Digital image processing and analysis

8. Image filtering: feature detection and non-linear filters

Professor Ela Claridge
School of Computer Science

Previous lecture:

- Causes of image blur
- How human visual system sharpens images
- Digital filtering for image sharpening
    - High-pass filters
    - Sharpening filters*
- Filtering and frequency

In this lecture we shall find out about:

- Edge detection filters
  - Their types
  - How and why they work
  - How they can be combined
  - Where they can be found in the brain
- Median, min and max filters
- Edge preserving smoothing

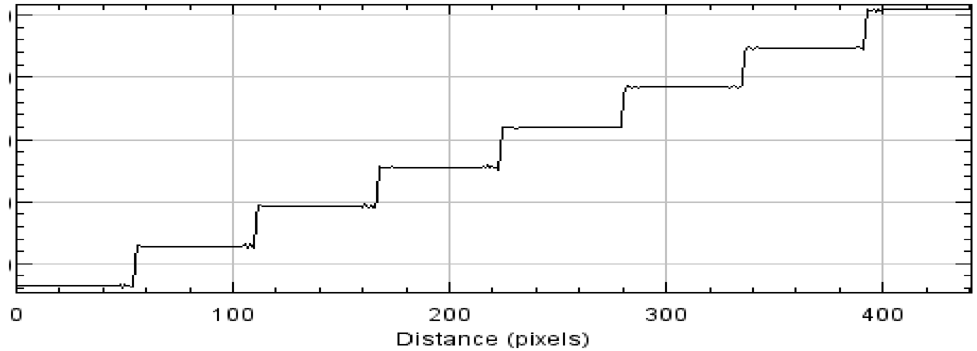
Frequency filtering operations

Sharpening

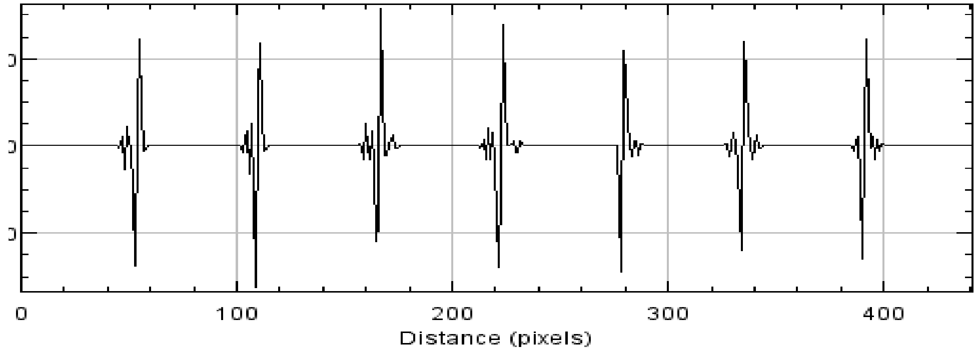
Image profiles

Previous lecture

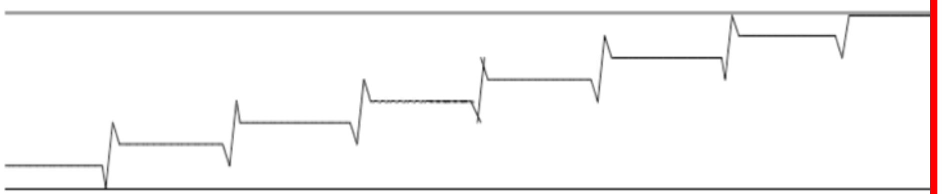
Image



Its high frequency component



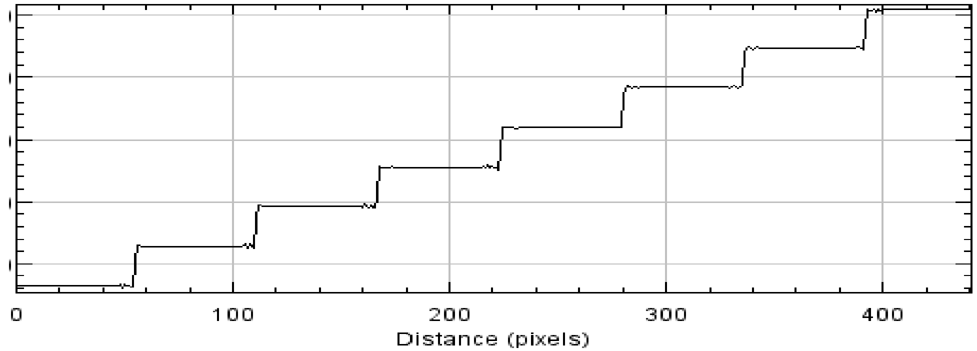
Perceived image =
Image + high frequency component



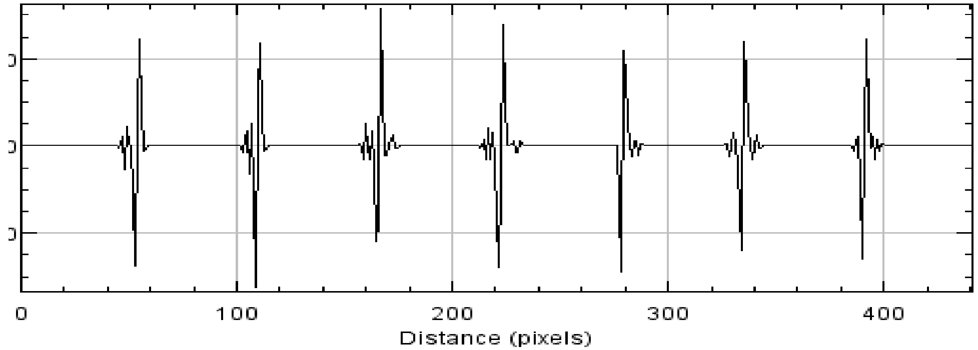
Frequency filtering operations

High-pass filters

Image profiles



Image



Its high frequency component

High frequency components correspond to spatial discontinuities in image values, i.e. **edges**.

High-pass filters are used as **edge detectors.**
(discussed in the next lecture).

Frequency filtering operations
High-pass filters

50	50	50	100	50
50	50	50	100	50
50	50	50	100	50
50	50	50	100	50
50	50	50	100	50

0	-1	0
-1	4	-1
0	-1	0

	0	-50	100	
	0	-50	100	
	0	-50	100	

50*0+ 50*(-1)+50*0+
50*(-1)+50*4+50*(-1)+
50*0+ 50*(-1)+50*0 =
0

50*0+ 50*(-1)+100*0+
50*(-1)+50*4+100*(-1)+
50*0+ 50*(-1)+100*0 =
-50

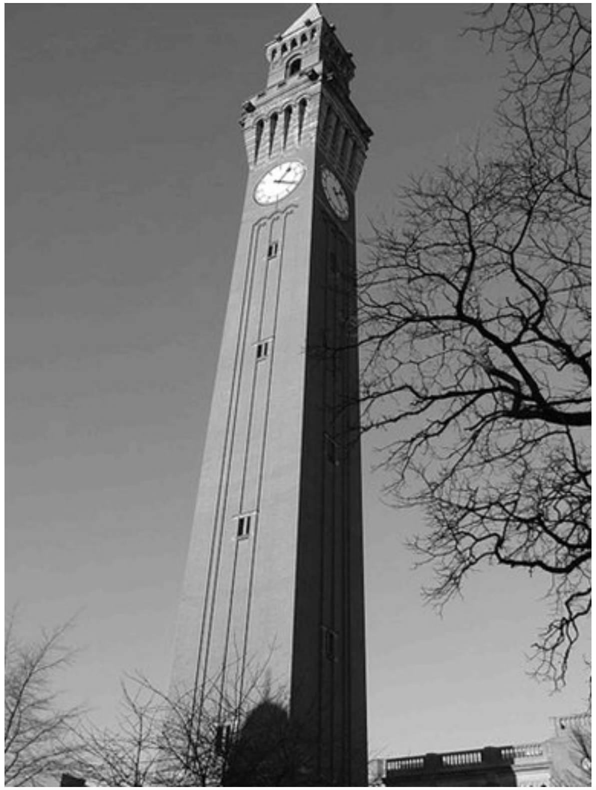
50*0+ 50*(-1)+50*0+
50*(-1)+50*4+50*(-1)+
50*0+ 50*(-1)+50*0 =
100

