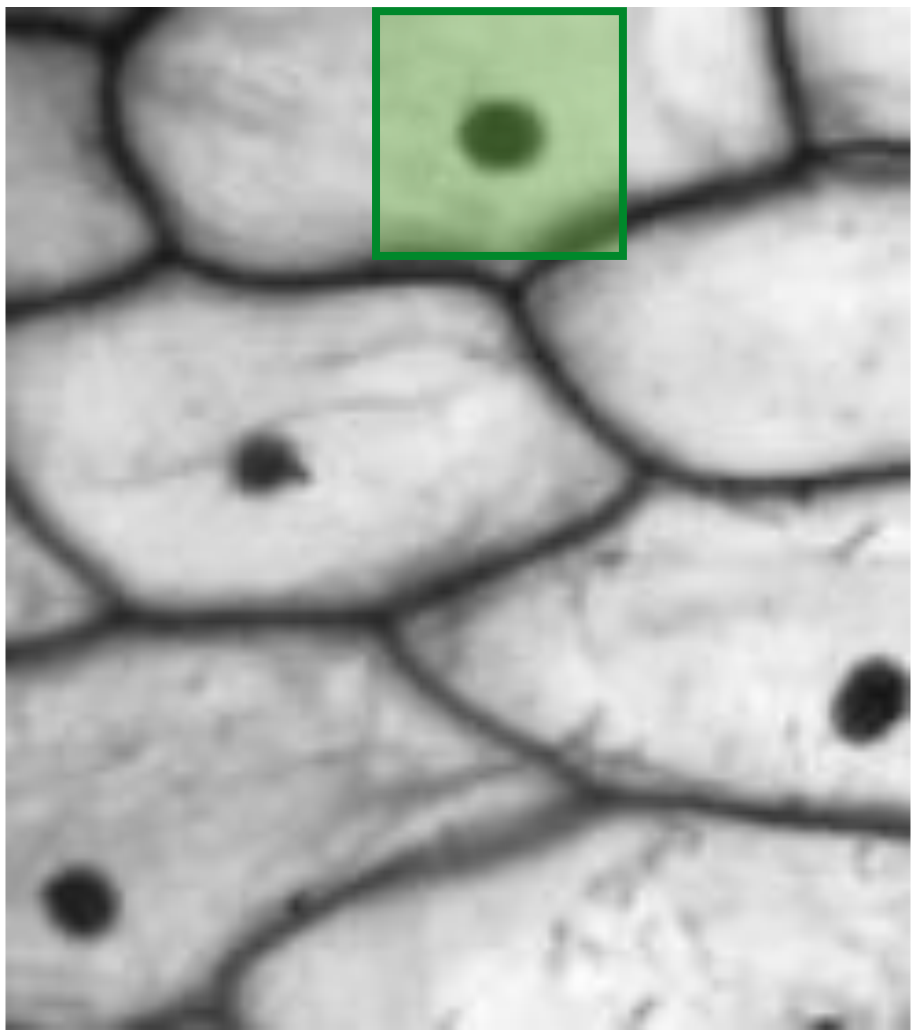
$$\cdot\, w < \tau$$

Sliding Window Classification



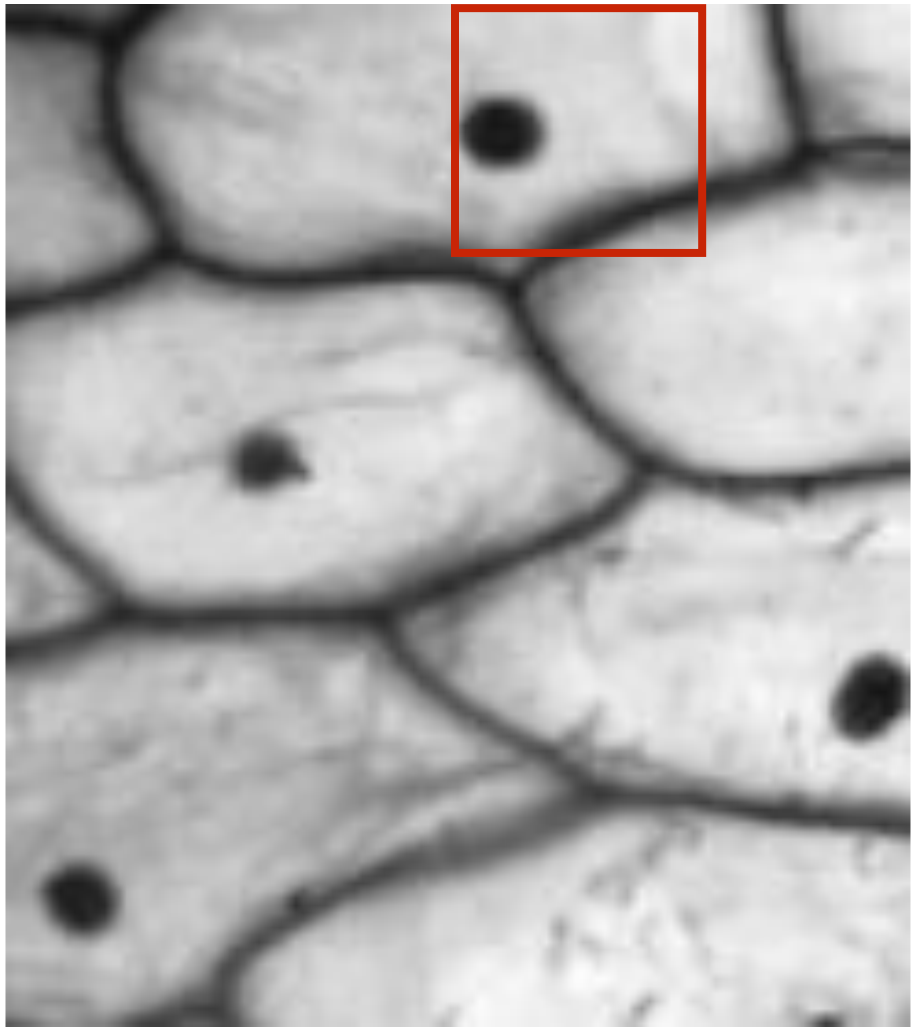
$$\cdot\, w < \tau$$

Sliding Window Classification



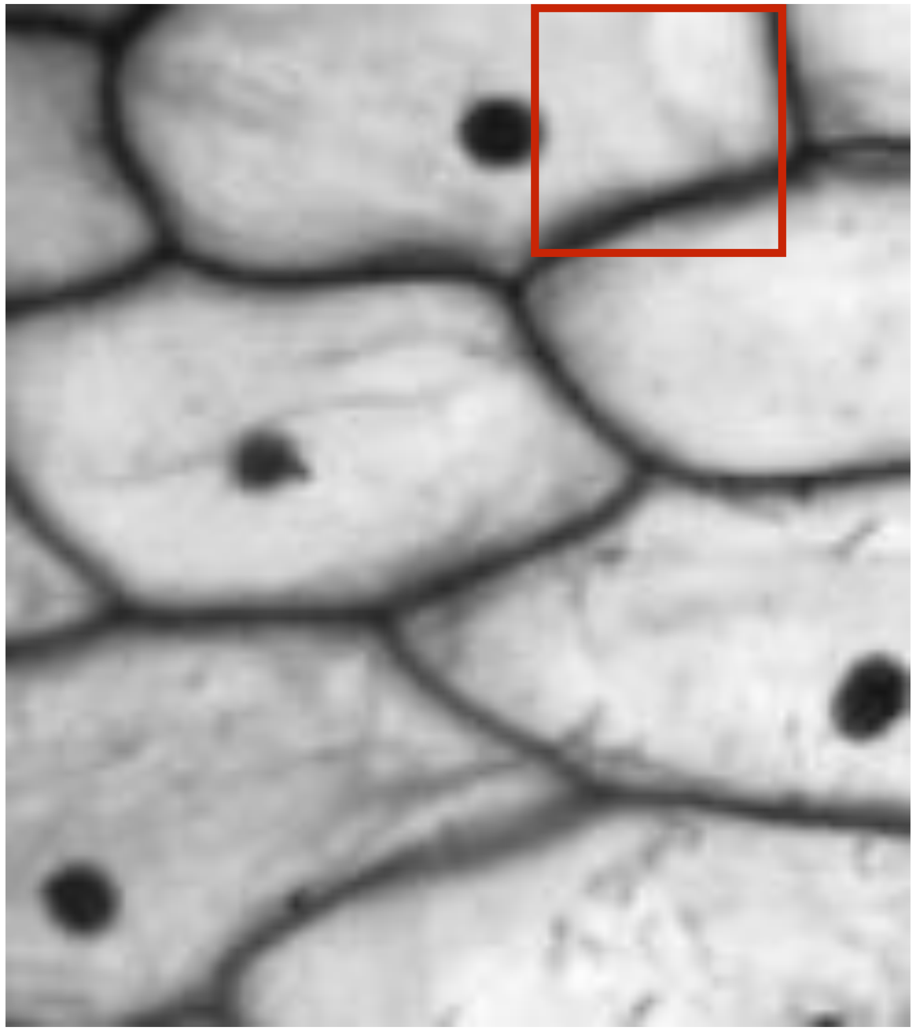
$$\cdot\, w > \tau$$

Sliding Window Classification



$$\cdot\, w < \tau$$

Sliding Window Classification



$$\cdot\, w < \tau$$

Sliding Dot Product

$$w = \frac{1}{5}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5} \begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5} \begin{array}{|c|c|c|} \hline 0 & 1 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 1 & 0 \\ \hline \end{array}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

	0					

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{bmatrix}0 & 1 & 0\\ 1 & 1 & 1\\ 0 & 1 & 0\end{bmatrix}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

	0					

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

	0	1				

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

	0	1				

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{array}{|c|c|c|}\hline 0 & 1 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 1 & 0 \\ \hline \end{array}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

	0	1	2			

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

	0	1	2	1	0	
	1	5	6	4	1	
	2	6				

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

	0	1	2	1	0	
	1	5	6	4	1	
	2	6	8			

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{array}{|c|c|c|}\hline 0 & 1 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 1 & 0 \\ \hline\end{array}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

