Friedrich-Alexander-Universität
Technische Fakultät

Winter 2024

Computer Vision Project

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Pattern Recognition Lab (CS5)
14th October 2024

Today‘s Outline

(1) Organization of this project

(2) Motivation

(3) What is Computer Vision?

(4) **Lecture 1**: Image Processing for Grayscale and Distance Images

Organization
Project Structure and Content

Organization – Grades and Certificates

Project for Computer Science and Medical Engineering

Option 1 (5 ECTS)	Option 2 (10 ECTS)	Option 3 (10 ECTS)
Academic Lab i. Lectures ii. Exercises (group)	Academic & Research Lab i. Lectures ii. Exercises (group) iii. Additional exercises (individual)	Academic & Research Lab i. Lectures ii. Exercises (group) iii. Research project (individual)

Grade for Hochschulpraktikum, if necessary, based on short talk (about a state-of-the-art research paper)

The research project is mostly related to one of the discussed topics

Forschungspraktikum only: Contact us or any other PhD student at the lab for a research project. Feel free to come up with your own idea or participate in a suitable challenge. (Overview: https://lme.tf.fau.de/teaching/thesis/)

Organization – Exercises

- Exercises are coded in **Python**
- You should work in **groups of two** (individual is also okay if really want that)

- Tasks are complementary to the lecture of the previous week. It is mandatory to **complete all of them**
  - You can work from **home** or in the **CIP pool**
  - It is strongly recommended to begin with the programming tasks before the exercise!

- Submissions are to be uploaded to StudOn and presented to the respective lecturer
- All tasks have to be finished by their individual deadlines (more later)

Organization – Exercises

- Prepare questions or problems **before** the exercise

- **Own virtual hardware**
  Virtual CIP-Pools: https://remote.cip.cs.fau.de/ (Xpra)

- You can ask additional questions via **StudOn Forum** (make use of this option!)

Organization – Lectures and Exercises

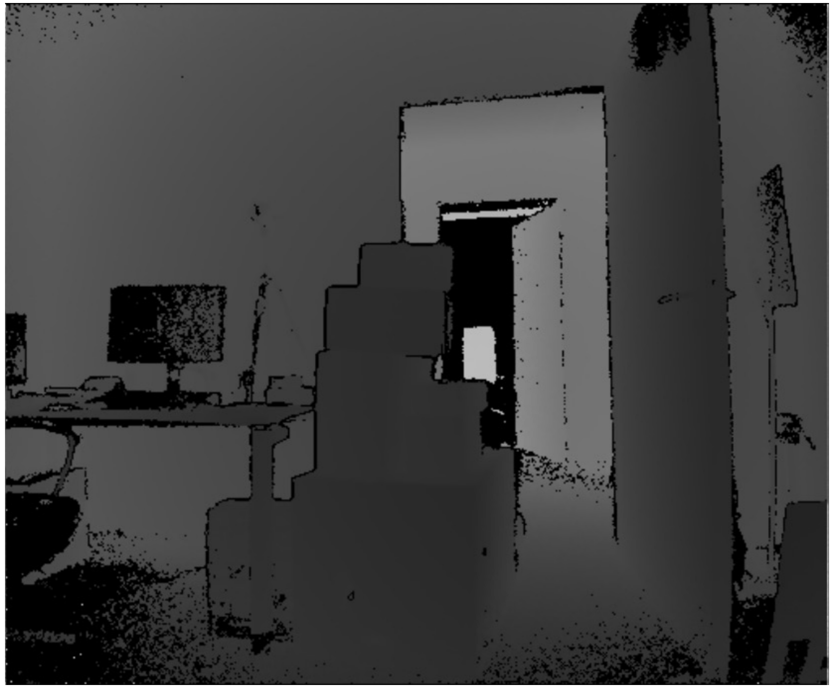
Preliminary schedule

Date	Lecture (In person)	Exercise (Online)
14.10.	Lecture 1 – Thomas Gorges	TODAY
21.10.	---	Ex. 1
28.10.	Lecture 2 – Mathias Seuret	**Deadline Ex. 1**
04.11.	---	Ex. 2
11.11.	---	Ex. 2
18.11.	Lecture 3 – Vincent Christlein	**Deadline Ex. 2**
25.11.	---	Ex. 3
02.12.	---	Ex. 3
09.12.	Lecture 4 – Thomas Köhler	**Deadline Ex. 3**
16.12.	---	Ex. 4
13.01.	Lecture 5 – Mathias Zinnen	**Deadline Ex. 4**
20.01.	---	Ex. 5
27.01.	---	**Deadline Ex. 5**
17.02.	---	**Deadline Individual Ex.**

- All exercise deadlines are at **2 pm**
- Each project team has to **present their exercise submission** to the respective lecturer (separate meeting in the week of the deadline)

Organization - Topics

- Basic image processing of grayscale and distance images
- Writer Identification/Retrieval
- Color image reconstruction via demosaicing
- Face Recognition
- Image Recognition for Humanities



2D distance image

Organization - Topics

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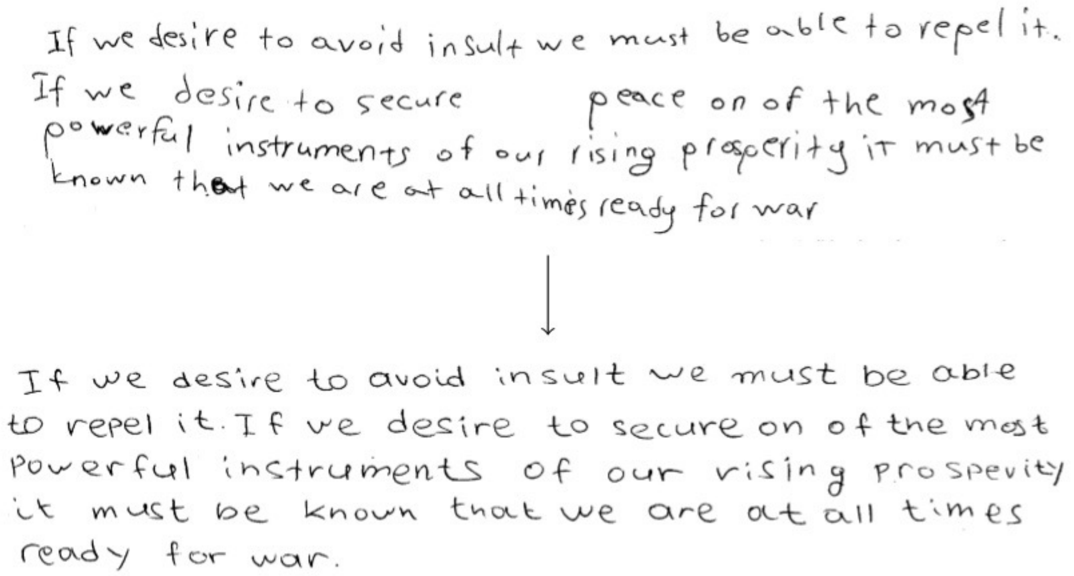