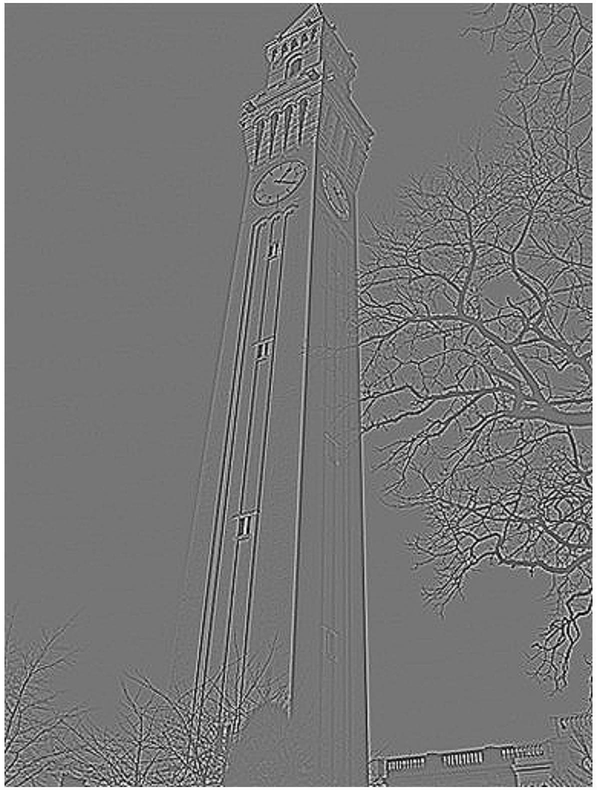
Frequency filtering operations
High-pass filters

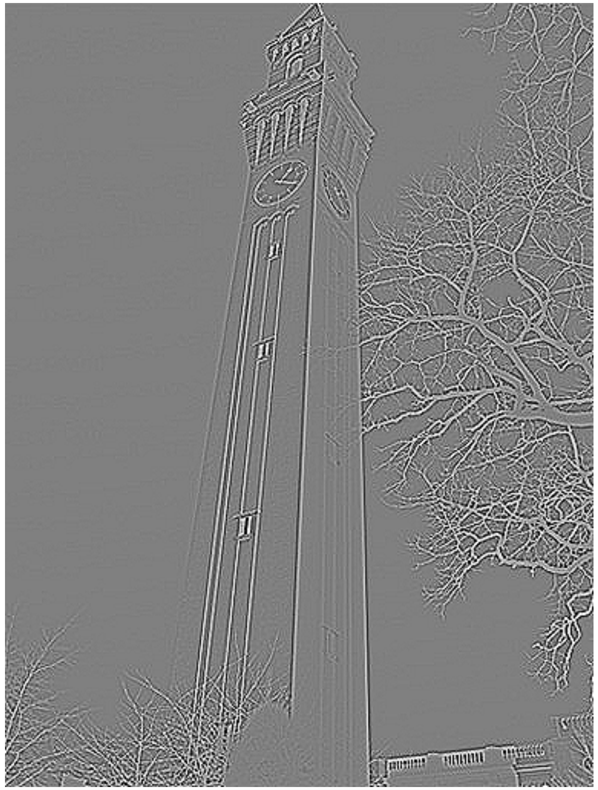
Results of convolution with

0	-1	0
-1	4	-1
0	-1	0

0	1	0
1	-4	1
0	1	0





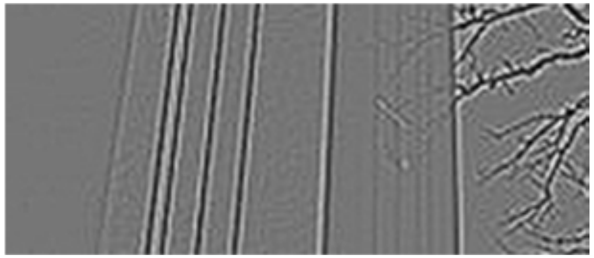


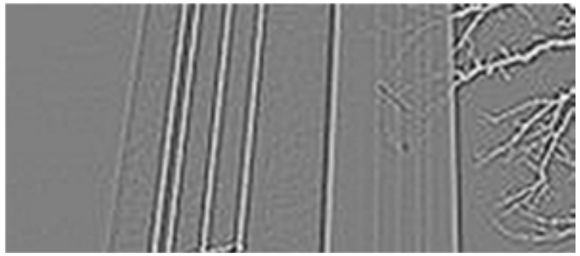
Frequency filtering operations
High-pass filters

Results of convolution with

0	-1	0
-1	4	-1
0	-1	0

0	1	0
1	-4	1
0	1	0





Observe the difference in filter response

Frequency filtering operations
High-pass filters

- High pass filter reduces or suppresses low-frequency components and emphasises high frequency components.

Examples of high pass filters

0	-1	0
-1	4	-1
0	-1	0

0	1	0
1	-4	1
0	1	0

0	0	1	0	0
0	1	2	1	0
1	2	-16	2	1
0	1	2	1	0
0	0	1	0	0

Can you deduce the principles?

Frequency filtering operations
High-pass filters

Can you deduce the principles?

k_1	k_2	k_3
k_4	k_5	k_6
k_7	k_8	k_9

$k_1+k_2+ \dots +k_9 = 0$

$k_{centre}>0$ and the remaining $k_i<0$ (on-centre)

or

$k_{centre}<0$ and the remaining $k_i>0$ (off-centre)

Frequency filtering operations
High-pass filters

Can you deduce the principles?

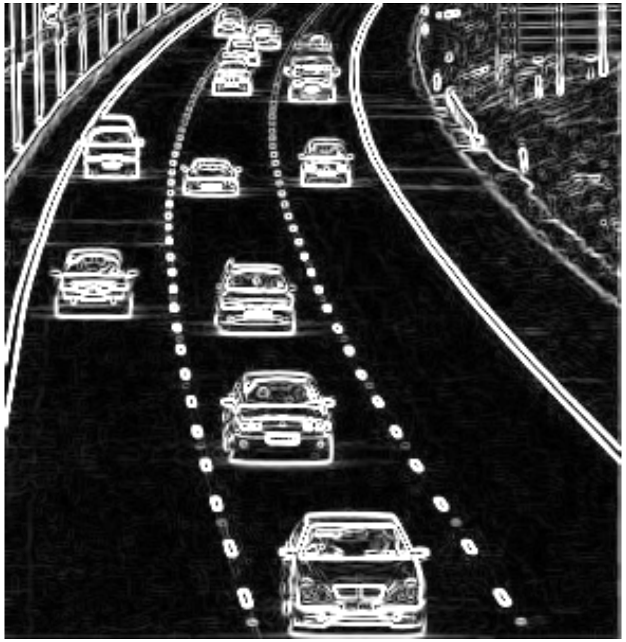
k_1	k_2	k_3
k_4	k_5	k_6
k_7	k_8	k_9

Intuitive hints

- All pixels in the image region have the same value (no edge) - the result: zero
- Same image values = frequency 0 (lowest), so not passed
- Pixel values in the image region change rapidly (edge)
- High frequencies emphasised (weighted difference between the centre and the surround)

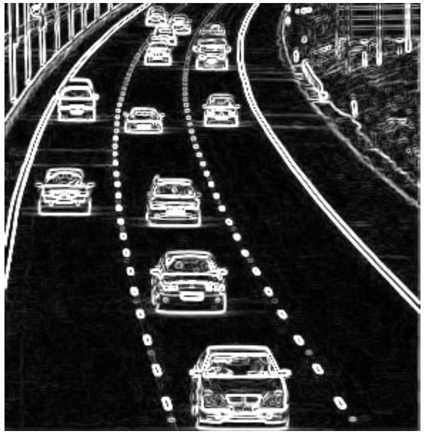
Edge detection filters

- High-pass filters respond to sharp transitions in image values, i.e. image intensity discontinuities
- Object boundaries show up commonly as intensity discontinuities in an image



Edge detection filters

- Edge detection (extraction) filters normally produce a *parametric (intrinsic)* image which contains only edge information, i.e. intensity information is lost.
- That information is then used by higher-level algorithms for feature extraction and/or object recognition, or for visual edge enhancement by combining an edge image with the original image.
- A parametric image shows *local* discontinuities, which subsequently can be composed into more elaborate boundary by higher level processing methods.



Edge detection filters
Edge filters

- Different types of edges may require different filter kernels (or *edge operators*)

- Most edge operators compute:
  - Magnitude - measure of that change (in terms of grey level values)
  - Direction - aligned with the direction of max grey level change

- Most common filters:
  - Difference
  - Gradient
  - Laplacian (second derivative)

Edge detection filters
Difference filters

- A difference filter is an example of ***directional*** *filter*
- It can extract vertical, horizontal and diagonal edges *independently*.
- For example, to detect the presence of vertical edges:
  - Shift an image to the left by one pixel
  - Subtract from original
  - This produces a brightness difference
  - $$I'(x,y) = I(x+1,y) - I(x,y)$$
  - Similar brightness - low output value
  - Dissimilar brightness (edge) - high output value
- To detect edges in other orientations, analogous method is used.