	0	1	2	1	0	
	1	5	6	4	1	
	2	6	8	4	1	
	1	4	4	2	0	
	0	1	1	0	0	

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

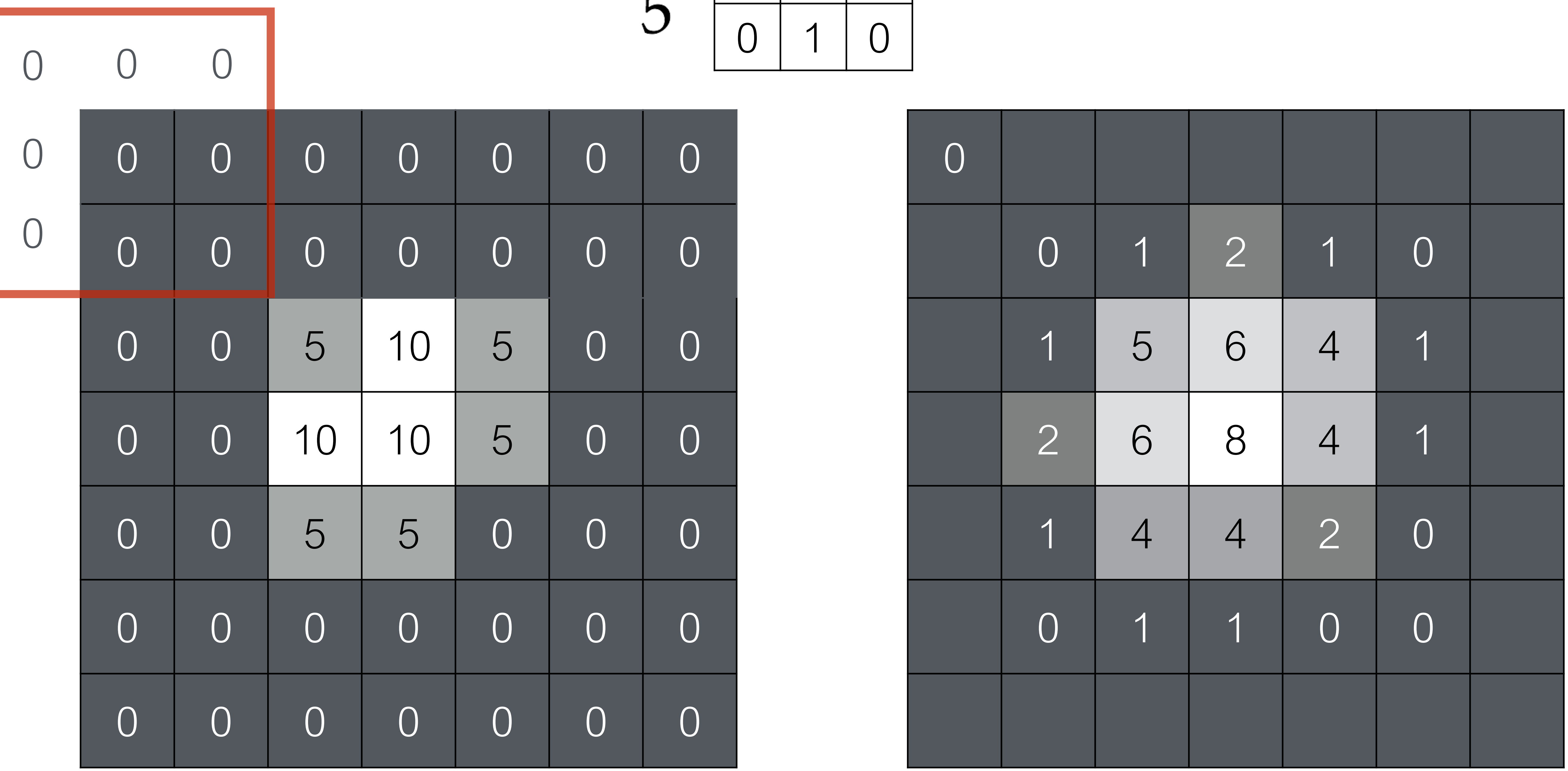
I

	0	1	2	1	0	
	1	5	6	4	1	
	2	6	8	4	1	
	1	4	4	2	0	
	0	1	1	0	0	

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$



I $\qquad\qquad$ $I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

0	0	0				
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

I

0	0					
	0	1	2	1	0	
	1	5	6	4	1	
	2	6	8	4	1	
	1	4	4	2	0	
	0	1	1	0	0	

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{array}{|c|c|c|}\hline 0 & 1 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 1 & 0 \\ \hline\end{array}$$

0	0	0	0	0	0	0	
0	0	0	0	0	0	0	
0	0	5	10	5	0	0	
0	0	10	10	5	0	0	
0	0	5	5	0	0	0	
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
					0	0	0

I

0	0	0	0	0	0	0
0	0	1	2	1	0	0
0	1	5	6	4	1	0
0	2	6	8	4	1	0
0	1	4	4	2	0	0
0	0	1	1	0	0	0
0	0	0	0	0	0	0

$I \otimes w$

Sliding Dot Product

$$w = \frac{1}{5}\begin{array}{|c|c|c|}\hline 0 & 1 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 1 & 0 \\ \hline\end{array}$$

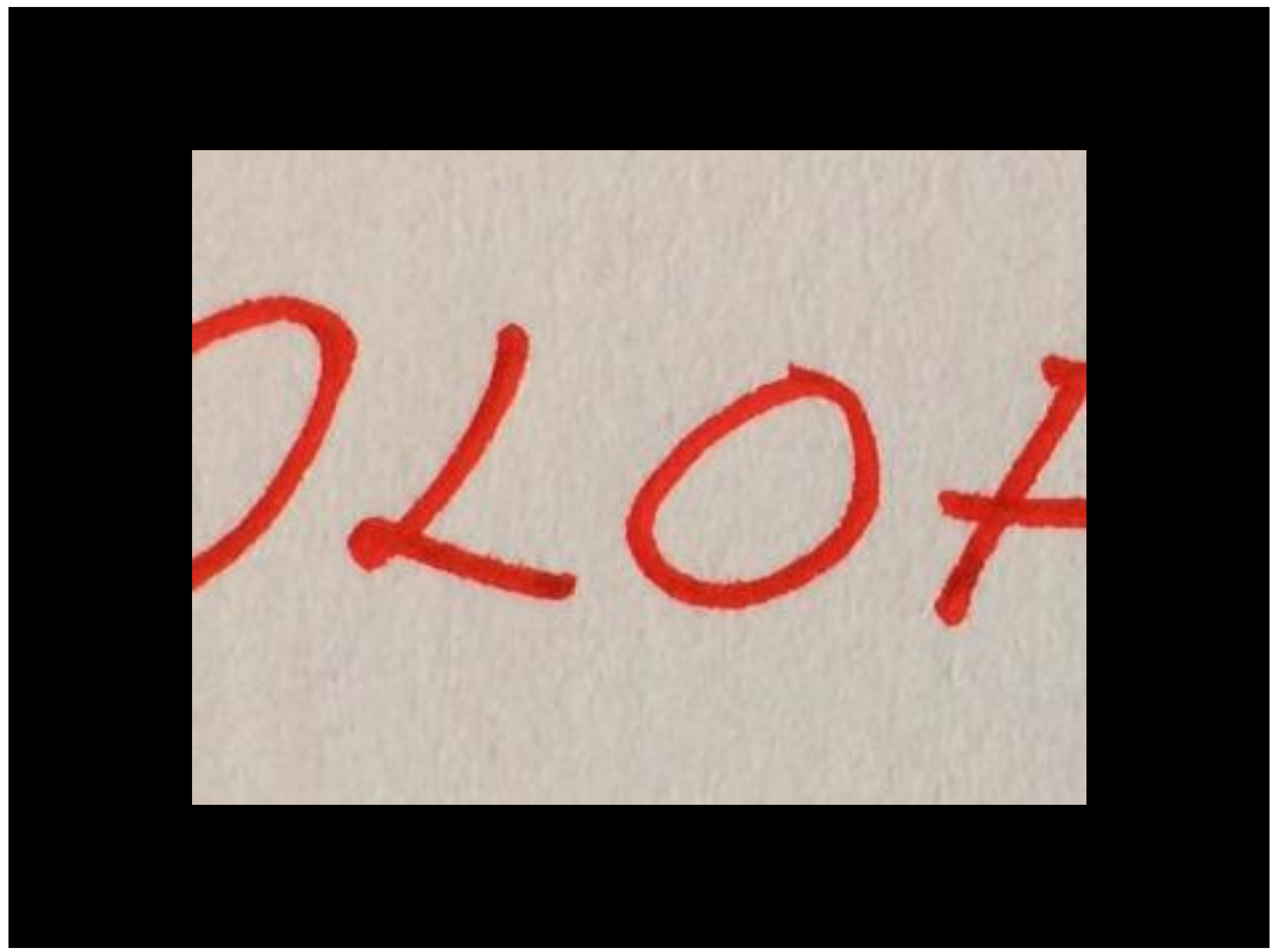
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	5	10	5	0	0
0	0	10	10	5	0	0
0	0	5	5	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