Writer identification/retrieval system

Organization - Topics

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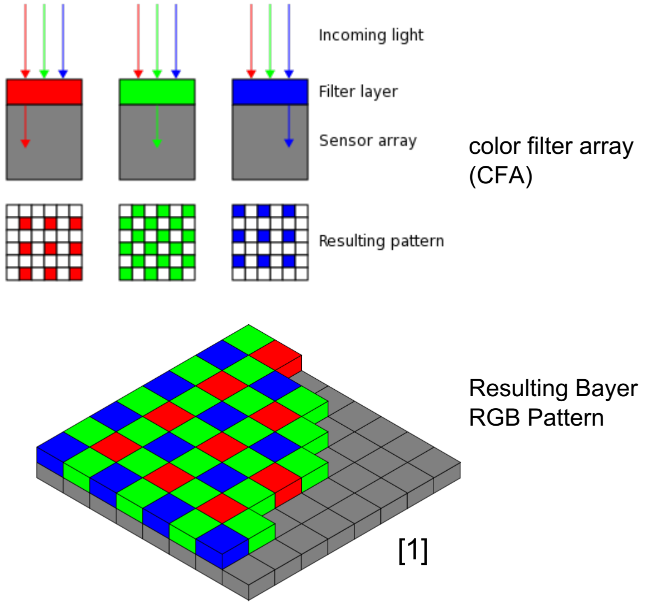

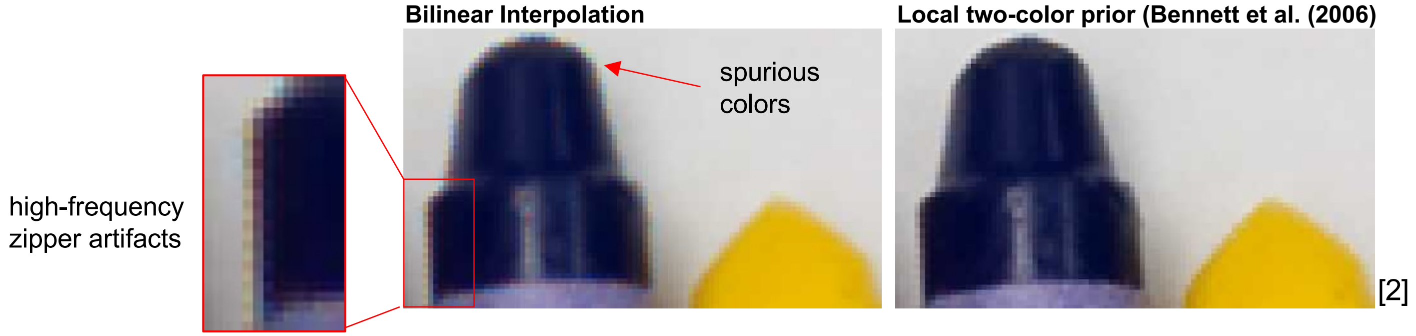

[1] https://rawpedia.rawtherapee.com/Demosaicing
[2] http://szeliski.org/Book

Organization - Topics

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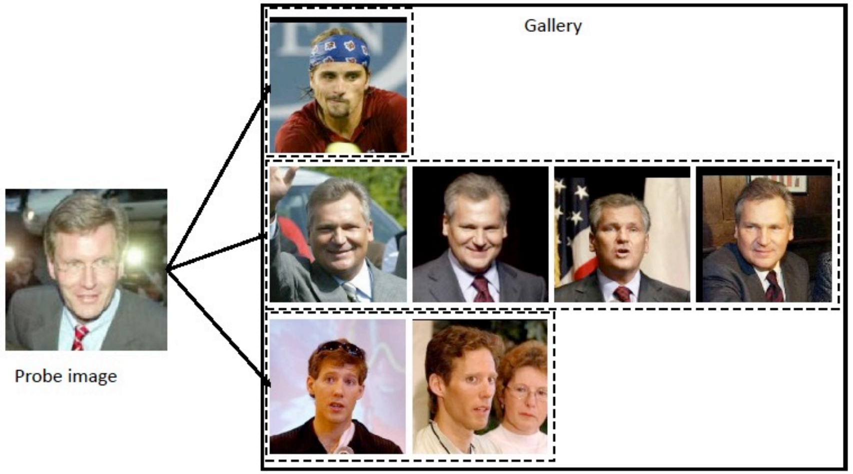

Figure: Supervised learning (face identification)

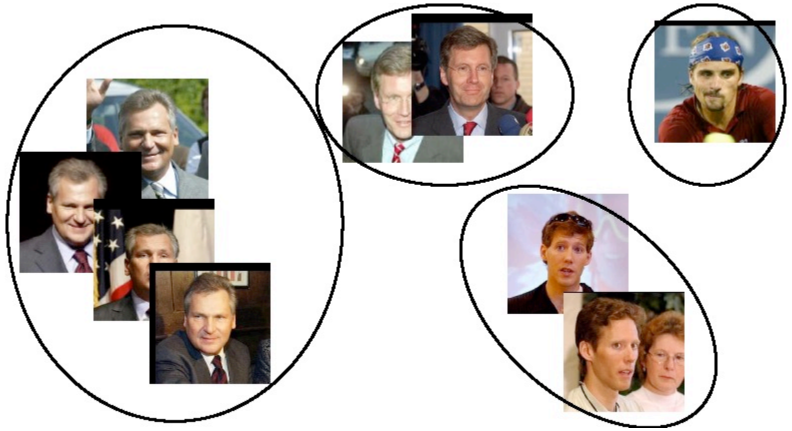
Figure: Unsupervised learning (face clustering)

Organization - Topics

- Basic image processing of grayscale and distance images
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Organization
Questions?

Motivation
Applications of Computer Vision

Example 1: Collision Avoidance

→ Use cameras to observe a human/machine environment.

→ Avoid collisions by fusing camera and robot position information.

Example 2: Autonomous Driving

→ Use **radar/lidar/camera sensors** to capture the surrounding.

→ Utilize computer vision techniques to **semantically analyze the scene** and potentially make autonomous decisions.

Motivation: Hand Tracking

→ Detect salient keypoints on the hand anatomy.

→ Track individual keypoints across video frames.

Computer Vision Primer

Computer Vision is about extracting information from images

- **RGB**
- Grayscale
- Multispectral
- 2.5D and 3D

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- RGB
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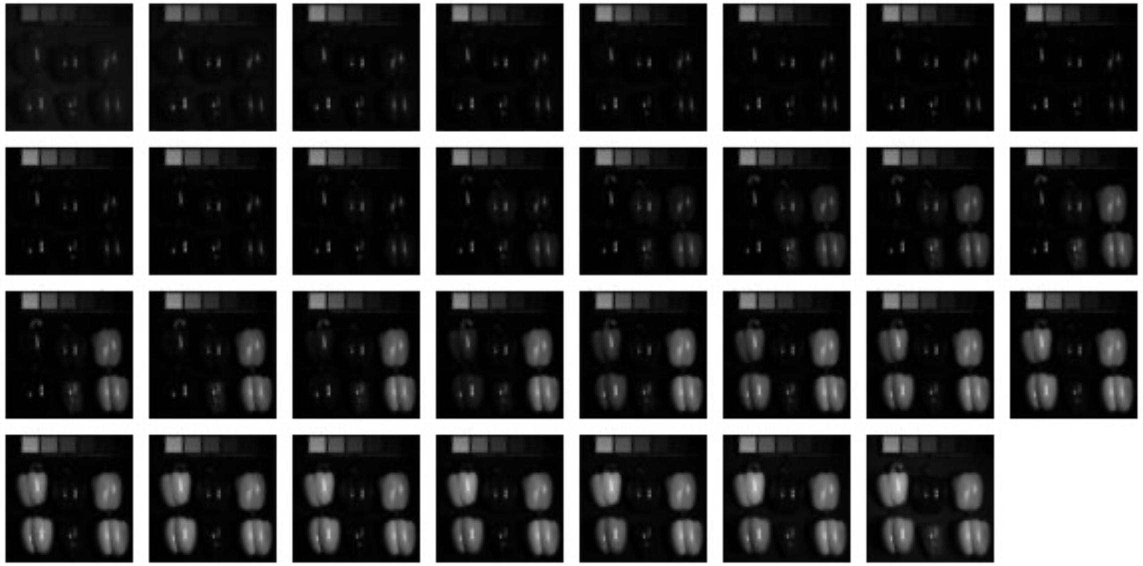


