Digital image processing and analysis

6. Image enhancement: manipulating image frequencies

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Previous lecture:

- Image enhancement and restoration
  - Image histogram
  - Manipulating image brightness
  - Contrast enhancement
  - LUT operations

In this lecture we shall find out about:

- Common types of image corruption
  - Noise
  - Blur
- Image frequencies
- Tools and methods for noise removal
  - Image profile
  - Image filtering operations
  - Convolution
  - Low-pass (smoothing) filters

Image corruption
Causes

- An input digital image is never perfect, but is always "noisy" and distorted to some extent.

Image corruption
Causes

- An input digital image is never perfect, but is always "noisy" and distorted to some extent by:
  - Non-linearities of electronic components of sensors
  - Sampling and quantisation errors
  - Suboptimal imaging conditions
  - Data transmission artefacts

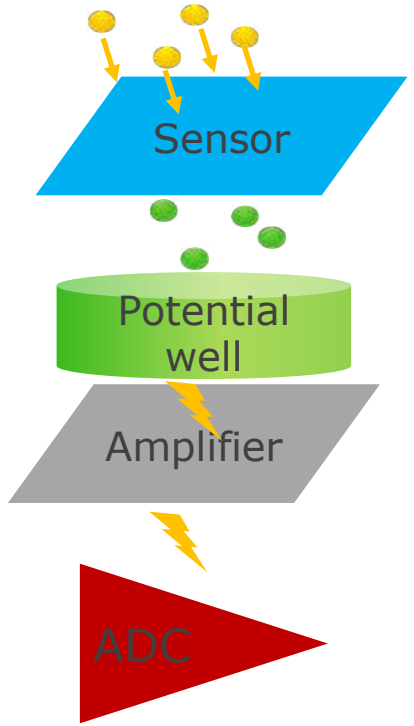


Image corruption
Noise and blur

Uncorrupted image

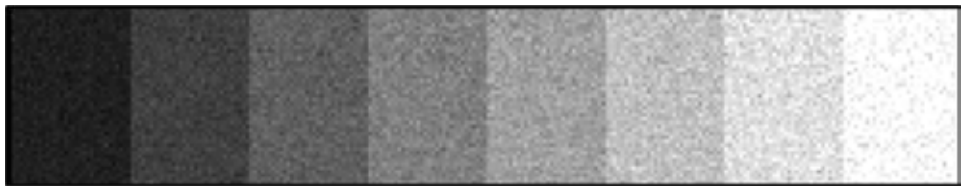
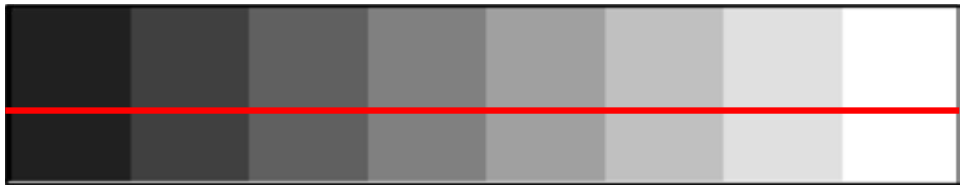
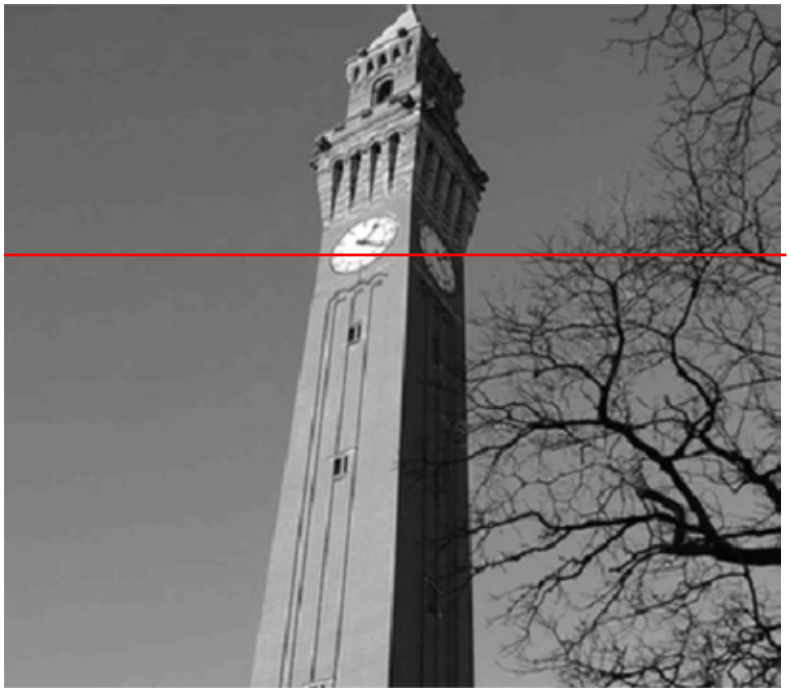


