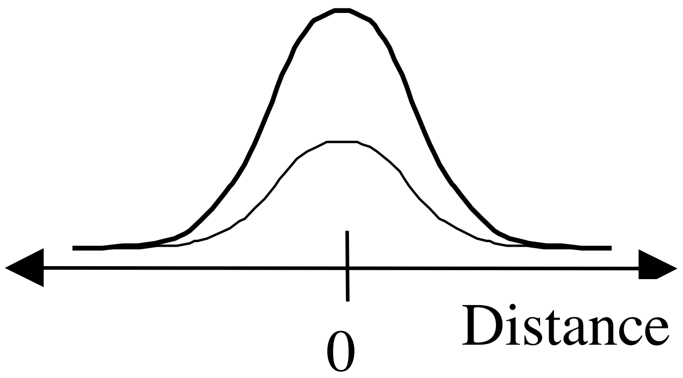
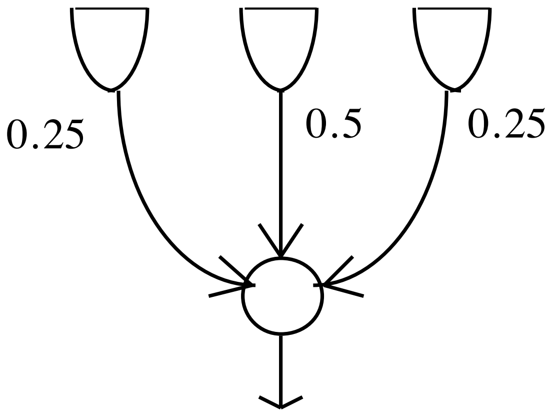
IMAGE ENHANCEMENT

Image enhancement on human retina

Spatial response to light

Excitatory response (positive) -
lateral excitatory connections between the neighbouring cells





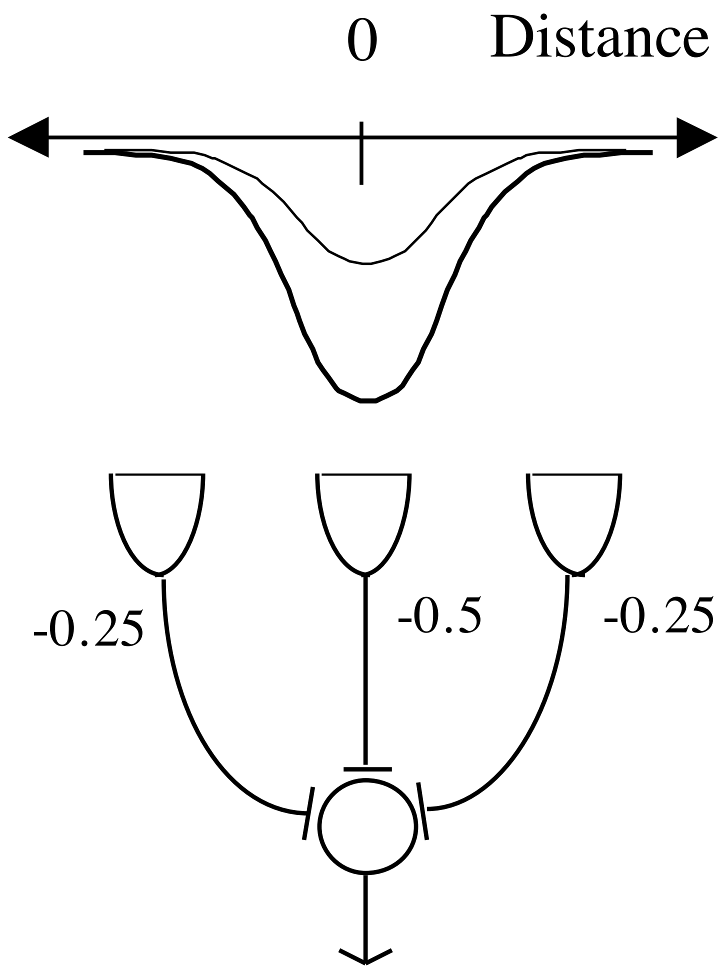
strength of excitation:

decreases with distance

increases with brightness

Inhibitory response -

lateral inhibitory connections between the cells



strength of inhibition:

decreases with distance

increases with brightness

Effects

What happens for uniform brightness?