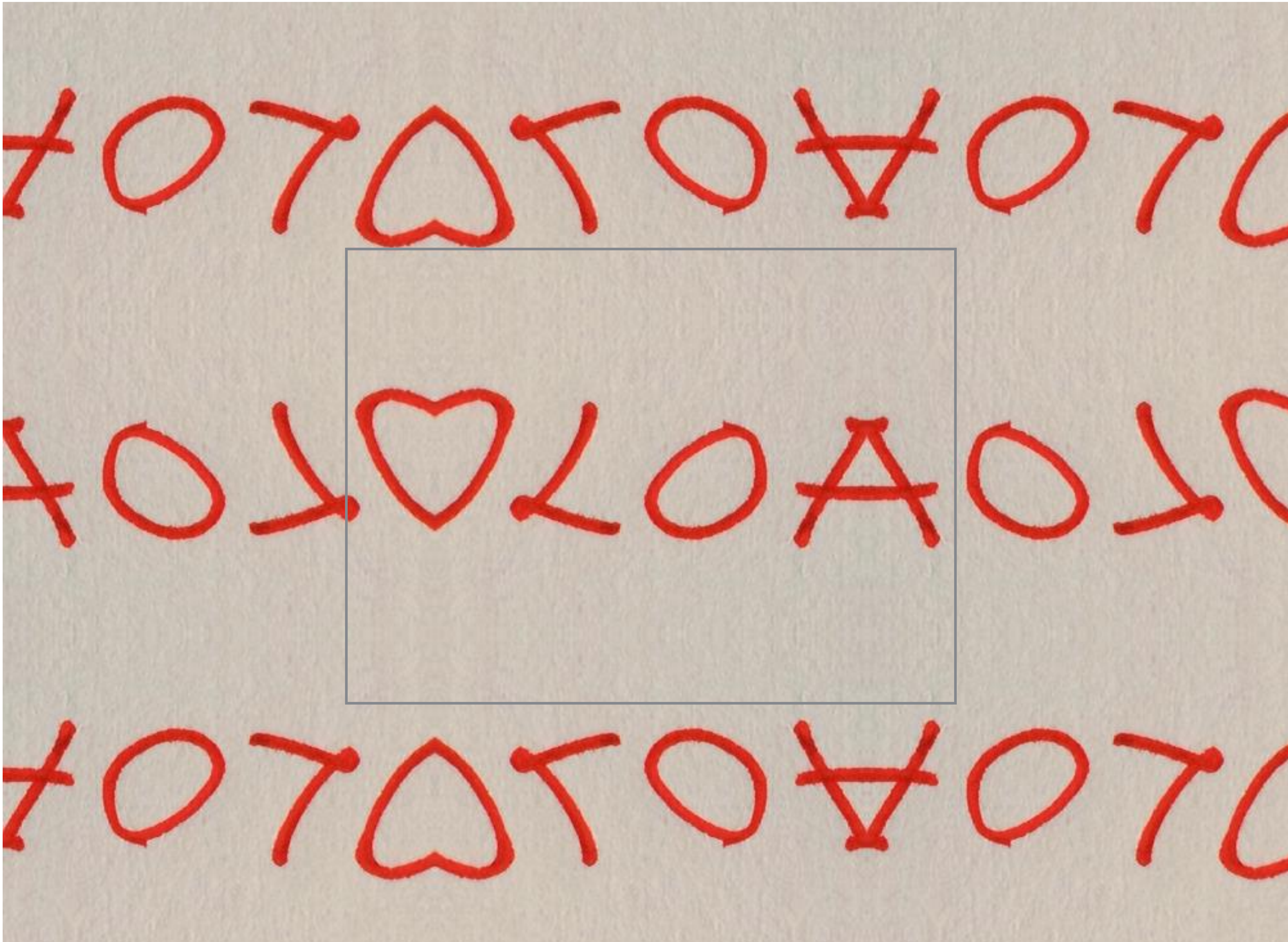
I

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

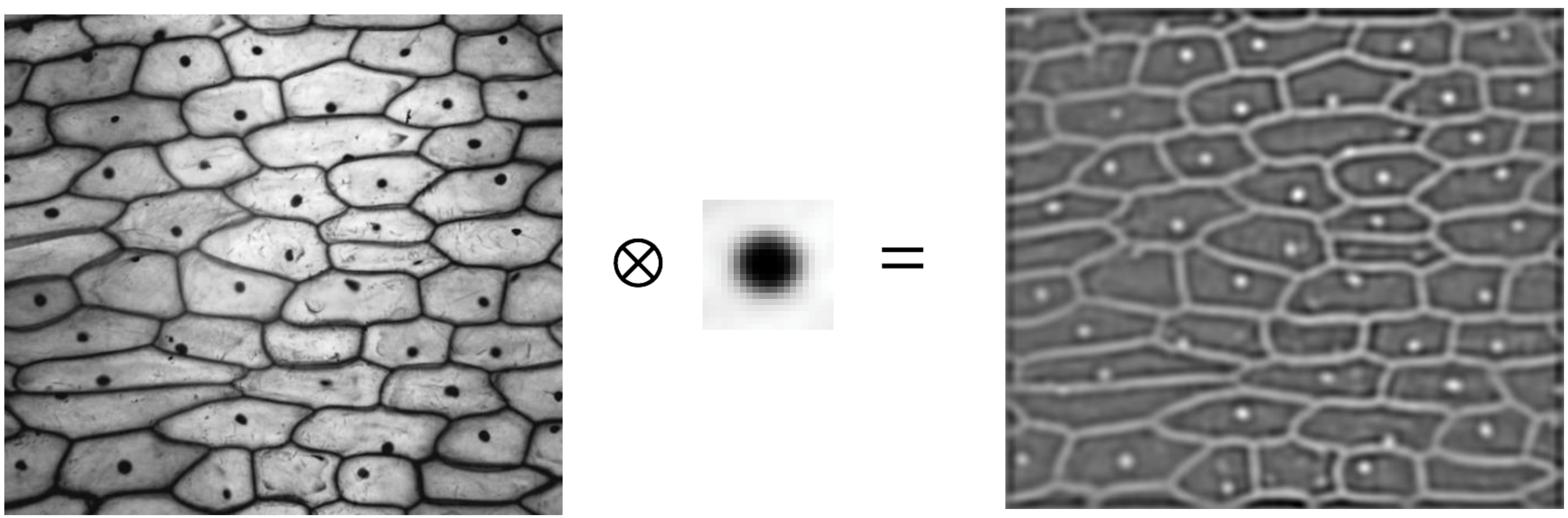
$I \otimes w > 4$

Boundary Padding

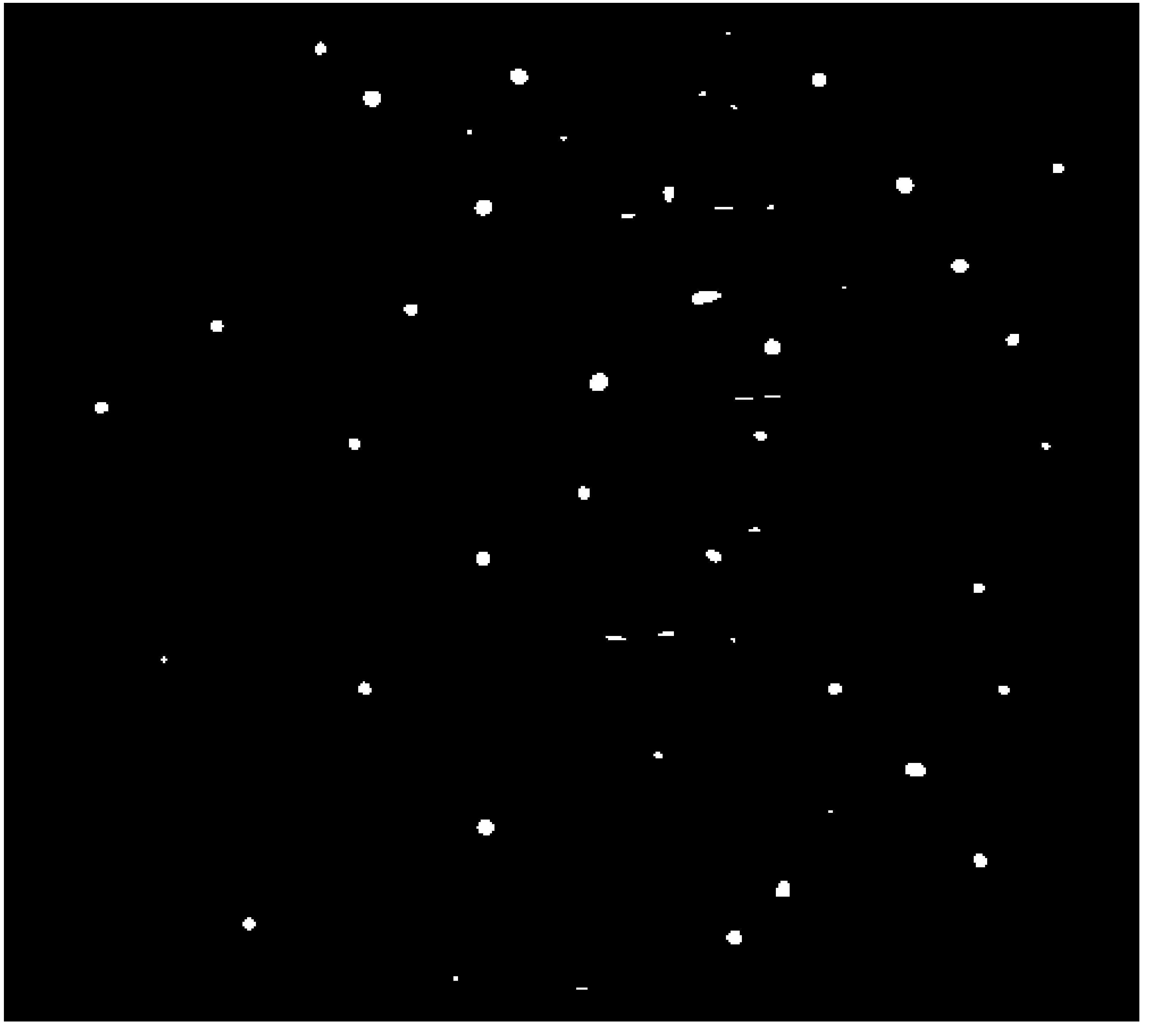




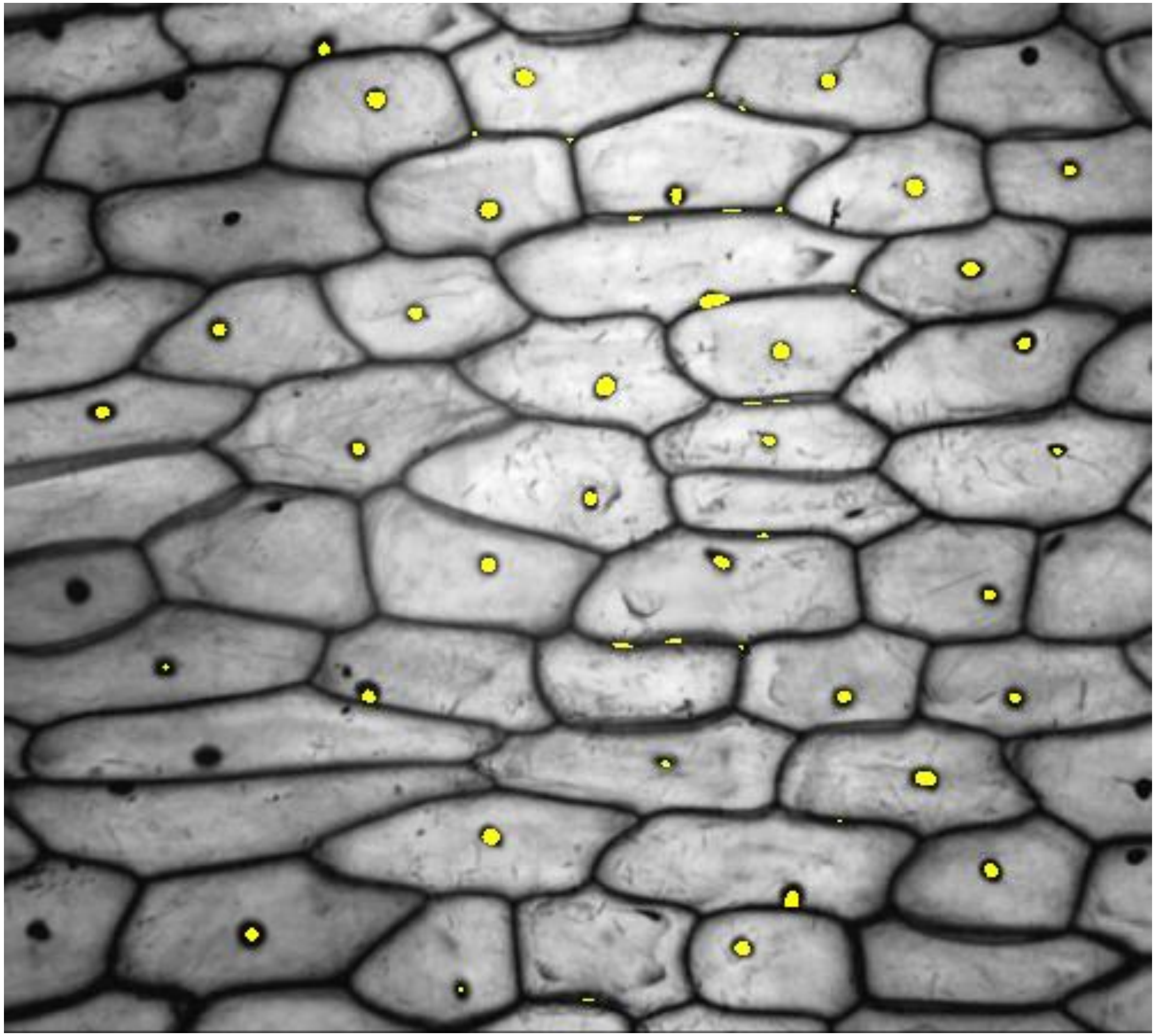
Sliding Window Classification



Per-Pixel Classification Results



Per-Pixel Classification



Maximum Filter / Non-Maximum Suppression

Is this pixel larger than its neighbors?

1	2	1	2	3	4	2
11	21	22	21	14	6	7
12	20	45	32	21	12	11
11	12	11	16	21	12	21
21	22	23	25	35	22	20
12	11	16	17	16	6	0
0	7	0	21	12	11	0

input

	0					

result

Nonlinear Filters

