Digital image processing and analysis

7. Image enhancement: sharpening via manipulating image frequencies

Professor Ela Claridge
School of Computer Science

Previous lecture:

- 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

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In this lecture we shall find out about:

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

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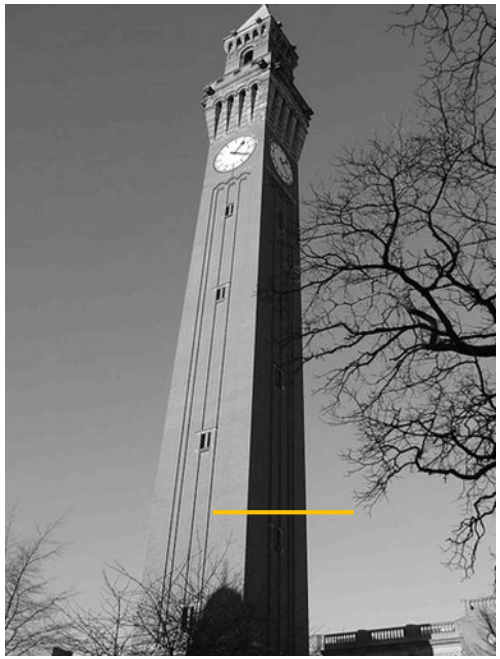
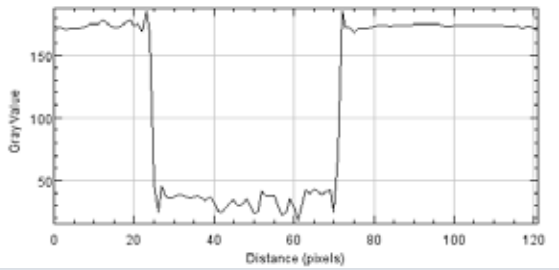
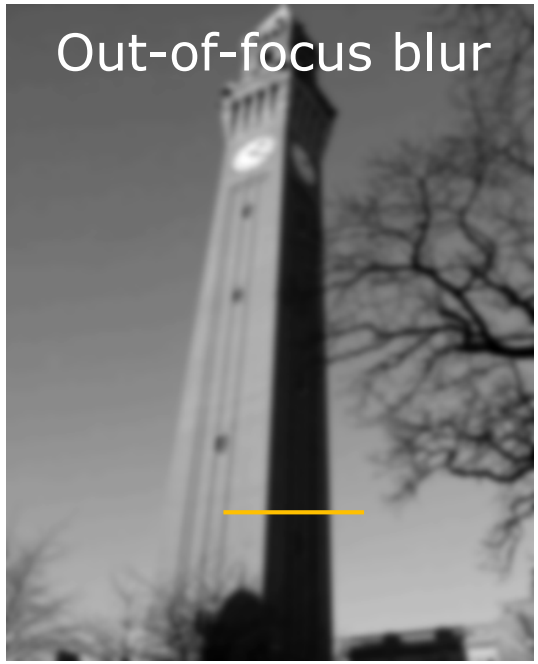
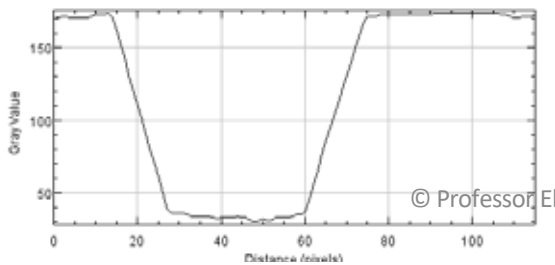
Image corruption

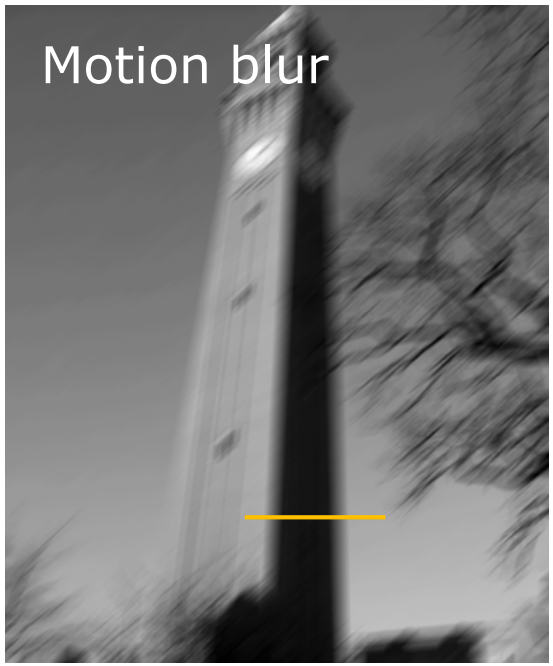
- An input digital image is never perfect, but is always "noisy" and distorted to some extent.











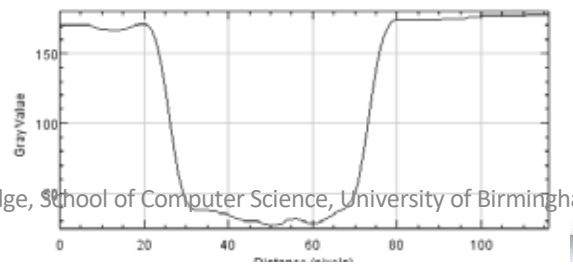


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Image blur
Causes

- Common causes of blur
  - Poorly focused image
  - Camera motion (e.g. image taken from a moving car)
  - Light scatter (e.g. air, fog or smoke)

- Blur effect on image frequencies?

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Image corruption
Noise and blur

(previous lecture)

Uncorrupted image

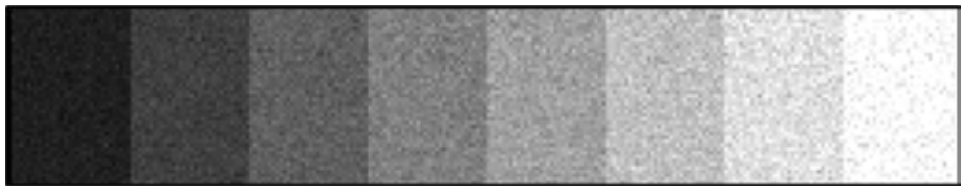
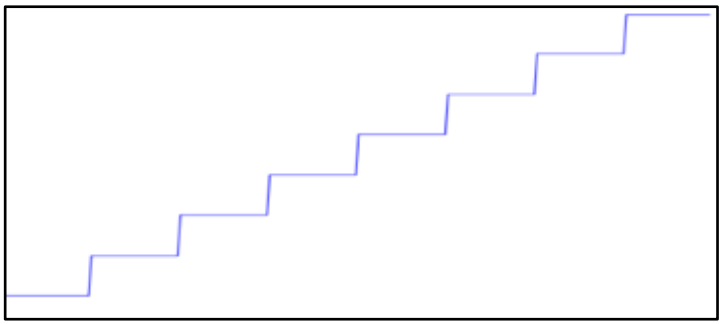
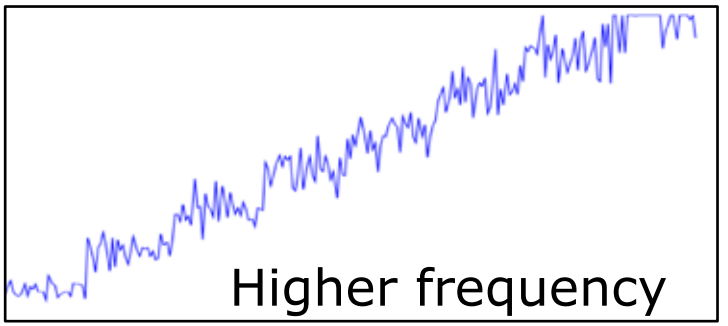


Image corrupted by noise

Image corrupted by blur

Image profiles





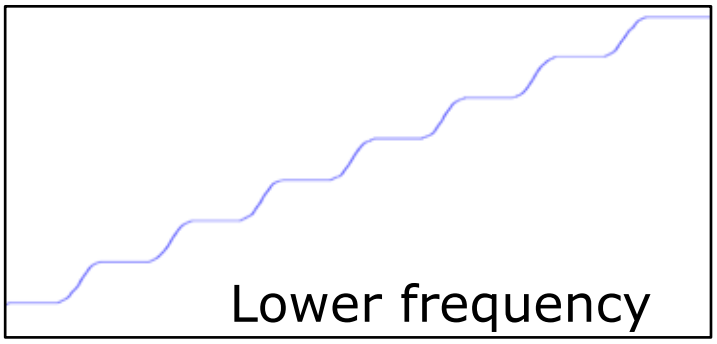


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Image frequencies
Frequency decomposition

Image profiles

It is possible to decompose an image into its constituent frequency components.