Computer Vision Primer

Computer Vision is about extracting information from images

- RGB
- Grayscale
- Multispectral
- **2.5D and 3D**

Dataset by Johannes Schauer, Andreas Nüchter from the University of Würzburg, Germany

Computer Vision Primer

Computer Vision is about extracting information from images
→ What kind of information?

Content	object detection, face identification
Text	sign detection, text extraction
Movement	tracking, motion capturing
Geometry	multi-camera setups, shape extraction, SLAM
Medical Imaging	segmentation, tumor detection
Quality Control	find production errors

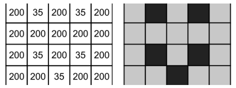
...

Lecture 1

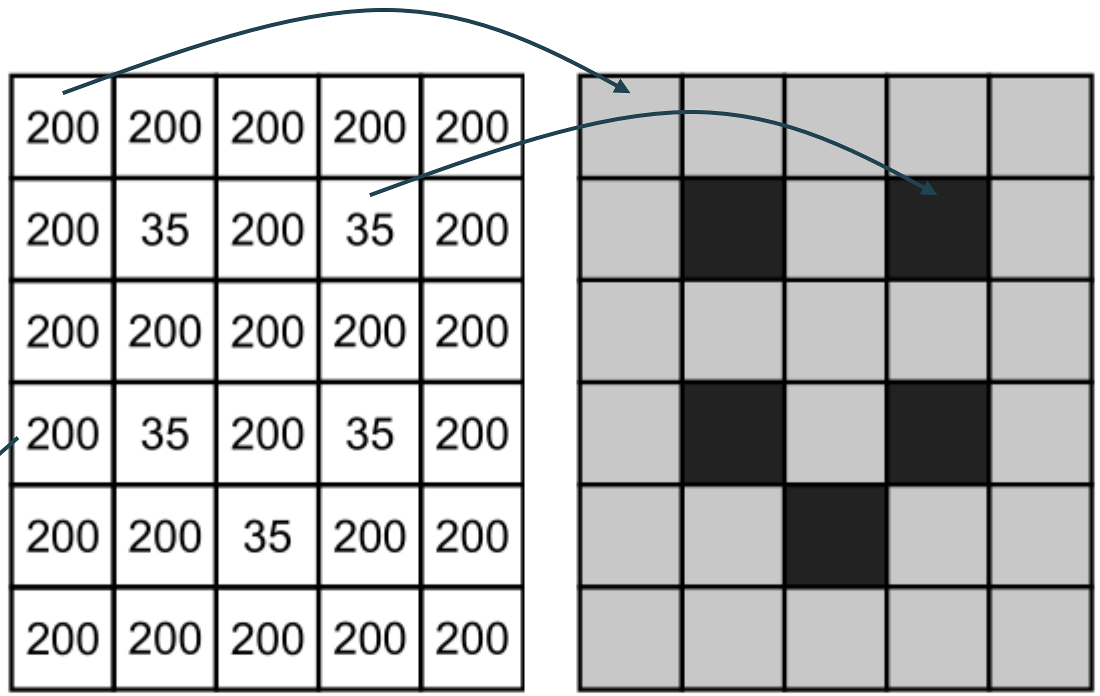
Processing on Grayscale and Distance Images

Image Formation

Images



Images can be represented as 2D arrays of a certain type, e.g., byte for grayscale images.



Gray scale image (ubyte/int8)

Num. of bits	Min. value	Max. value
8 bit	0	255
16 bit	0	65535
32 bit	0	4294967295
64 bit	0	2^64 - 1

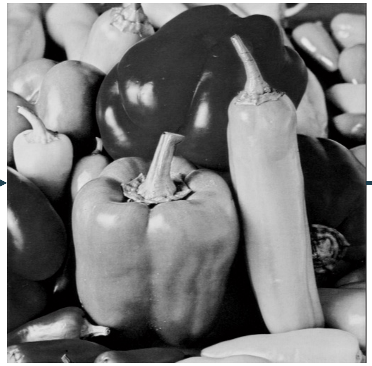
* Excluding floating point numbers

(A) Thresholding

Thresholding Simple operation that is used to separate regions of different „colors“

Returns a mask array of the same size as the original image

Input



Isolated channel: **Green**

Threshold
Value at $(x, y) > t$

Example t = 150

Resulting mask

Apply mask: Green peppers

(A) Thresholding on Distance Images

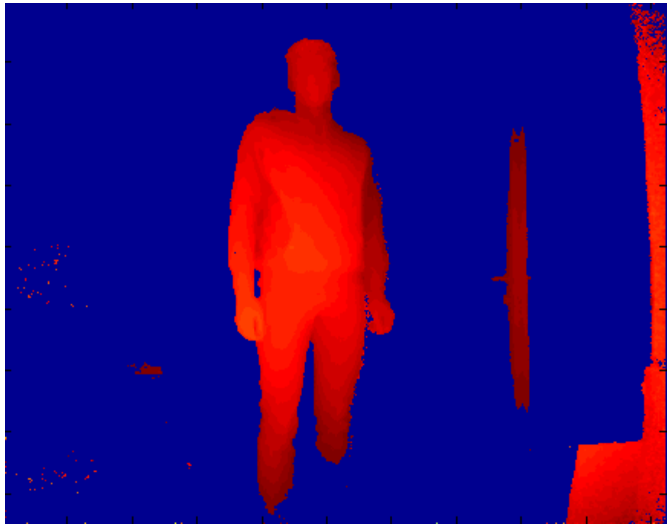
Pixels contain distance information. „Color" encodes the distance.

