

02502

Image Analysis

Week 4 - Neighbourhood Processing

<http://courses.compute.dtu.dk/02502/>

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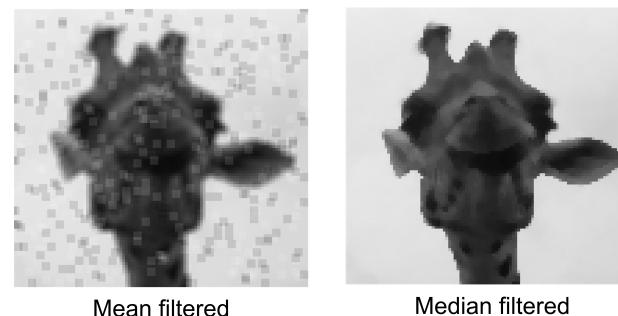
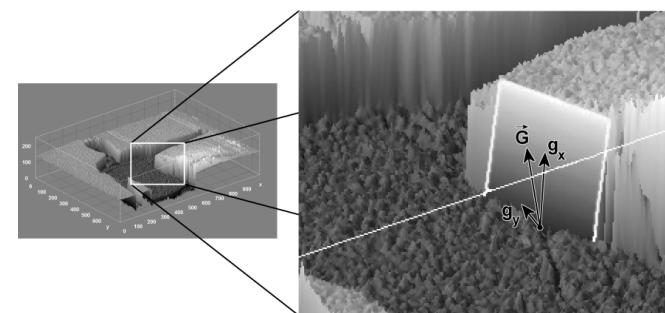
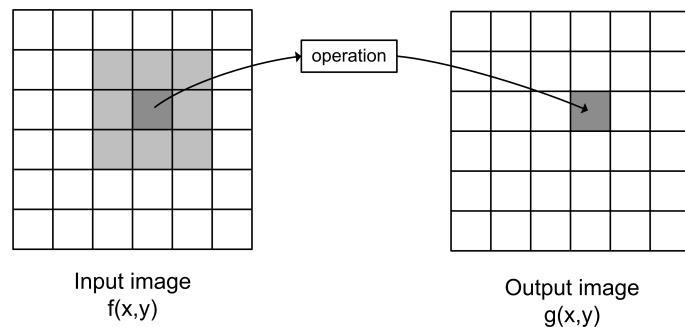
&

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Plenty of slides adapted from Thomas Moeslunds lectures

Lecture 4

Neighbourhood Processing



What can you do after today?

- Describe the difference between point processing and neighbourhood processing
- Compute a rank filtered image using the min, max, median, and difference rank filters
- Compute a mean filtered image
- Decide if median or average filtering should be used for noise removal
- Choose the appropriate image border handling based on a given input image
- Implement and apply template matching
- Compute the normalised cross correlation and explain why it should be used
- Apply given image filter kernels to images
- Use edge filters on images
- Describe finite difference approximation of image gradients including the magnitude and the direction
- Compute the magnitude of the gradient
- Describe the concept of edge detection

Go to www.menti.com and use the code **12 81 90**

 [Mentimeter](#)

Quiz : What is a filter?

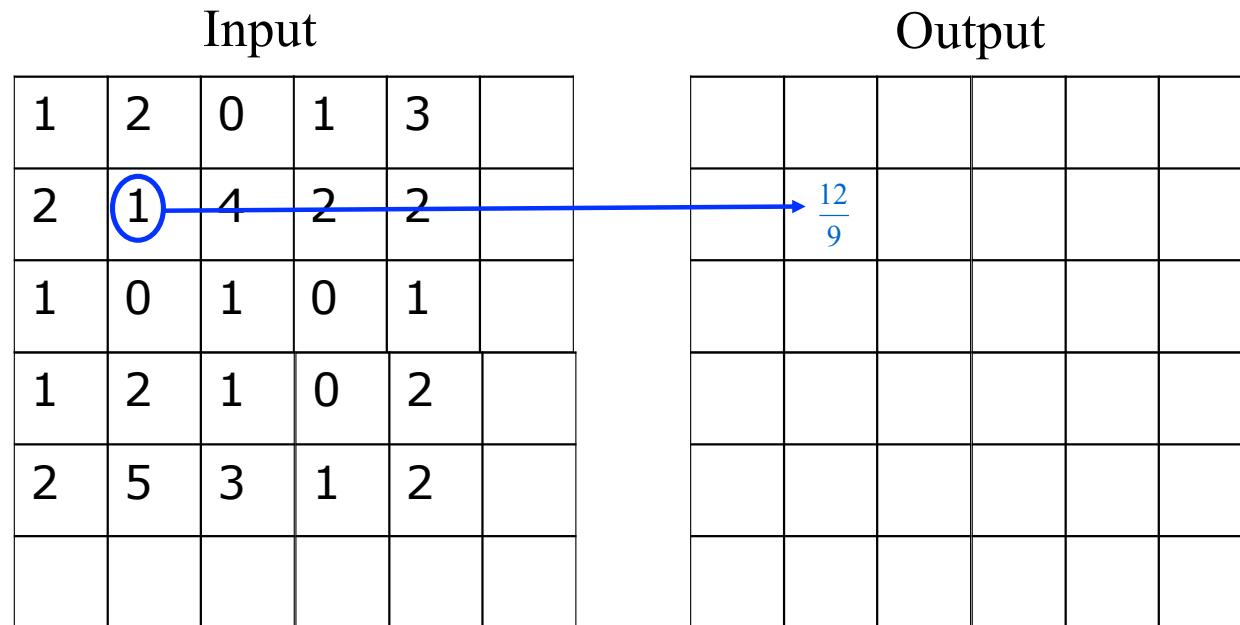
- | | | | | |
|----------------------|-----------------------|------------------------------------|--|------------|
| 0 | 0 | 0 | 0 | 0 |
| A) For making coffee | B) For cleaning water | C) It is a selective hearing thing | D) For separating light colours e.g. a prism | E) A brick |

Show image

Show correct answer

 0

Point processing



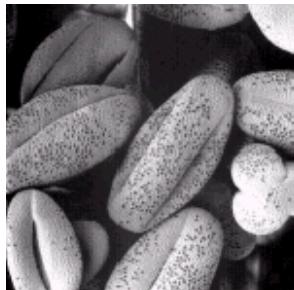
- The value of the output pixel is only dependent on the value of one input pixel
- A global operation – changes all pixels

Point processing

■ Grey level enhancement

- Process one pixel at a time independent of all other pixels
- For example used to correct Brightness and Contrast

Correct



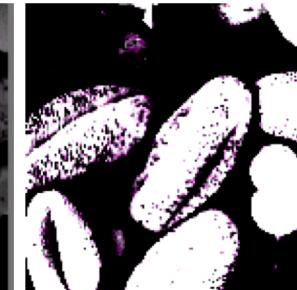
Too high
brightness



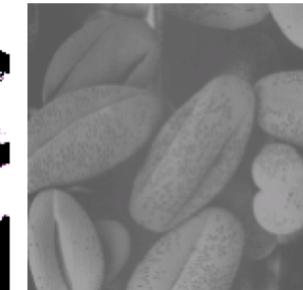
Too low
brightness



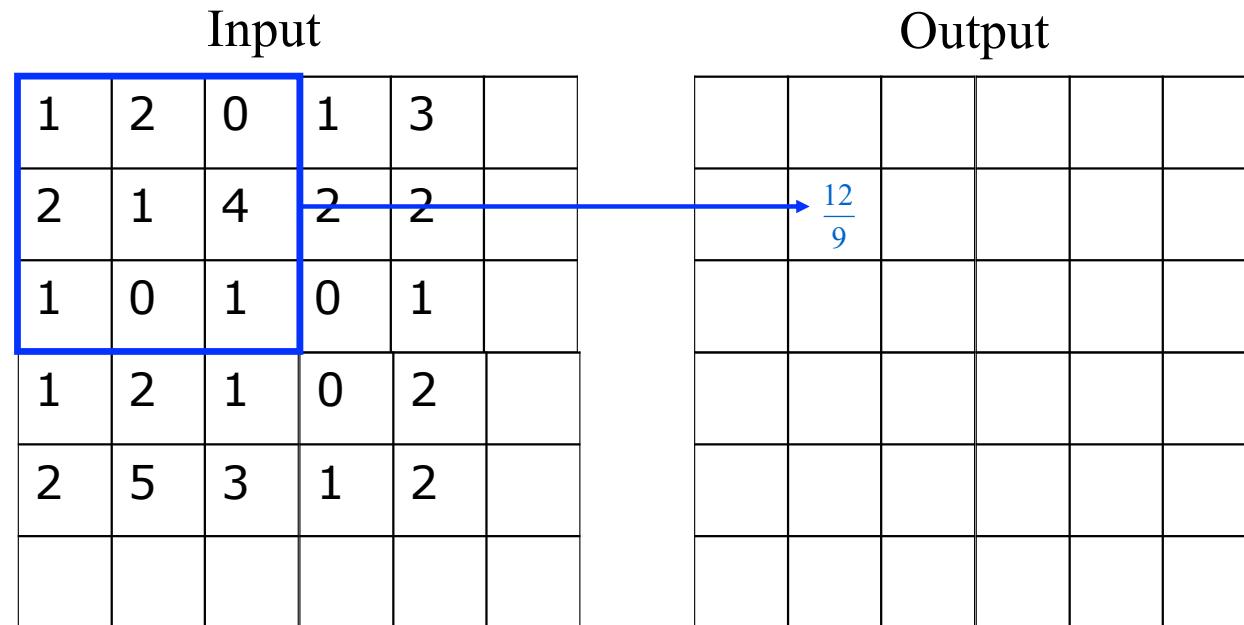
Too high
contrast



Too low
contrast



Neighbourhood processing



- Several pixels in the input has an effect on the output

Use of filtering



Noise removal



Enhance edges



Smoothing

- Image processing
- Typically done before actual image analysis

Salt and pepper noise



- Pixel values that are very different from their neighbours
- Very bright or very dark spots
- Scratches in X-rays

What is that?

Salt and pepper noise



- Fake example
 - Let us take a closer look at noise pixels

169	169	173	170	170	172	171	171	169
172	173	172	172	169	171	168	171	170
168	171	169	168	0	169	170	169	255
173	175	170	172	173	168	170	169	171
169	175	170	172	170	255	169	255	169
173	172	255	171	170	172	169	169	170
176	175	172	173	172	171	169	168	173
173	172	169	168	166	0	170	165	166
170	172	172	170	169	169	169	168	172
174	172	172	166	167	168	168	170	172

They are all 0 or 255

Should we just remove all the 0's and 255's from the image?

What is so special about noise?

169	169	173	170	170	172	171	171	169
172	173	172	172	169	171	168	171	170
168	171	169	168	0	169	170	169	255
173	175	170	172	173	168	170	169	171
169	175	170	172	170	255	169	255	169
173	172	255	171	170	172	169	169	170
176	175	172	173	172	171	169	168	173
173	172	169	168	166	0	170	165	166
170	172	172	170	169	169	169	168	172
174	172	172	166	167	168	168	170	172

172, 169, 171, 168, 0, 169, 172, 173, 168

- What is the value of the pixel compared to the neighbours?
- Average of the neighbours
 - 170
- Can we compare to the average?
 - Difficult – should we remove all values bigger than average+1 ?
- It is difficult to detect noise!

Noise – go away!

169	169	173	170	170	172	171	171	169
172	173	172	172	169	171	168	171	170
168	171	169	168	0	169	170	169	255
173	175	170	172	173	168	170	169	171
169	175	170	172	178	255	169	255	169
173	172	255	171	170	172	169	169	170
176	175	172	173	172	171	169	168	173
173	172	169	168	166	0	170	165	166
170	172	172	170	169	169	169	168	172
174	172	172	166	167	168	168	170	172

- We can not tell what pixels are noise
 - One solution
 - Set all pixels to the average of the *neighbours* (and the pixel itself)
 - Oh no!
 - Problems!
 - The noise “pollutes” the good pixels

Quiz 1: What is the median Value?

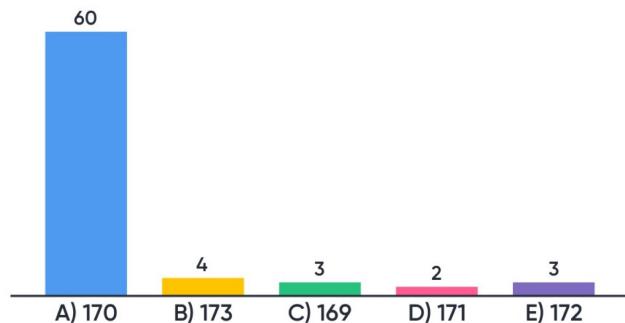
- A) 170
- B) 173
- C) 169
- D) 171
- E) 172

169, 168, 0, 170, 172, 173, 170, 172, 170

0, 168, 169, 170, 170, 170, 172, 172, 173

Quiz 1: What is the median value?