Edge detection filters
Difference filters

- A difference operator can be computed by
  - Directly by shifting and subtracting
  - By using filters

0	0	0
-1	1	0
0	0	0

Vertical

0	-1	0
0	1	0
0	0	0

Horizontal

-1	0	0
0	1	0
0	0	0

Vertical & horizontal

Edge detection filters
Shift and subtract

50	50	100	100	100
50	50	100	100	100
50	50	100	100	100
50	50	100	100	100
50	50	100	100	100

minus

50	50	100	100	100
50	50	100	100	100
50	50	100	100	100
50	50	100	100	100
50	50	100	100	100

Equals

	0	50	0	
	0	50	0	
	0	50	0	

Edge detection filters
Difference filters

Convolve

50	50	50	100	100
50	50	50	100	100
50	50	50	100	100
50	50	50	100	100
50	50	50	100	100

0	0	0
0	-1	1
0	0	0

	0	50	0	
	0	50	0	
	0	50	0	

Result of convolution of image with a difference filter

Using this difference filter gives the same result as direct subtraction.
High positive responses for horizontal transitions from dark to light.
Zero responses where there are no changes in horizontal direction.

Edge detection filters
Difference filters

→

50	50	50	100	100
50	50	50	100	100
50	50	50	100	100
50	50	50	100	100
50	50	50	100	100

0	0	0
0	1	-1
0	0	0

	0	-50	0	
	0	-50	0	
	0	-50	0	

High negative responses for horizontal transitions from dark to light.
Zero responses where there are no changes in horizontal direction.

Edge detection filters
Difference filters

50	50	50	100	100
50	50	50	100	100
50	50	50	100	100
50	50	50	100	100
50	50	50	100	100

0	-1	0
0	1	0
0	0	0

	0	0	0	
	0	0	0	
	0	0	0	

Zero responses where there are no changes in vertical direction.

Vertical difference filter

Horizontal difference filter

Edge detection filters
Difference filters

- Properties of difference filters:
    - Sensitive to noise
    - Highlight only dark-to-light edges in a single direction
    - Light-to-dark edges yield negative values and are normally set to 0 (black)

Edge detection filters
Gradient filter

Output value is a measure of *edge strength (gradient magnitude)*, i.e. difference between neighbouring intensities in a particular direction.

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

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

Sobel filters

0	0	0
-1	0	1
0	0	0

0	1	0
0	0	0
0	-1	0

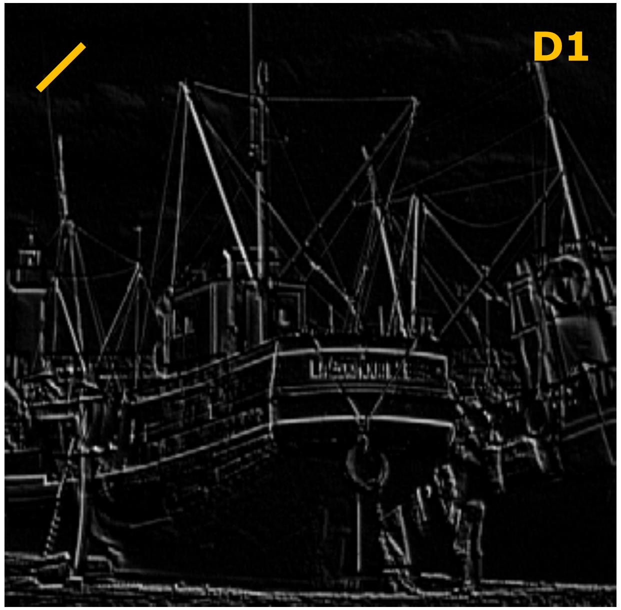
0	0	1
0	0	0
-1	0	0

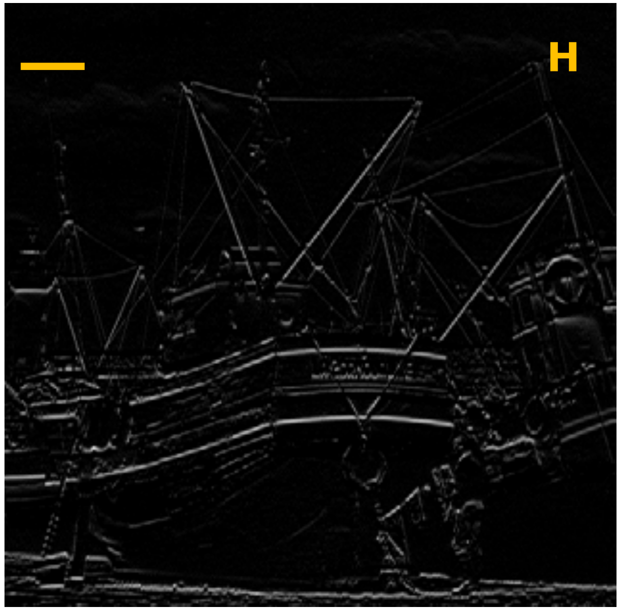
1	0	0
0	0	0
0	0	-1

Roberts filters

Edge detection filters
Gradient filter

- Properties of gradient filters:
  - Can selectively analyse edges in a particular direction
  - Does not show all the edges at once
  - Two outputs can be generated: edge gradient and edge direction
  - Negative differences turned into 0
- Several gradient filters can be combined





max(V,H,D1,D2)
(non-linear operation)

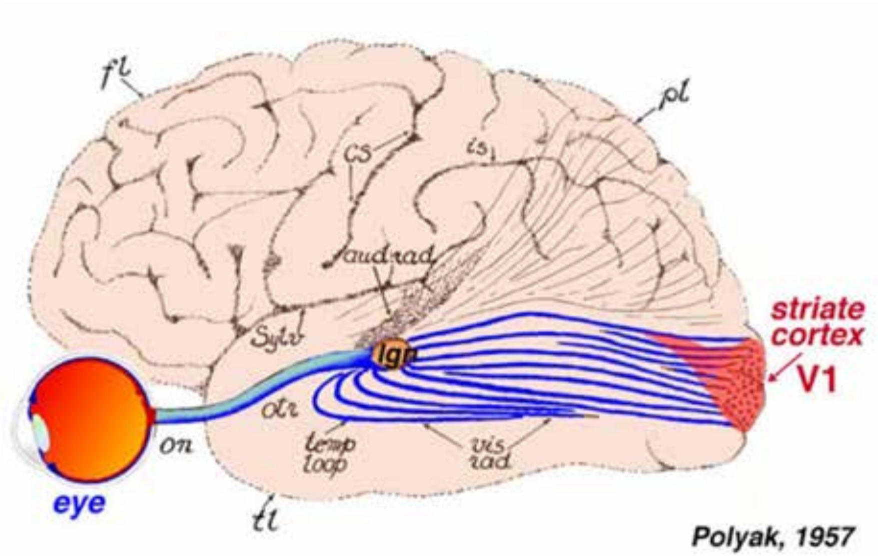
Edge detection filters
Laplacian (second derivative) filter