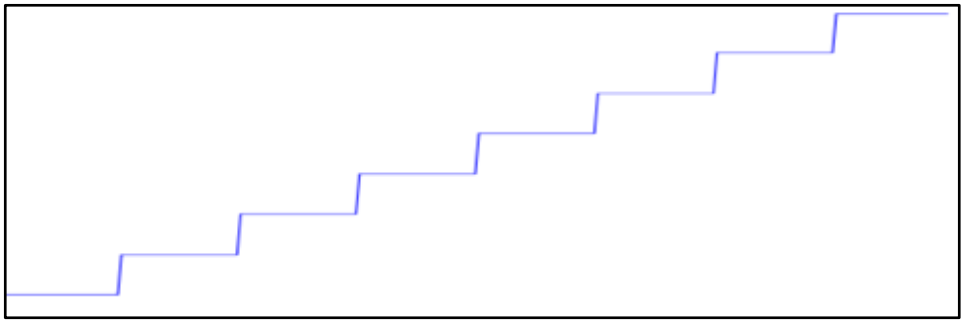
Image corrupted by noise

Image corrupted by blur

Frequency
Image profile







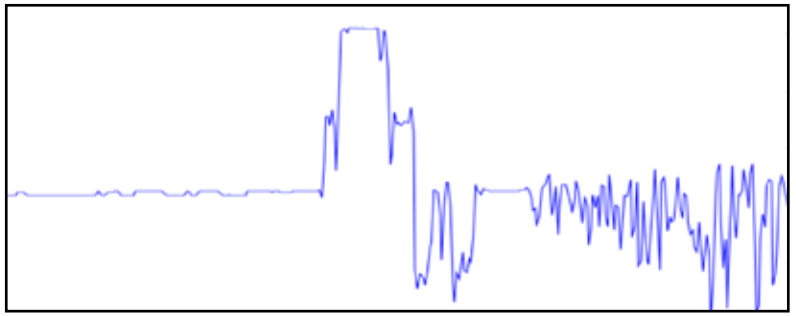
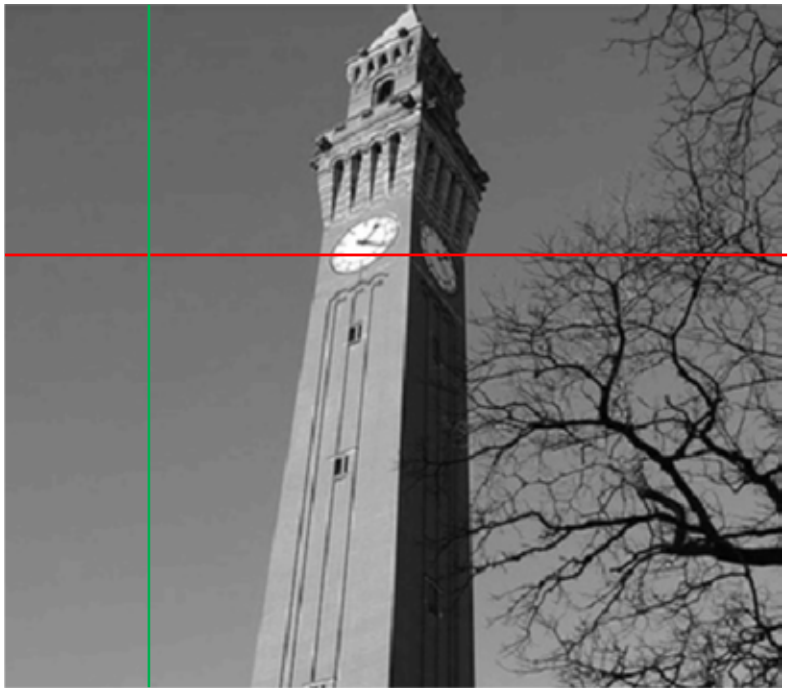
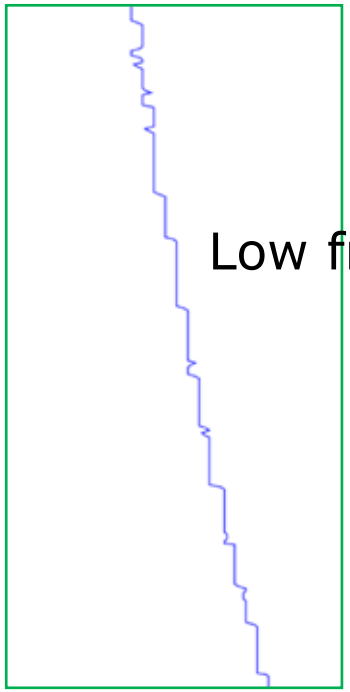
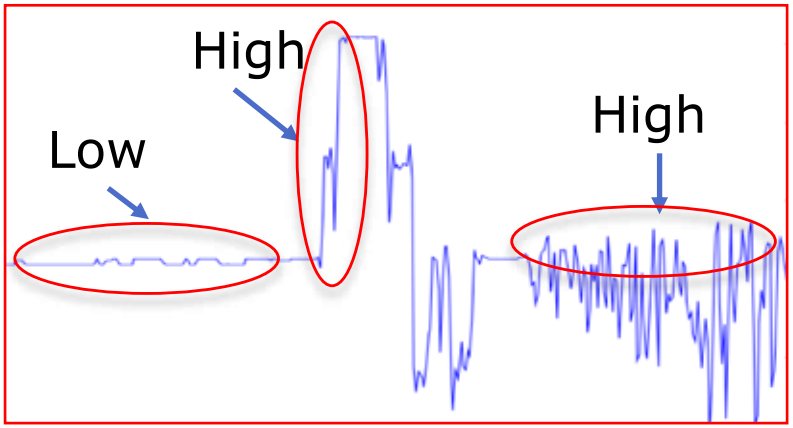


Image profile

Frequency
Image profile







Frequency
Image profile

Uncorrupted image

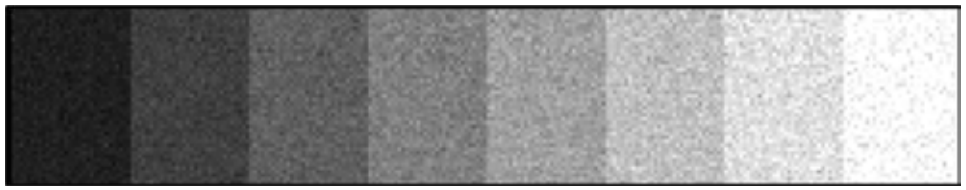
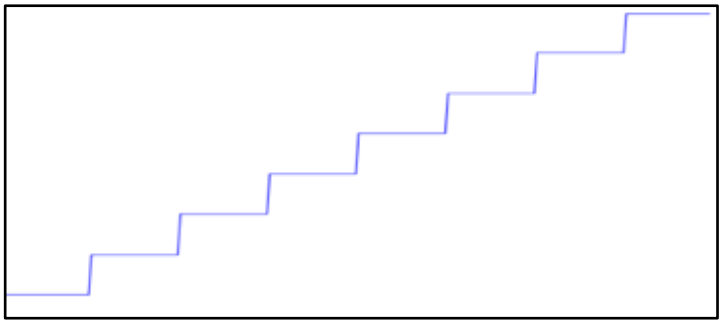
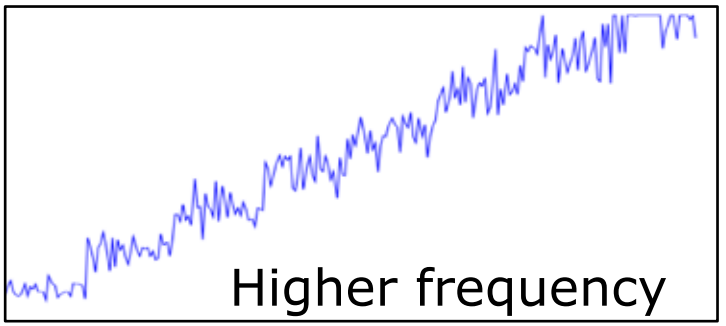