Mentimeter



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The median value

- The values are sorted from low to high
- The middle number is picked
 - The median value is found at position: $(N+1)/2$ where N is the count of numbers

169, 168, 0, 170, 172, 173, 170, 172, 170

0, 168, 169, 170, 170, 170, 172, 172, 173

Median

Noise has no influence on the median!

Quiz 2: What is the median Value?

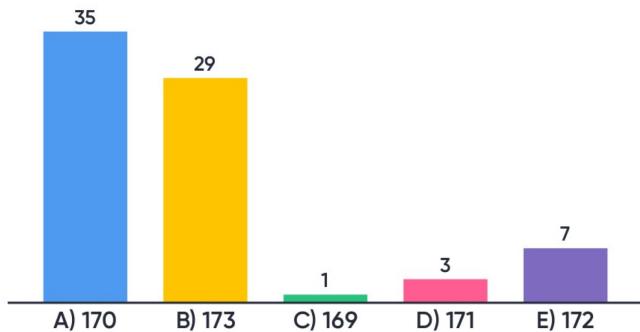
- A) 170
- B) 173
- C) 169
- D) 171
- E) 172

169, 168, 0, 170, 175, 177, 176, 180, 170, 177

0, 168, 169, 170, 170, 175, 176, 177, 177, 180

Quiz 2: What is the median value?

Mentimeter



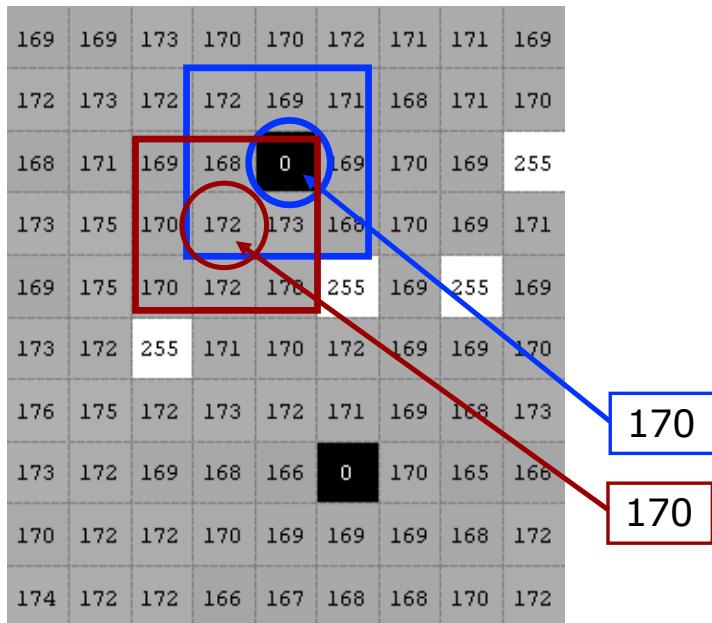
Even count of numbers:

Median at position: $(N+1)/2 = 5,5$

So Median = $(170+175)/2 = 172,5$

You then round up or down (In math then round up)

Noise away – the median filter

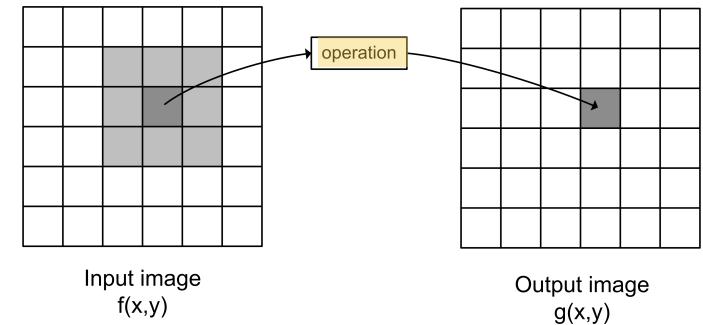


172, 169, 171, 168, 0, 169, 172, 173, 168

169, 168, 0, 170, 172, 173, 170, 172, 170

- All pixels are set to the median of its neighbourhood
- Noise pixels do not pollute good pixels

Noise removal – average filter



Scanned X-ray with salt and pepper noise



Average filter (3x3)

Noise removal – median filter



Scanned X-ray with salt and pepper noise



Median filter (3x3)

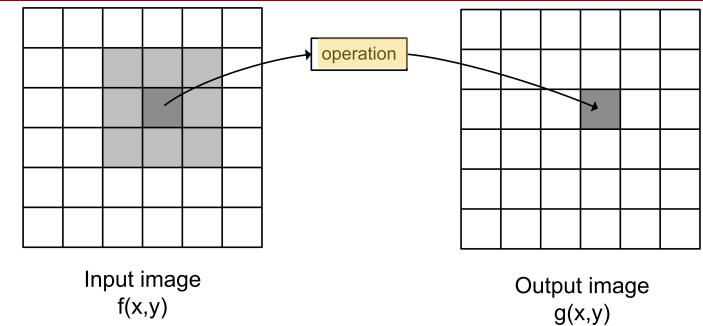


Image Filtering

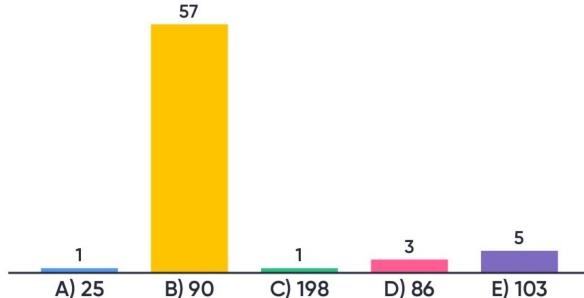
169	169	173	170	170	172	171	171	169
172	173	172	172	169	171	168	171	170
168	171	169	168	0	169	170	169	255
173	175	170	172	173	168	170	169	171
169	175	170	172	170	255	169	255	169
173	172	255	171	170	172	169	169	170
176	175	172	173	172	171	169	168	173
173	172	169	168	166	0	170	165	166
170	172	172	170	169	169	169	168	172
174	172	172	166	167	168	168	170	172

- Creates a new *filtered* image
- Output pixel is computed based on a neighbourhood in the input image
- 3 x 3 neighbourhood
 - Filter size 3 x 3
 - Kernel size 3 x 3
 - Mask size 3 x 3
- Larger filters often used
 - Size?
 - 7 x 7
 - Number of elements?
 - 49

Quiz 3: Median filter

- A) 25
- B) 90
- C) 198
- D) 86
- E) 103

Quiz 3: Median filter



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The image is filtered with a 3×3 median filter.
What is the result in the pixel marked with a circle?

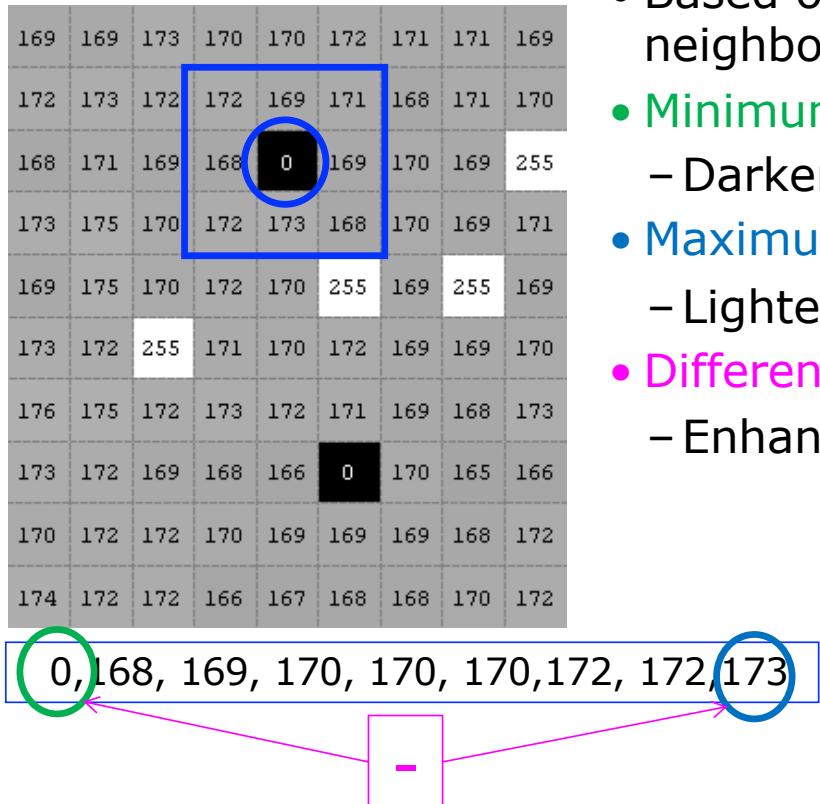
- 1. 25
- 2. 90
- 3. 198
- 4. 86
- 5. 103

4, 25, 34, 86, 90, 103, 125, 209, 230

66	222	102	230	199	147	166	175
204	148	19	241	99	15	187	47
110	140	61	125	62	60	165	94
232	37	31	125	103	90	115	160
46	218	47	86	25	209	139	199
67	159	61	230	34	4	76	21
37	89	106	94	240	11	190	237
35	131	13	28	244	43	48	198

Figur 4: Billede

Rank filters

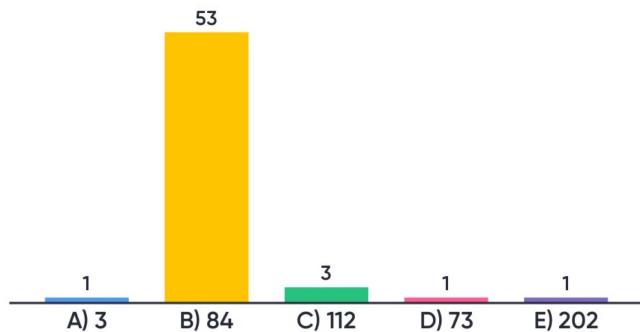


- Based on sorting the pixel values in the neighbouring region
- **Minimum** rank filter
 - Darker image. Noise problems.
- **Maximum** rank filter
 - Lighter image. Noise problems.
- **Difference** filter (max-min)
 - Enhances changes (edges). Noise problems

Quiz 4: Median filter

- A) 3
- B) 84
- C) 112
- D) 73
- E) 202

Quiz 4: Median Filter



Mentimeter

Opgave 11.14

The image is filtered with a 3×3 median filter (medI). The image (the original) is also filtered with a 5×5 minimum rank filter (minI). The final image is made by subtracting minI from medI. What is the result in the marked pixel?

- 1. 3
- 2. 84
- 3. 112
- 4. 73
- 5. 202

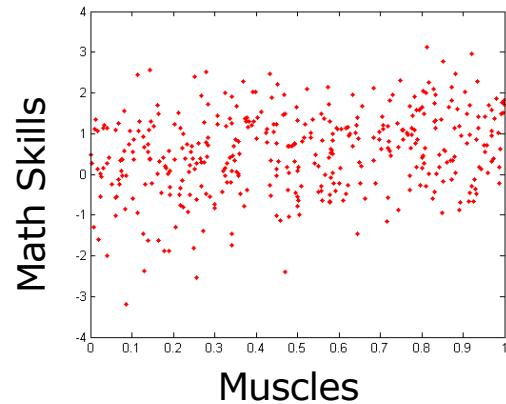
medI: 15, 60, 62, 90, 99, 103, 115, 165, 187

minI: 15

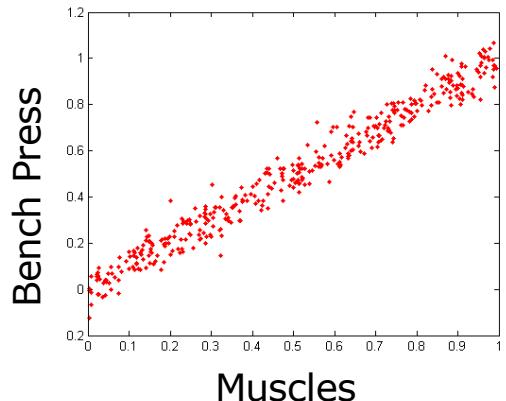
67	159	61	230	34	4	76	21
37	89	106	94	240	11	190	237
35	131	13	28	244	43	48	198
222	102	230	199	147	166	175	124
148	19	241	99	15	187	47	111
140	61	125	62	60	165	94	114
37	31	125	103	90	115	160	78
218	47	86	25	209	139	199	130

Figur 9: Grayscale billede

Correlation



Low

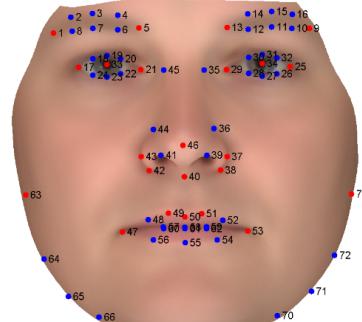


High

- What is it?
- Two measurements
 - Low correlation
 - High correlation
- High correlation means that there is a *relation* between the values
- They *look* the same
- Correlation is a *measure of similarity*

Why do we need similarity?