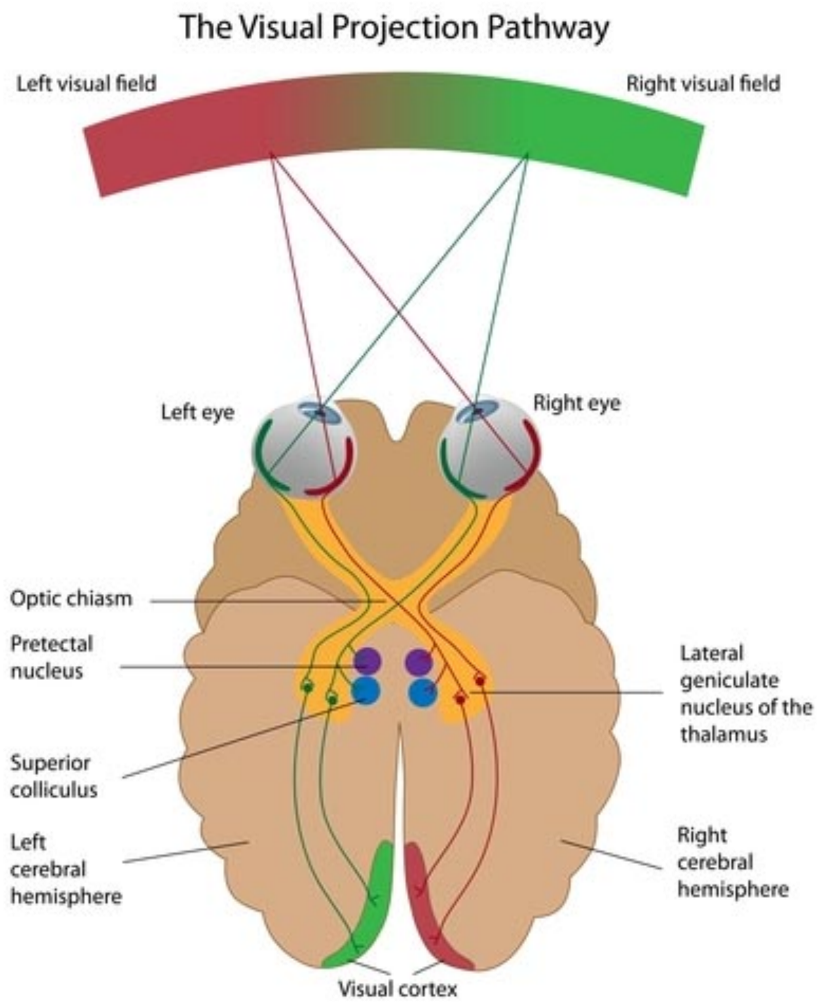
- Laplacian filter is an example of *omni-directional* (*isotropic filter)* because it simultaneously detects edges in all directions.

0	1	0
1	- 4	1
0	1	0

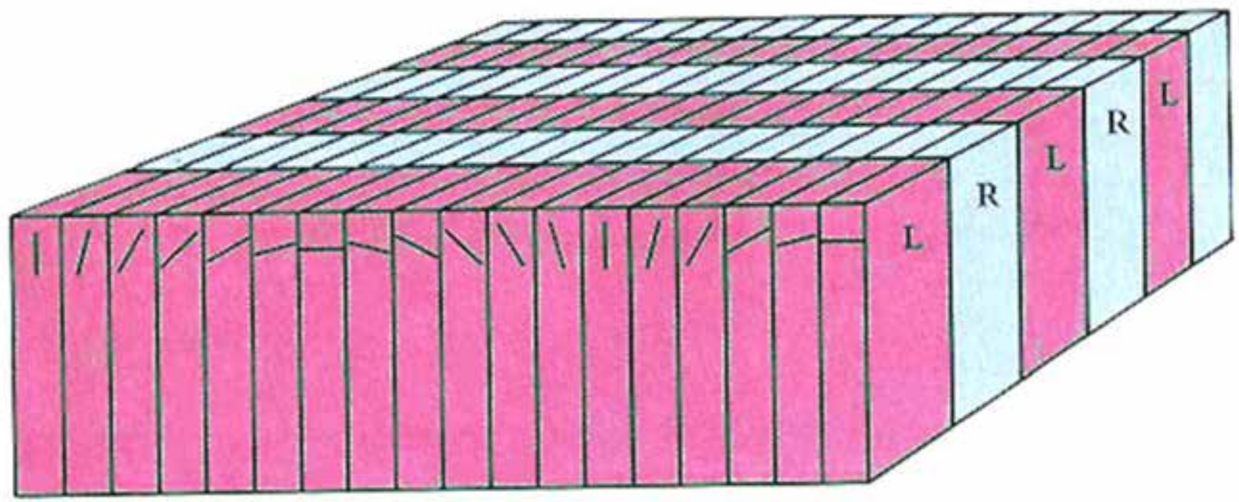
This is a high-pass filter we have met before!

Edge detection in the brain





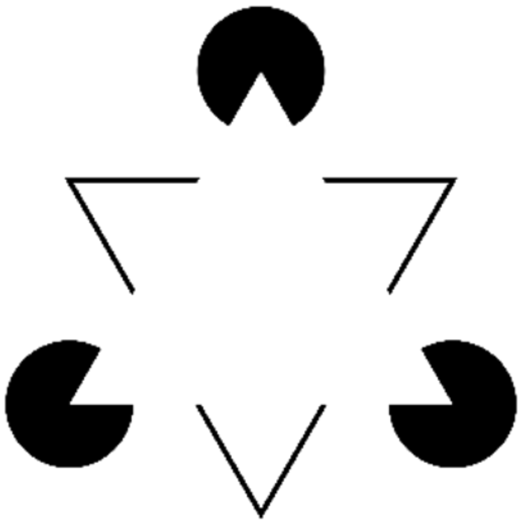
Edge detection in the brain
Orientation and ocular dominance columns



Schematic of cortex organisation, area V1

http://webvision.med.utah.edu/imageswv/columns.jpg

Edge detection in the brain
Visual illusions

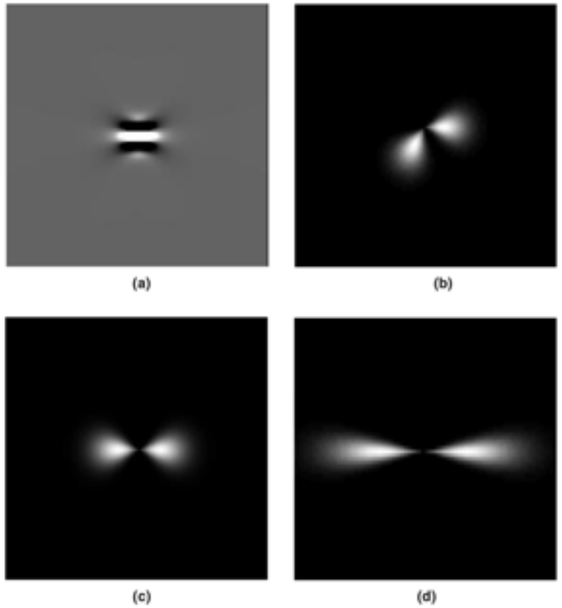


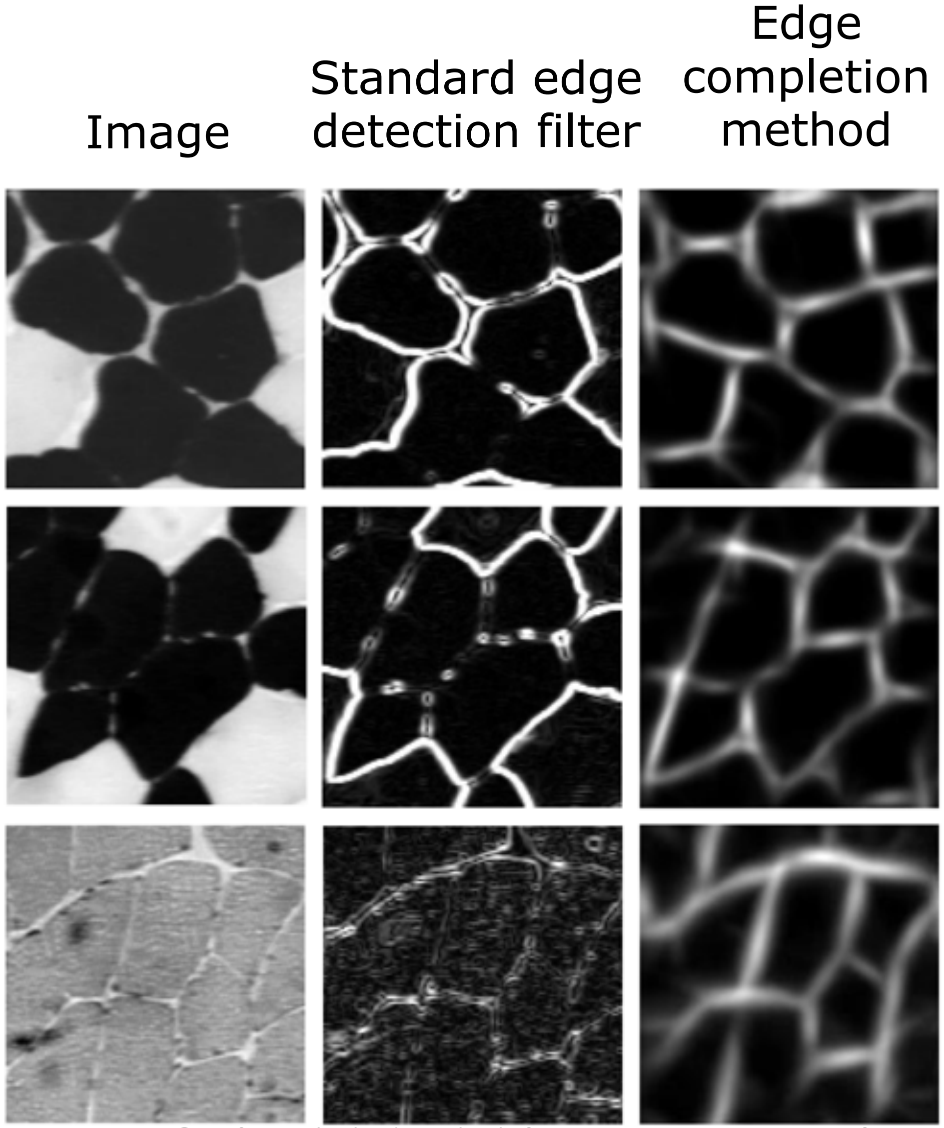
Hypothesis:
Orientation-sensitive cells in the visual cortex generate perception of the edges that would be expected in the real 3-dimensional world.