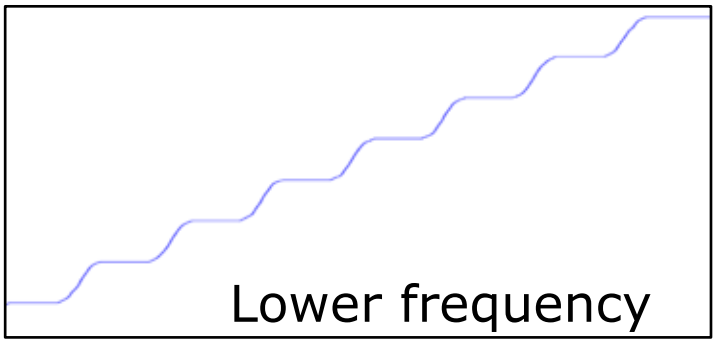
Image corrupted by noise

Image corrupted by blur

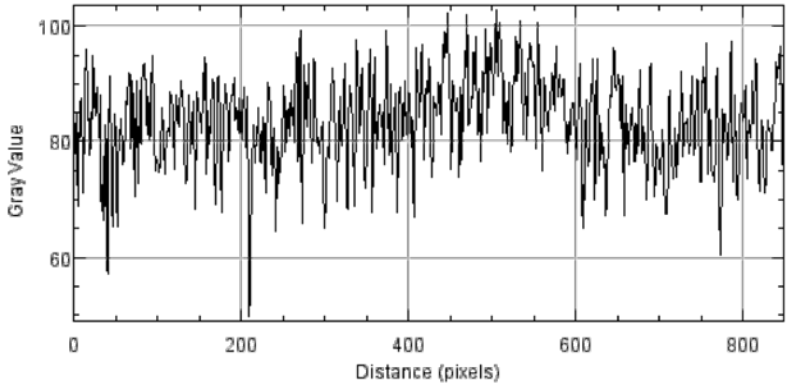
Image profiles







Frequency
Image profile



Frequency filtering operations
Tool for reducing frequency distortions

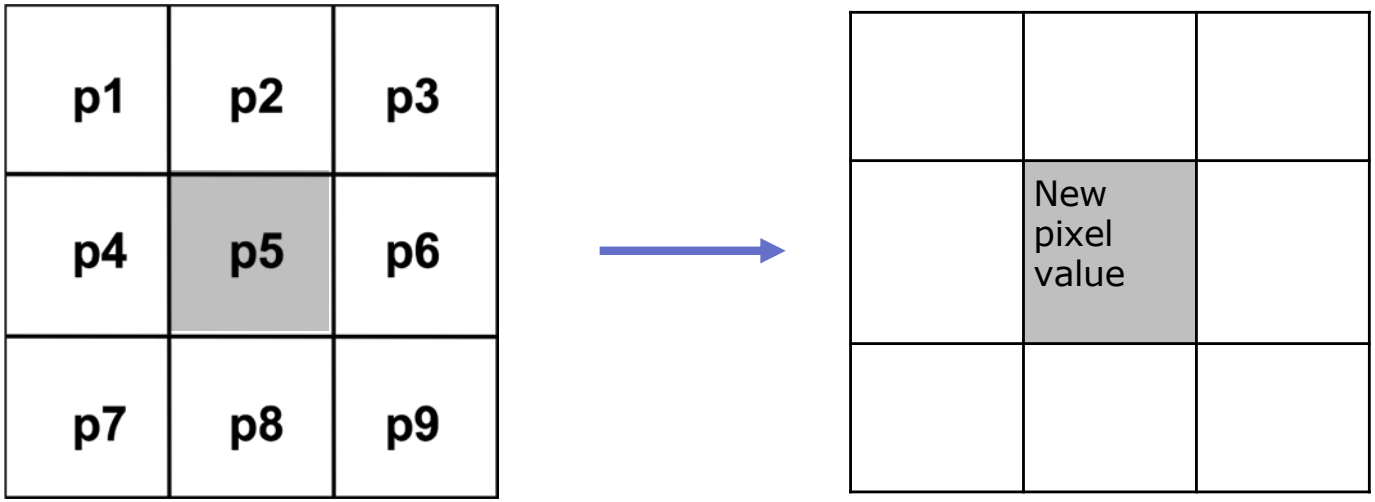
- Frequency filtering operations separate frequency components within an image into different frequency ranges, most often into:
  - low frequency components
  - high frequency components

- Following this separation
  - unwanted components can be rejected or,
  - low and high frequency components can be processed separately and then re-combined.

Frequency filtering operations
Smoothing: low pass filter

- One of the simplest methods to remove noise is to average the incoming signal over the number of sensors.
- The **spatial averaging** produces visually smoother image; this is because the unwanted high frequencies are eliminated by averaging.
- This process of ***smoothing*** works by removing rapid changes in brightness (high frequency component) but at the same time retaining slow changes (low frequency component).
- Averaging of pixel values is an example of a simple digital image processing technique for reducing high frequency component of an image.

Frequency filtering operations
Smoothing: low pass filter

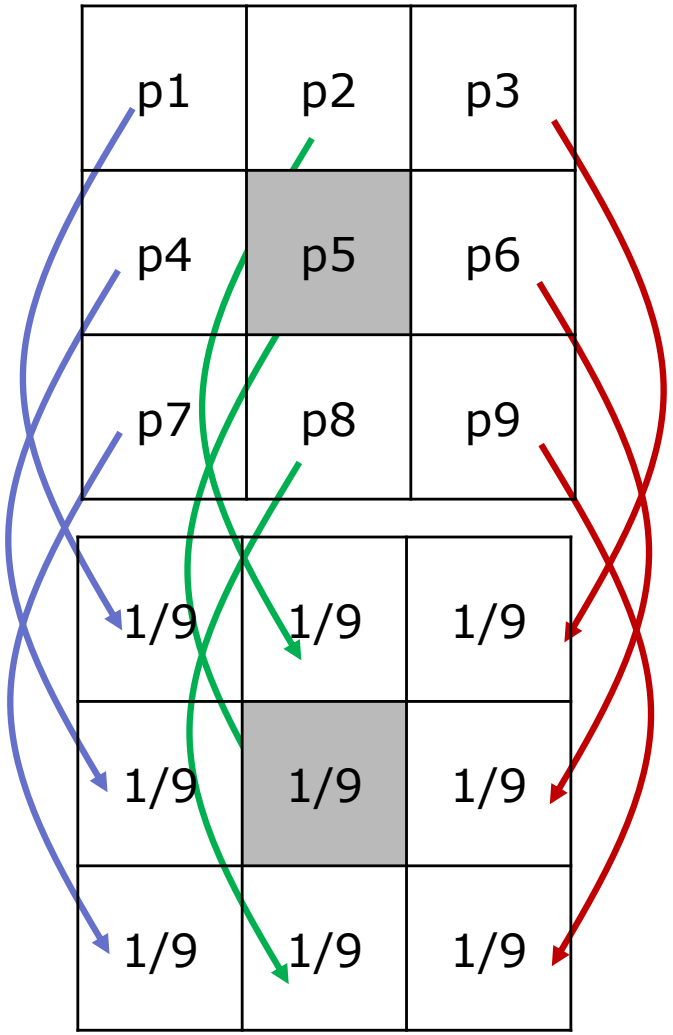


To smooth the image, for every pixel in the original image the average pixel value is calculated for 3x3 pixel area of the image (here pixels p1 – p9) and inserted in the position of the original pixel in a new image (here at the location of pixel p5).

$$\text{new pixel value} = \frac{1}{9}p1 + \frac{1}{9}p2 + \frac{1}{9}p3 + \frac{1}{9}p4 + \frac{1}{9}p5 + \frac{1}{9}p6 + \frac{1}{9}p7 + \frac{1}{9}p8 + \frac{1}{9}p9$$

$$= \frac{1}{9}(p1 + p2 + p3 + p4 + p5 + p6 + p7 + p8 + p9)$$

Frequency filtering operations
Smoothing: low pass filter

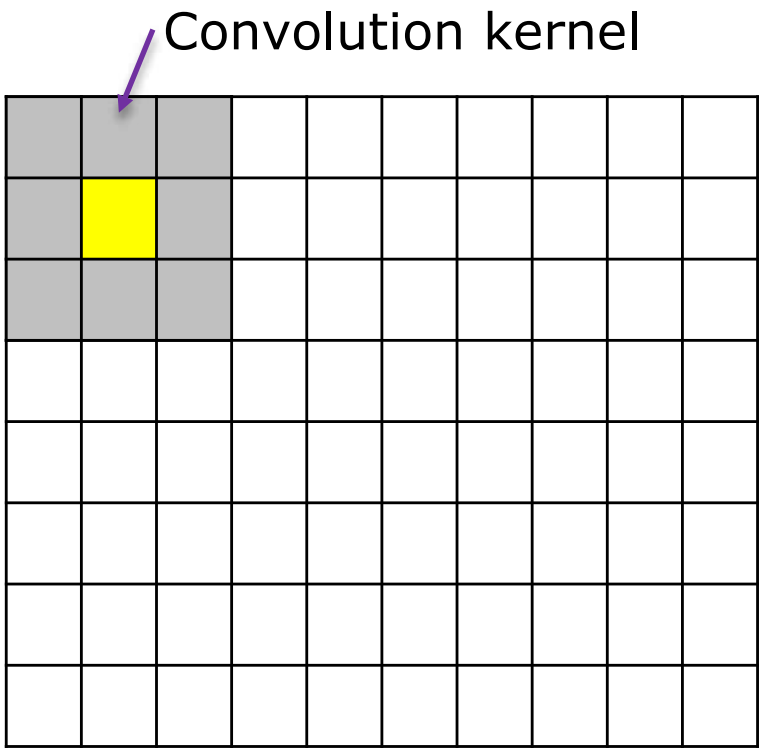


This is equivalent to multiplying pixel values p1 - p9 by values stored in a small 3x3 matrix called a ***convolution kernel*** (or a convolution mask or a **filter**).