Image

Its low frequency component

Its high frequency component

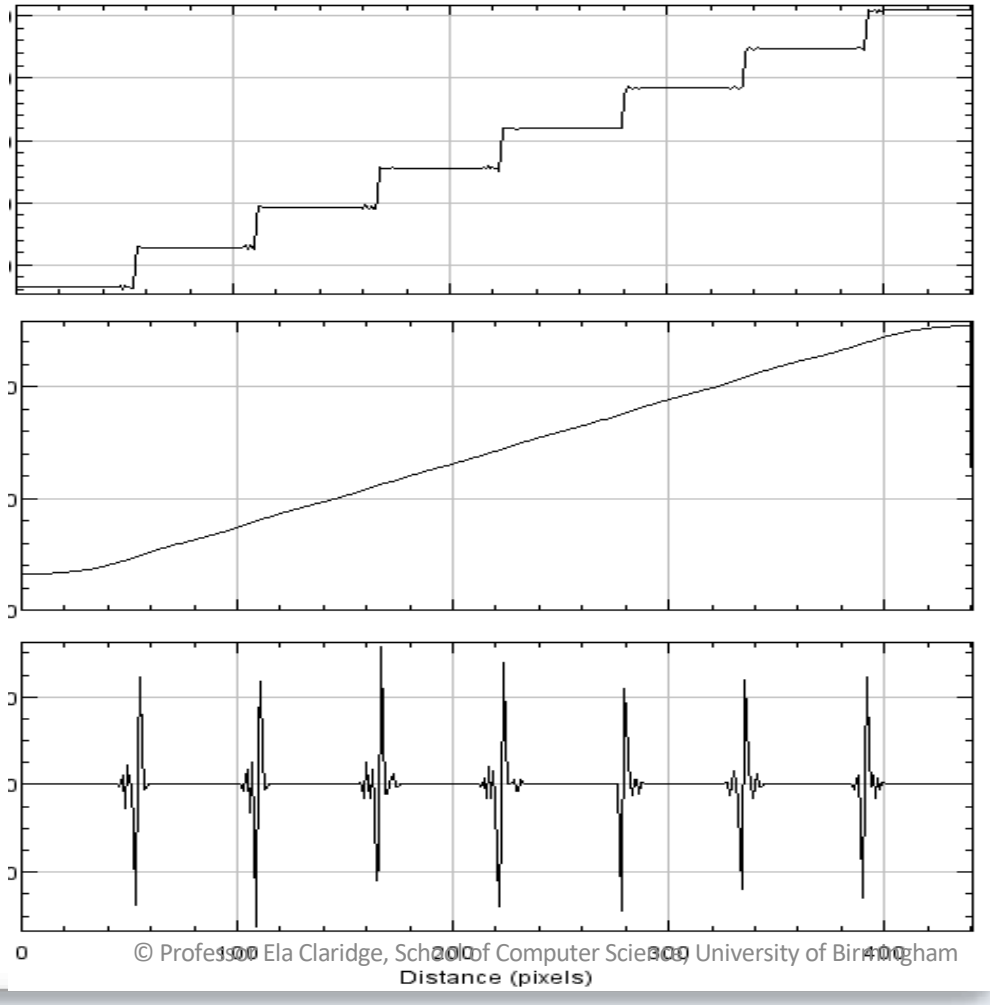

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Image blur
Causes

- Common causes of blur
  - Poorly focused image
  - Camera motion (e.g. image taken from a moving car)
  - Light scatter (e.g. air, fog or smoke)
- Blur effect on image frequencies
  - Blurred images lack high frequency components
- **Are high frequencies just noise?**

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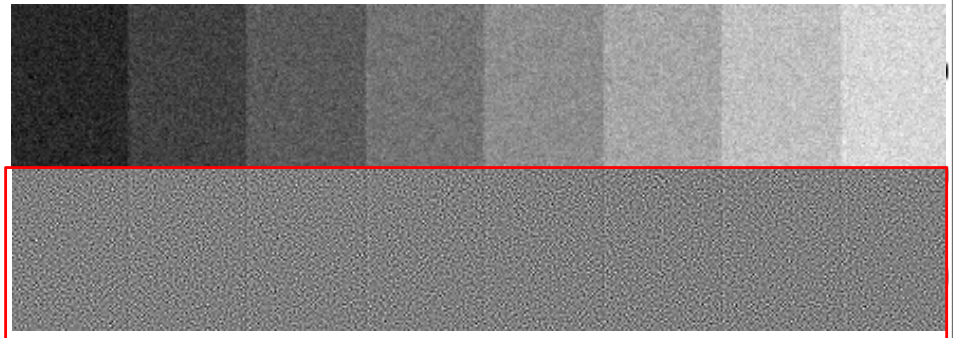
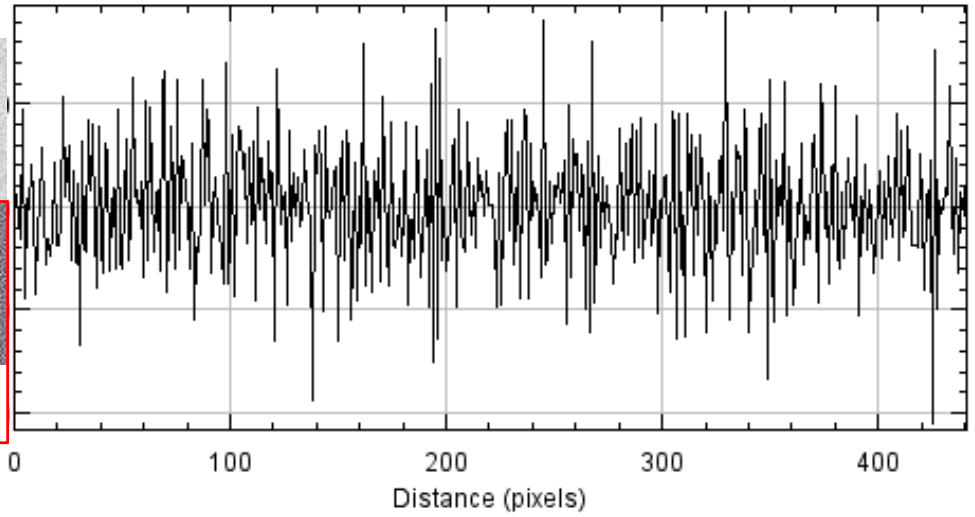
Image frequencies
Frequency decomposition

Image profiles

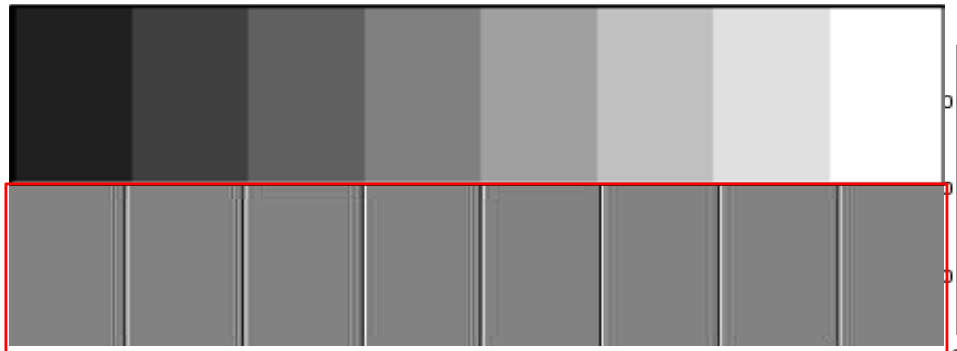
Noisy image



Its high frequency component



Uncorrupted image



Its high frequency component

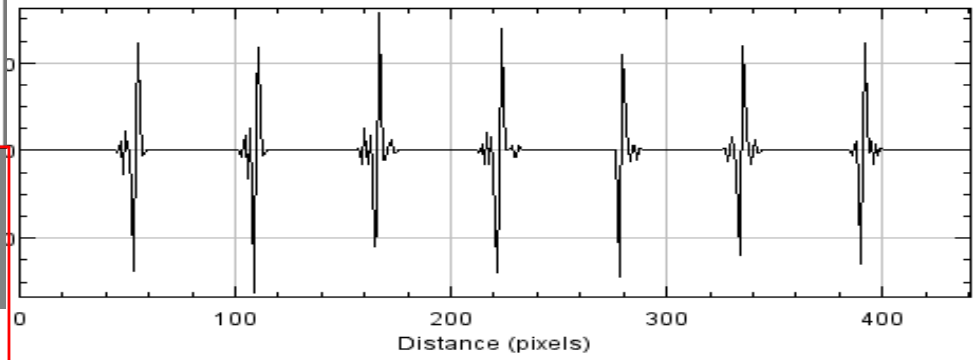


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Image blur
Causes

- Common causes of blur
  - Poorly focused image
  - Camera motion (e.g. image taken from a moving car)
  - Light scatter (e.g. air, fog or smoke)