- Image analysis is also about recognition of patterns
- Often an example pattern is used
 - Often with some kind of meta data to apply to the targets
- We need something to tell us if there is a high match between our pattern and a part of the image

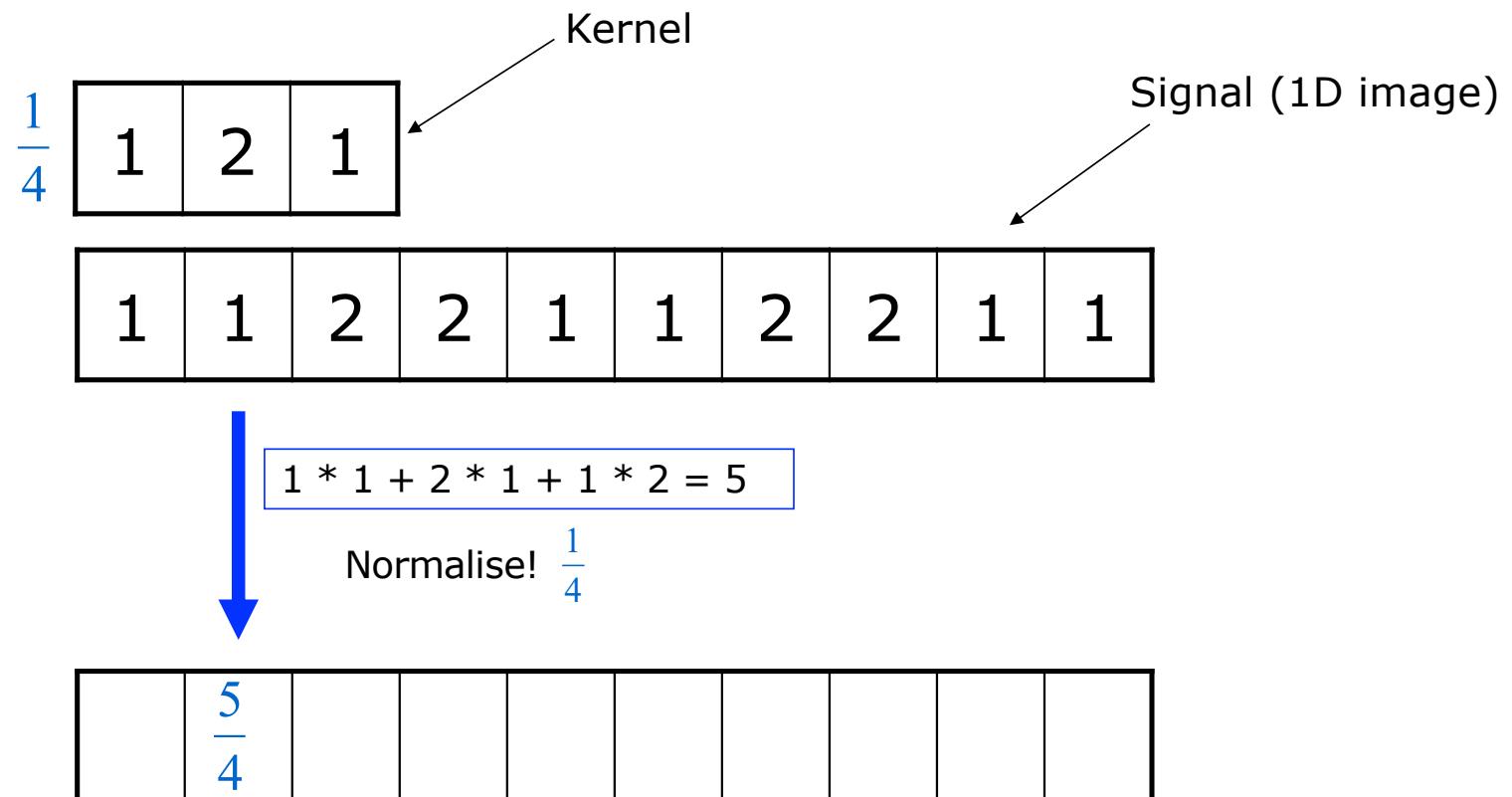


Find
matches

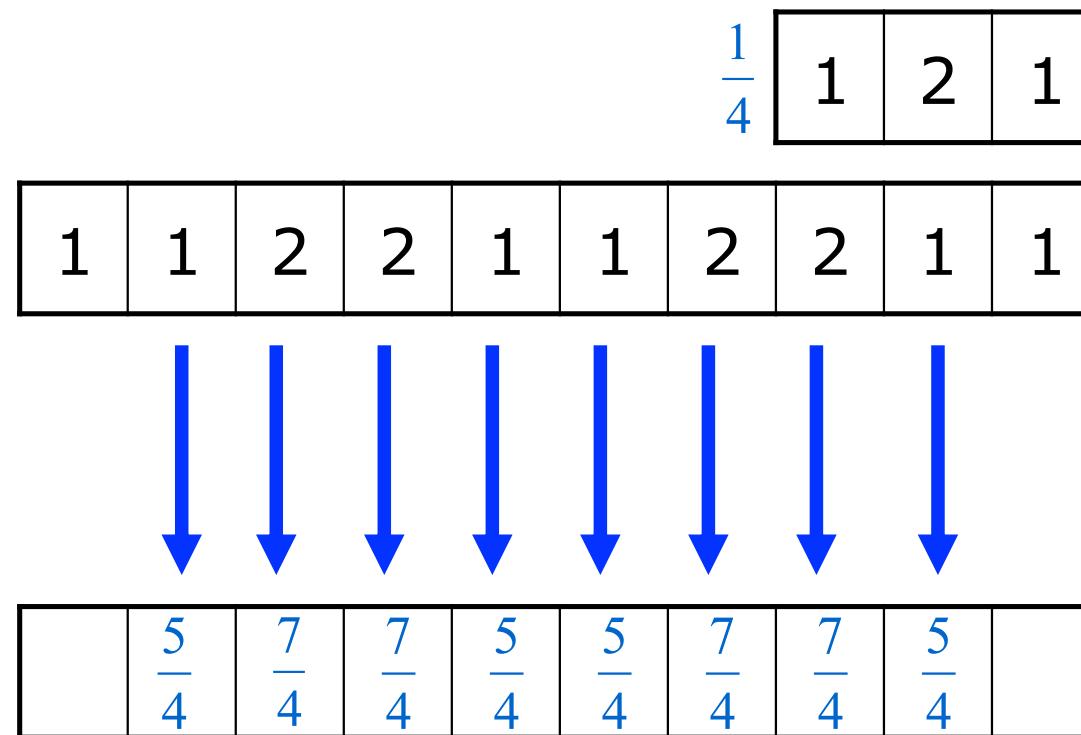


With meta information

Correlation (1D)



Correlation (1D)



Normalisation

- The sum of the kernel elements is used
- Keep the values in the same range as the input image

$$\frac{1}{4} \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline \end{array}$$

Sum is 4

$$\begin{array}{|c|c|c|c|c|c|c|c|c|c|} \hline 1 & 1 & 2 & 2 & 1 & 1 & 2 & 2 & 1 & 1 \\ \hline \end{array}$$

$$1 * 1 + 2 * 1 + 1 * 2 = 5$$

Normalise! $\frac{1}{4}$

$$\begin{array}{|c|c|c|c|c|c|c|c|c|c|} \hline & \frac{5}{4} & & & & & & & & \\ \hline \end{array}$$

Normalisation

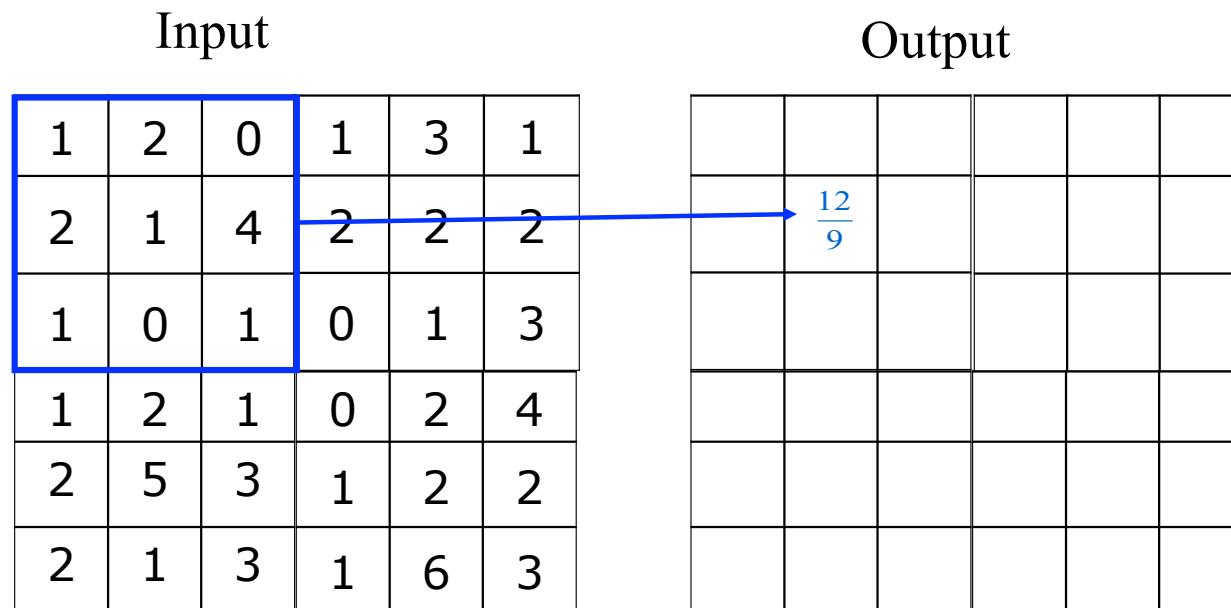
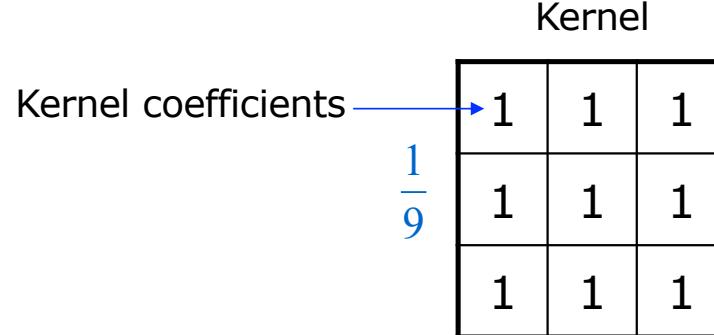
- Normalisation factor
 - Sum of kernel coefficients

$$h(x) \quad \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline \end{array}$$

$$\sum_x h(x) = 1 + 2 + 1$$

Correlation on images

- The filter is now 2D



Correlation on images

$\frac{1}{9}$	1	1	1
	1	1	1
	1	1	1

Input

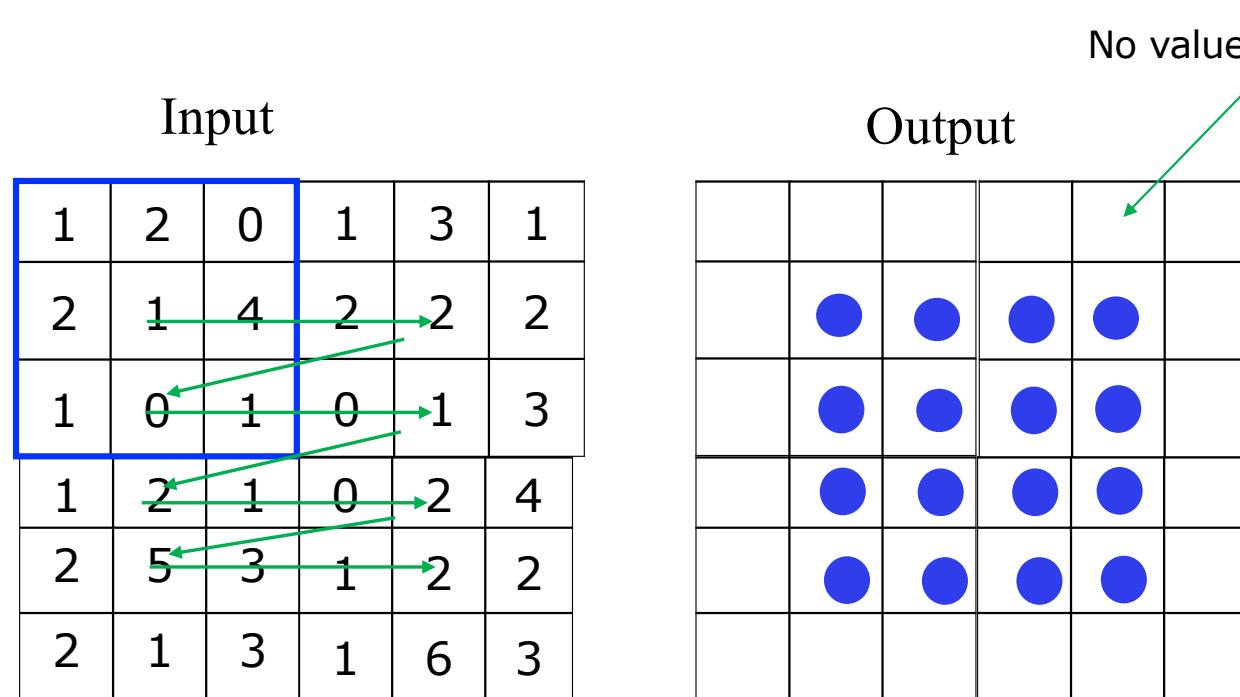
1	2	0	1	3	1
2	1	4	2	2	2
1	0	1	0	1	3
1	2	1	0	2	4
2	5	3	1	2	2
2	1	3	1	6	3