What happens on the boundary between two areas of different brightness?

Digital filtering via convolution

Images are never perfect, but always “noisy” and distorted by:

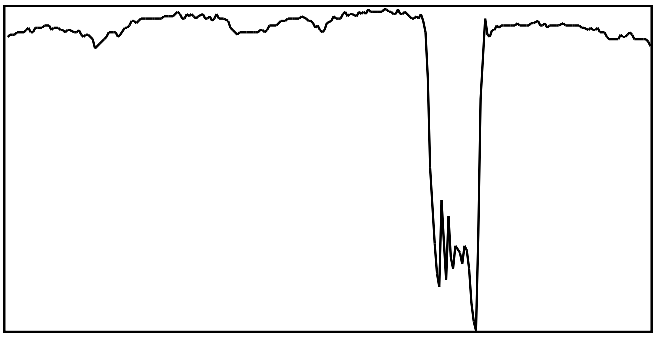
- non-linearities of sensors
- sampling and quantisation errors
- data transmission artefacts
-

Corrections

- Integration over sensors
- Smoothing
- - spatial domain
- - frequency domain

Characteristics of noise

Noise is normally characterised by high frequency components.



Smoothing out noise

- rapid changes in brightness removed, but slow retained

- spatial averaging removes noise

- the same result can be achieved by **convolution** with smoothing filters in spatial domain or in frequency domain.