Example: On distance images thresholding can be used to separate fore- from background

Distance image with person

Threshold
Value at $(x, y) < t$

Example t = 1.85m



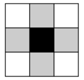
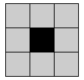
Scene foreground

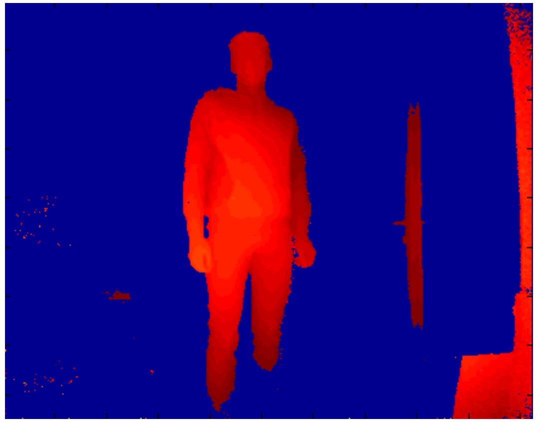
(B) Connected Components

Connected components are regions in an image that are „**connected**“

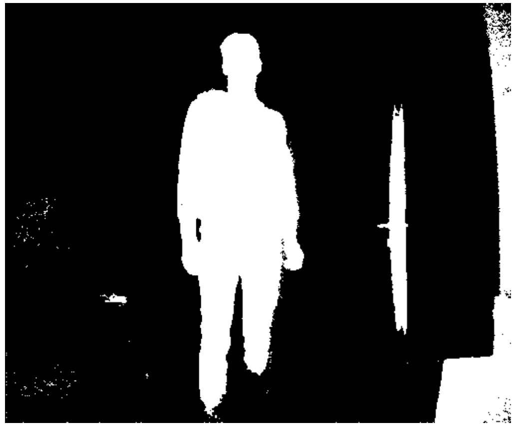
A pixel is **connected** to another pixel if they are in the same **neighborhood**

The **neighborhood** can be defined arbitrarily. Common neighborhoods are:

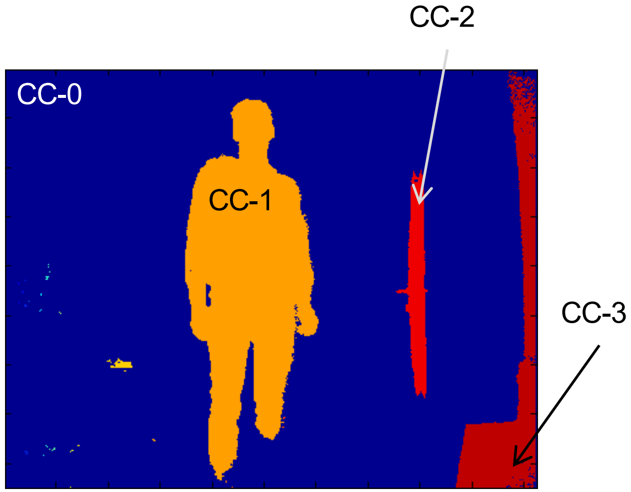
- 4-connected neighborhood 
- 8-connected neighborhood 