Output

$\frac{12}{9}$	\rightarrow	$\frac{11}{9}$		

Correlation on images

The mask is moved row by row



Design your filter

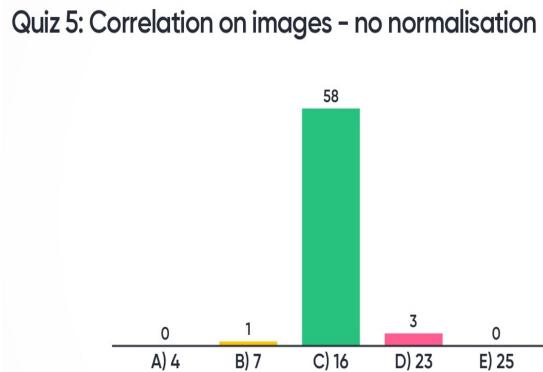
1	2	1
1	3	1
1	2	1

-1	-2	-1
0	0	0
1	2	1

Quiz 5: Correlation on images – no normalisation

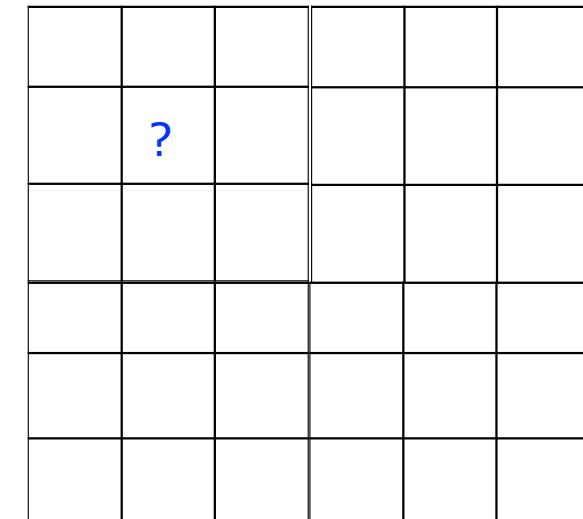
- A) 4
 - B) 7
 - C) 16
 - D) 23
 - E) 25

1	2	1
1	3	1
1	2	1



Mentimeter

1	2	0	1	3	1
2	1	4	2	2	2
1	0	1	0	1	3
1	2	1	0	2	4
2	5	3	1	2	2
2	1	3	1	6	3



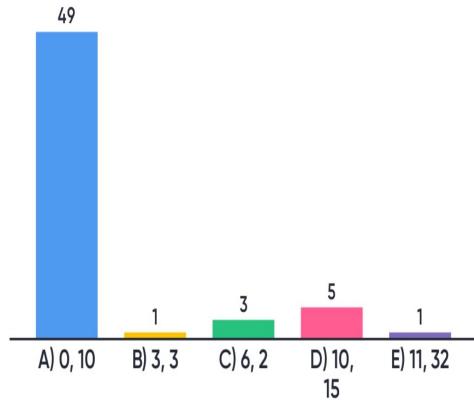
Quiz 6: Correlation on images – no normalisation 2

- A) 0, 10
 - B) 3, 3
 - C) 6, 2
 - D) 10, 15
 - E) 11, 32

-1	-2	-1
0	0	0
1	2	1

Quiz 6: Correlation on images - no normalisation 2

Mentimeter



1	2	0	1	3	1
2	1	4	2	2	2
1	0	1	0	1	3
1	2	1	0	2	4
2	5	3	1	2	2
2	1	3	1	6	3

					?
			?		

Mathematics of 2D Correlation

$$g(x, y) = f(x, y) \circ h(x, y)$$

Correlation
operator

1	2	0	1	3	1
2	1	4	2	2	2
1	0	1	0	1	3
1	2	1	0	2	4
2	5	3	1	2	2
2	1	3	1	6	3

f

1	2	1
1	3	1
1	2	1

h

Mathematics of 2D Correlation

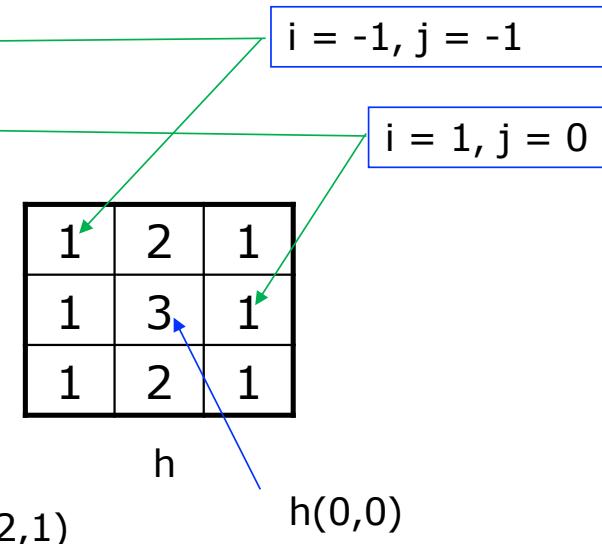
$$g(x, y) = \sum_{j=-R}^R \sum_{i=-R}^R h(i, j) \cdot f(x + i, y + j)$$

Example $g(2,1)$

1	2	0	1	3	1
2	1	4	2	2	2
1	0	1	0	1	3
1	2	1	0	2	4
2	5	3	1	2	2
2	1	3	1	6	3

f

$f(2,1)$



Mathematics of 2D Correlation

$$g(x, y) = \sum_{j=-R}^R \sum_{i=-R}^R h(i, j) \cdot f(x + i, y + j)$$

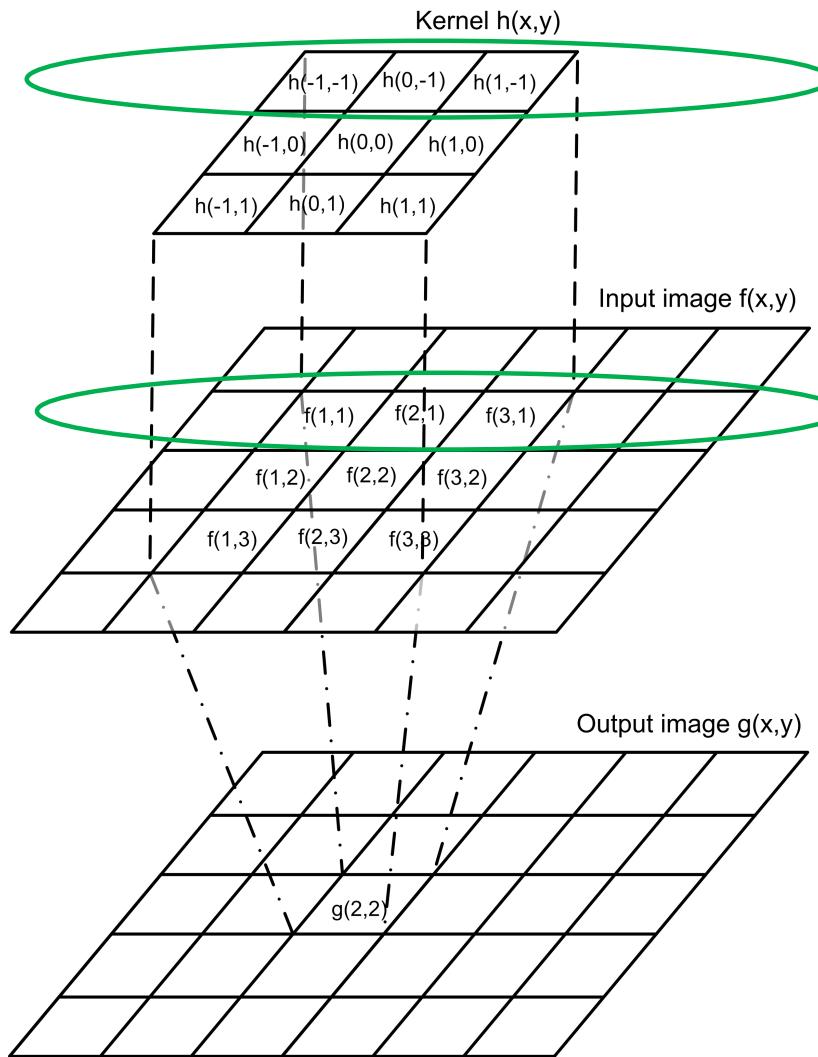
$$g(x, y) = 1 \cdot 2 + 2 \cdot 0 + 1 \cdot 1 + 1 \cdot 1 + 3 \cdot 4 + 1 \cdot 2 + 1 \cdot 0 + 2 \cdot 1 + 1 \cdot 0$$

1	2	0	1	3	1
2	1	4	2	2	2
1	0	1	0	1	3
1	2	1	0	2	4
2	5	3	1	2	2
2	1	3	1	6	3

f

1	2	1
1	3	1
1	2	1

h



$$g(x,y) = \sum_{j=-R}^R \sum_{i=-R}^R h(i,j) \cdot f(x+i, y+j)$$

$$g(2,2) =$$

$$h(-1,-1) \cdot f(1,1) + h(0,-1) \cdot f(2,1) + h(1,-1) \cdot f(3,1) +$$

$$h(-1,0) \cdot f(1,2) + h(0,0) \cdot f(2,2) + h(1,0) \cdot f(3,2) +$$

$$h(-1,1) \cdot f(1,3) + h(0,1) \cdot f(2,3) + h(1,1) \cdot f(3,3)$$

2D Kernel Normalisation

Normalisation factor:

$$\sum_x \sum_y h(x, y)$$

$$1+2+1+1+3+1+1+2+1=13$$

1	2	1
1	3	1
1	2	1

h

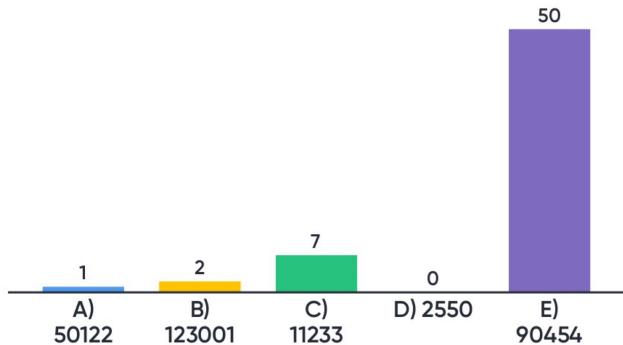
Quiz 7: Correlation

- A) 50122
- B) 123001
- C) 11233
- D) 2550
- E) 90454



Quiz 7: Correlation

Mentimeter



A template match is done on the image to the left with the template seen to the right. To find the best match the correlation is computed. What is the correlation in the marked pixel?

227	208	90	97	145	42	58	27
245	62	212	145	120	154	233	245
140	237	149	19	3	67	39	1
35	89	140	14	86	167	211	198
38	50	234	135	41	176	137	208
66	64	73	199	203	191	254	222
214	157	193	238	79	115	20	22
65	121	192	33	135	21	113	102

66	232	37
204	46	35
110	67	222

1. 50122
2. 123001
3. 11233
4. 2550
5. 90454

Smoothing filters

- Also know as
 - Smoothing kernel, Mean filter, Low pass filter, blurring
- The simplest filter:
 - *Spatial low pass filter*
 - Removes high frequencies
- Another mask:
 - Gaussian filter

Why Gaussian?

$$\frac{1}{9}$$

1	1	1
1	1	1
1	1	1

$$\frac{1}{16}$$

1	2	1
2	4	2
1	2	1

Use of smoothing

- Various sizes of smoothing filters



3x3



7x7



11x11



15x15

Use of smoothing



3x3



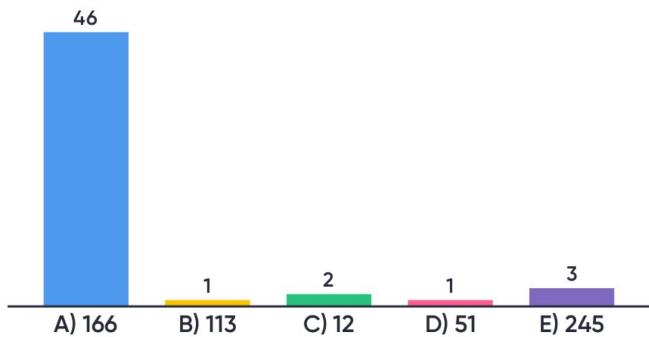
15x15

- Large kernels smooth more
- Removes high frequency information
- Good at enhancing *big structures*

Quiz 8: Mean filter

- A) 166
- B) 113
- C) 12
- D) 51
- E) 245

Quiz 8: Mean filter



Mentimeter

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A 3x3 mean filter is applied to the image. The result in the marked pixel is 86. What is the value of the pixel, where the value is missing?