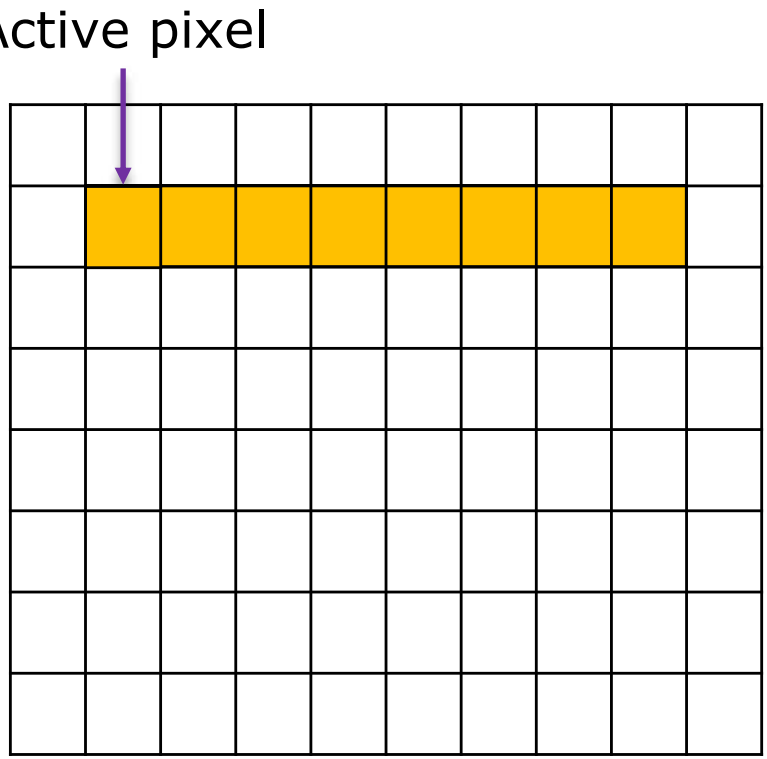
A convolution kernel can also be thought of as a set of spatial **weights** applied to an input signal.

new pixel value $= \frac{1}{9}p1 + \frac{1}{9}p2 + \frac{1}{9}p3 + \frac{1}{9}p4 + \frac{1}{9}p5 + \frac{1}{9}p6 + \frac{1}{9}p7 + \frac{1}{9}p8 + \frac{1}{9}p9$