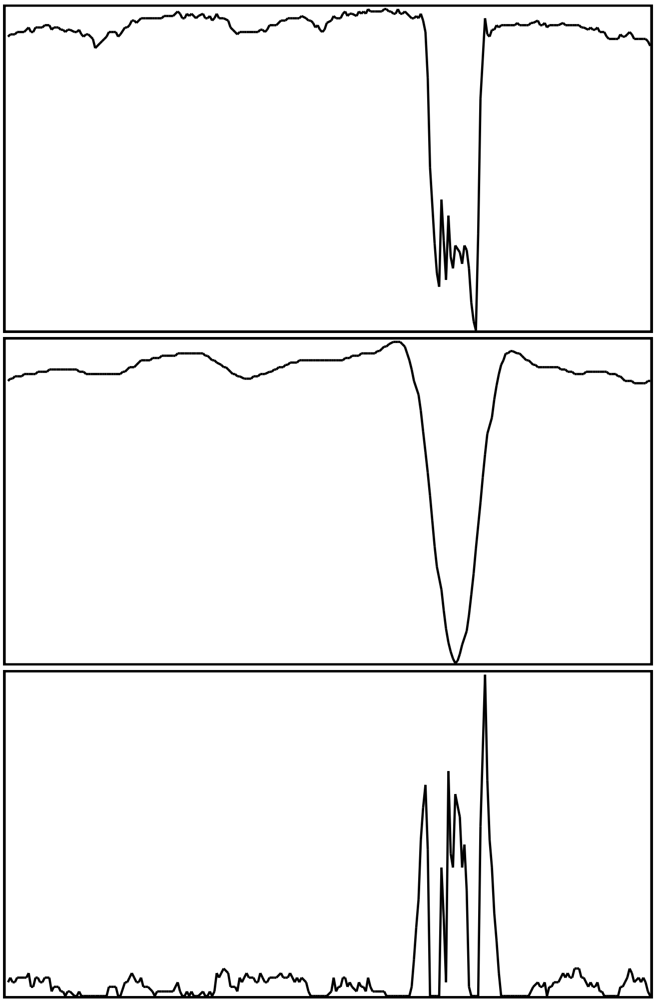
Frequency filtering operations

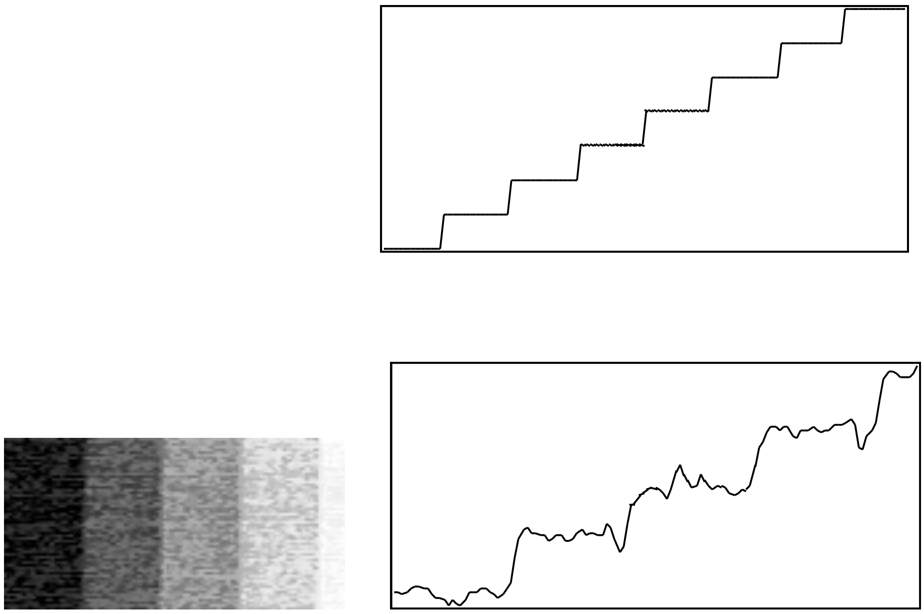
Separation of frequency components within an image into