1. 166
2. 113
3. 12
4. 51
5. 245
6. Ved ikke

$$\frac{1}{9}$$

1	1	1
1	1	1
1	1	1

$$(608+x \cdot 1)/9 = 86 \rightarrow x=166$$

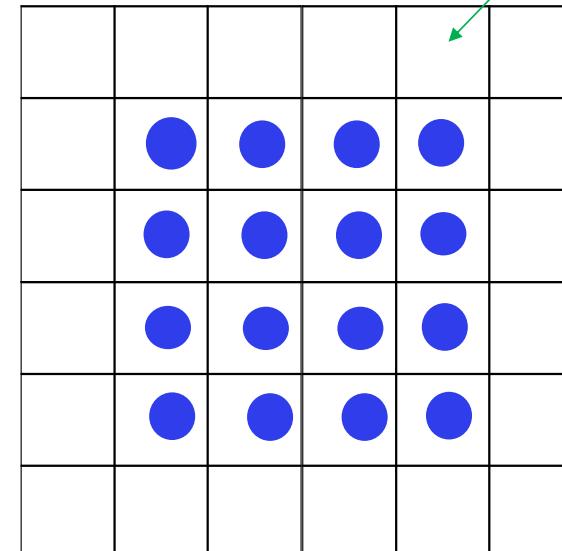
227	208	90	97	145	42	58	27
245	62	212	145	120	154	233	245
140	237	149	19	3	67	39	1
35	89	140	14	86		211	198
38	50	234	135	41	176	137	208
66	64	73	199	203	191	254	222
214	157	193	238	79	115	20	22
65	121	192	33	135	21	113	102

Border handling

Input

1	2	0	1	3	1
2	1	4	2	2	2
1	0	1	0	1	3
1	2	1	0	2	4
2	5	3	1	2	2
2	1	3	1	6	3

Output

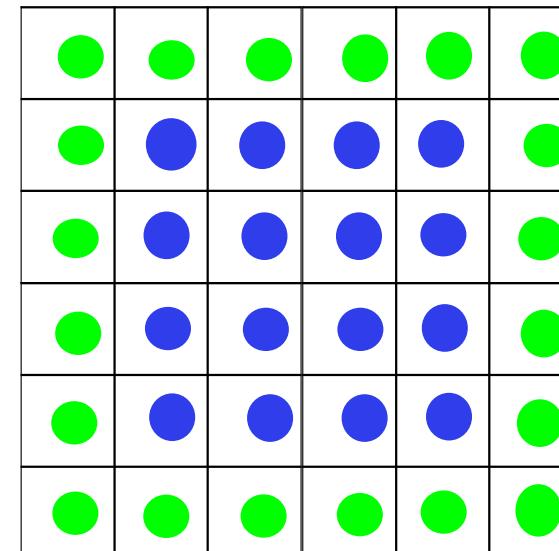


Border handling – extend the input

Input

0	0	0	0	0	0	
0	1	2	0	1	3	1
0	2	1	4	2	2	2
0	1	0	1	0	1	3
0	1	2	1	0	2	4
	2	5	3	1	2	2
2	1	3	1	6	3	

- Zero padding – what happens?
- Zero is black – creates dark border around the image



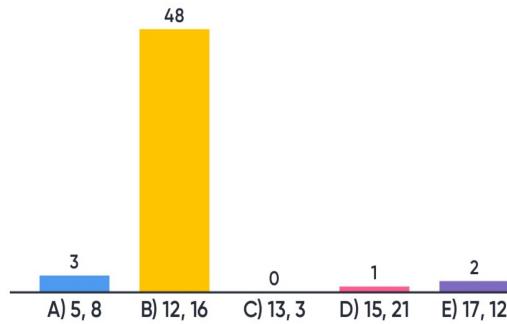
Quiz 9: Correlation with zero padding

- A) 5, 8
- B) 12, 16
- C) 13, 3
- D) 15, 21
- E) 17, 12

1	2	1
1	3	1
1	2	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

Quiz 9: Correlation with zero padding



Mentimeter

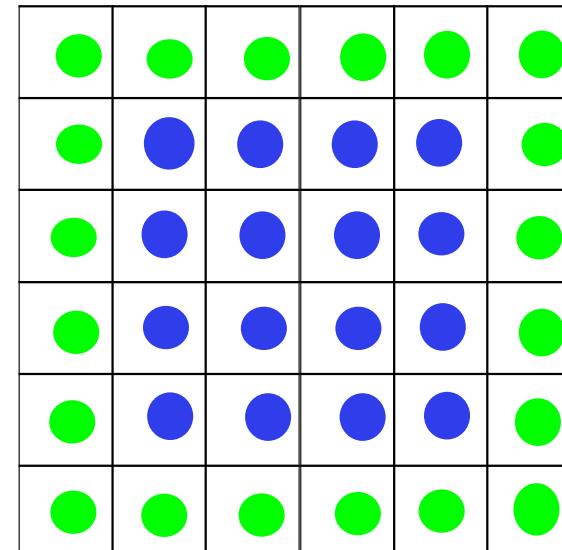
Border handling – extend the input

Input

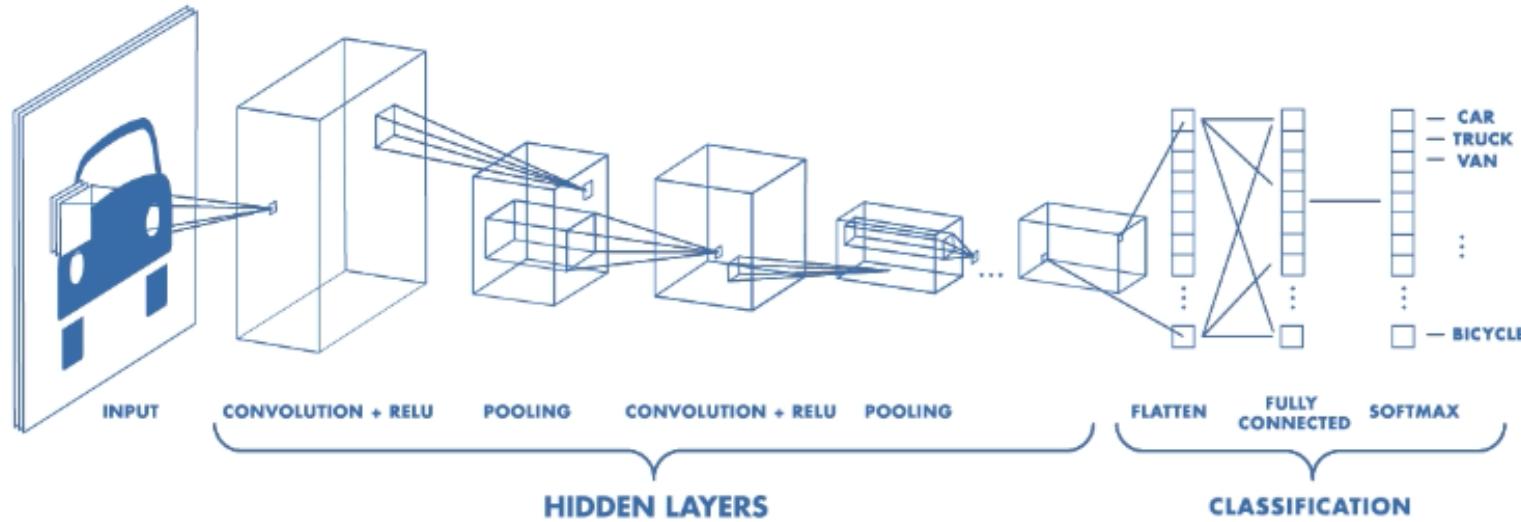
1	1	2	0	1	3	
1	1	2	0	1	3	1
2	2	1	4	2	2	2
1	1	0	1	0	1	3
1	1	2	1	0	2	4
	2	5	3	1	2	2
2	1	3	1	6	3	

- Reflection

- Normally better than zero padding



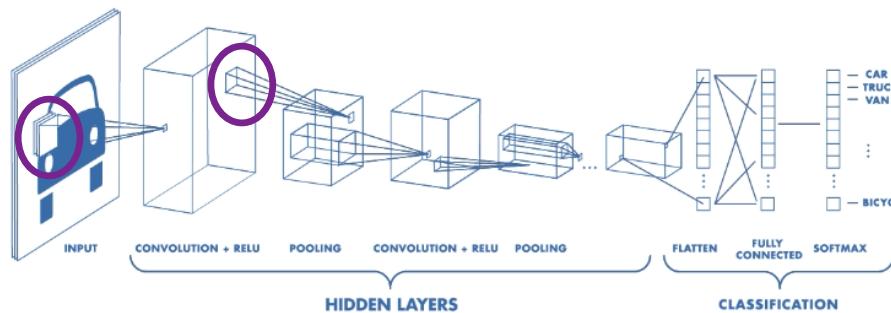
What is the connection to deep learning?



<https://se.mathworks.com/videos/introduction-to-deep-learning-what-are-convolutional-neural-networks--1489512765771.html>

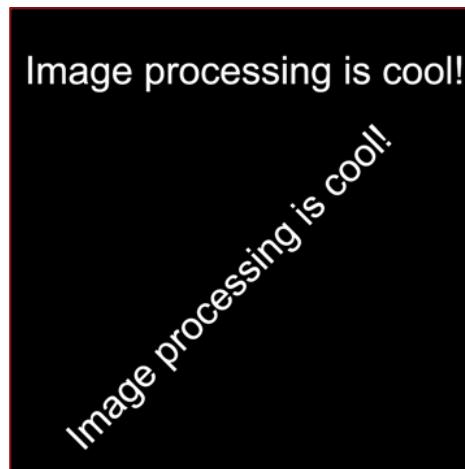
Banks of filters

- The part of the network that touches the image consists of a bank of filters
 - Organised in a multi-level hierarchy
- The weights of the filters are adapted to the problem



Template Matching

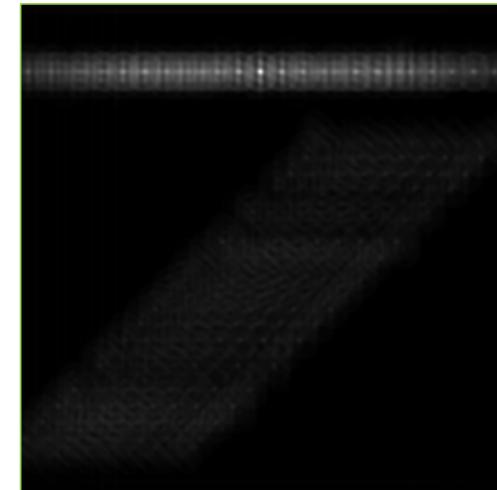
- Template
 - *Skabelon* på dansk
- Locates objects in images