Frequency filtering operations
Convolution

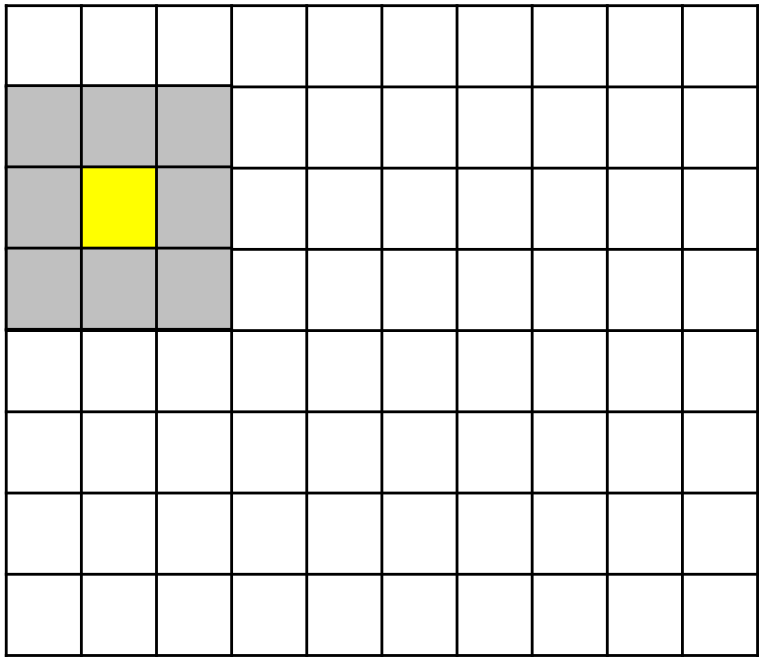


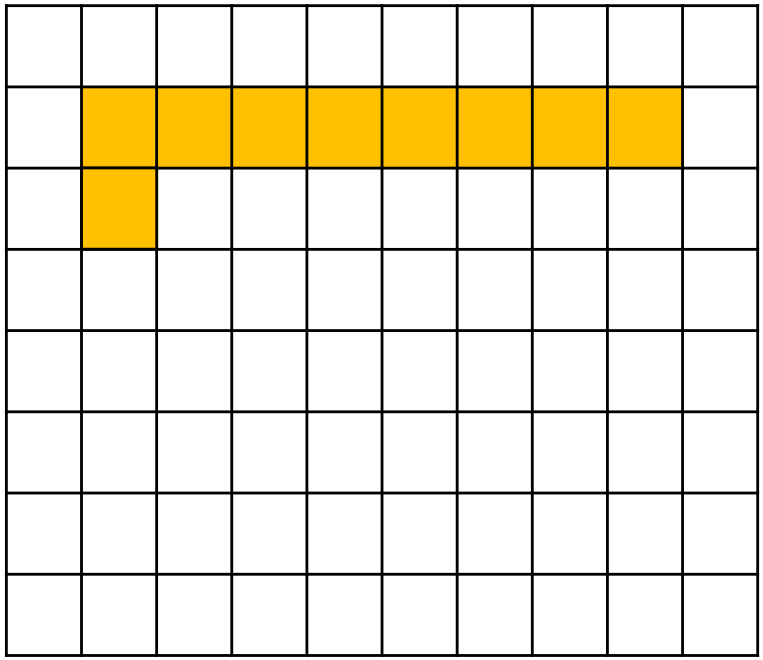
Input image



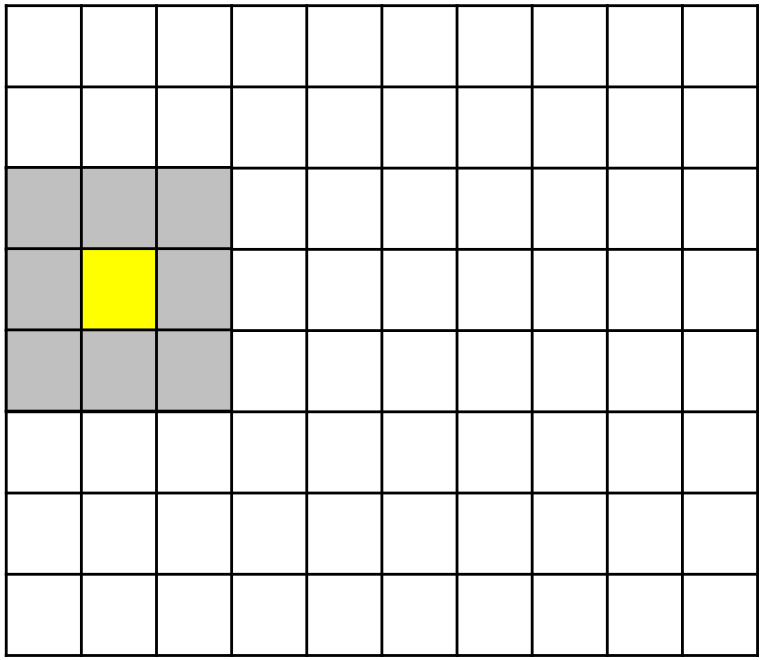
Resulting output image

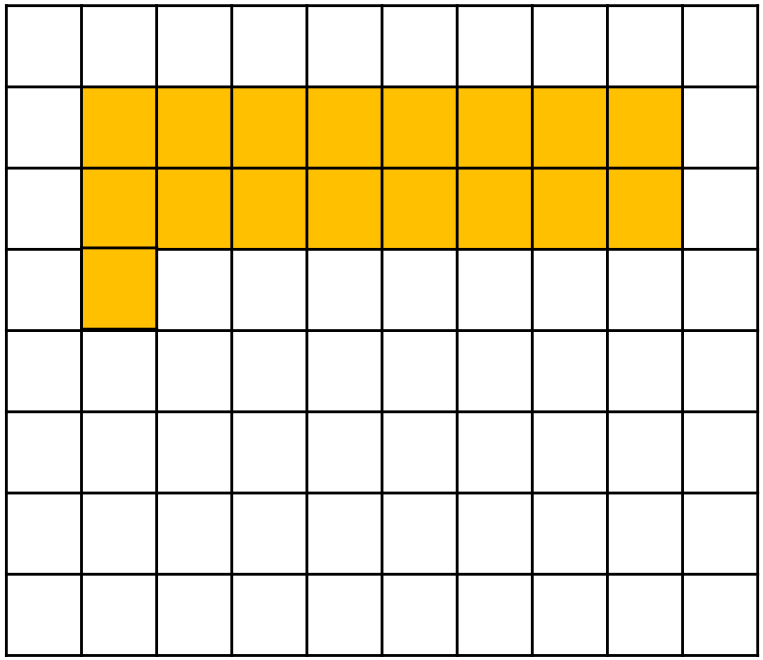
Frequency filtering operations
Convolution



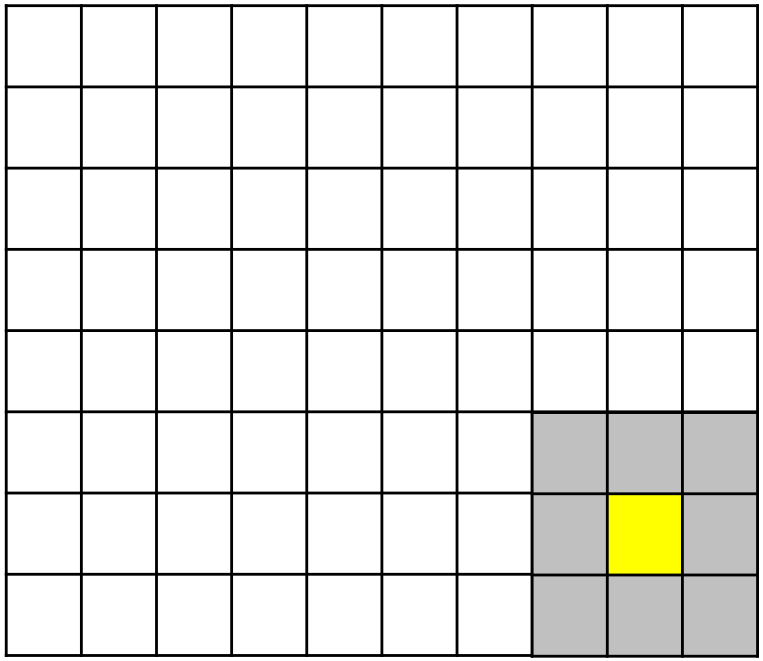


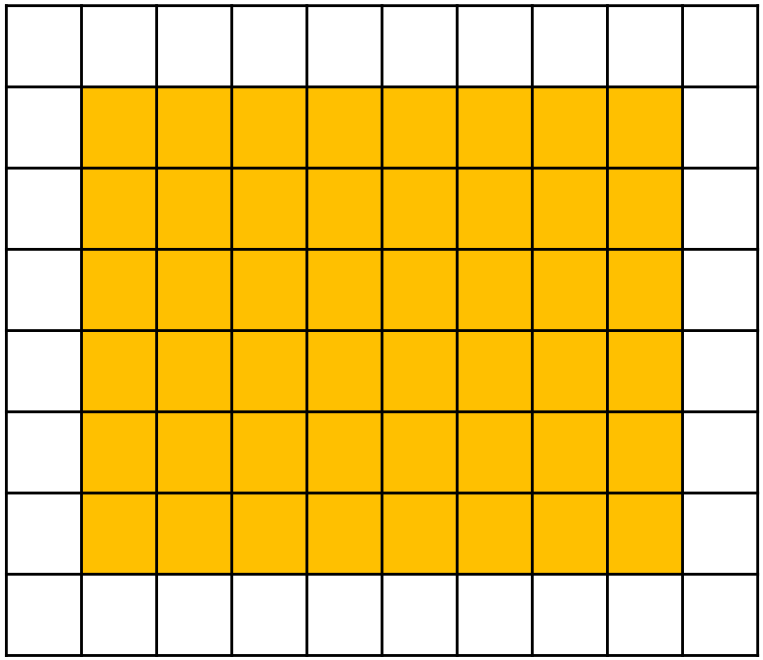
Frequency filtering operations
Convolution





Frequency filtering operations
Convolution





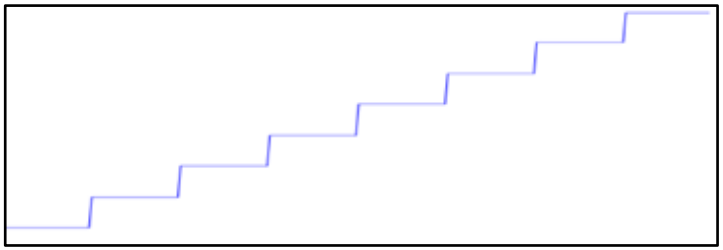
Frequency filtering operations
Convolution

- Convolution is a very important image processing operation. It is an example of a so-called *linear transformation* because the only operations necessary are that of addition and multiplication.

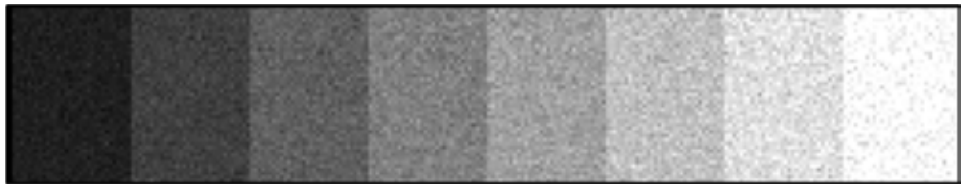
- Depending on the weights in the kernel, many different image processing operations can be carried out using convolution.