Low-level grouping mechanisms for contour completion

Alison G. Todman *, Ela Claridge

Examples of filters





Non-linear filters

- The filters discussed so far are linear filters
- Non-linear filters are so called because their operation cannot be implemented using addition and multiplication.
- Non-linear operations may involve
  - Sorting of image values.
  - Selecting a particular range of values (e.g. only zero, or greater and equal zero, etc.).
  - Applying different operation depending on a neighbourhood of a given pixel.

Median filter

- Median value (Wikipedia)
  - The median is the value separating the higher half of a data sample.
  - In simple terms, it may be thought of as the "middle" value of a data set.
  - For example, in the data set {1, 3, 3, 6, 7, 8, 9}, the median is 6, the fourth number in the sample.

Median filter

Computing median for the image fragment:

Median image filter replaces each pixel value by the median value of its neighbourhood.

0	**1**	**1**
2	**50**	**2**
1	**1**	**2**

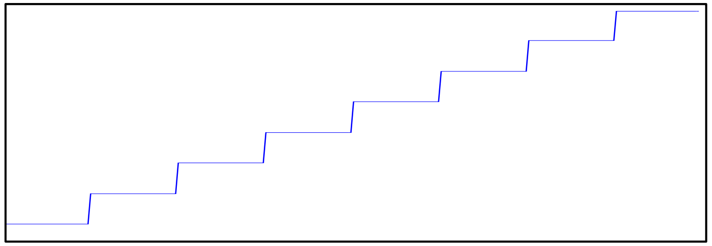
=> 0 1 1 1 <u>1</u> 2 2 2 50 =>

	1	

Here pixel with value 50, which is a clear outlier (“noise”), is replaced by the most common value in the 3 x 3 neighbourhood.

Median filter
Noise removal

Uncorrupted image



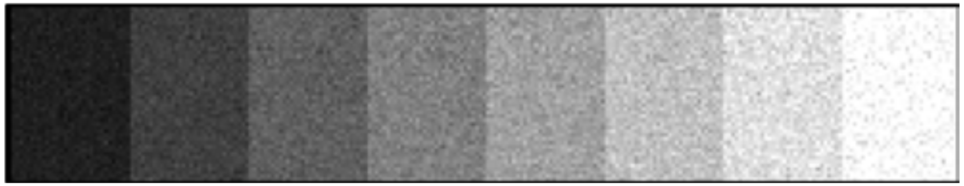
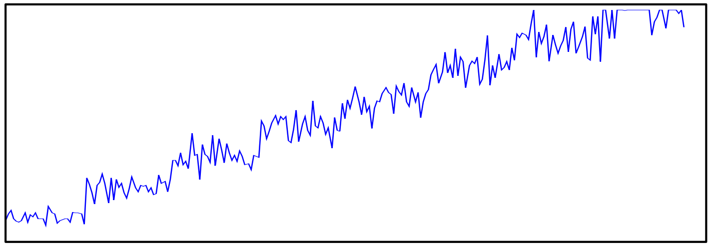


Image corrupted by noise



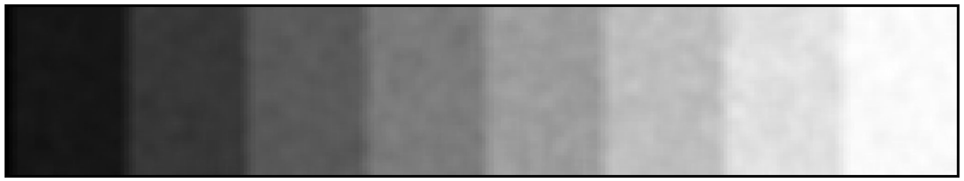


Image restored by low-pass filtering

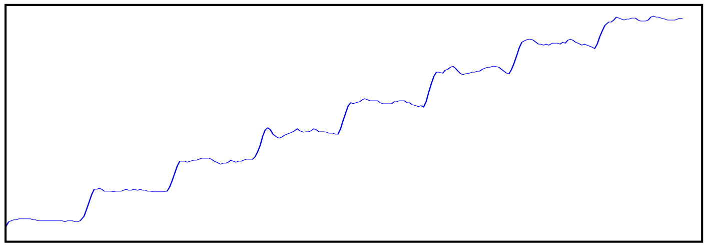
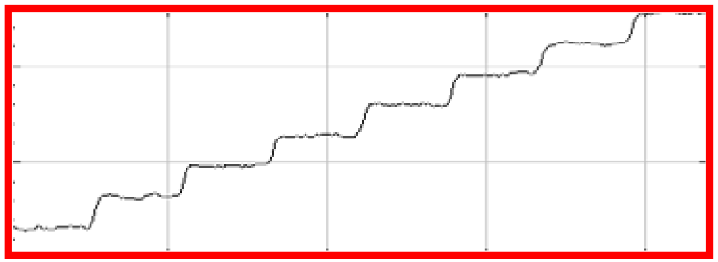
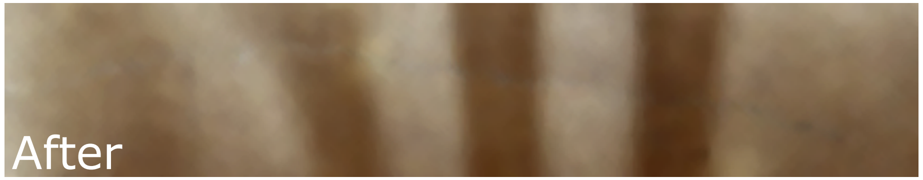