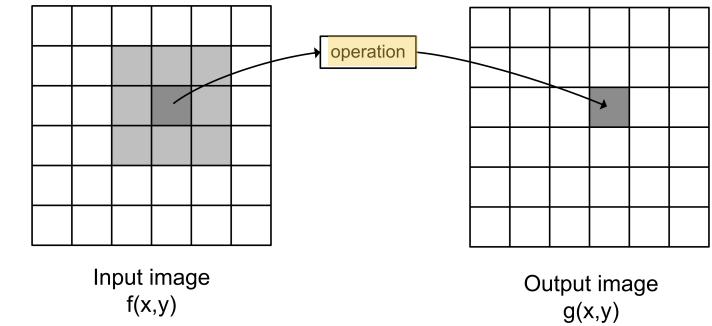
Input

processing

Template

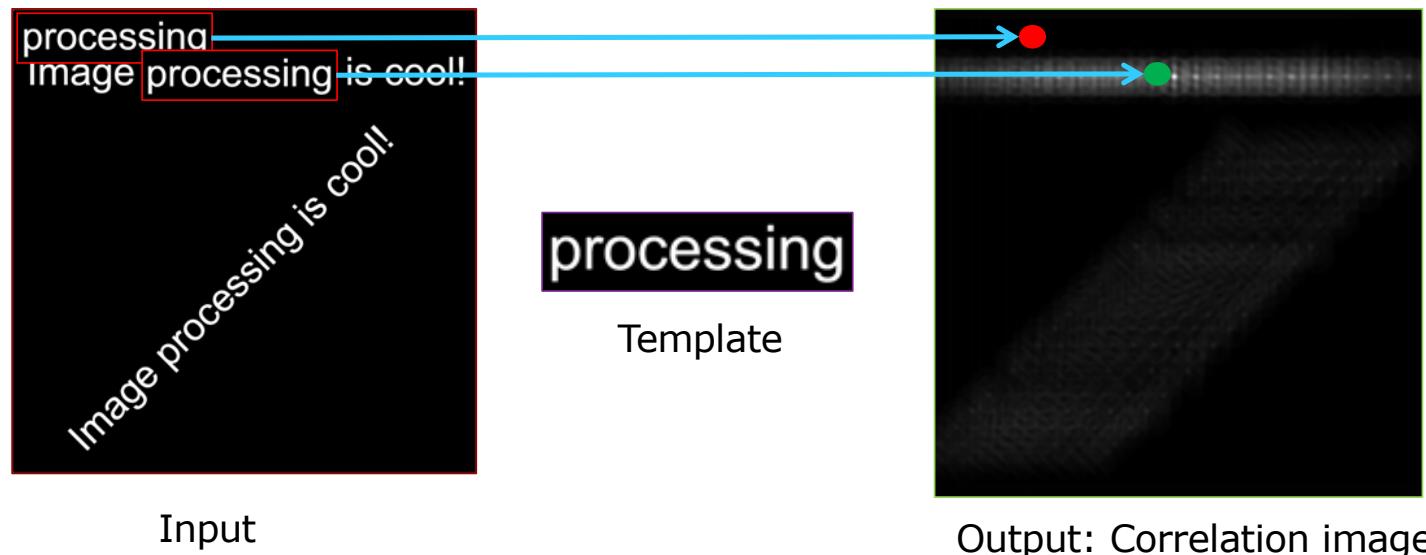


Output: Correlation image



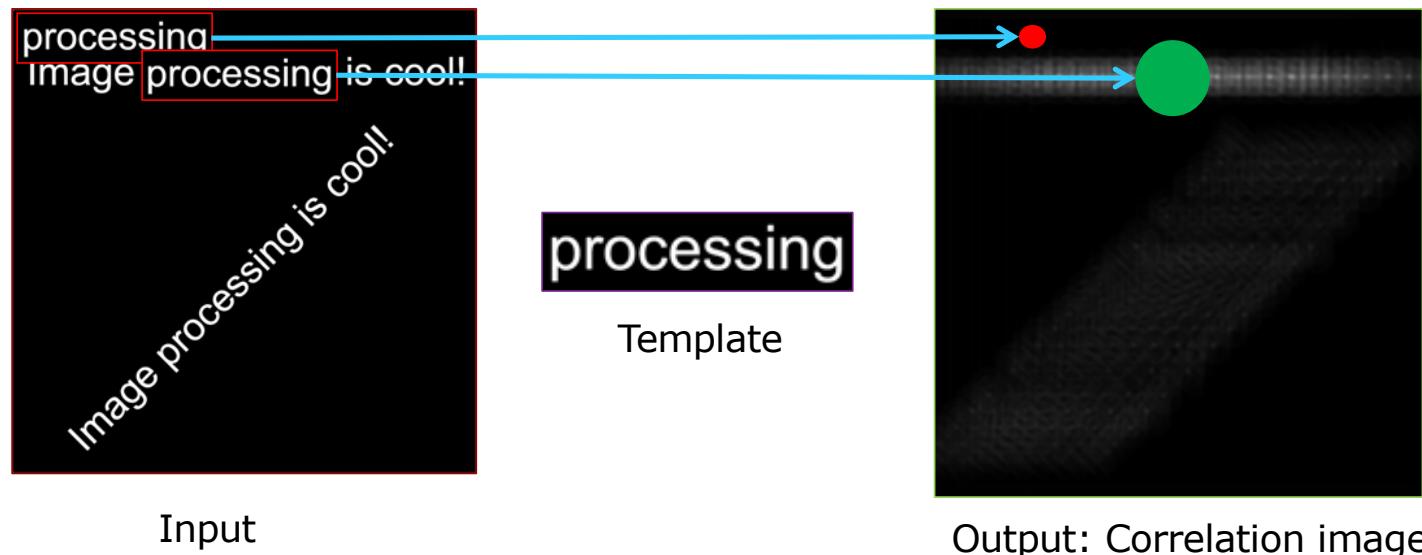
Template Matching

- The correlation between the template and the input image is computed for each pixel



Template Matching

- The pixel with the highest value is found in the output image
 - Here is the highest correlation



Template Matching

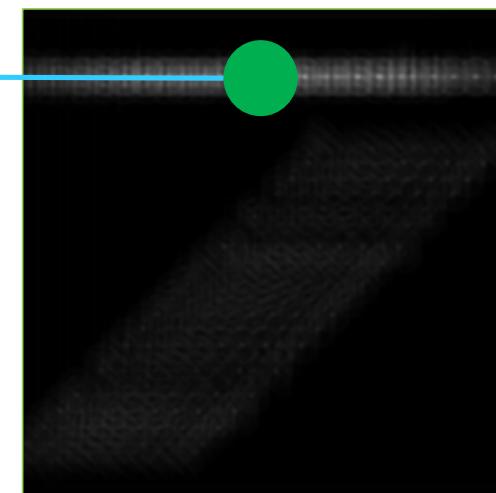
- This corresponds to the found pattern in the input image



Input



Template



Output: Correlation image

Problematic Correlation

- Correlation matching has problem with light areas – why?

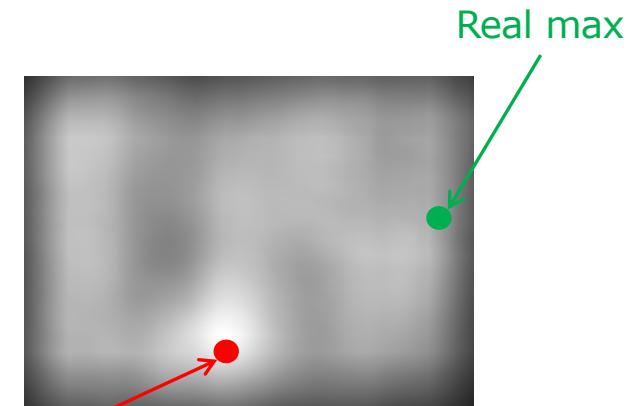
$$g(x, y) = \sum_{j=-R}^R \sum_{i=-R}^R h(i, j) \cdot f(x + i, y + j)$$



Input (f)



Template (h)



Fake max Output: Correlation image

Normalised Cross Correlation

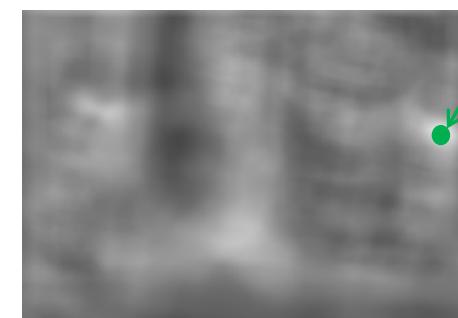
$$\text{NCC}(x, y) = \frac{\text{Correlation}}{\text{Length of image patch} \cdot \text{Length of template}}$$



Input (f)



Template
(h)



Output: Correlation image

Length of template

- Vector length
 - Put all pixel values into a vector
 - Compute the length of this vector
- Describes the intensity of the template
 - Bright template has a large length
 - Dark template has a small length

$$\text{Length of template} = \sqrt{\sum_{j=-R}^R \sum_{i=-R}^R h(i,j) \cdot h(i,j)}$$



Template
(h)

Length of image patch

- Vector length based on pixel values in image patch
- Describes the intensity of the image patch



Input (f) with patch



Template
(h)

Normalised Cross Correlation

- The length of the image patch and the length of template normalise the NCC
- If the image is very bright the NCC will be “pulled down”

$$\text{NCC}(x, y) = \frac{\text{Correlation}}{\text{Length of image patch} \cdot \text{Length of template}}$$

Normalised Cross Correlation

- NCC will be between
 - 0 : No similarity between template and image patch
 - 1 : Template and image patch are identical

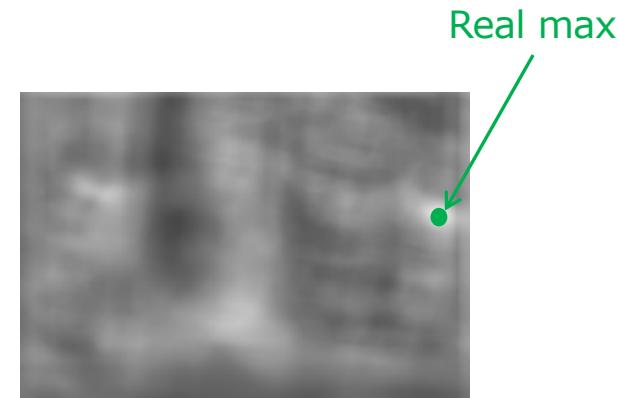
$$\text{NCC}(x, y) = \frac{\text{Correlation}}{\text{Length of image patch} \cdot \text{Length of template}}$$



Input (f)



Template
(h)



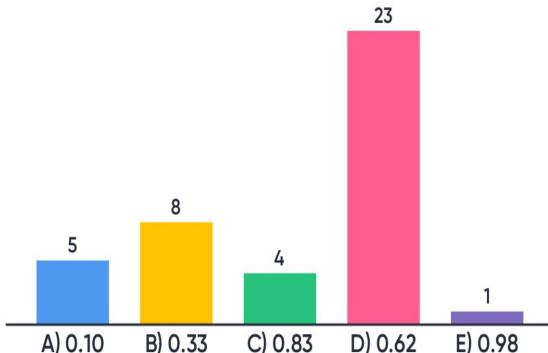
Output: Correlation image

Quiz 10: Normalised Cross Correlation

- A) 0.10
- B) 0.33
- C) 0.83
- D) 0.62
- E) 0.98

Quiz 10: Normalised Cross Correlation

Mentimeter



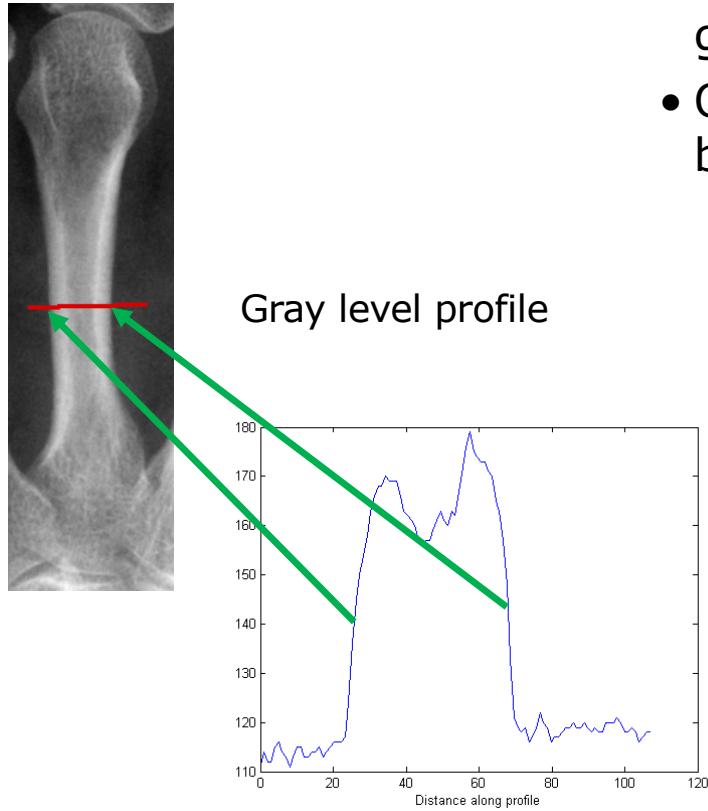
A template match using normalised cross correlation is performed.
What is the resulting value in the marked pixel?

227	208	90	97	145	42	58	27
245	62	212	145	120	154	233	245
140	237	149	19	3	67	39	1
35	89	140	14	86	167	211	198
38	50	234	135	41	176	137	208
66	64	73	199	203	191	254	222
214	157	193	238	79	115	20	22
65	121	192	33	135	21	113	102

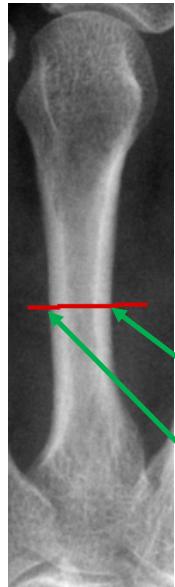
A heatmap representation of the 8x8 template matching matrix. The matrix contains numerical values ranging from 1 to 245. A green circle highlights the value 14 at position (4,4), which corresponds to the marked pixel in the original matrix. The matrix is color-coded based on its values, with darker shades representing higher values.