Frequency filtering operations
Low-pass filters

- Low pass filters ***remove*** high frequency components and pass through low frequency components. Most low frequency filters suffer from the side effect: blur.



Uncorrupted image



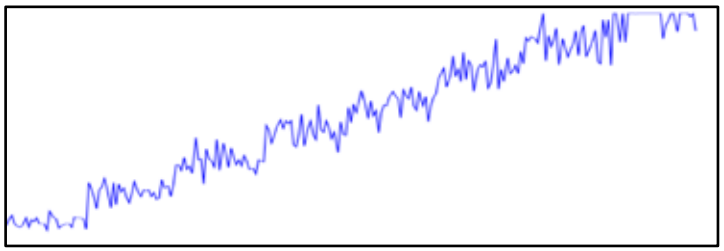


Image corrupted by noise

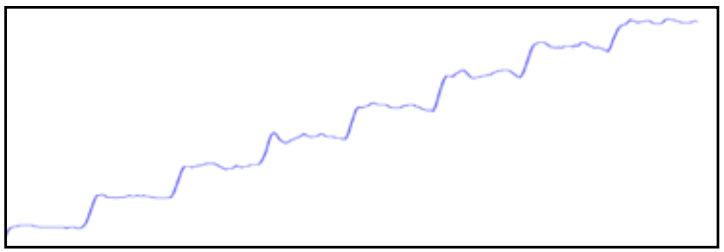


Image restored by low-pass filtering

Frequency filtering operations
Low-pass filters

Examples of low pass filters

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

1/10	1/10	1/10
1/10	1/5	1/10
1/10	1/10	1/10

1/16	1/8	1/16
1/8	1/4	1/8
1/16	1/8	1/16

Can you deduce the principles?

Frequency filtering operations
Low-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

$k_1+k_2+ \ldots +k_9 = 1$

$0 \leq k_i < 1$

$k_{centre} \geq$ remaining k_i

Frequency filtering operations
Low-pass filters

Examples of low pass filters (again)

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

1/10	1/10	1/10
1/10	1/5	1/10
1/10	1/10	1/10

1/16	1/8	1/16
1/8	1/4	1/8
1/16	1/8	1/16

Frequency filtering operations
Low-pass filters

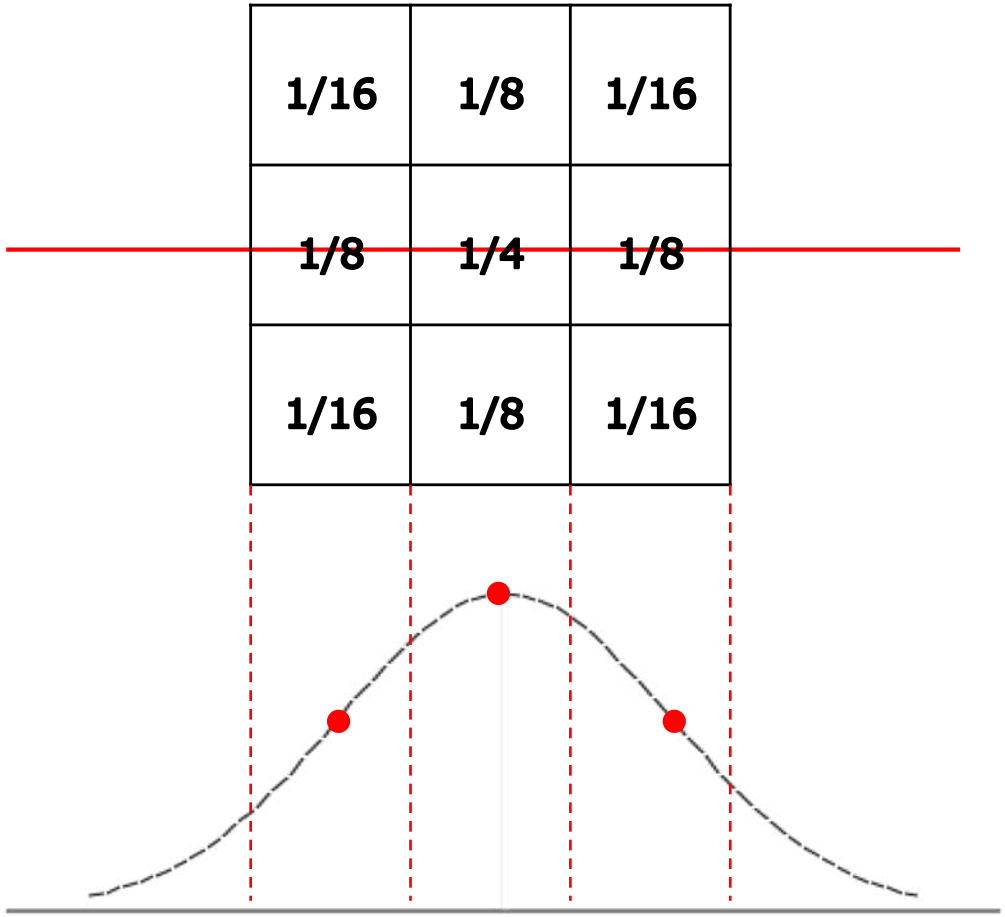
Can you deduce the principles?

k_1	k_2	k_3
k_4	k_5	k_6
k_7	k_8	k_9

Intuitive hints

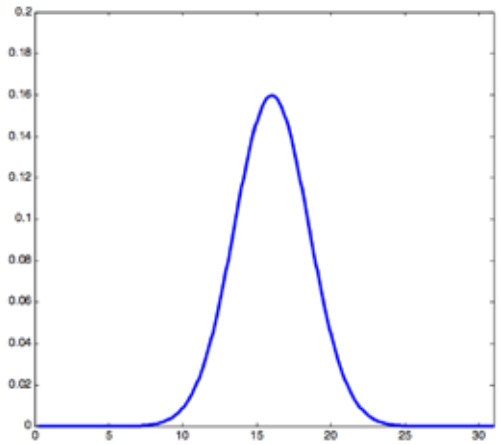
- If all pixels in a small image region have the same value, the result of convolution is that constant value.
- The same image values => frequency 0 (lowest), so "passed through" a low-pass filter
- If pixel values in a small image region change rapidly, the result of convolution is the average value over the region.
- High frequencies "removed", only low frequency "base" value passed through.