- Blur effect on image frequencies
  - Blurred images lack high frequency components

- Are high frequencies just noise?
  - **No, they also define edges, i.e. sharp transitions from one brightness / colour to another.**

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Image blur
Causes

- Common causes of blur
  - Poorly focused image
  - Camera motion (e.g. image taken from a moving car)
  - Light scatter (e.g. fog or smoke)
- Blur effect on image frequencies
  - Blurred images lack high frequency components
- Blur reduction
  - Restore the missing high frequency components (HARD)
  - Over-emphasise high frequency components (EASY)

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Frequency filtering operations
Tool for reducing frequency distortions

(previous lecture)

- 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.

Smoothing

Sharpening

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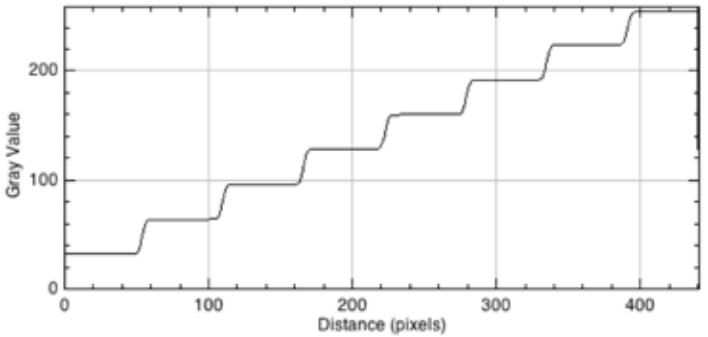
Image frequencies
Image sharpening

Image profiles

Image with blur



Its high frequency component

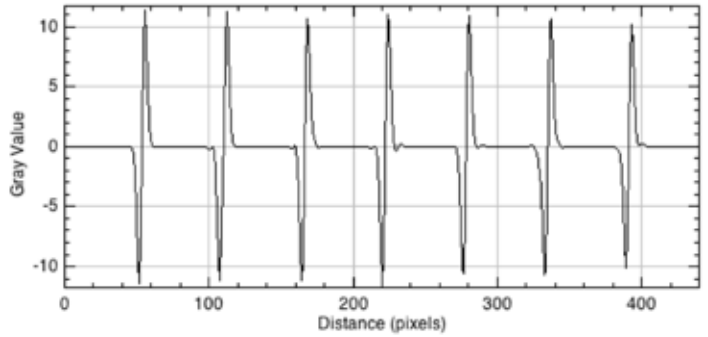


Image + its high frequency component = sharper image

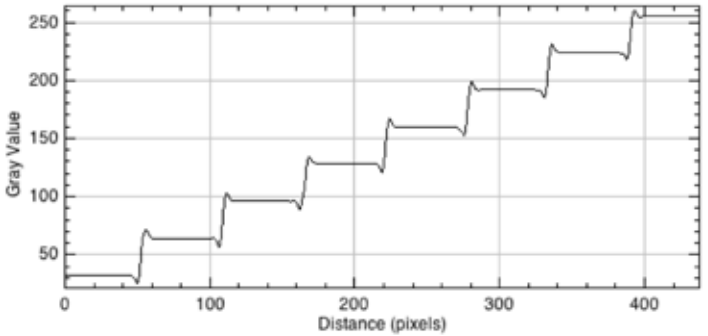


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Image frequencies
Frequency decomposition