Image restored by median filter

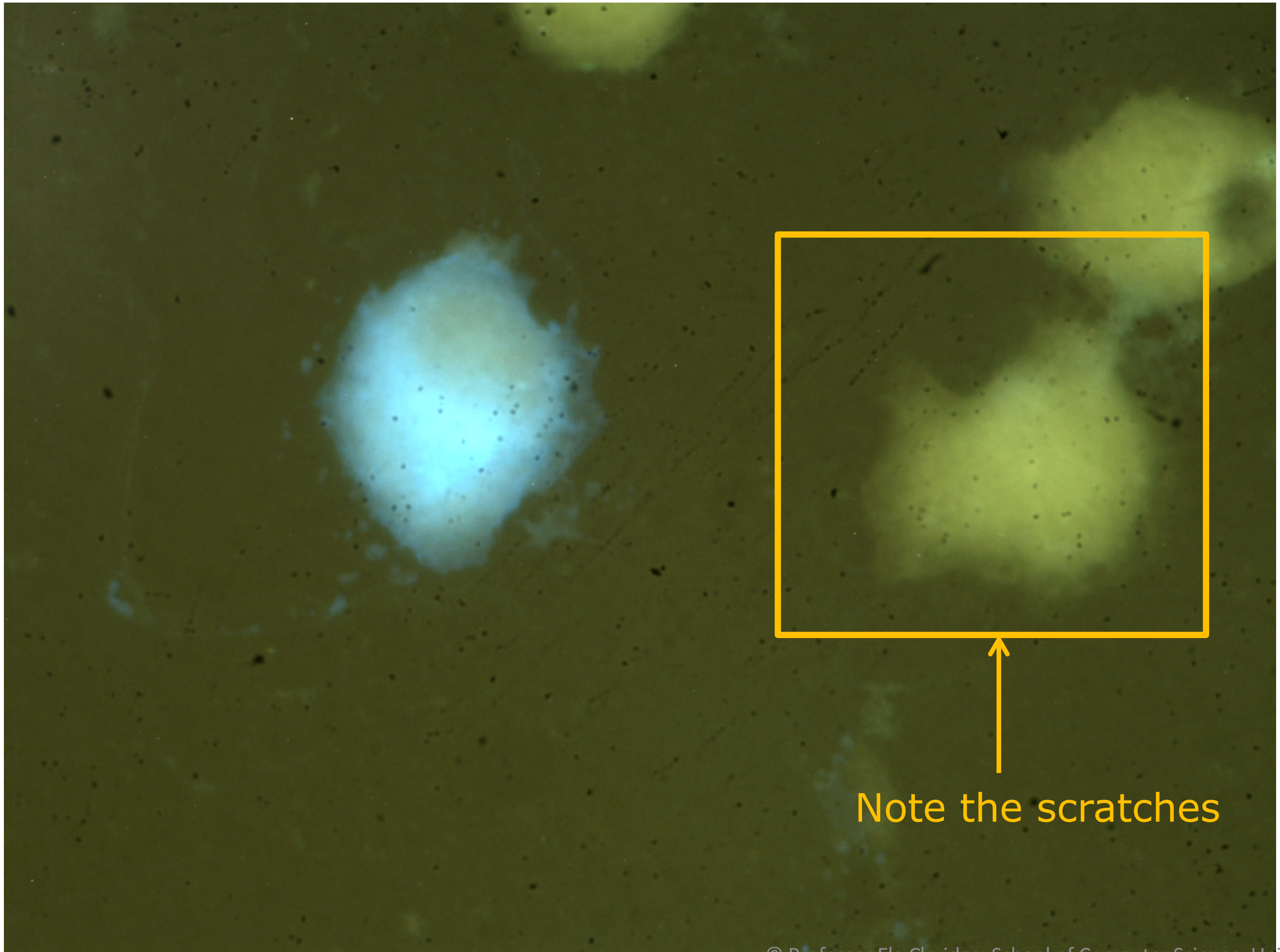


Median filter
Example of crack repair

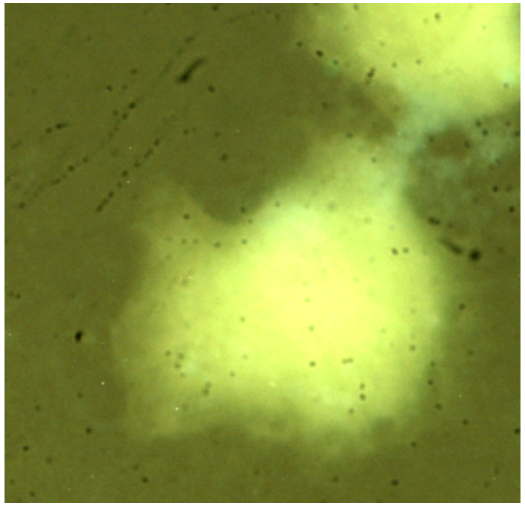


Comparison

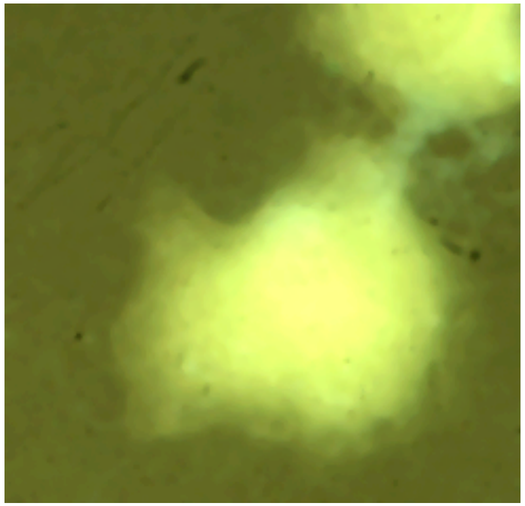
Median filter
Comparison



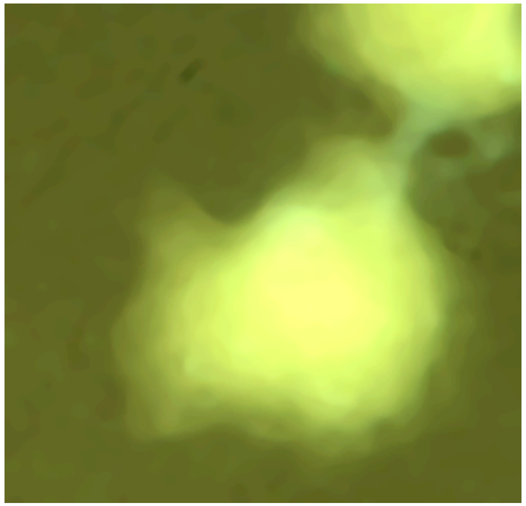
Median filter
Comparison – filter size



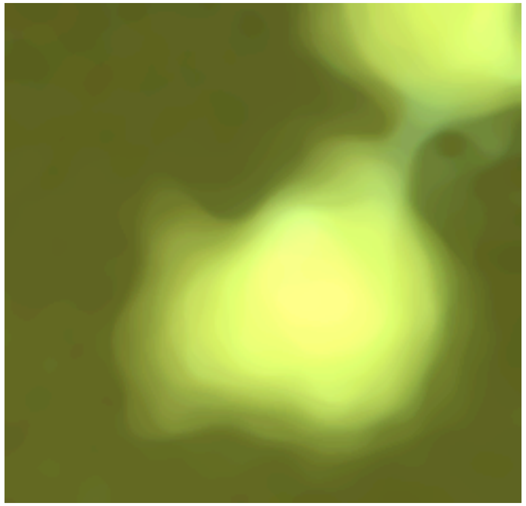
Original (enhanced, for visibility of scratches)



3 x 3



7 x 7



11 x 11

Median filter
Artistic effects

Original

Processed

median filter

median filter + unsharp masking

median filter + unsharp masking

Min filter

Computing minimum for the image fragment:

Min image filter replaces each pixel value by the minimum value of its neighbourhood.

0	**1**	**1**
2	**50**	**2**
1	**1**	**2**

=> 0 1 1 1 1 2 2 2 50 =>

	0	

Max filter

Computing maximum for the image fragment:

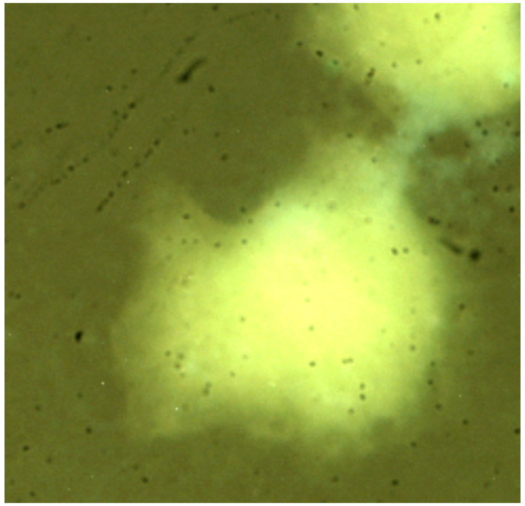
Max image filter replaces each pixel value by the maximum value of its neighbourhood.

0	**1**	**1**
2	**50**	**2**
1	**1**	**2**

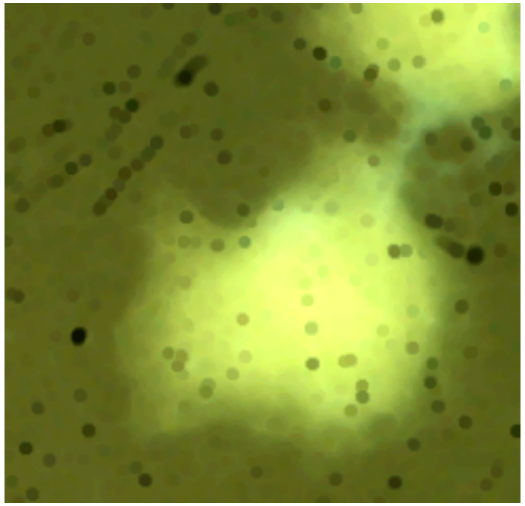
=> 0 1 1 1 1 2 2 2 <u>50</u> =>

	50	

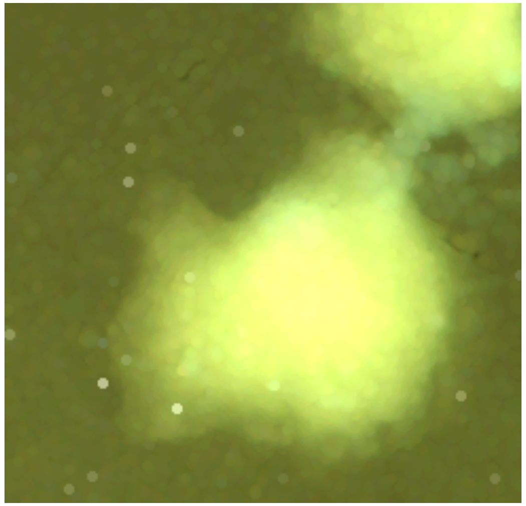
Min and max filters
Comparison



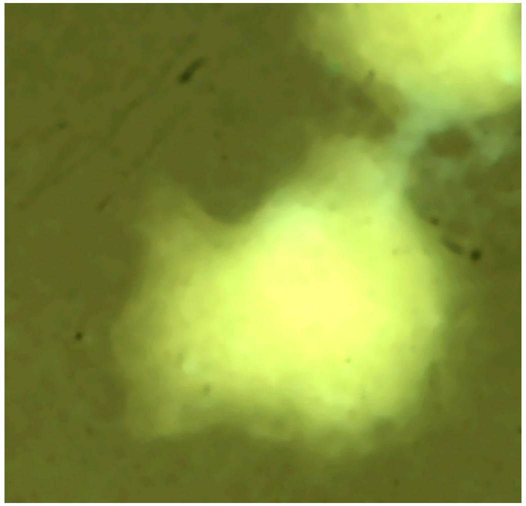
Original (enhanced, for visibility of scratches)