Is this pixel larger than its neighbors?

1	2	1	2	3	4	2
11	21	22	21	14	6	7
12	20	45	32	21	12	11
11	12	11	16	21	12	21
21	22	23	25	35	22	20
12	11	16	17	16	6	0
0	7	0	21	12	11	0

input

	0	0				

result

Nonlinear Filters

Is this pixel larger than its neighbors?

1	2	1	2	3	4	2
11	21	22	21	14	6	7
12	20	45	32	21	12	11
11	12	11	16	21	12	21
21	22	23	25	35	22	20
12	11	16	17	16	6	0
0	7	0	21	12	11	0

input

	0	0	0	0	0	
	0	1				

result

Nonlinear Filters

Is this pixel larger than its neighbors?

1	2	1	2	3	4	2
11	21	22	21	14	6	7
12	20	45	32	21	12	11
11	12	11	16	21	12	21
21	22	23	25	35	22	20
12	11	16	17	16	6	0
0	7	0	21	12	11	0

input

	0	0	0	0	0	
	0	1	0			

result

Nonlinear Filters

Is this pixel larger than its neighbors?

1	2	1	2	3	4	2
11	21	22	21	14	6	7
12	20	45	32	21	12	11
11	12	11	16	21	12	21
21	22	23	25	35	22	20
12	11	16	17	16	6	0
0	7	0	21	12	11	0

input

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

result

Nonlinear Filters

Is this pixel larger than its neighbors?

1	2	1	2	3	4	2
11	21	22	21	14	6	7
12	20	45	32	21	12	11
11	12	11	16	21	12	21
21	22	23	25	35	22	20
12	11	16	17	16	6	0
0	7	0	21	12	11	0

input

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

result

Nonlinear Filters

Is this pixel larger than its neighbors?