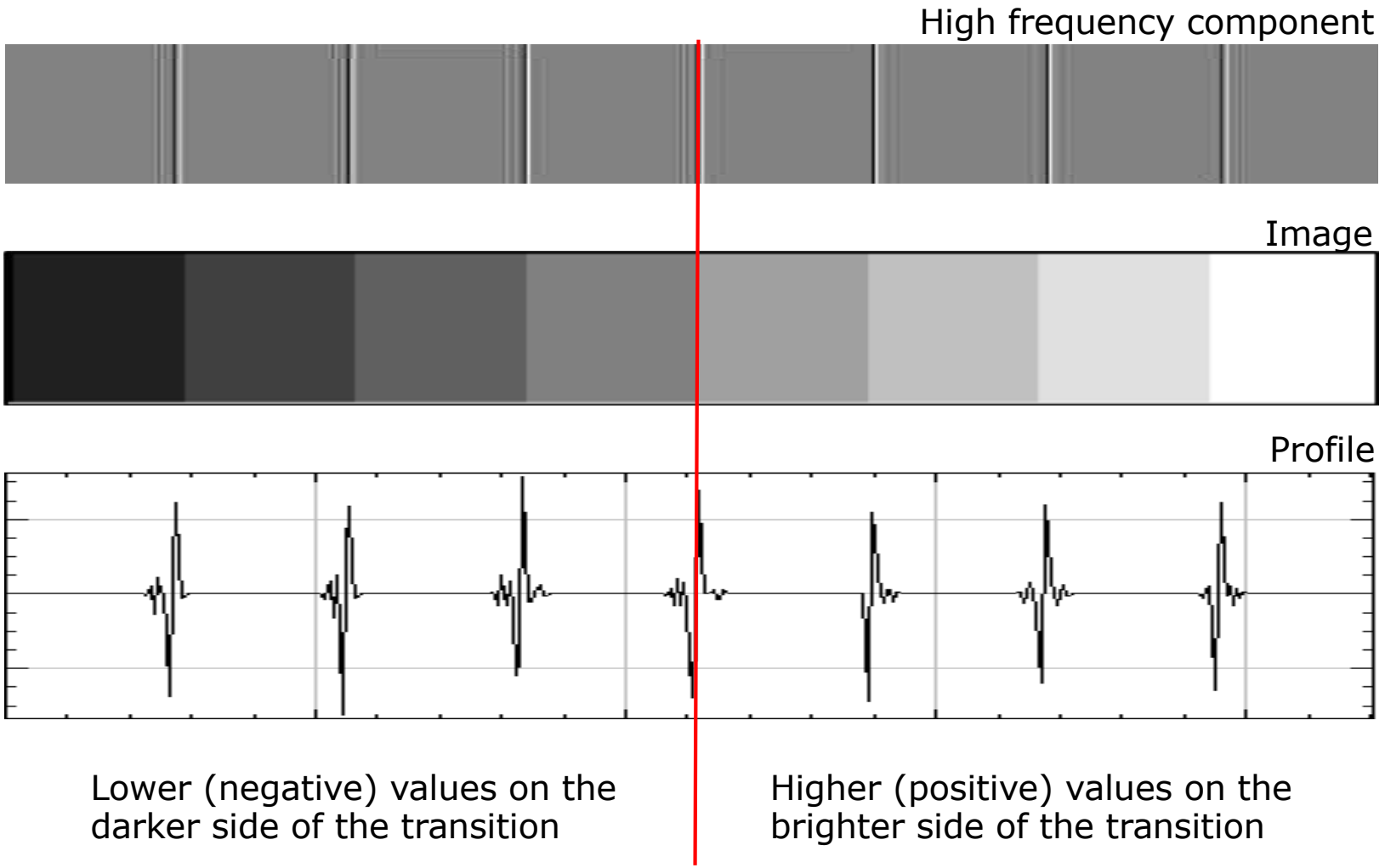

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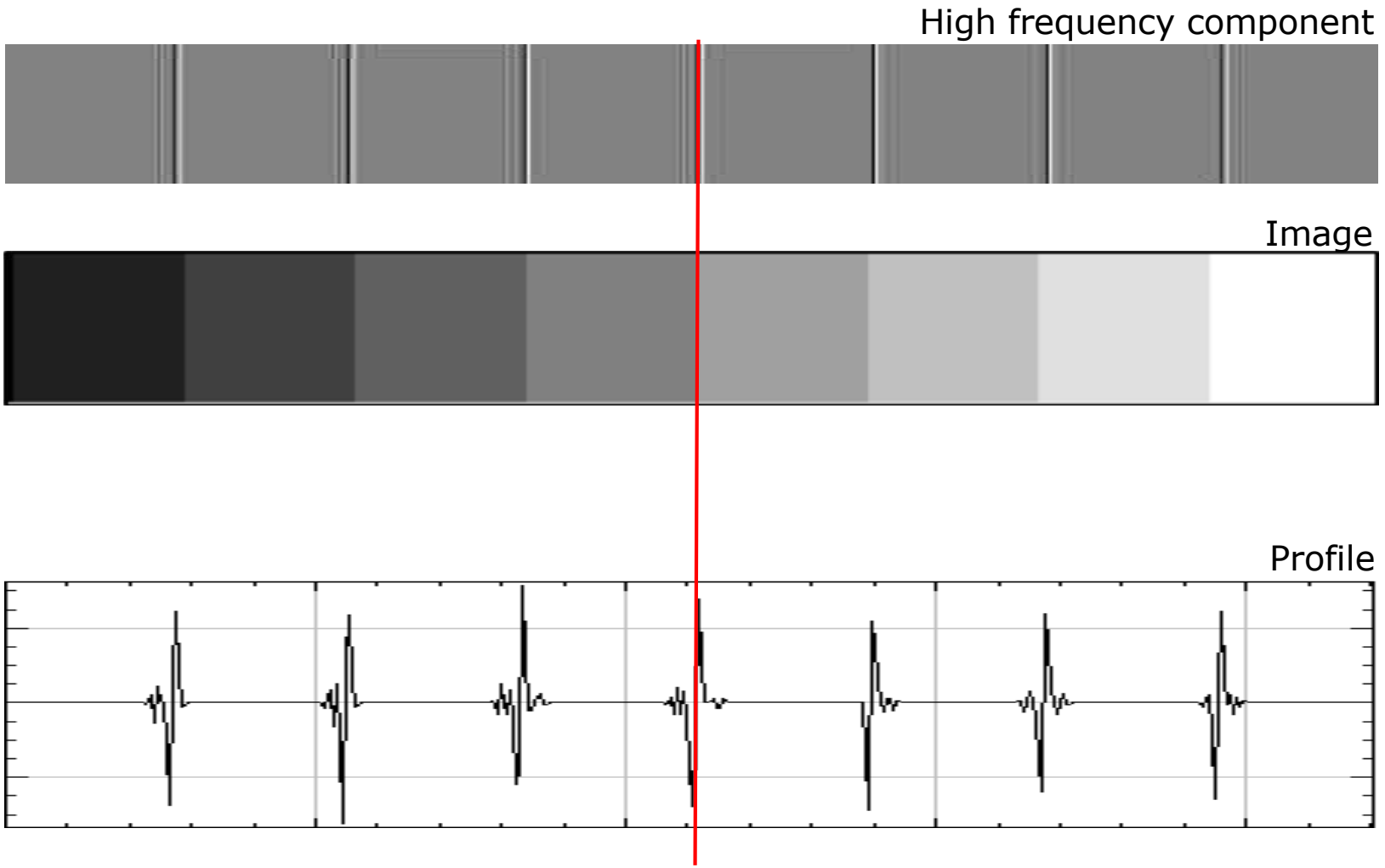
Image frequencies
Frequency decomposition



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Frequency filtering operations
Sharpening filters - concepts

Extract high frequency component and add the result to the original values

Image values (3 pixels in a row)	50	50	100
Filter coefficients	-1	2	-1
Image values * filter coefficients	-50	100	-100
Add the above (result is high frequency component)		-50	
Add the above to the original image value (result is sharpened image)		0	

Pixel values change from low to high
Filtered value lower than original

Image values (3 pixels in a row)	50	100	100
Filter coefficients	-1	2	-1
Image values * filter coefficients	-50	200	-100
Add the above (result is high frequency component)		50	
Add the above to the original image value (result is sharpened image)		150	

Pixel values change from high to low
Filtered value higher than original

Image values (3 pixels in a row)	100	100	100
Filter coefficients	-1	2	-1
Image values * filter coefficients	-100	200	-100
Add the above (result is high frequency component)		0	
Add the above to the original image value (result is sharpened image)		100	

Pixel values do not change
Filtered value the same as original

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Frequency filtering operations
Sharpening filters - concepts

Directly sharpen the image with a sharpening filter

Image values (3 pixels in a row)	50	50	100
Filter coefficients	-1	3	-1
Image values * filter coefficients	-50	150	-100
Add the above (result is sharpened image)		0	

Pixel values change from low to high
Filtered value lower than original

Image values (3 pixels in a row)	50	100	100
Filter coefficients	-1	3	-1
Image values * filter coefficients	-50	300	-100
Add the above (result is sharpened image)		150	

Pixel values change from high to low
Filtered value higher than original

Image values (3 pixels in a row)	100	100	100
Filter coefficients	-1	3	-1
Image values * filter coefficients	-100	300	-100
Add the above (result is sharpened image)		100	

Pixel values do not change
Filtered value the same as original

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Frequency filtering operations
Sharpening filters in image processing

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	5	-1
0	-1	0

	50	0	200	
	50	0	200	
	50	0	200	

50*0+ 50*(-1)+50*0+
50*(-1)+50*5+50*(-1)+
50*0+ 50*(-1)+50*0 =
50

50*0+ 50*(-1)+100*0+
50*(-1)+50*5+100*(-1)+
50*0+ 50*(-1)+100*0 =
0

50*0+ 50*(-1)+50*0+
50*(-1)+50*5+50*(-1)+
50*0+ 50*(-1)+50*0 =
200

This is convolution with a sharpening filter

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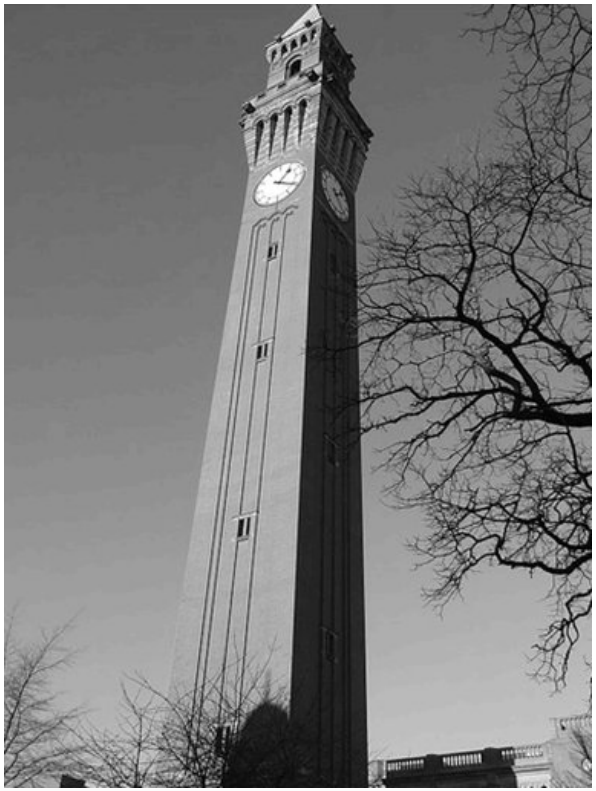
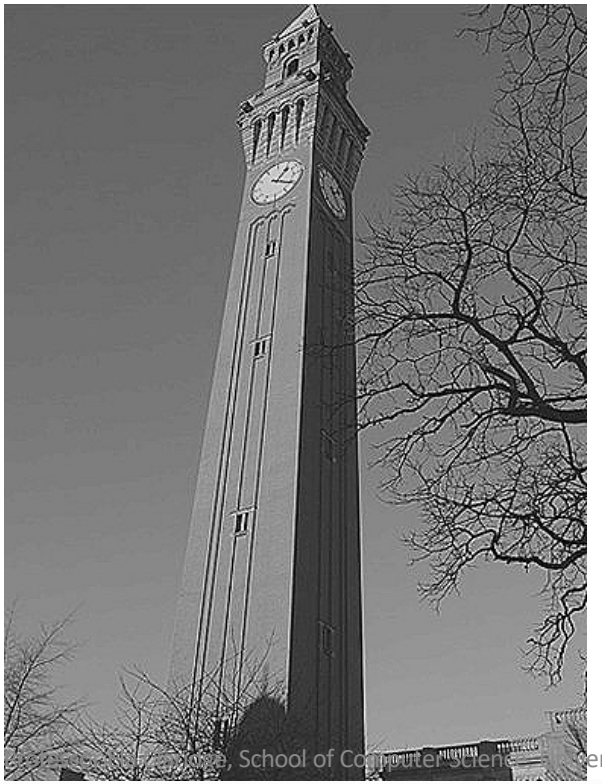
Frequency filtering operations
Sharpening filters in image processing