Input image



Mask image



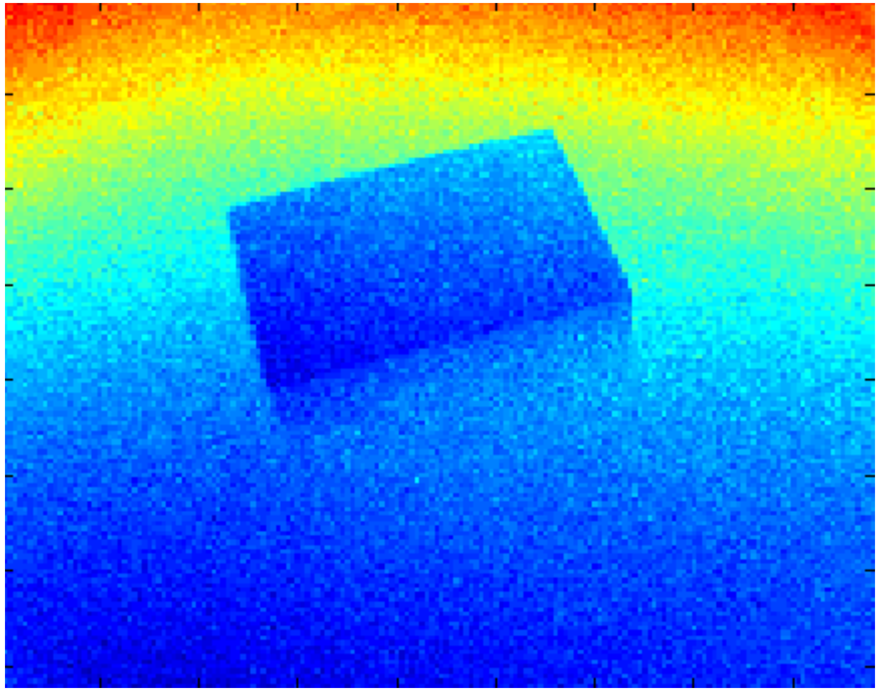
Connected Components

(C) Smoothing: Mean Filter

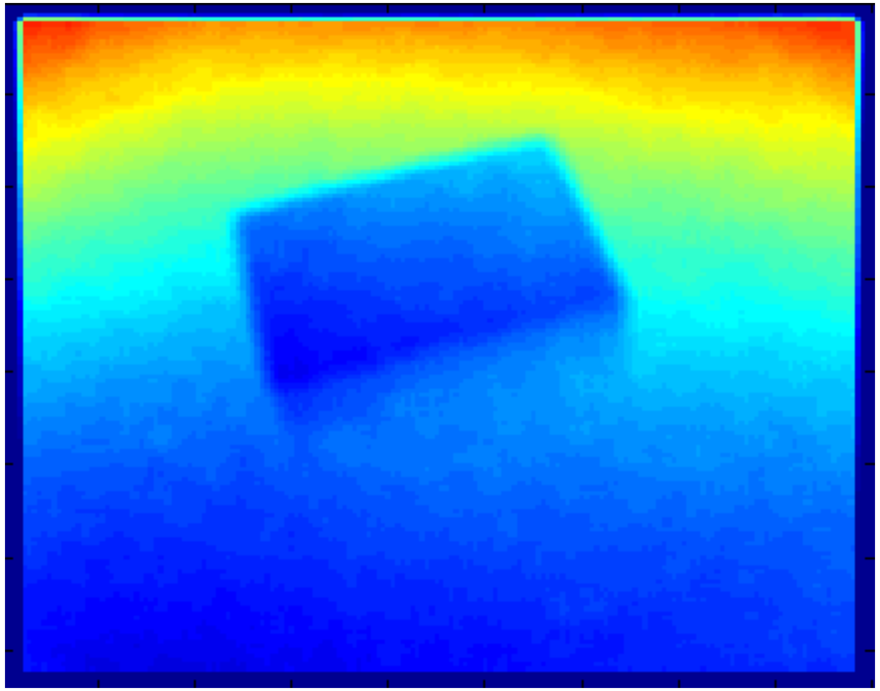
Mean Filter

Smoothes the image by **averaging pixel values** within a **certain window**

Commonly represented as a **convolution**

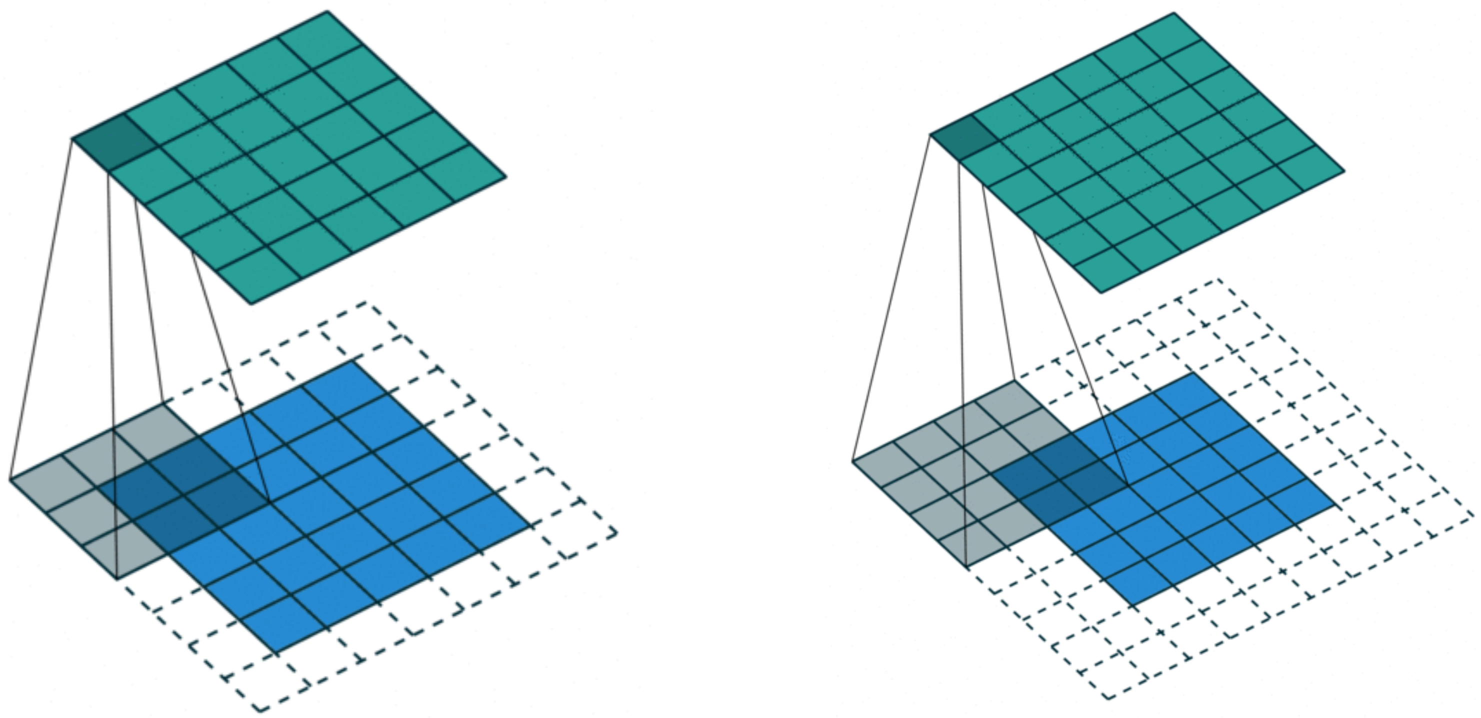


Original image from noisy measurement



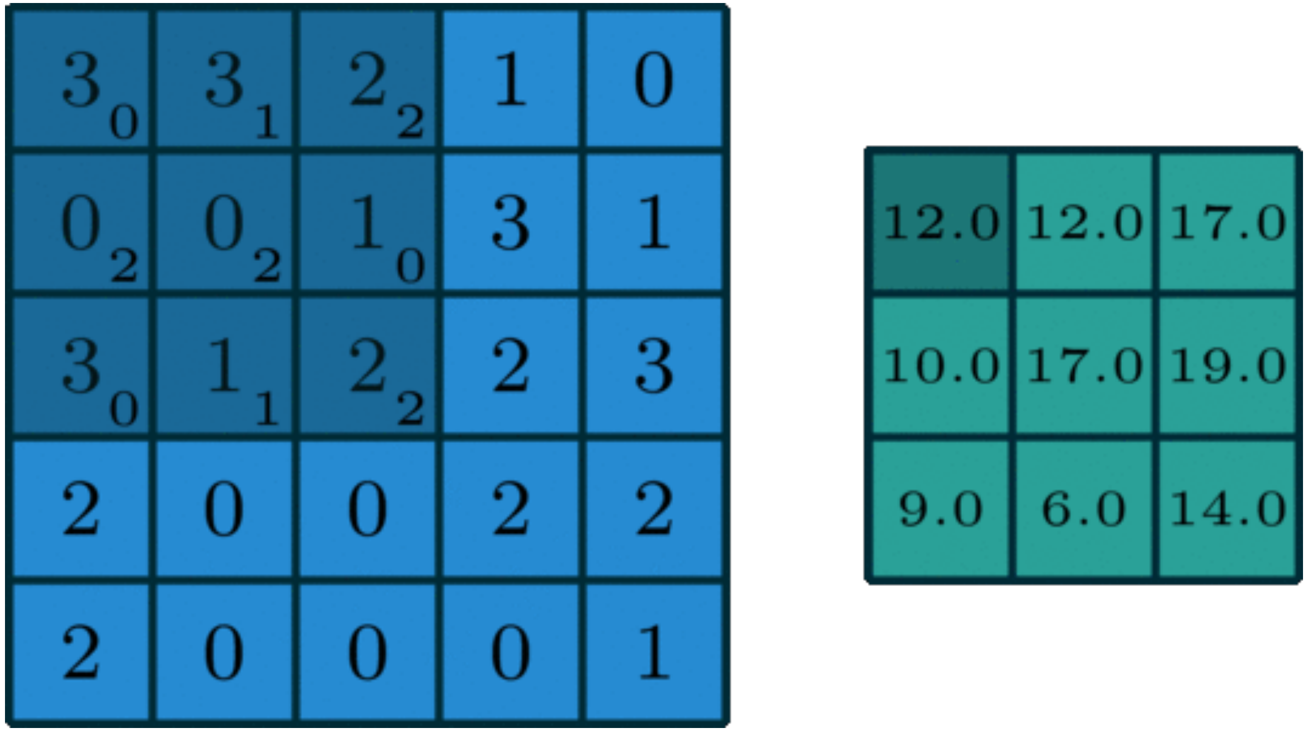
Mean filter (3x3 kernel)