3 x 3 Min filter



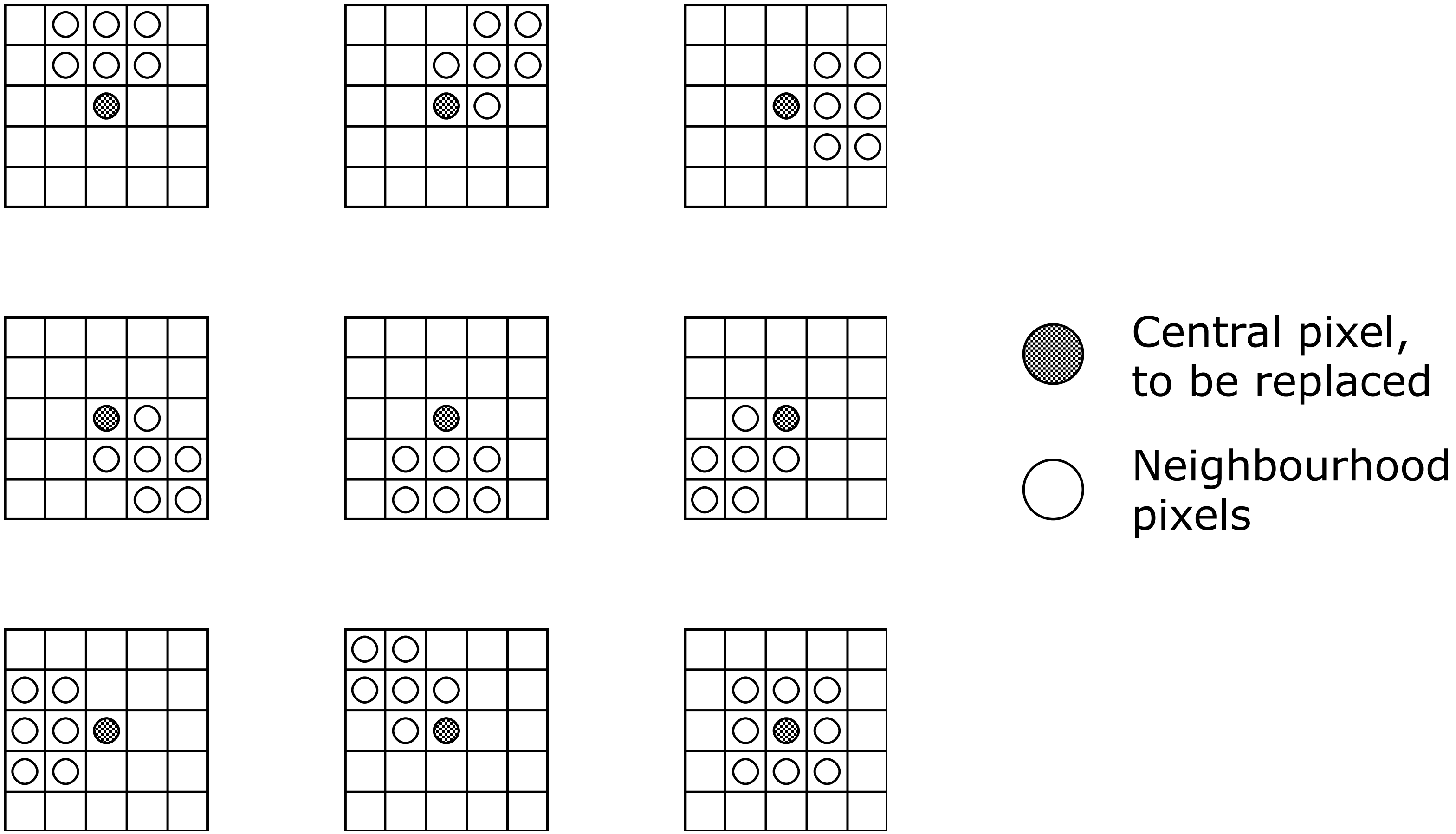
3 x 3 Max filter



3 x 3 Median filter

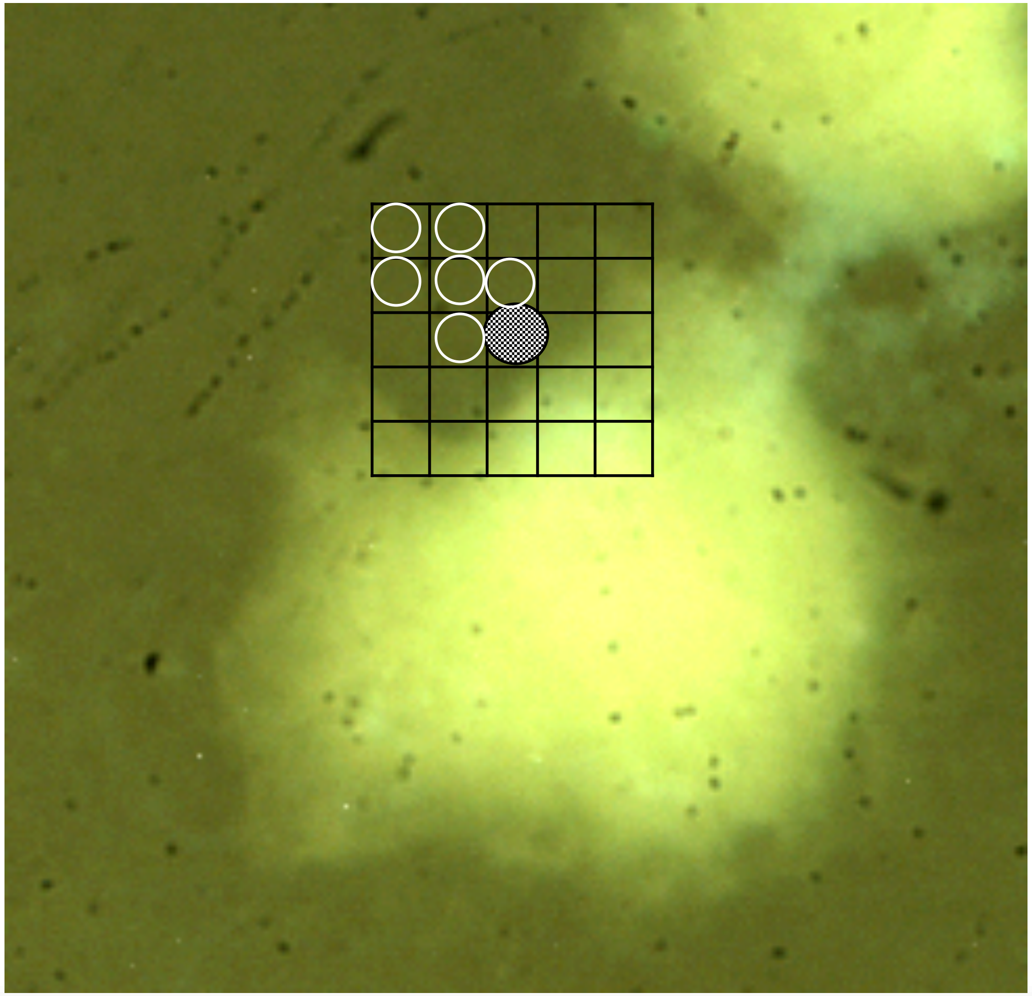
Edge-preserving smoothing

Replace each pixel by the mean value of a portion of its neighbourhood with the smallest standard deviation