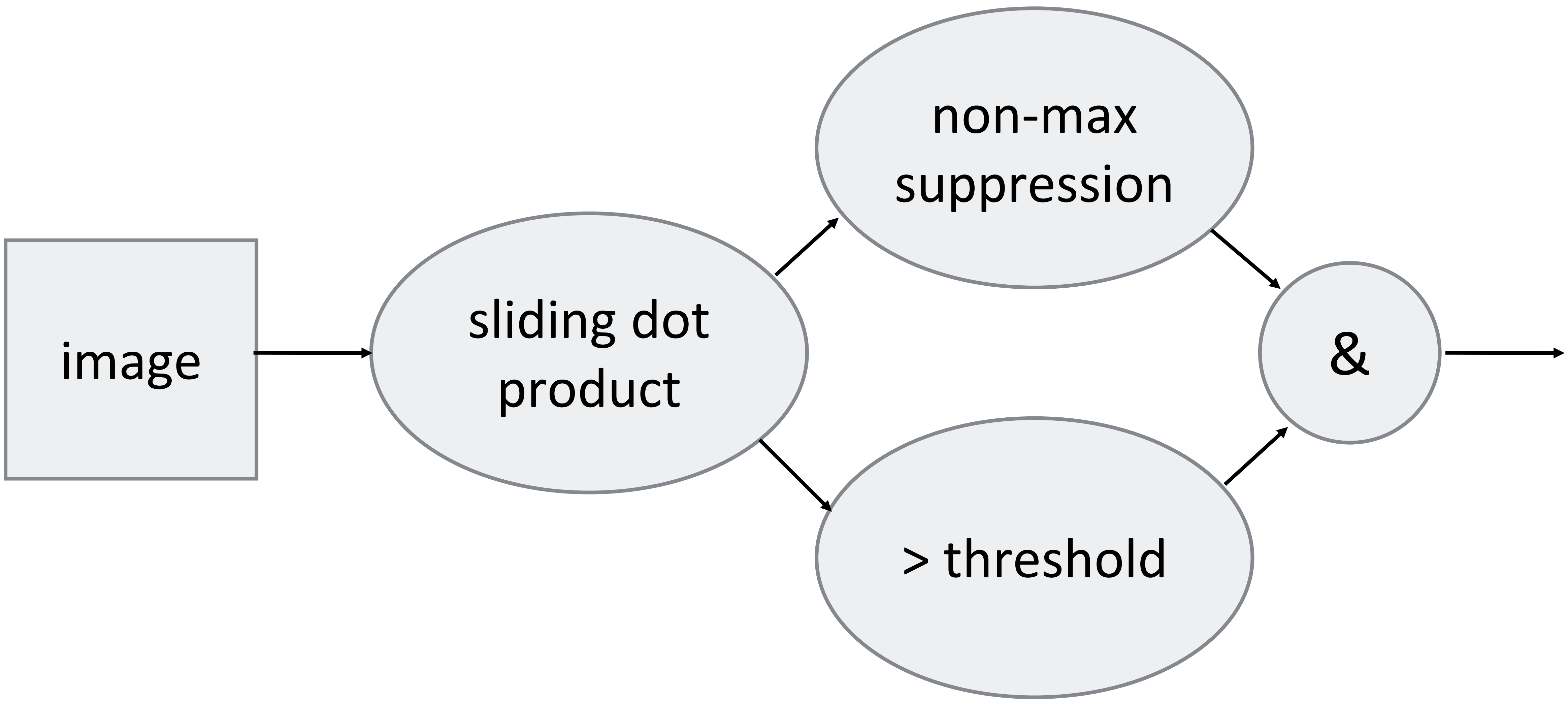
1	2	1	2	3	4	2
11	21	22	21	14	6	7
12	20	45	32	21	12	11
11	12	11	16	21	12	21
21	22	23	25	35	22	20
12	11	16	17	16	6	0
0	7	0	21	12	11	0

input

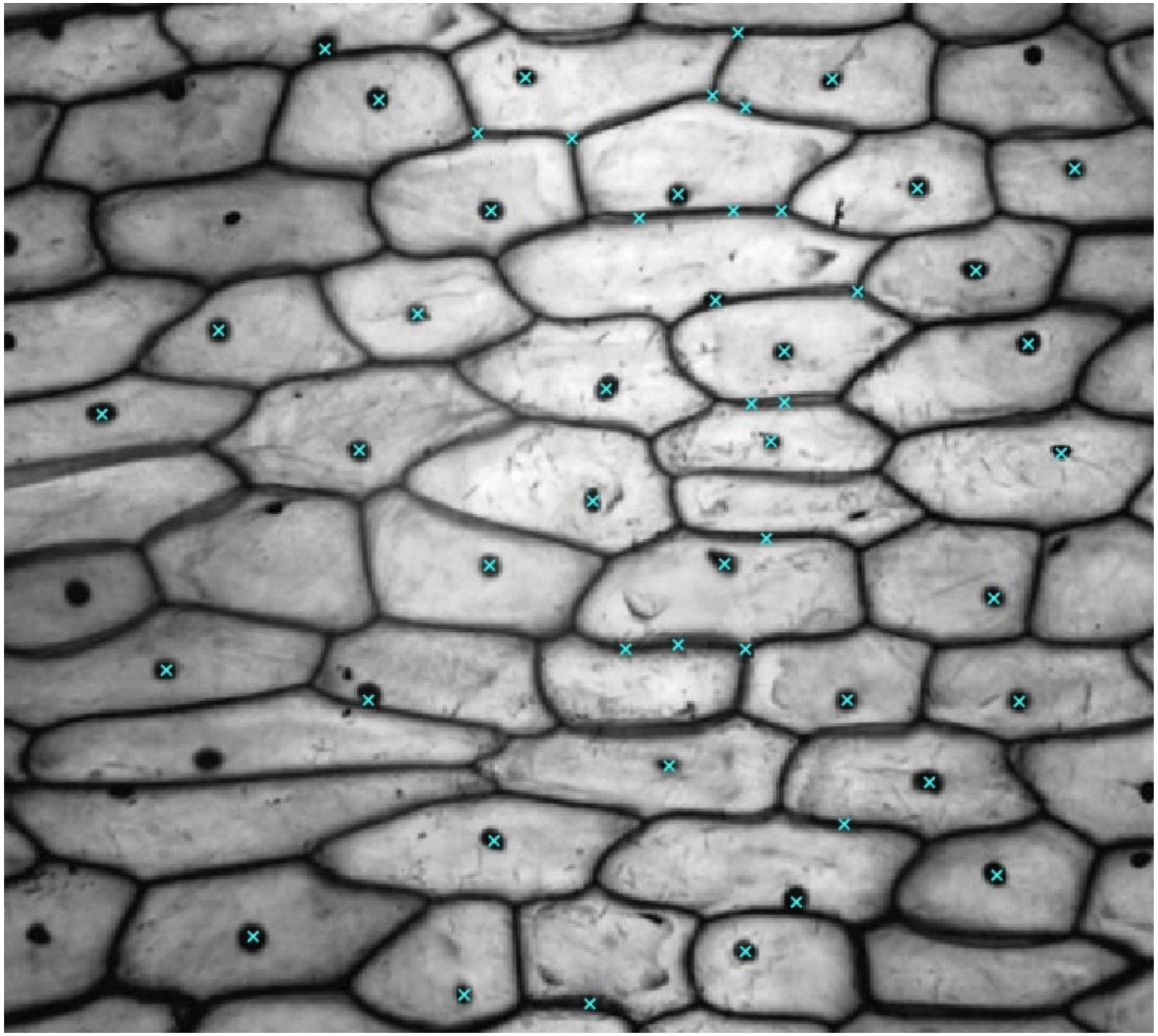
	0	0	0	0	0	
	0	1	0	0	0	
	0	0	0	0	0	
	0	0	0	1	0	
	0	0	0	0	0	