Results of convolution with

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





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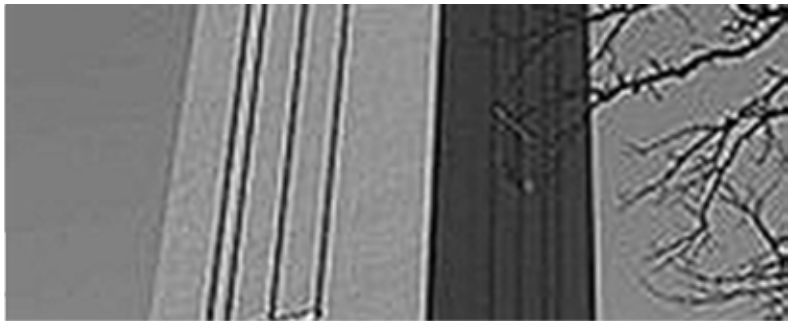
Frequency filtering operations
Sharpening filters in image processing

Results of convolution with

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



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Frequency filtering operations
Sharpening filters in image processing

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

noise pixel

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

	50	0	50	
	0	300	0	
	50	0	50	

noise pixel

Beware: a sharpening filter will enhance noise (increase high frequency components)!

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Frequency filtering operations
Sharpening filters in image processing

- Sharpening filter emphasises high frequency components.

Examples of sharpening filters

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

0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	17	-2	-1
0	-1	-2	-1	0
0	0	-1	0	0

Can you deduce the principles?

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Frequency filtering operations
Sharpening filters in image processing

Can you deduce the principles?

k_1	k_2	k_3
k_4	k_5	k_6
k_7	k_8	k_9

Absolute value of the sum

↓

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

$k_{centre}>0$ and the remaining $k_i<0$

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Frequency filtering operations
Sharpening filters in image processing

- The process of ***sharpening*** works by adding a high frequency component to the original image data. This emphasises high frequencies (edges, but also noise!) while retaining all the original image frequencies.

- Applications
  - **Visually** compensating for blur present in an image

- **Side effect:** increases noise

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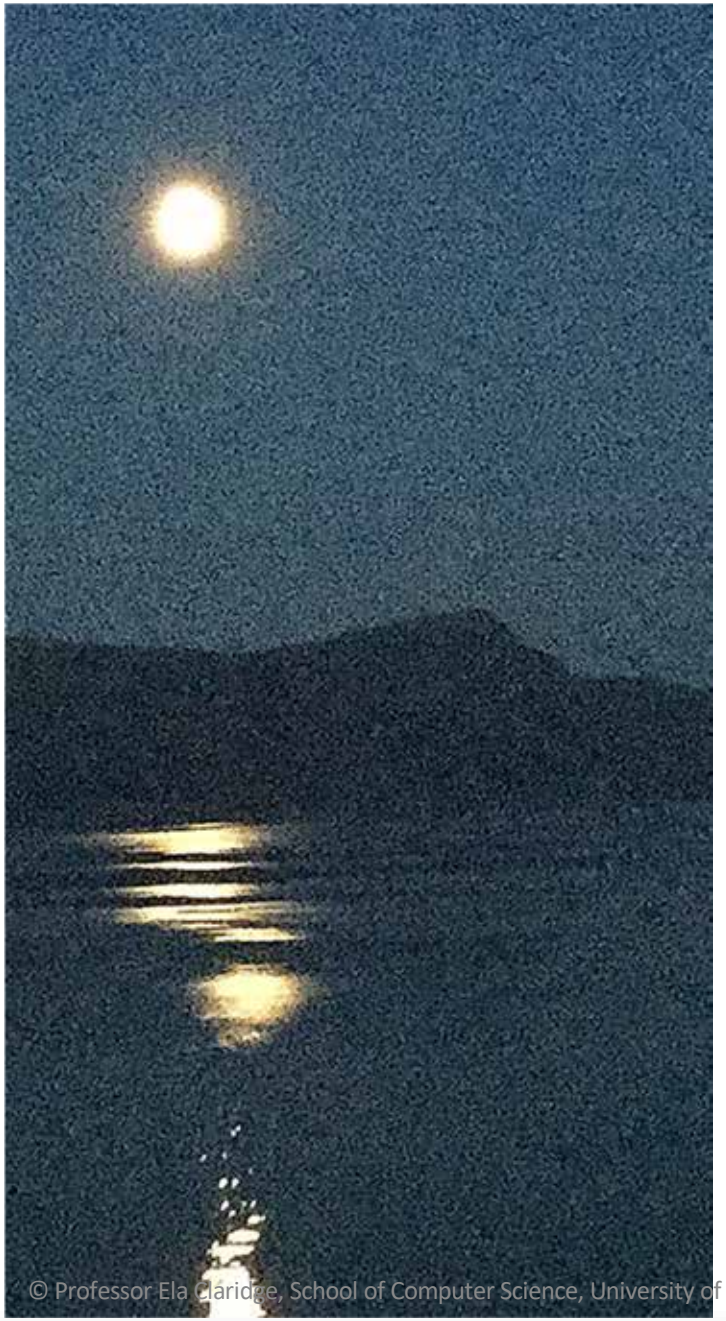
Effects of sharpening



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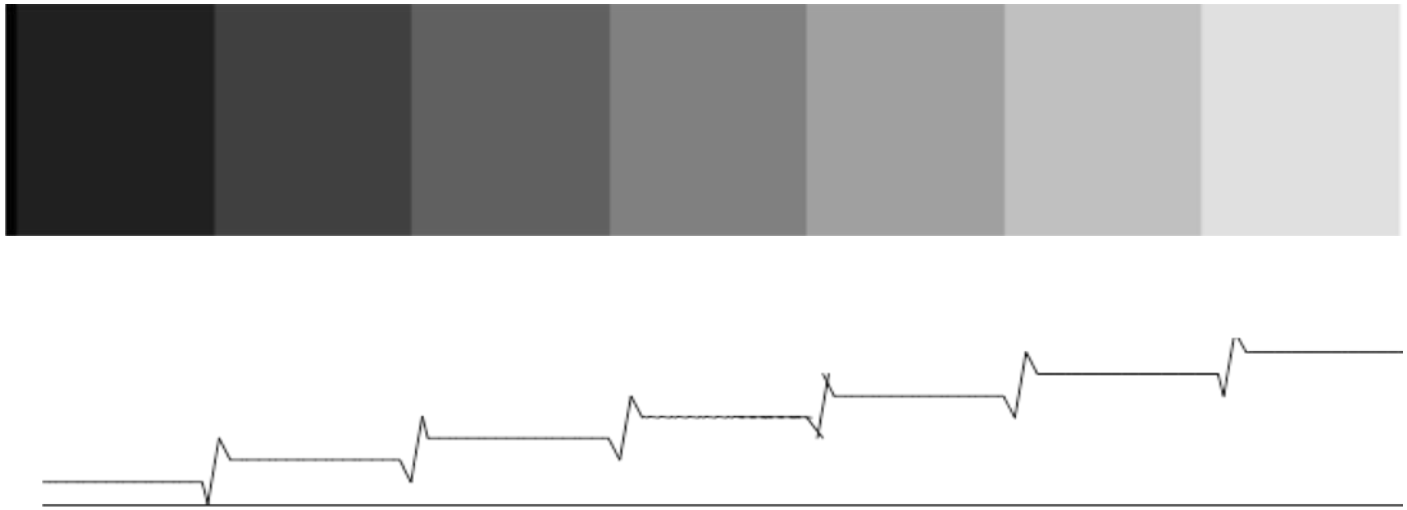
Mach bands
Sharpening filters in nature