(C) Recap Convolution / Cross-correlation



https://github.com/vdumoulin/conv_arithmetic

(C) Recap Convolution / Cross-correlation

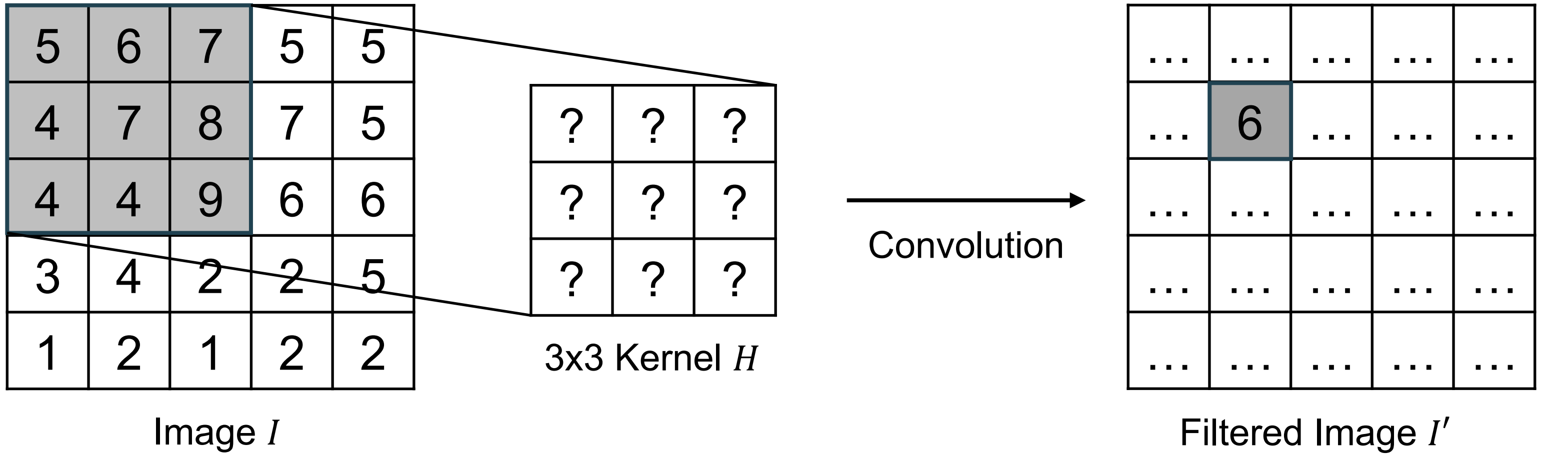


https://towardsdatascience.com/intuitively-understanding-convolutions-for-deep-learning-1f6f42faee1

(C) Smoothing: Mean Filter

Smoothes the image by averaging pixel values within a certain window

Commonly represented as a convolution



(C) Smoothing: Mean Filter

Smoothes the image by averaging pixel values within a certain window

Commonly represented as a convolution

5	6	7	5	5
4	7	8	7	5
4	4	9	6	6
3	4	2	2	5
1	2	1	2	2

Image I

$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$

3x3 Kernel H

Convolution

…	…	…	…	…
…	6	…	…	…
…	…	…	…	…
…	…	…	…	…
…	…	…	…	…

Filtered Image I'

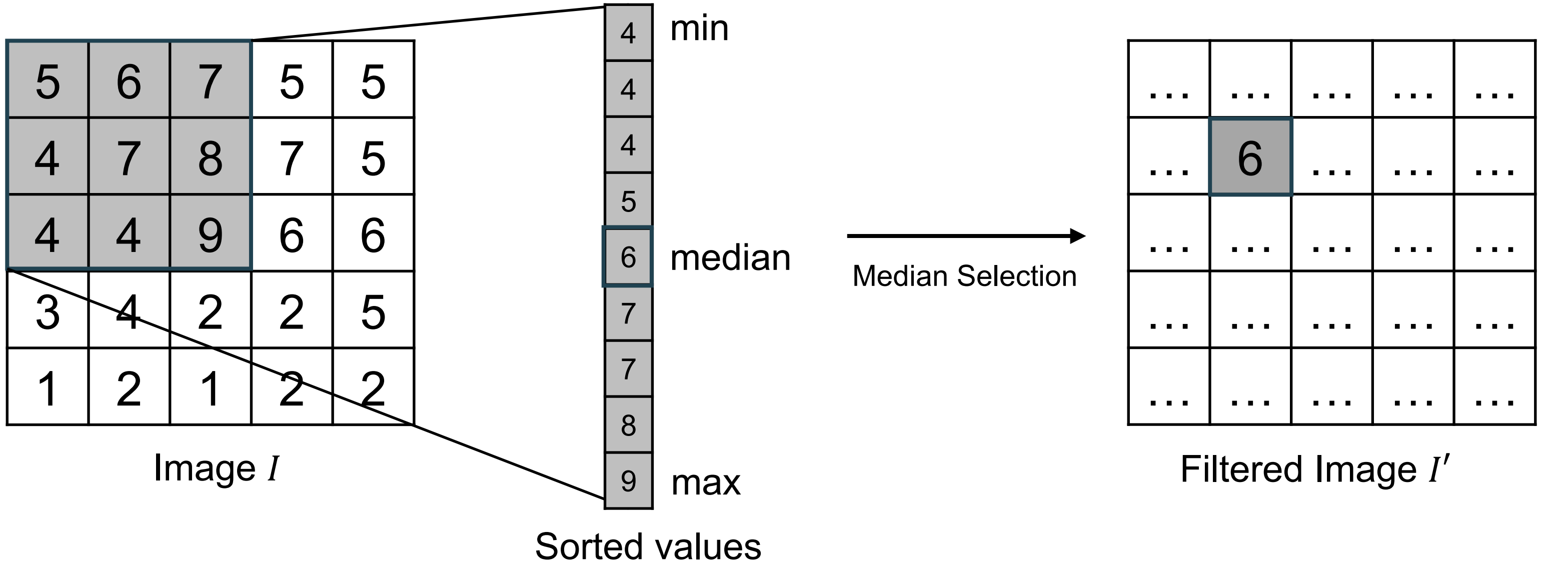
$$I' = I \boxed{*} H = I * \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Asterix denotes the convolution operator

(C) Smoothing: Median Filter

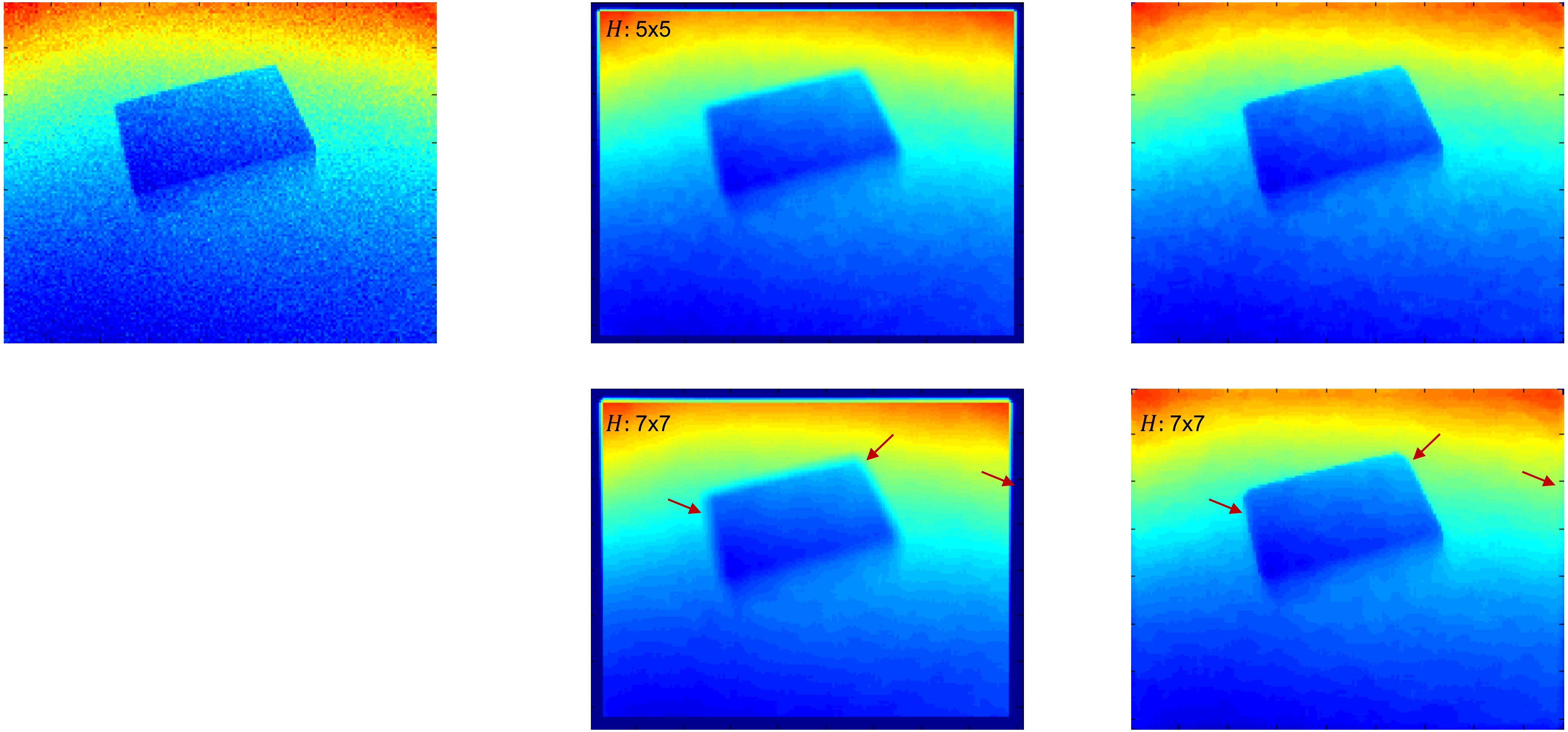
Sorts all pixel values within a certain window and uses the median of the sorted list as new pixel value