Frequency filtering operations
Low-pass filters

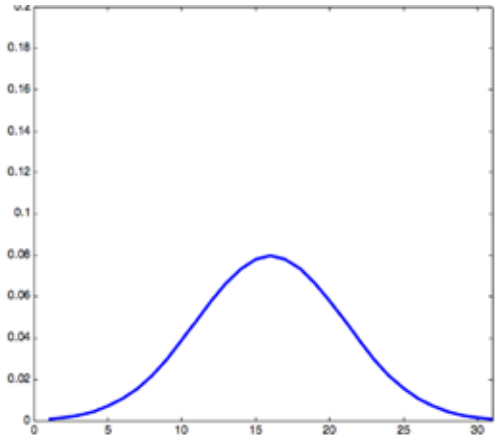


A typical profile of a low-pass filter

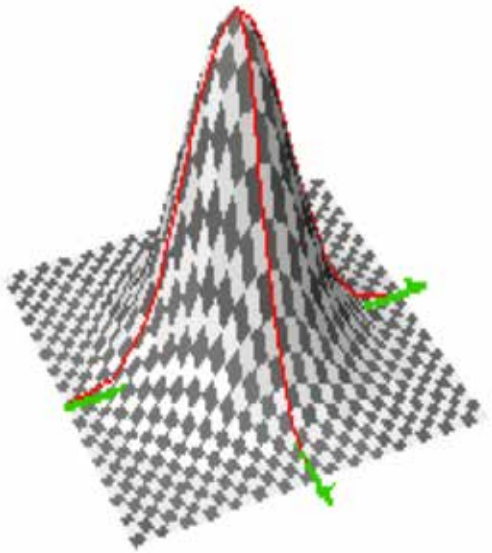
Frequency filtering operations
Low-pass filters: Gaussian smoothing



σ = 2.5



σ = 5

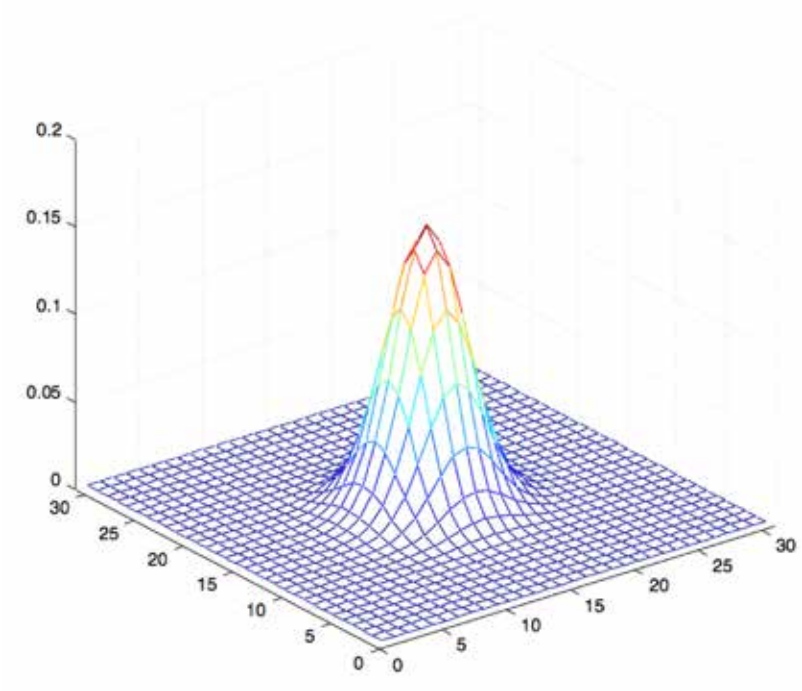


A two-dimensional **Gaussian** function makes a flexible smoothing kernel.
The formula is:

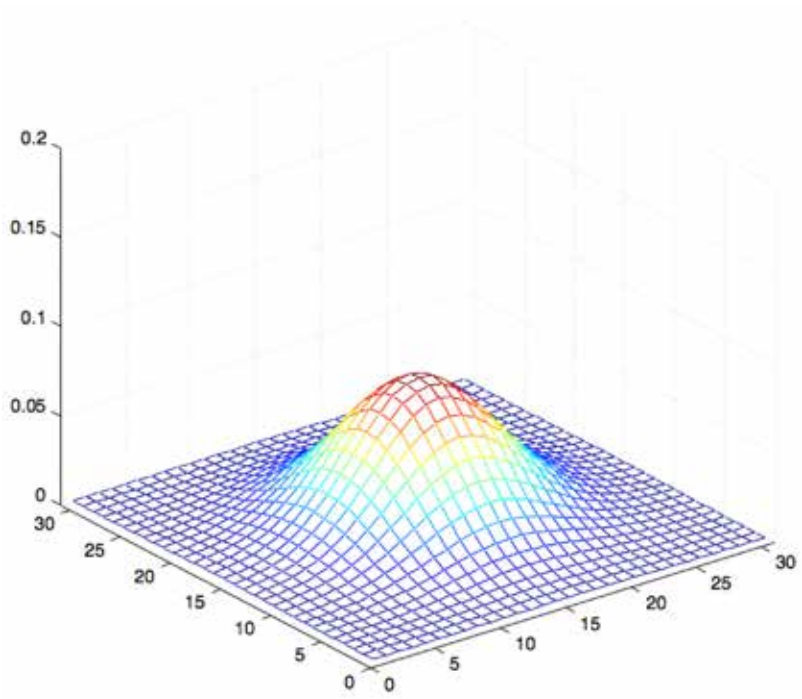
$$G(x,y,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

The amount of smoothing depends on the value of σ:
the greater the σ the stronger the effect of smoothing.