Perceived image = Image + high frequency component

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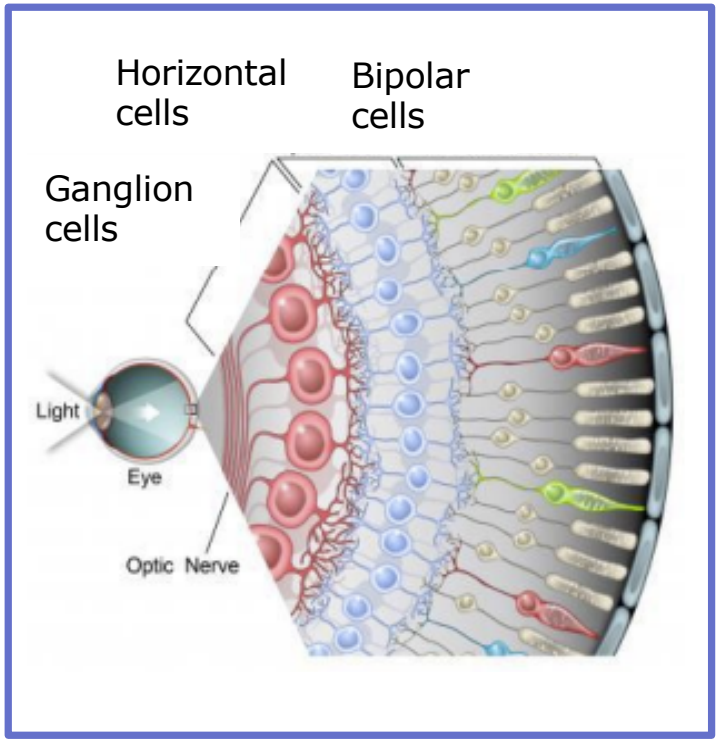
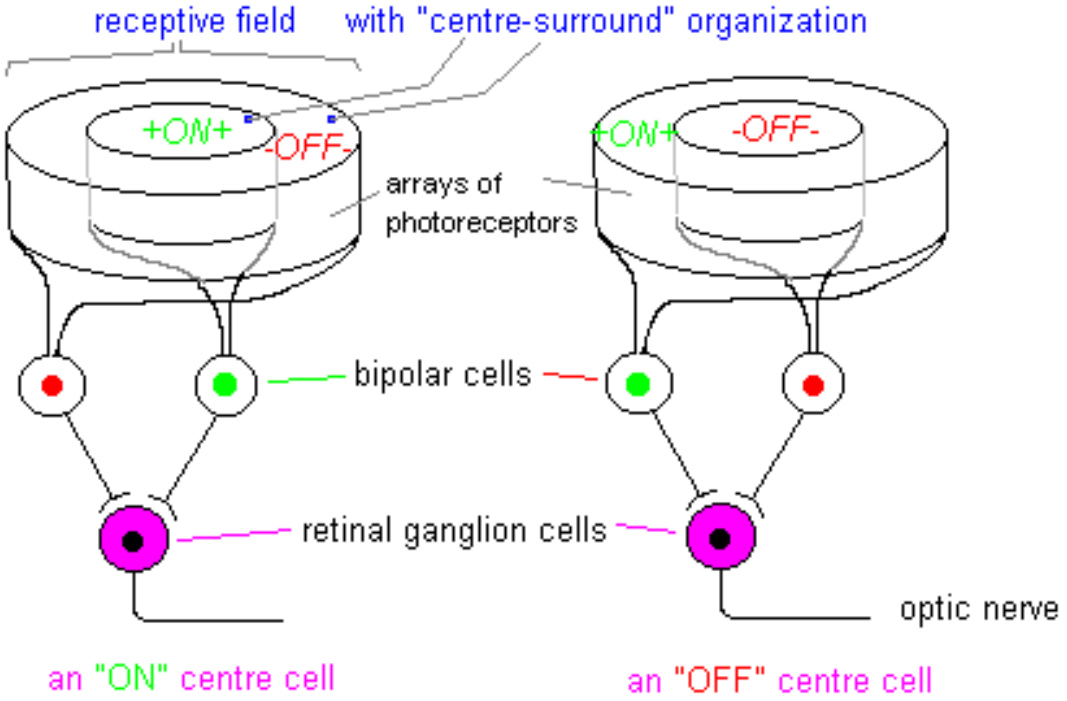
Frequency filtering operations
Sharpening filters in nature





http://www.cardiff.ac.uk/biosi/staffinfo/jacob/teaching/sensory/vision.html

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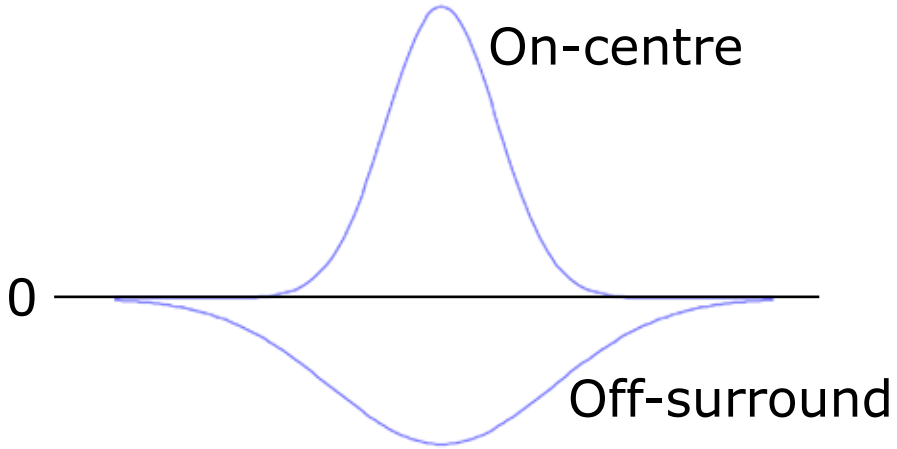
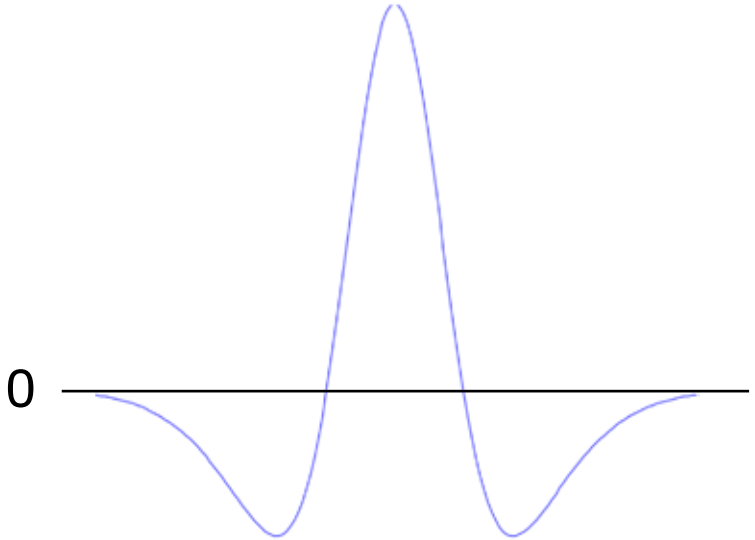
Frequency filtering operations
Sharpening filters in nature