- Nonlinear filter → cannot be represented using a convolution
- Popular to remove salt-and-pepper noise



(C) Smoothing: Mean vs. Median Filtering

Distance image (box on surface) | Mean filter (linear) | Median filter (non-linear)



(C) Smoothing

There exist more smoothing filters and algorithms out of which some are based on convolutions while others are not.

- Gaussian smoothing
- Bilateral filtering
- Guided filtering
- ...

(D) Morphological Operators

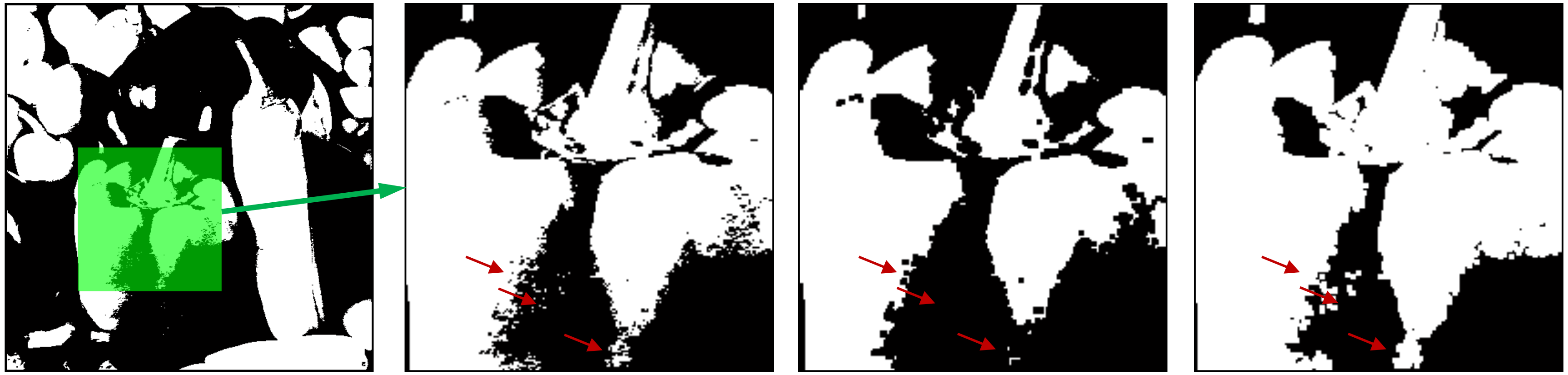
Morphological operators typically work on **binary images** (e.g. masks with only values of 0 a. 255)

→ Analyze pixels within a certain window/structuring element B

Basic operators are:

Erosion → Smooth out fuzzy edges

Dilation → Smooth out nooks and crannies



Binary image | Input region | *Erosion* (3x3) | **Dilation** (3x3)

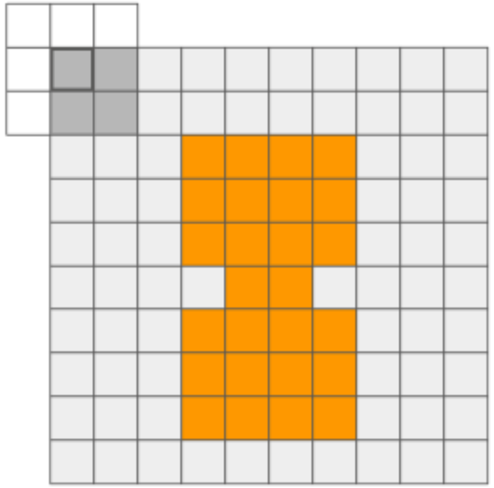
(D) Erosion

Erosion

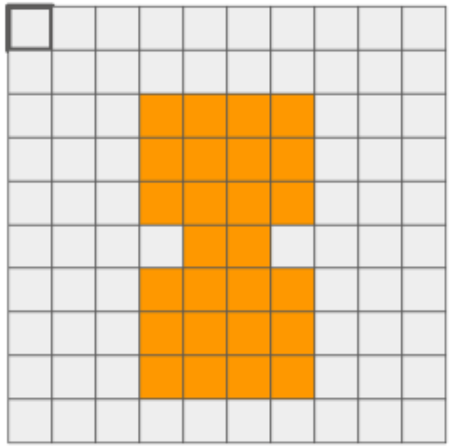
Morphological operation denoted by operator $\ominus$

→ **Rule**: Given an input image $\boldsymbol{A}$**,** a pixel in the output $\boldsymbol{A'}$ is **1** (is retained) if a structuring element $\boldsymbol{B}$ is completely contained in $\boldsymbol{A}$

$\boldsymbol{A}$



$\boldsymbol{A'}$



Struct. Elem. $\boldsymbol{B}$

1	1	1
1	1	1
1	1	1

https://penny-xu.github.io/blog/mathematical-morphology

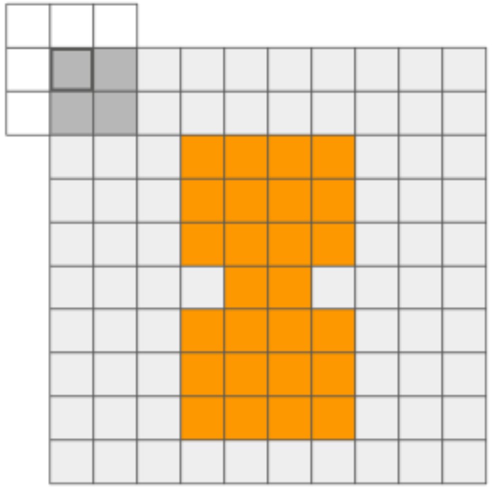
(D) Dilation

Dilation

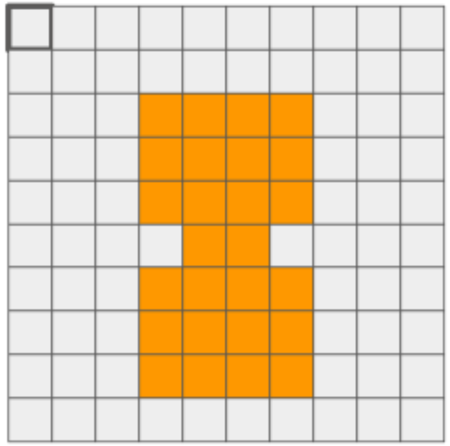
Morpholocial operation denoted by operator $\oplus$