- low frequency components

- high frequency components

Rejection of unwanted components
or
Separate processing and re-combination





Averaging through filtering

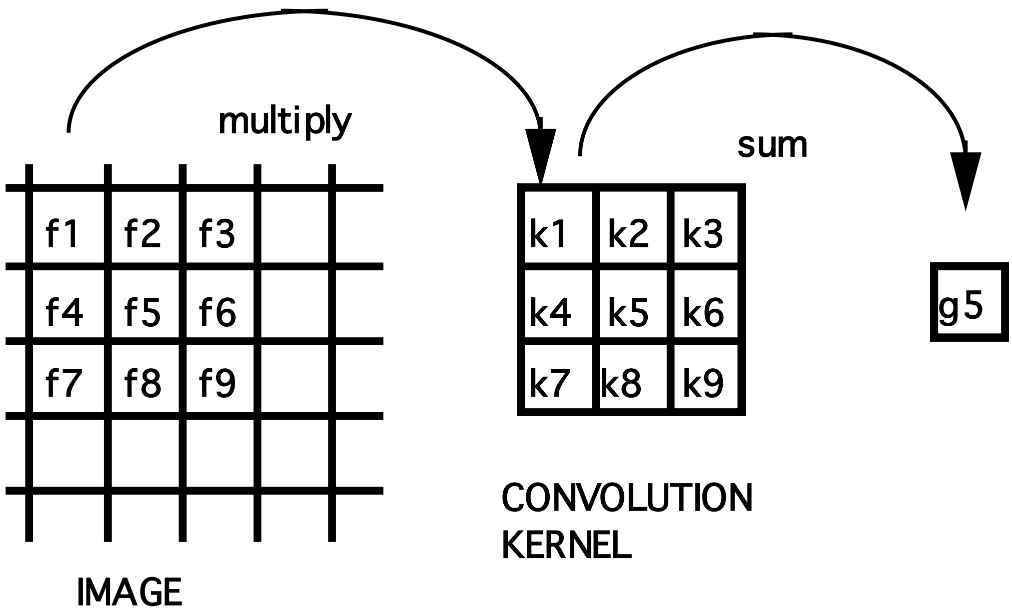
f1	f2	f3
f4	f5	f6
f7	f8	f9

(f1 + f2 + f3 + f4 + f5 + f6 + f7 + f8 + f9) / 9 =

$$\frac{1}{9}f1 + \frac{1}{9}f2 + \frac{1}{9}f3 + \frac{1}{9}f4 + \frac{1}{9}f5 + \frac{1}{9}f6 + \frac{1}{9}f7 + \frac{1}{9}f8 + \frac{1}{9}f9$$

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

Convolution in spatial domain



g5 = f1*k1 + f2*k2 + f3*k3 + f4*k4 + f5*k5

+ f6*k6 + f7*k7 + f8*k8 + f9*k9

g5 = f1*k1 + f2*k2 + f3*k3 + f4*k4 + f5*k5

+ f6*k6 + f7*k7 + f8*k8 + f9*k9

$$g(x,y) = \sum_{i=-n/2}^{n/2} \sum_{j=-n/2}^{n/2} k(i,j)\ f(x+i,\ y+j)$$

Low pass filters

Passes through low frequency components
High frequencies “removed”

- coefficients in the kernel sum up to 1 and are all positive numbers

Examples of low pass filters (3 x 3)

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

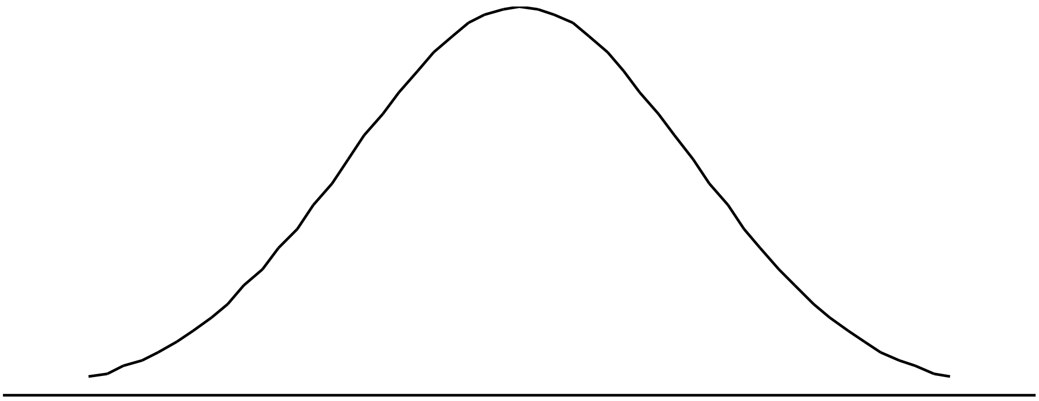
1/10	1/10	1/10
1/10	1/5	1/10
1/10	1/10	1/10

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

- applications
  - removing visual "noise" present in an image
  - smoothing - removing high frequency components to examine low frequency ones

- side effect: blur

Gaussian smoothing - integration of receptor inputs over the receptive field.