Bipolar and ganglion cells



Further integrate and regulate the input from multiple photoreceptor cells



On-centre - Off-surround

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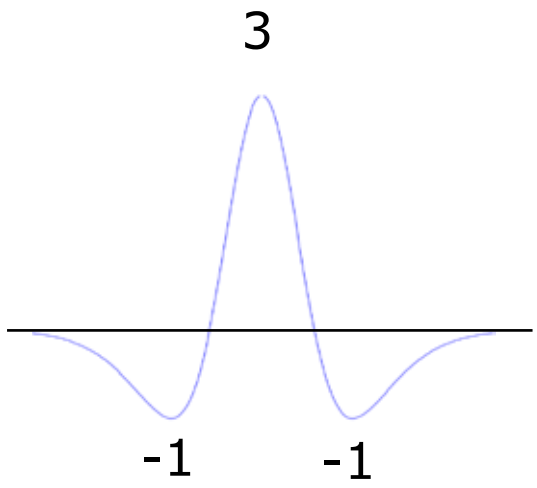
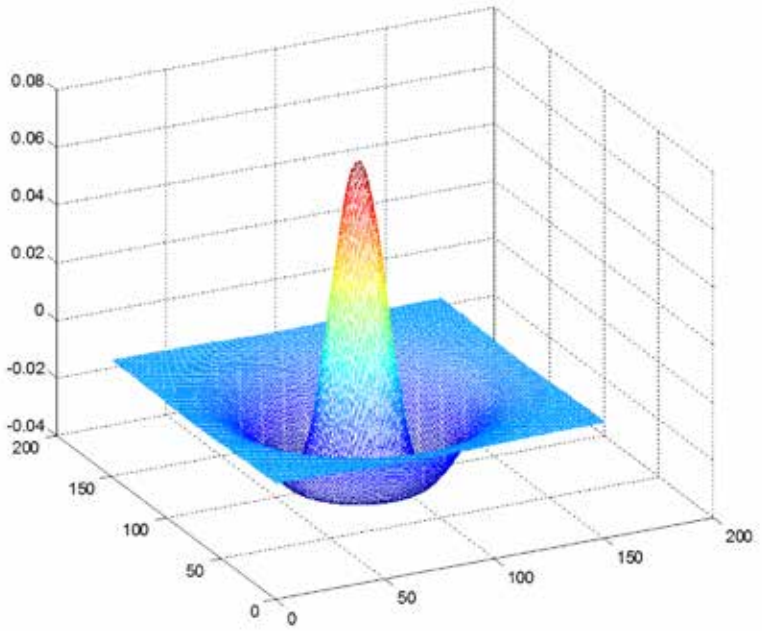
Frequency filtering operations
Sharpening filters in nature

On-centre - Off-surround





"Mexican hat" filter

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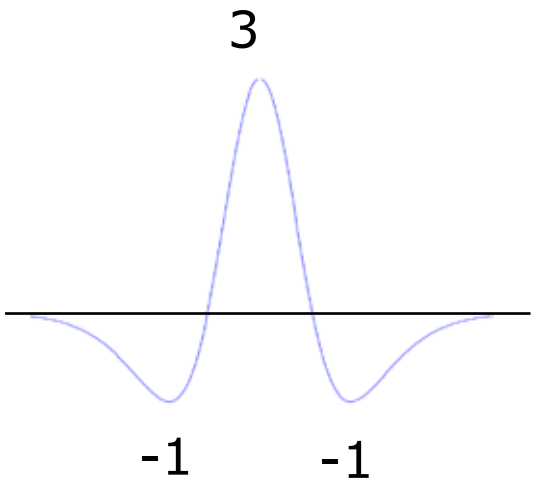
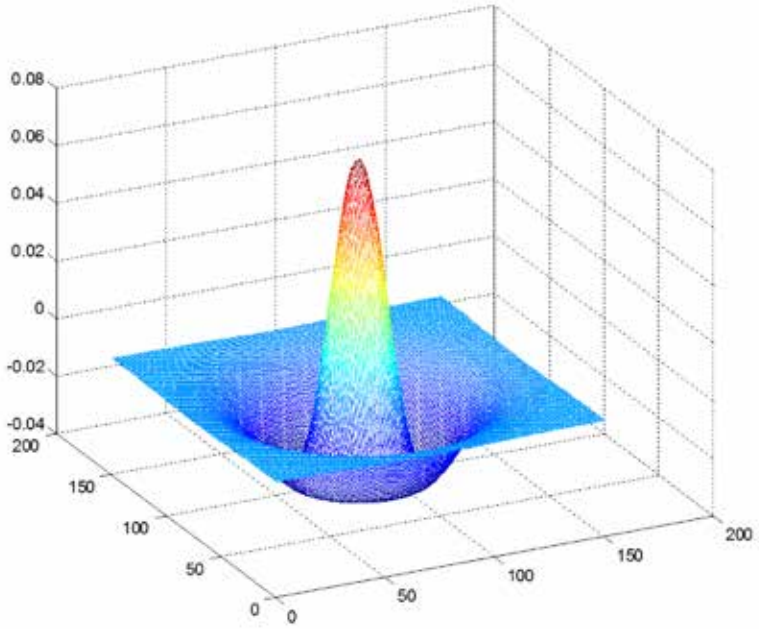
Frequency filtering operations
Sharpening filters in image processing





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

2D convolution kernel for enhancement of bright spots and bright lines on dark background

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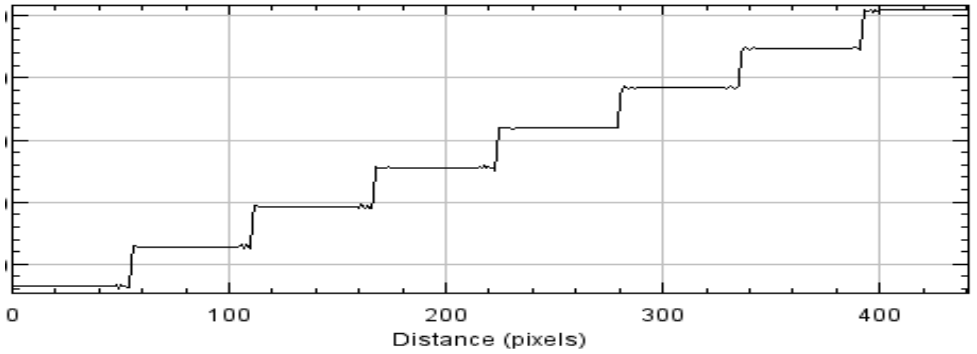
Frequency filtering operations