→ **Condition**: Superimpose $\boldsymbol{B}$ on each pixel in $\boldsymbol{A}$ that has the value of 1**.** The output image $\boldsymbol{A'}$ includes every pixel of $\boldsymbol{B}$ that is **1**

$\boldsymbol{A}$



$\boldsymbol{A'}$



Struct. Elem. $\boldsymbol{B}$

1	1	1
1	1	1
1	1	1

https://penny-xu.github.io/blog/mathematical-morphology

(D) Morphological Operators

Opening

First **erode**, then **dilate:** $A' = (A \ominus B) \oplus B$ → Remove noise smaller than the structuring element

Closing

First **dilate**, then **erode**: $A' = (A \oplus B) \ominus B$ → Close holes („black dots“) in the foreground

Binary image | Input region | Opening (3x3) | Closing (3x3)

(D) Further Example

(a) (b) (c) (d) (e)

http://szeliski.org/Book/

a) Input image
b) Dilation (5x5)
c) Erosion (5x5)
d) Opening (5x5)
e) Closing (5x5)

(E) Further Reading

There exist different filters for a multitude of tasks

Edge detection (Sobel, Scharr, Canny)

Second order derivatives (Laplacian of Gaussian)

Corner detectors [Harris88]

Circle detectors [Loy03]

...

Edges: Sobel

Edges: Canny

Corners: Harris

(F) Optimization with RANSAC

RANdom Sampling And Consensus is a simple optimization strategy for noisy data

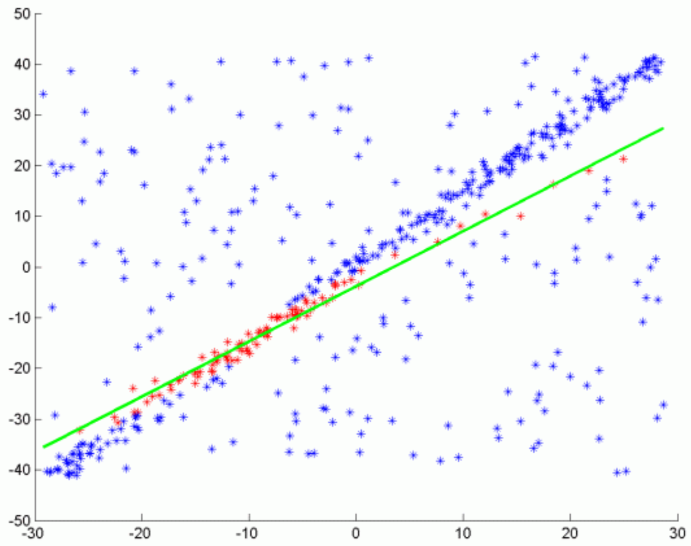
Assumes that a data set contains

(1) **Inliers**

(2) **Outliers** (noisy samples)

Can be used for all kinds of models: lines, planes, rotations, projection matrices, ...

→ We will learn more about this in the exercise!



https://de.wikipedia.org/wiki/RANSAC-Algorithmus

```
max_inliers = 0
best_model = null
while (i < N) {
        samples = minimal_sample(k, all_points)
        model = estimate_model(samples)
        n_inliers = computeInliers(all_points, model)
        if (n_inliers > max_inliers)  {
                best_model = model
                max_inliers = n_inliers
        }
}
```

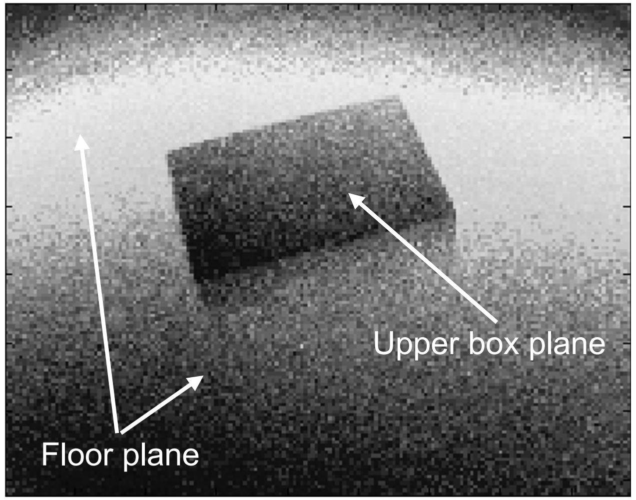
Lecture 1
Questions?

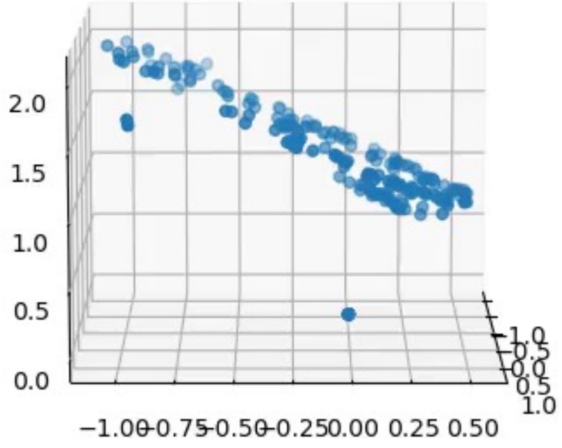
Exercise 1
Teaser

Exercise 1: Box Detection

What you get

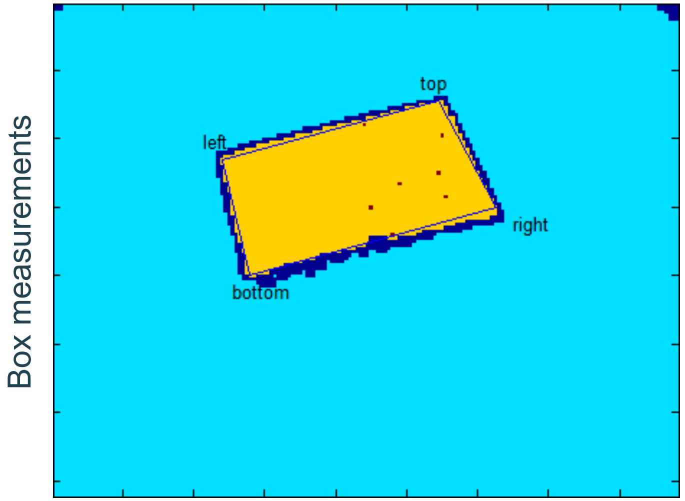
- 2D distance image of a simple packaging box on a table
- Its corresponding 3D point cloud measurement





Your goal is to

- Find the floor plane
- Find the box
- Estimate the size of the box



...with the tools you have learned today
  (**RANSAC, Filtering, Smoothing,** etc.)

References

References

[Harris88] C. Harris and M. Stephens (1988). "*A combined corner and edge detector*“, 1988

[Loy03] G. Loy, „*Fast radial symmetry for detecting points of interest*,” 2003