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

Smoothing by non-linear filtering

Median filter

replace each pixel by the median value of its neighbourhood

0	**1**	**1**
2	**5**	**2**
1	**1**	**2**

0 1 1 1 <u>**1**</u> 2 2 2 5 => **1**

Order-n filter

replace each pixel by the n-th ordered value of its neighbourhood

0	**1**	**1**
2	**5**	**2**
1	**1**	**2**

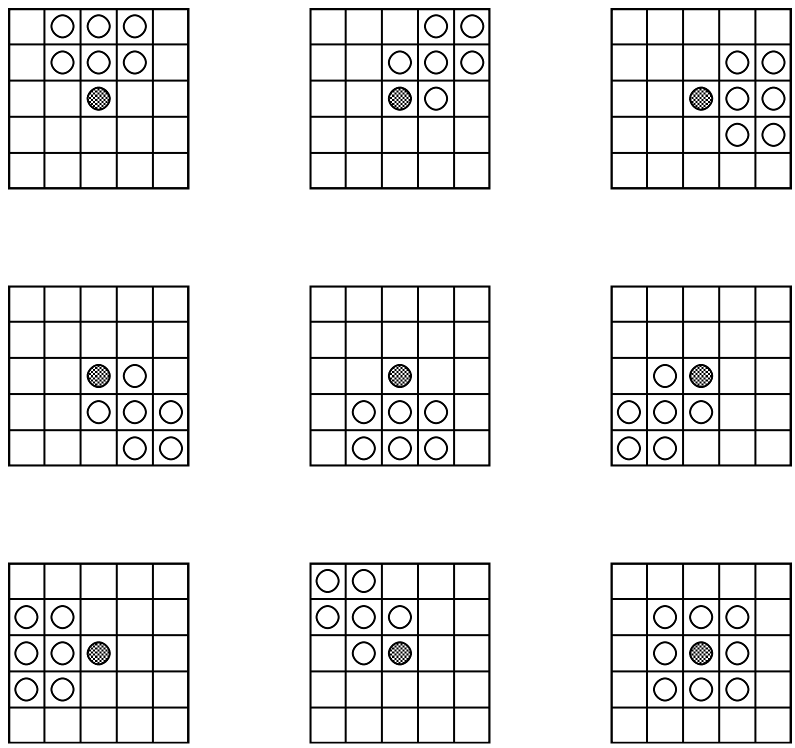
Order 1: **0** 1 1 1 1 2 2 2 5 => 0

Order 7: 0 1 1 1 1 2 **2** 2 5 => 2

Order 9: 0 1 1 1 1 2 2 2 **5** => 5

Edge-preserving smoothing

replace each pixel by the average value of a portion of its neighbourhood with the smallest standard deviation



Blur

Causes
- out of focus image
- light scatter
- motion

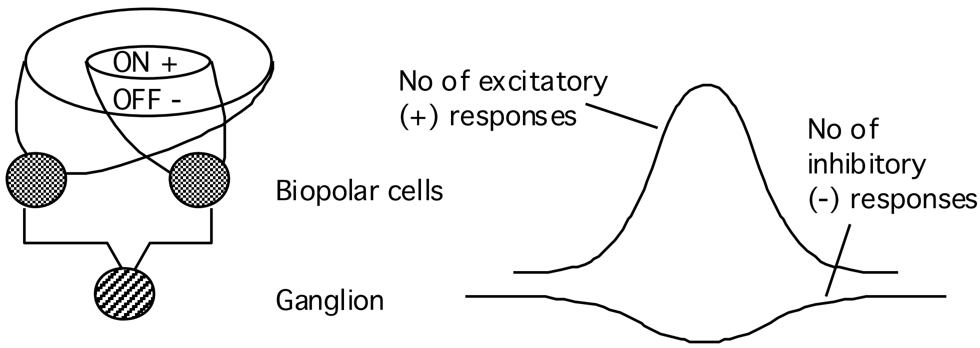
Blur removal
- tracking and integration
- frequency domain filtering
    - sharpening
    - phase correction