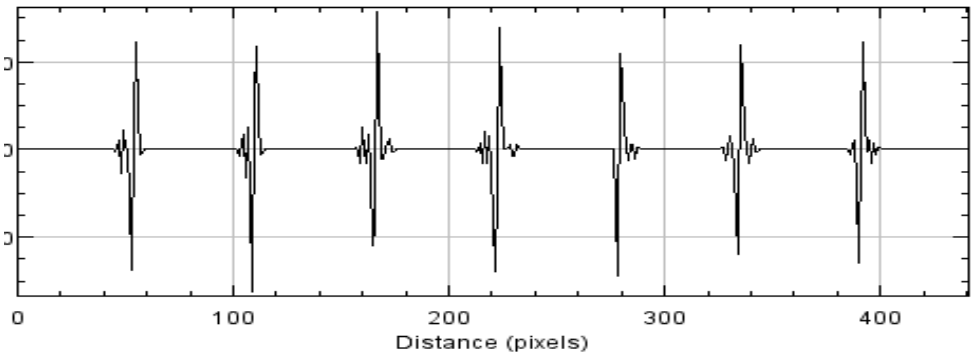
Sharpening

Image profiles

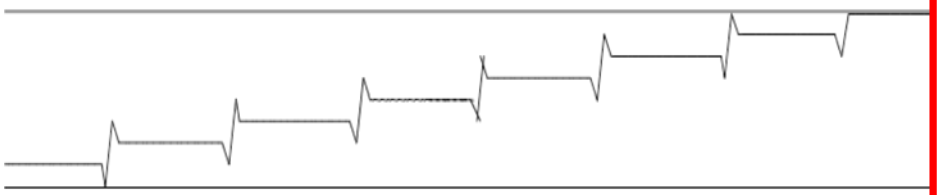
Image



Its high frequency component



Perceived image =
Image + high frequency component



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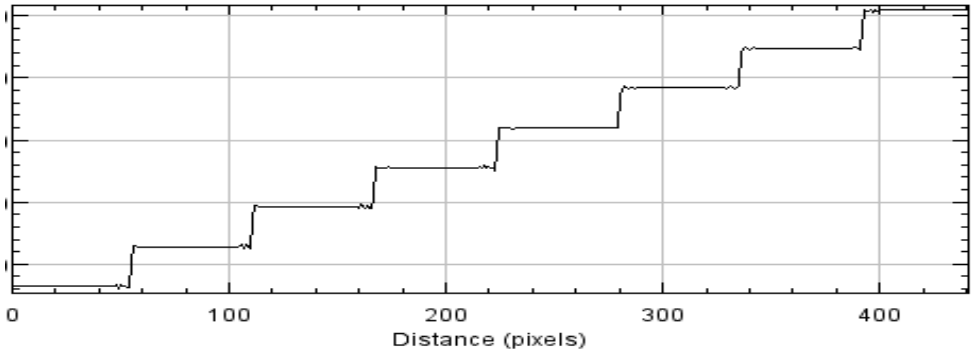
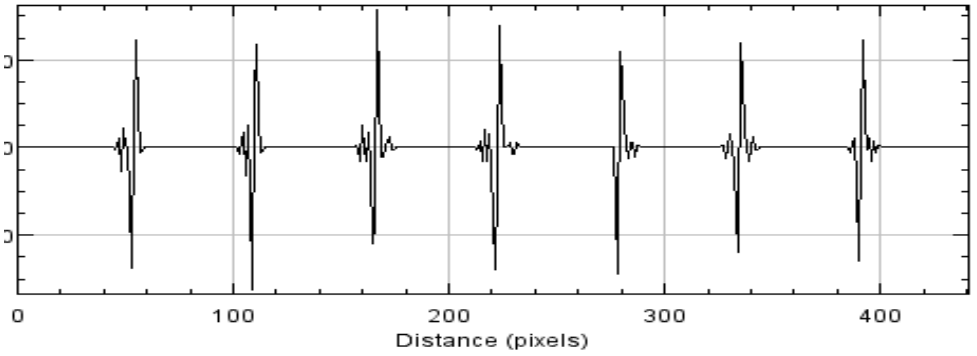
Frequency filtering operations
High-pass filters

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).

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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

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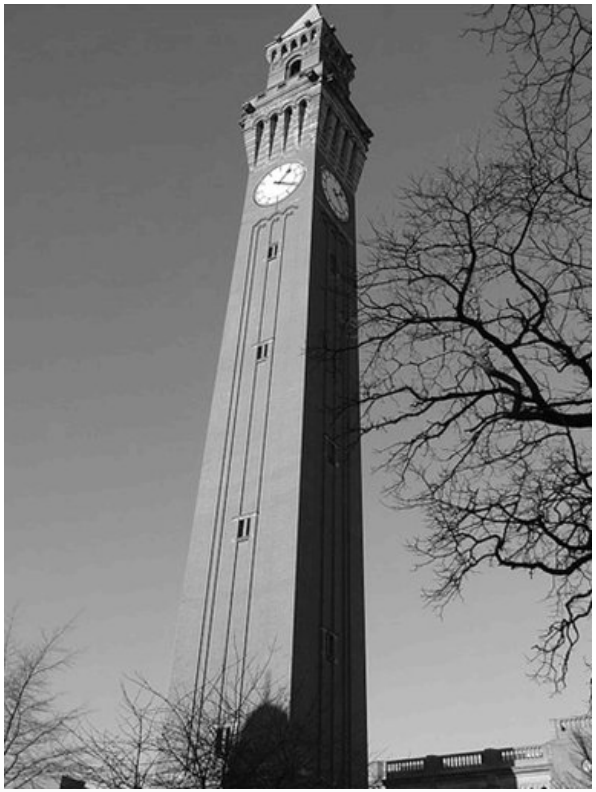
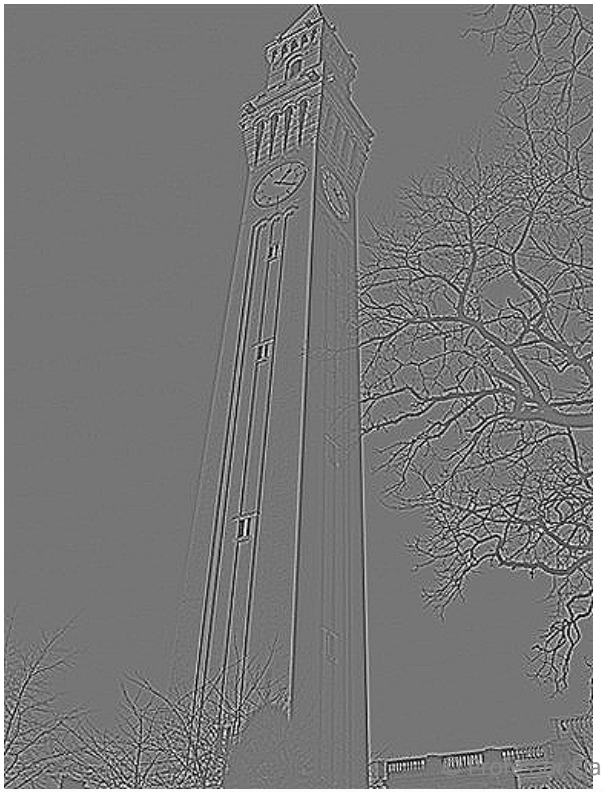
Frequency filtering operations
High-pass filters

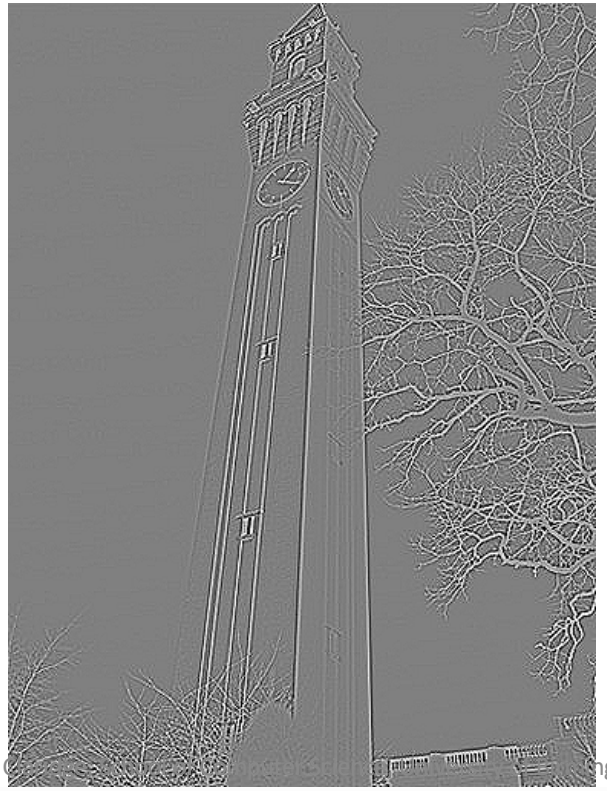
Results of convolution with

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

0	1	0
1	-4	1
0	1	0





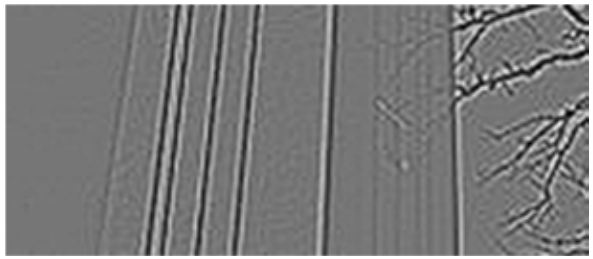


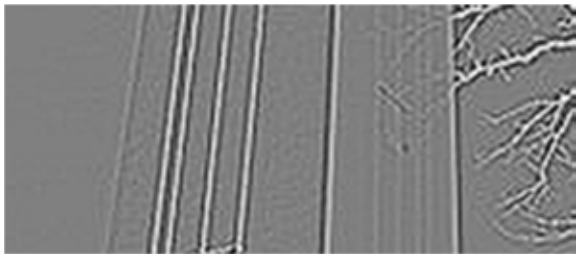
Frequency filtering operations
High-pass filters

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

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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?

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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

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

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

or

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

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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)

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In this lecture we have covered:

- 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

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Next lecture:

- 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

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Further reading and experimentation

- **Book chapters**:
- Gonzalez, R.C. & Woods, R.E. Digital Image Processing, Addison-Wesley (various editions), 4.3.3, 4.4.1, 4.4.2

- **Image Filtering: Noise Removal, Sharpening, Deblurring**
- http://homepages.inf.ed.ac.uk/rbf/HIPR2/filtops.htm

- **Unsharp masking**
- https://en.wikipedia.org/wiki/Unsharp_masking
- Unsharp filter: http://homepages.inf.ed.ac.uk/rbf/HIPR2/unsharp.htm

- **Ganglion cells**
  http://www.bioon.com/bioline/neurosci/course/eyeret.html
- **On-centre off-surround**
  https://www.youtube.com/watch?v=hgZFuq2S15A

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