Frequency filtering operations
Low-pass filters: Gaussian smoothing

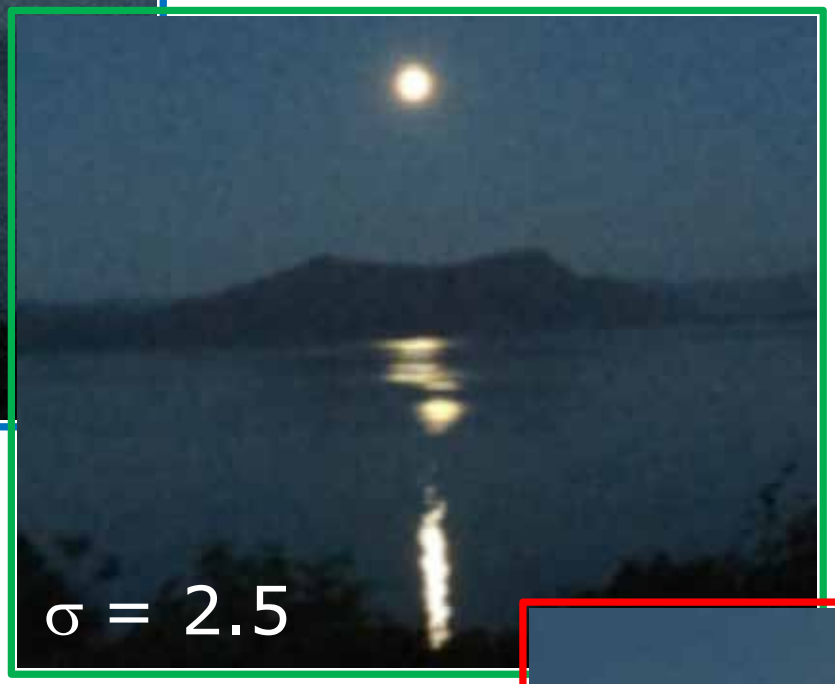


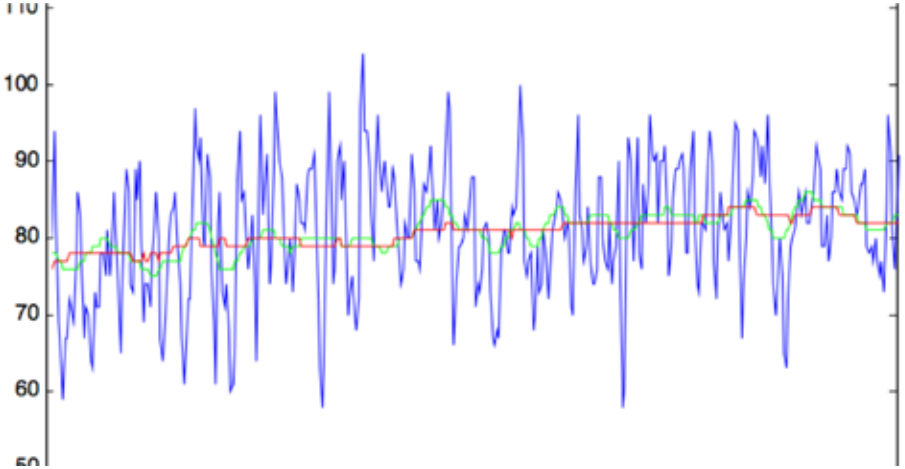
$\sigma = 2.5$



$\sigma = 5.0$

Effects of Gaussian smoothing



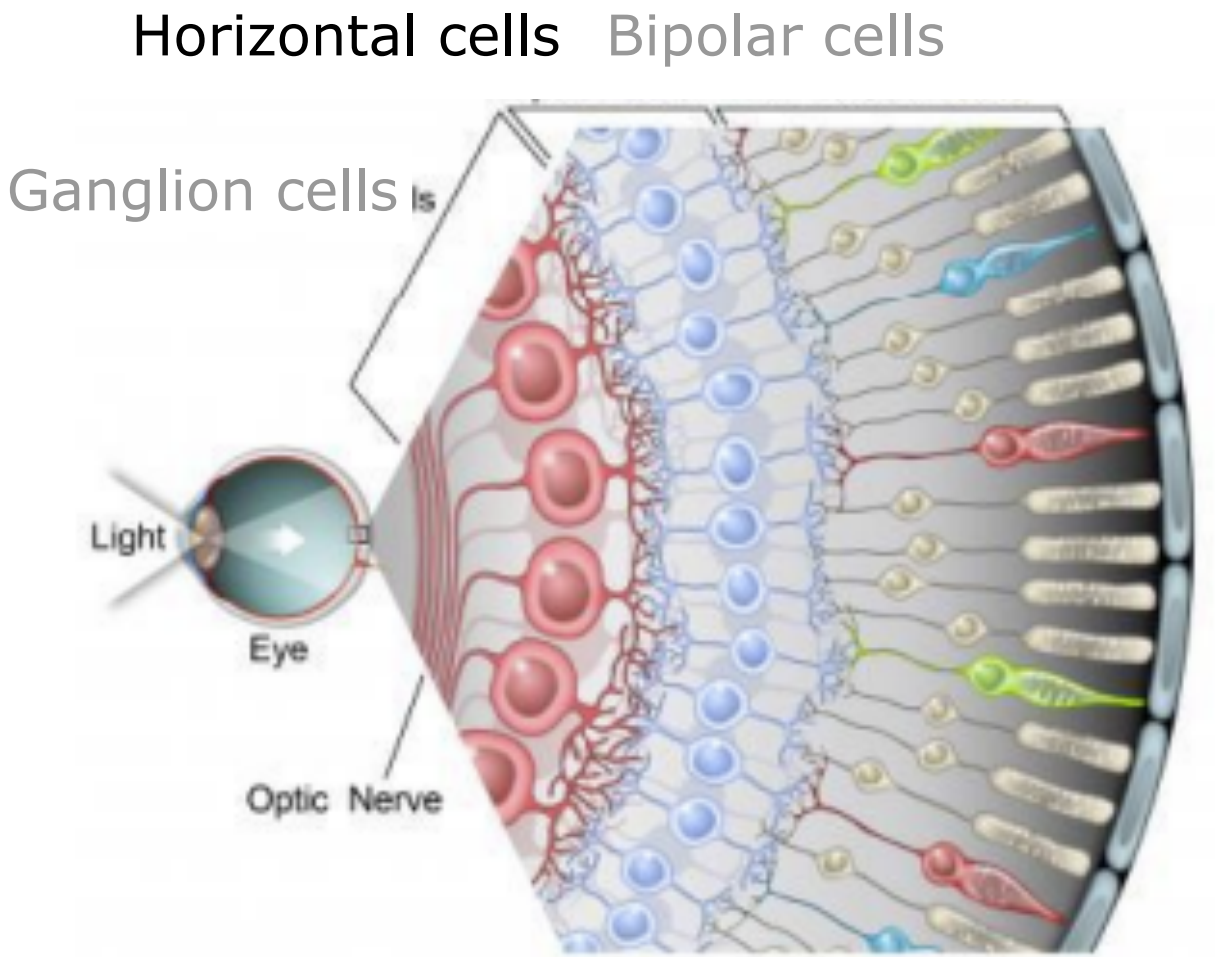


Frequency filtering operations
Low-pass filters

- Applications
  - Removing visual "noise" present in an image
  - Smoothing - removing high frequency components to examine low frequency ones

- **Side effect:** blur

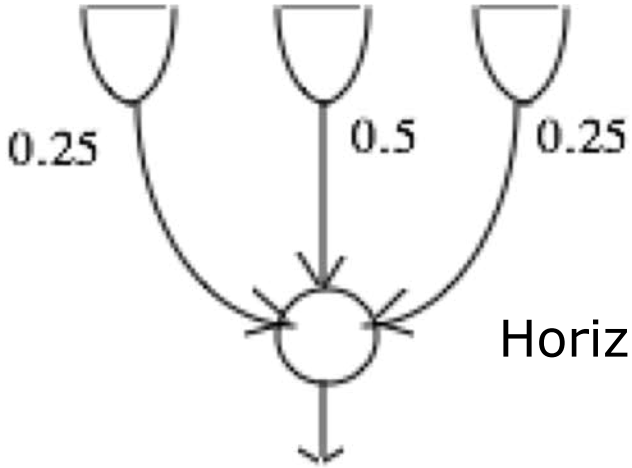
Frequency filtering operations
Low-pass filters in nature



Frequency filtering operations
Low-pass filters in nature

Horizontal cells

Integrate and regulate the input from multiple photoreceptor cells



Retinal receptors

Weights

Horizontal cell

Effect: weighted averaging of inputs

In this lecture we have covered:

- Common types of image corruption
  - Noise
  - Blur
- Image frequencies
- Tools and methods for noise removal
  - Image profile
  - Image filtering operations
  - Convolution
  - Low-pass (smoothing) filters

Next lecture:

- Causes of image blur
- Combining frequencies for image sharpening
- Digital filtering for image sharpening
  - Sharpening filters
  - High-pass filters
- How human visual system sharpens images

Further reading and experimentation

- **Book chapters**:
- Sonka, M. Hlavac, V. Boyle, R. Image Processing, Analysis and Machine Vision, Chapman & Hall Computing (various editions), 4.3.1.
- Gonzalez, R.C. & Woods, R.E. Digital Image Processing, Addison-Wesley (various editions), 4.2.4, 4.3.2.
- Umbaugh, S.E. Computer vision and image processing : a practical approach using CVIPtools , Prentice Hall International (various editions), 3.2, 4.1, 4.2, 4.4.

- **Image noise**: https://photographylife.com/photo-noise-reduction-tutorial

- *HIPR2 resources*
- **Mean (average) filter**: http://homepages.inf.ed.ac.uk/rbf/HIPR2/mean.htm
- **Gaussian smoothing** http://homepages.inf.ed.ac.uk/rbf/HIPR2/gsmooth.htm