result

A Sliding-Window Detector



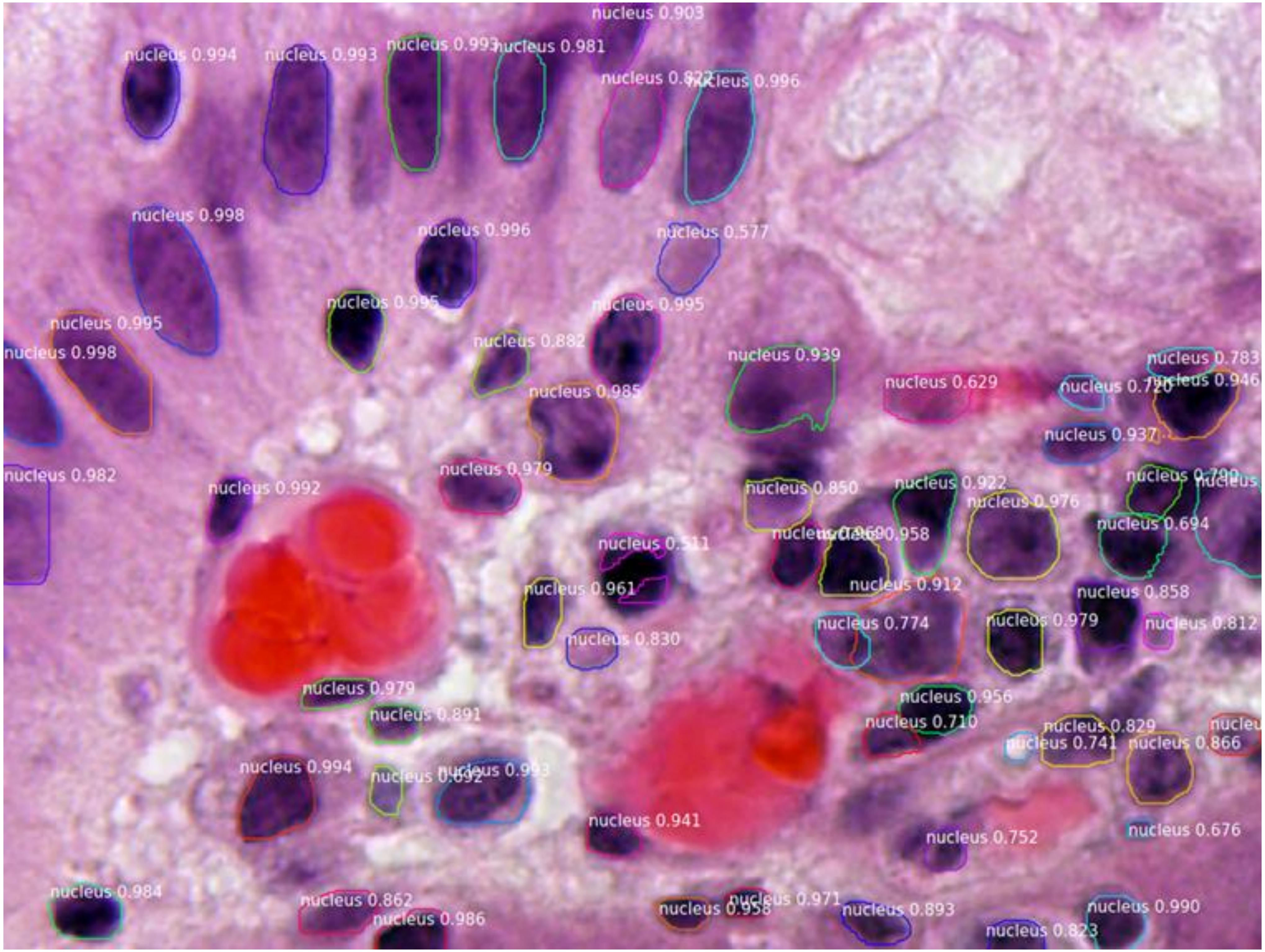
Result



Count: 52

Manual: 48

Instance Level Segmentation



[Result from applying Masked R-CNN]

Lessons Learned

- Main lessons from this lecture
  - Images are vectors: Addition, subtraction, dot product
  - Linear filters: Mean, dot product-based
  - Nonlinear filters: Non-maximum suppression
  - Sliding window classification
- Next lecture: More filtering, gradients, multi-scale processing

Next Lecture

Jan. 20	Introduction, Linear classifiers and filtering	
Jan. 23	**Filtering, gradients, scale**	Lab 1
Jan. 27	Local features	
Jan. 30	Learning a classifier	Lab 2
Feb. 3	Convolutional neural networks	
Feb. 6	More convolutional neural networks	
Feb. 10	Robust model fitting and RANSAC	Lab 3
Feb. 13	Image registration	
Feb. 17	Camera Geometry	Lab 4
Feb. 20	More camera geometry	
Feb. 24	Generative neural networks	
Feb. 27	Generative neural networks	
Mar. 2	TBA	
Mar. 9	TBA	