Edge-preserving smoothing

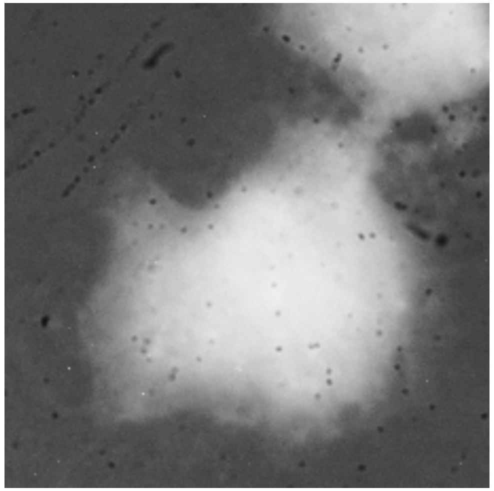
Replace each pixel by the mean value of a portion of its neighbourhood with the smallest standard deviation



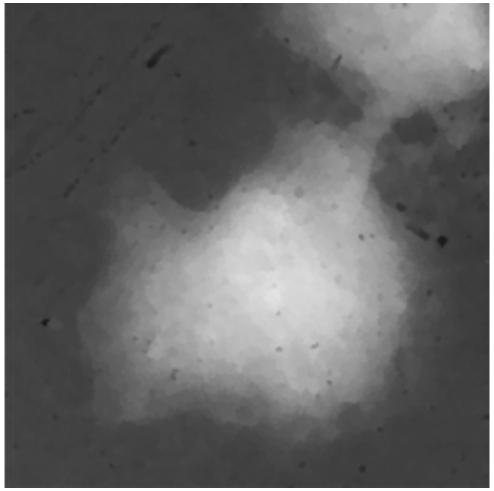
Central pixel, to be replaced

Neighbourhood pixels for which the mean and standard deviation are computed

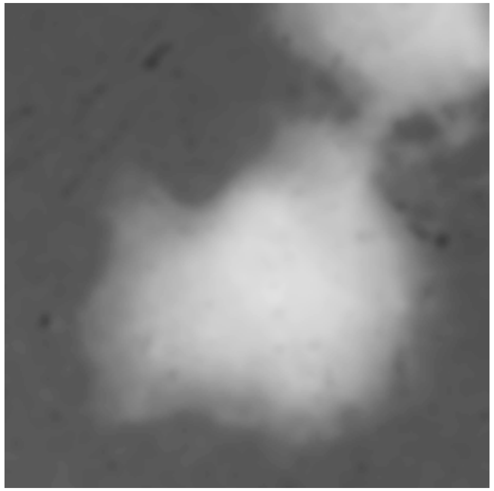
Edge preserving smoothing
Comparison



Original (monochrome)

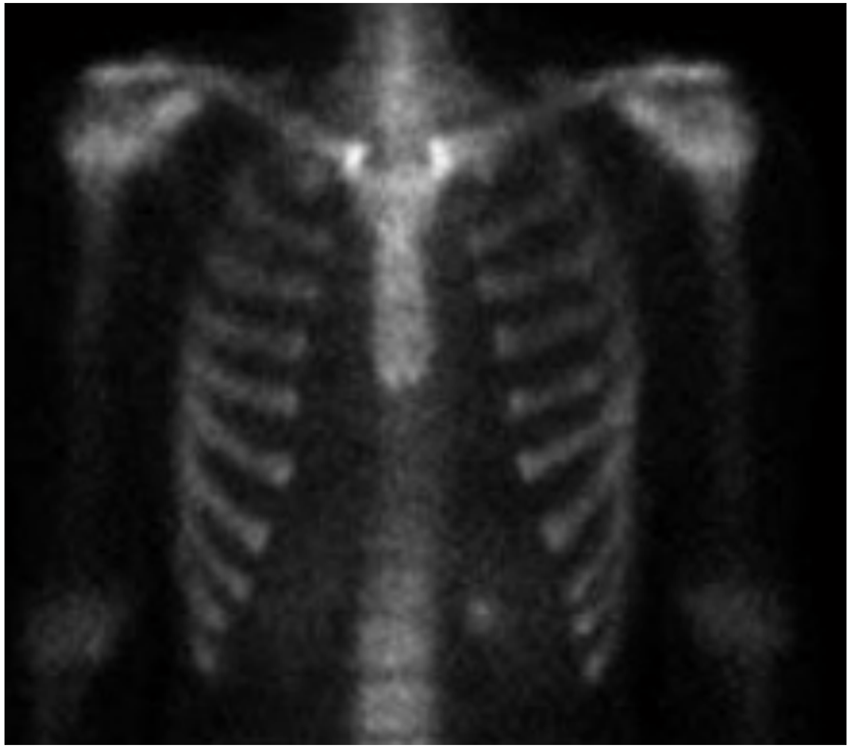


5 x 5 Edge preserving filter



5 x 5 Median filter

Edge preserving smoothing
Example



Original
(ribcage, molecular imaging)

After a 5 x 5 Edge preserving filter

Other non-linear filters

- A number of more complex edge detection methods utilise outputs from simple edge detection filters, e.g.:
  - Zero crossing of Laplacian filter
  - Canny edge detector

(see Further reading)

In this lecture we have covered:

- Edge detection filters
  - Their types
  - How and why they work
  - How they can be combined
  - Where they can be found in the brain
- Median, min and max filters
- Edge preserving smoothing

Next lecture:

- Image segmentation
  - Binary images
  - Thresholding
- Object extraction

Further reading and experimentation

- **Book chapters**:
- Gonzalez, R.C. & Woods, R.E. Digital Image Processing, Addison-Wesley (various editions), 7.1.
- Sonka, M. Hlavac, V. Boyle, R. (various editions) Image Processing, Analysis and Machine Vision, Chapman & Hall Computing, 4.3.

- **Edge preserving smoothing**
- https://arxiv.org/pdf/1503.07297v1

- **Other interesting filters and methods of image enhancement**
- https://imagej.net/Xlib

- *HIPR2 resources*
- **Edge detection filters** (Roberts, Sobel, Canny Compass, Zero crossing, Line detector)
- http://homepages.inf.ed.ac.uk/rbf/HIPR2/featops.htm
- **Median filter**
- http://homepages.inf.ed.ac.uk/rbf/HIPR2/median.htm

Additional slides

Edge detection filters
Gradient filter

- A gradient filter is also a *directional (anisotropic) filter.*
- Up to 8 gradient images can be generated:
- N, NE, E, SE, S, SW, W, NW
- Each enhances edges in one particular direction.

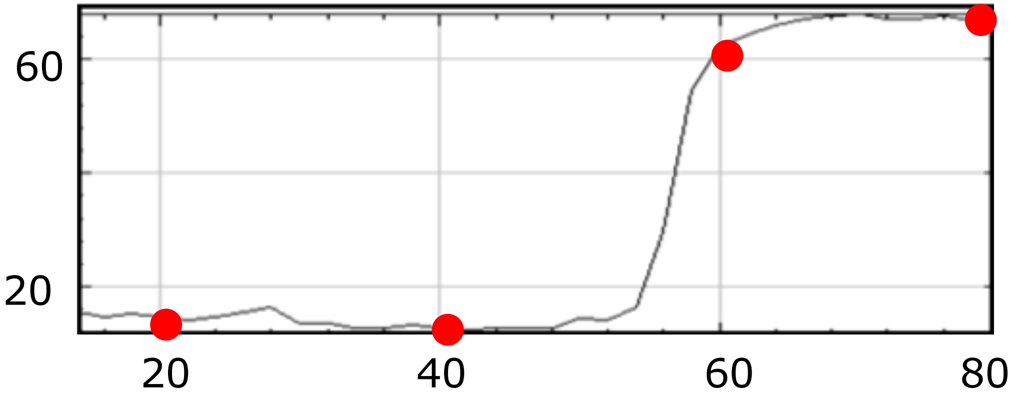
(Mathematically the gradient image function is defined in terms of directionally oriented spatial derivatives:

$$\partial f / \partial x = [\ f(\ x + \Delta x,\ y\ ) - f(\ x,y\ )\ ] / \Delta x$$

$$\partial f / \partial y = [\ f(\ x,\ y + \Delta x,y\ ) - f(\ x,y\ )\ ] / \Delta y\ )$$

Edge detection filters
Gradient

$$\frac{I(40)-I(20)}{40-20} = \frac{10-10}{40-20} = 0 \qquad \frac{60-10}{60-40} = 2.5 \qquad \frac{65-60}{80-60} = 0.25$$



$$\frac{30-20}{40-20} = 0.5 \qquad \frac{60-30}{60-40} = 1.5 \qquad \frac{100-60}{80-60} = 2 \qquad \frac{100-100}{100-80} = 0$$