Edges

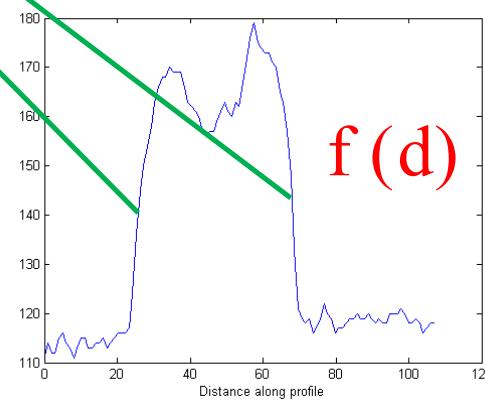
- An edge is where there is a high change in gray level values
- Objects are often separated from the background by edges



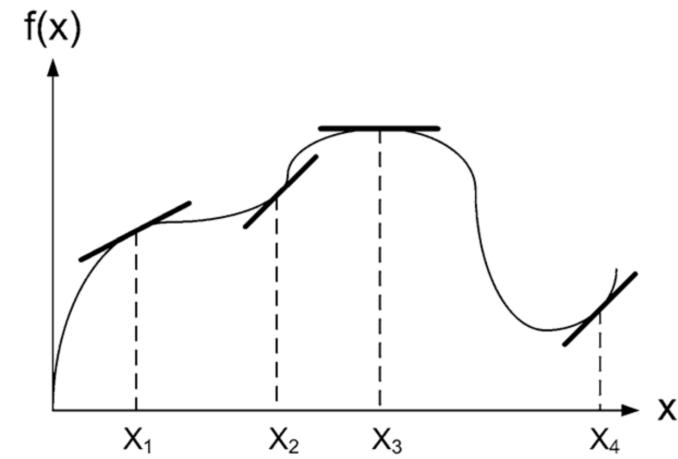
Edges



$$f'(d)$$



- The profile as a function $f(d)$ in the x -direction
- What value is high when there is an edge?
 - The slope of f
 - The slope of the tangent at d



Finite Difference

- Definition of slope

$$f'(d) = \lim_{h \rightarrow 0} \frac{f(d + h) - f(d)}{h}$$

(Continues functions only)

- Approximation

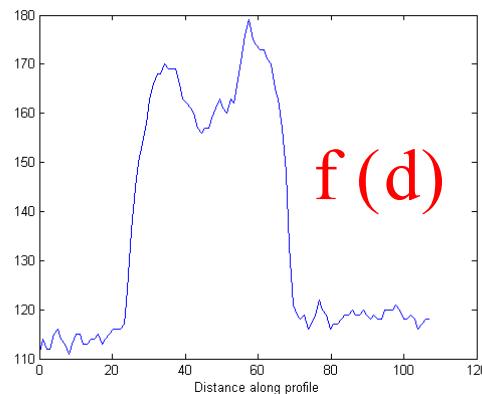
$$f'(d) \approx \frac{f(d + h) - f(d)}{h}$$

- Simpler approximation

$$f'(d) \approx f(d + 1) - f(d)$$

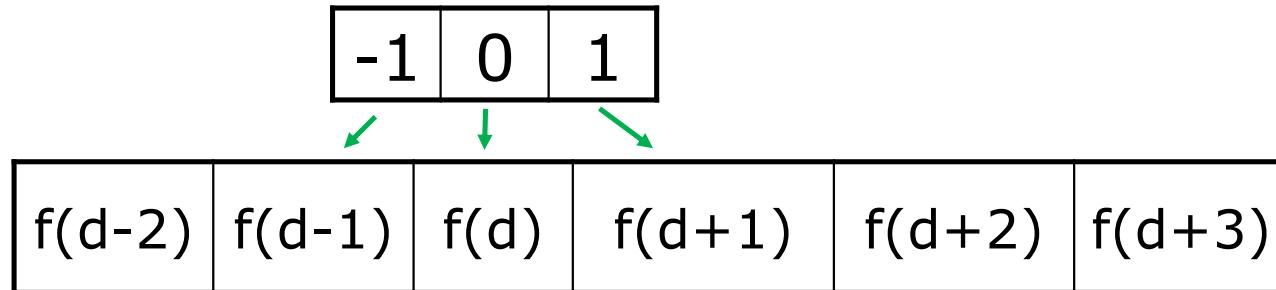
;Where h=1

Edges

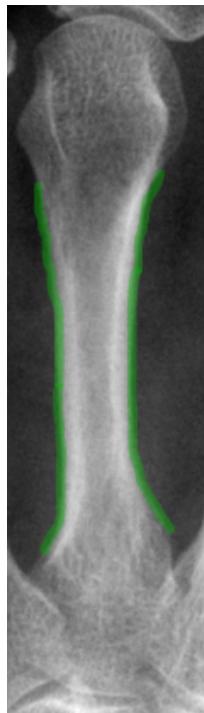


- Discrete approximation of $f'(d)$
- Can be implemented as a filter

$$f'(d) \approx f(d+1) - f(d)$$



Edges in 2D



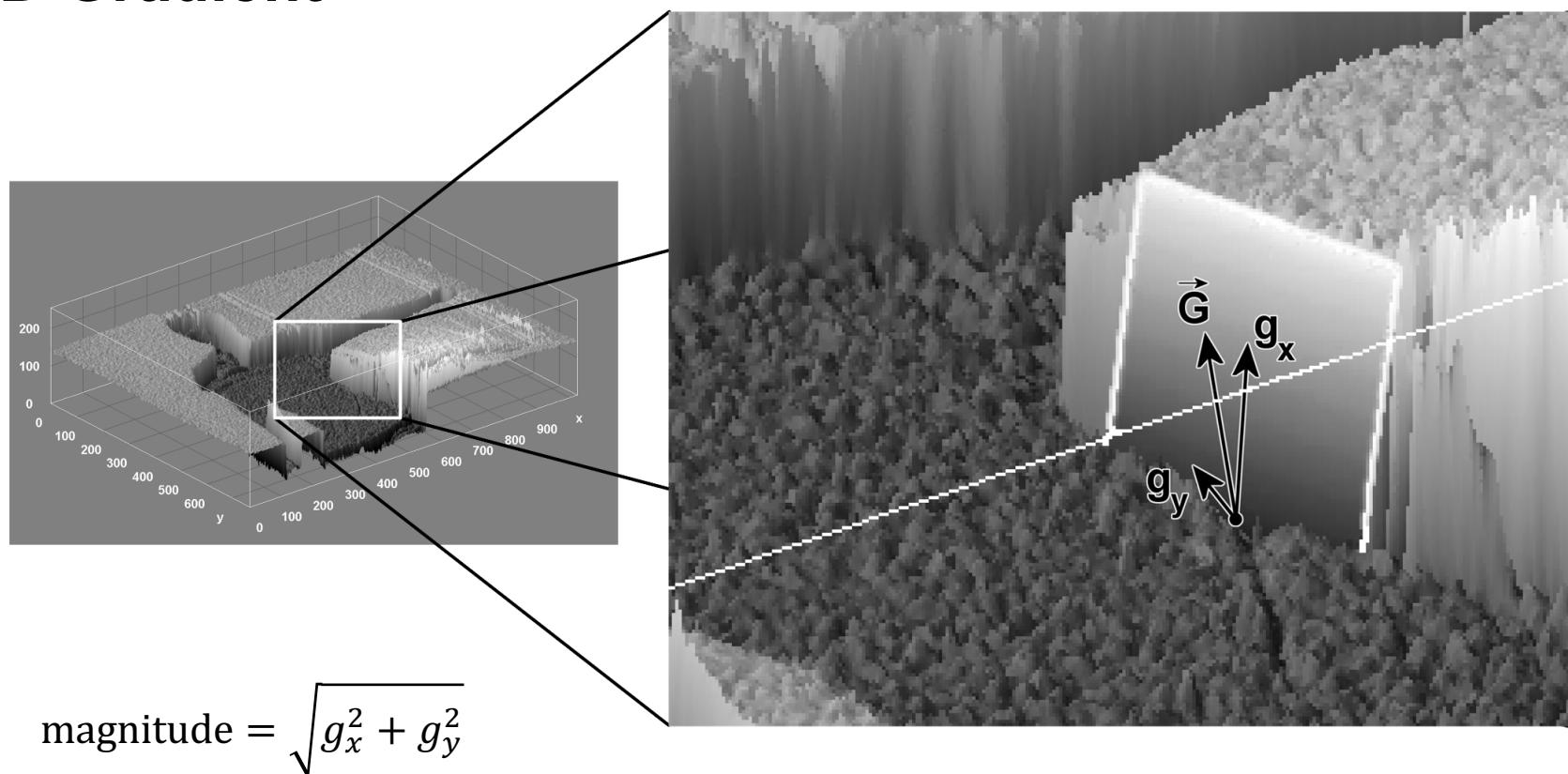
- Changes in gray level values
 - Image gradient
 - Gradient is the 2D derivative of a 2D function $f(x,y)$
 - Equal to the *slope* of the image
 - A steep slope is equal to an edge

$$\nabla f(x, y) = \vec{G}(g_x, g_y)$$

Where:

$$g_{x(x,y)} = f(x + 1, y) - f(x - 1, y)$$
$$g_{y(x,y)} = f(x, y + 1) - f(x, y - 1)$$

2D Gradient



Edge filter kernel

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

Vertical Prewitt filter i.e. g_x

- The Prewitt filter is a typical edge filter
- Output image has high values where there are edges
- $g_x(x,y)$: Vertical filter
- $g_y(x,y)$: Horizontal filter

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

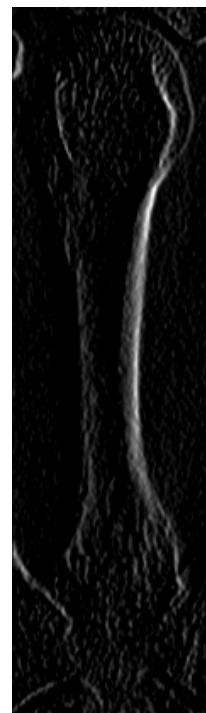
Horizontal Prewitt filter i.e. g_y

Prewitt filter

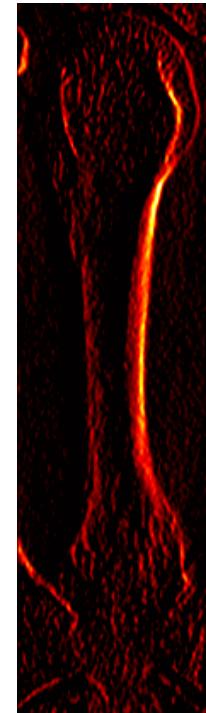
- Filter direction?



Original



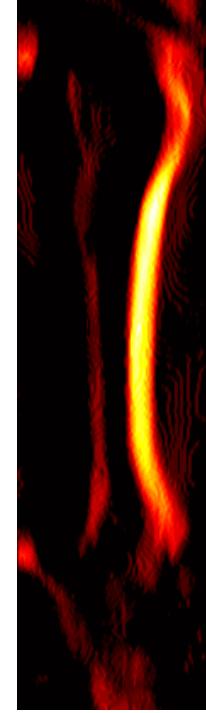
Prewitt



Prewitt
Hot colormap

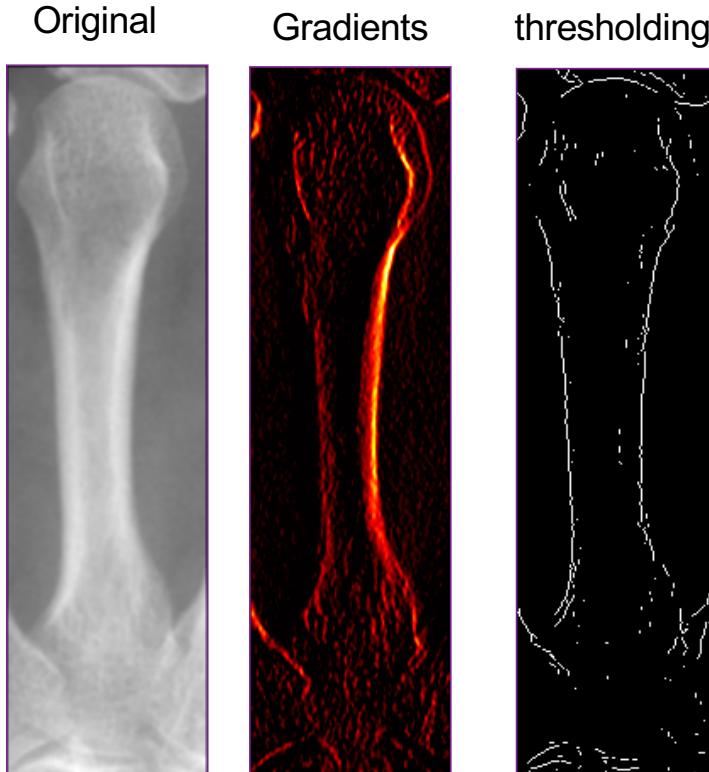


Smooth
15x15



Smooth 15x15
Prewitt

Edge detection

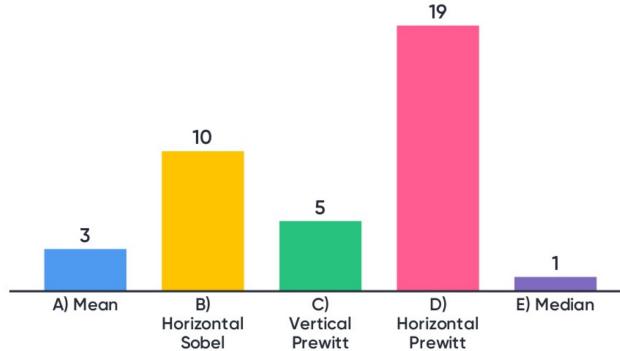


- Edge filter
 - Prewitt for example
- Thresholding
 - Separate edges from non-edges
- Output is binary image
 - Edges are white

Quiz 11: Edge filtering

- A) Mean
- B) Horizontal Sobel**
- C) Vertical Prewitt
- D) Horizontal Prewitt
- E) Median

Quiz 11: Edge filtering



A filtering (correlation) is done with a filter on the image. No normalisation is performed. The value in the marked pixel becomes -119. What 3×3 filter was used?