Sharpening in the retina

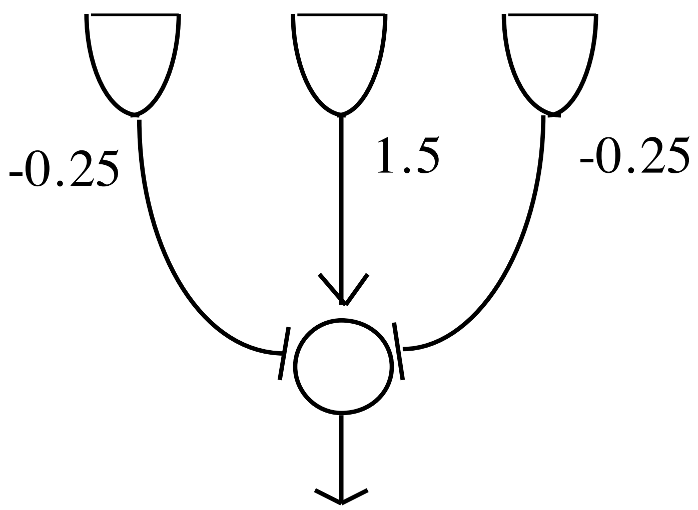
Pooling responses - retinal ganglion cells

The cells are arranged into units called **'centre-surround'**, where the centre response is excitatory and the surround response is inhibitory. There are also 'symmetrical' units, with opposite structure.

The shape of the response of the unit is made of two contributions



Total response at the Ganglion equals (-) response subtracted from (+) response


-0.25
1.5
-0.25

Effects of centre-surround architecture

What happens for uniform brightness?

What happens on the boundary between two areas of different brightness?

Environmental significance?

High pass filters

- emphasizes high frequency components, leaving low frequency ones untouched

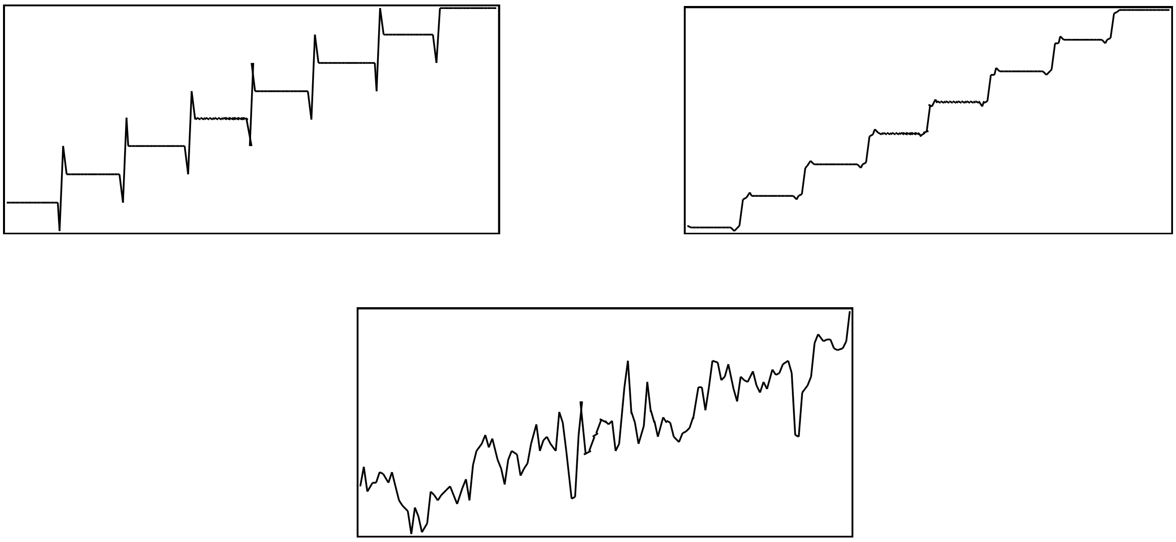
- coefficients in a kernel sum up to 1
  smaller coefficients surround larger positive centre

Examples of high pass filters

-1	-1	-1
-1	9	-1
-1	-1	-1

0	-1	0
-1	5	-1
0	-1	0

1	-2	1
-2	5	-2
1	-2	1



- applications
  - edge enhancement
  - sharpening
  - enhancement of high frequency components

- side effect : enhances noise