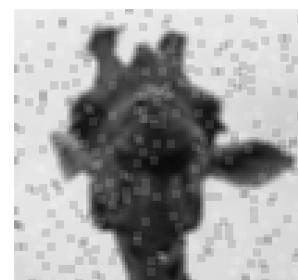
Horizontal Sobel

-1	-2	-1
0	0	0
1	2	1

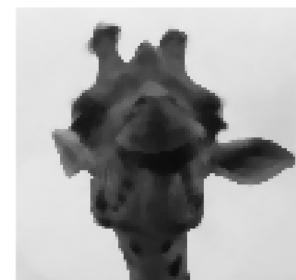
66	222	102	230	199	147	166	175
204	148	19	241	99	15	187	47
110	140	61	125	62	60	165	94
232	37	31	125	103	90	115	160
46	218	47	86	25	209	139	199
67	159	61	230	34	4	76	21
37	89	106	94	240	11	190	237
35	131	13	28	244	43	48	198

Future has become the past: What can you do after today?

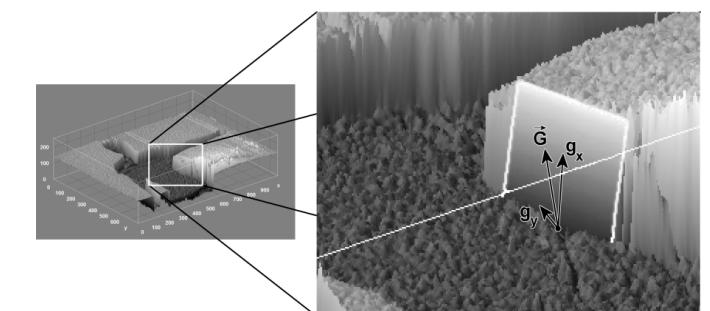
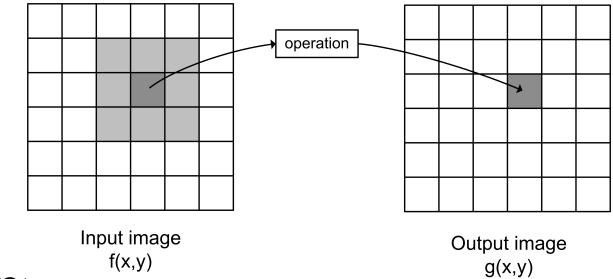
- Describe the difference between point processing and neighbourhood processing
- Compute a rank filtered image using the min, max, median, and difference rank filters
- Compute a mean filtered image
- Decide if median or average filtering should be used for noise removal
- Choose the appropriate image border handling based on a given input image
- Implement and apply template matching
- Compute the normalised cross correlation and explain why it should be used
- Apply given image filter kernels to images
- Use edge filters on images
- Describe finite difference approximation of image gradients including the magnitude and the direction
- Compute the magnitude of the gradient
- Describe the concept of edge detection



Mean filtered

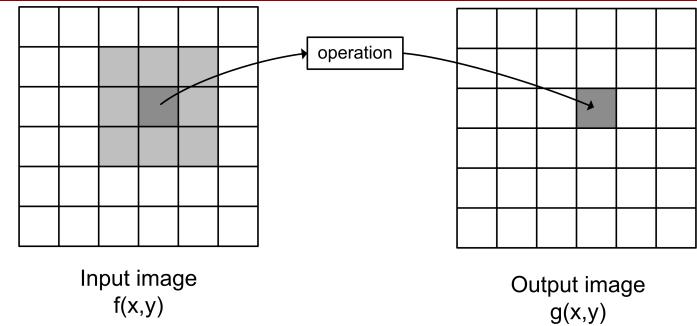


Median filtered

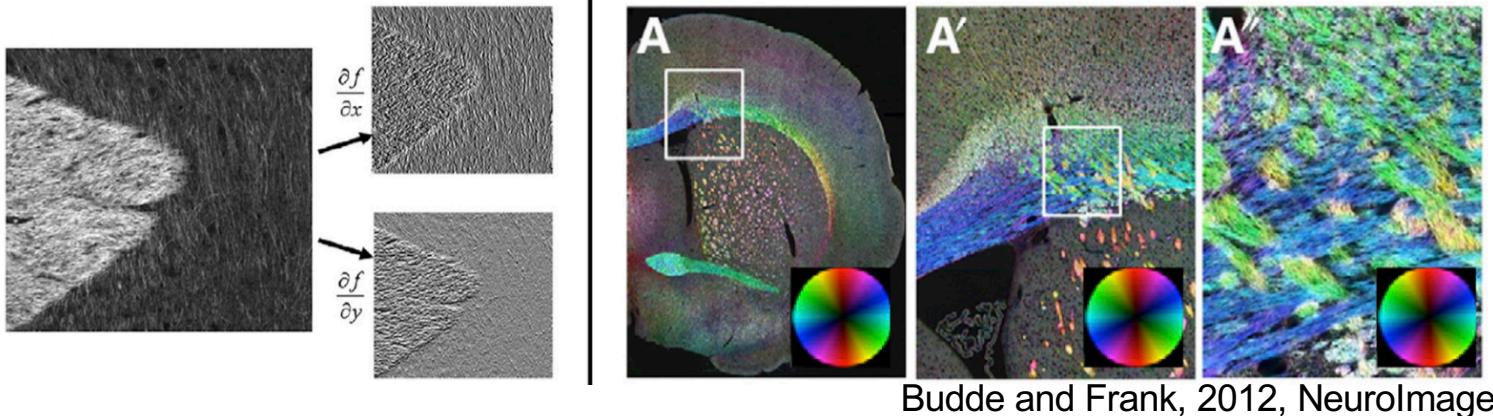


Neighbourhood Processing

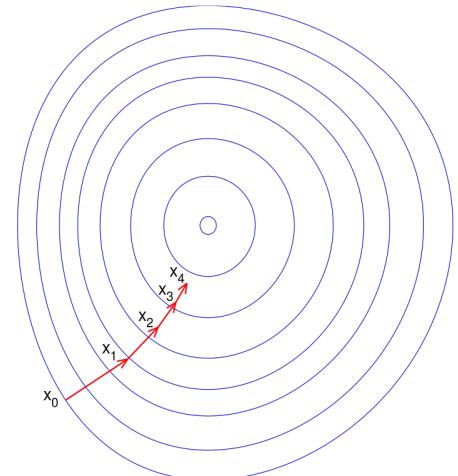
What can it be used for?



Gradients: Micro-image resolution of fiber directions from histology



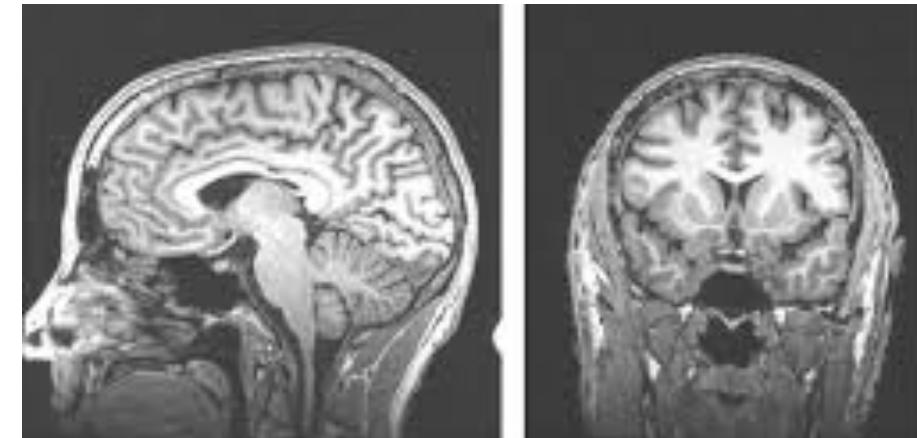
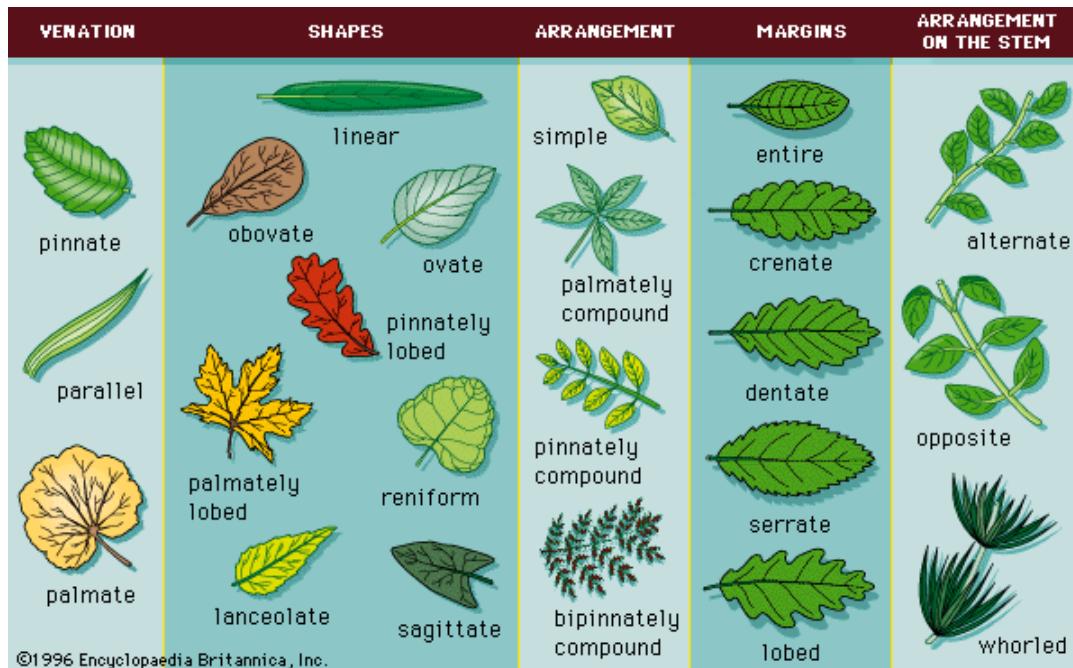
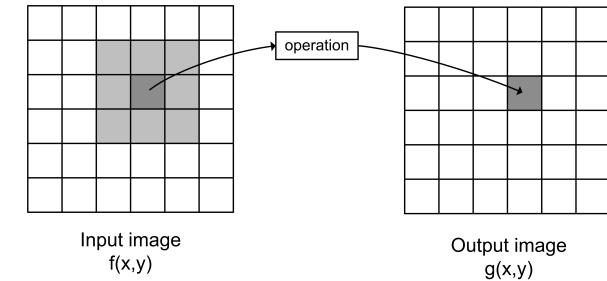
Gradients: A key component in non-linear algorithm optimisation



https://en.wikipedia.org/wiki/Gradient_descent#/media/File:Gradient_descent.svg

Next week 5: Morphology

- The science of *form*, *shape* and *structure*
- In biology: The form and structure of animals and plants



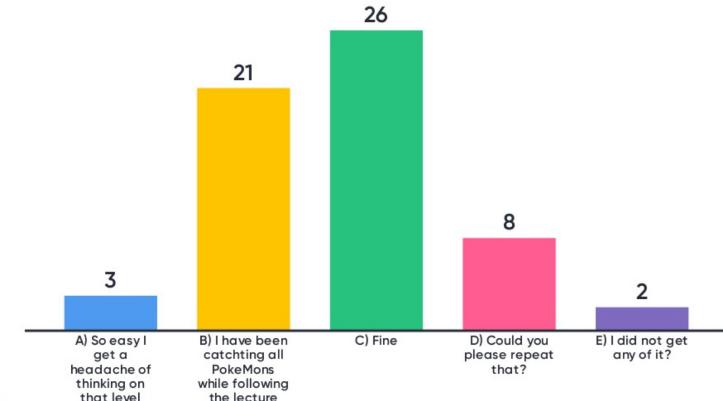
Common leaf morphologies

Quiz 12: Level of todays topic and lecture

- A) So easy I get a headache of thinking on that level
- B) I have been catchting all PokeMons while following the lecture
- C) Fine
- D) Could you please repeat that?
- E) I did not get any of it?

Quiz 12: Level of todays topic and lecture

Mentimeter



Quiz 13: What did I get out of the day?

- A) I learnt very little
- B) I did not get so much out of it
- C) The learning outcome was fine
- D) I learnt quite much
- E) I learnt a lot

Quiz 13: What did I get out of the day?

Mentimeter

