Exercise 1: Image formation

17 January 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. Draw parallels between a typical (still) camera and the following components of the eye:

   - Lens
   - Aperture
   - Shutter
   - Sensor

2. When the potential well in CCD becomes full?

3. Is there a “full well” equivalent in the human vision?

4. Lists the key steps on the CCD pathway from photons to digital image values.

5. Images can be generated from different forms of energy registered by a suitable sensor. Name three kinds of energy capable of generating images.

6. CCD sensors vary in physical size (e.g. 4.8 x 3.6 mm, 6.4 x 4.8 mm, etc) and the number of pixels (e.g 1.3 million, 2.1 million). Given two chips with the same sensor size but a different number of pixels,

   - A - 1.3 million,
   - B - 2.1 million,

   which one would you choose for imaging in low-light conditions, and why?

Exercise 2: Digital image

18 January 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. Name two key attributes of pixels in a monochrome image.

2. Which of the two images of size 500 x 400 pixels will look better when displayed on a screen:

   A - spatial resolution 1mm per pixel, or B - spatial resolution 2mm per pixel?

3. This question is based on an example from http://www.nightskyimages.co.uk/sampling_rate.htm.

   "*Imagine that you have a telescope with a focal length of 1,000mm and you wish to image a deep sky object using a digital camera with a sensor whose pixels are 5 micron square in size. The theoretical resolution of the system in arcseconds per pixel can be found by using the following calculation:-*

   *Resolution = (CCD Pixel Size / Telescope Focal Length) * 206.265*

   *In our example, Resolution = (5 / 1000) * 206.265 = 1.03 arcseconds/pixel.*"

   Is this sufficient to image the sky details of size 4 arcseconds/pixel? Why?

4. What radiometric resolution (in terms of bits per pixel) is sufficient for adequate perception of monochrome images?

5. A technical specification sheet of a camera provides the following information:

   - Full well capacity: 18,000 photoelectrons
   - Readout noise: 8 photoelectrons

   What is the camera's dynamic range in dB?

Exercise 3: Colour, part 1

24 January 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. What is the wavelength range (approximately) of visible light? Specify units for the wavelengths.

2. Why digital cameras and displays use RGB primaries?

3. What colour will you get by illuminating a yellow surface with a green light? Justify your answer.

4. What colour will you get by illuminating a magenta surface with a yellow light? Justify your answer.

5. Describe the key steps in the process of generating colour image using the Bayer filter array in the sensor chip.

6. Given the following Bayer filter mosaic, compute the RGB colours for the four central pixels (marked with crosses below).

255	255	255	255
0	255	0	127
255	255	255	255
127	255	0	127

	X	X	
	X	X	

Exercise 4: Colour, part 2

25 January 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. Specify colour definitions for the following colours in the RGB and CMY colour spaces assuming the range of the primaries 0-255.

   - Black
   - White
   - Bright orange
   - Light pink

2. Apple RGB colours are converted to CIE RGB values using the following (rounded-up) matrix (source: http://www.brucelindbloom.com/index.html?Eqn_RGB_XYZ_Matrix.html)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.45 & 0.32 & 0.18 \\ 0.24 & 0.67 & 0.08 \\ 0.03 & 0.14 & 0.92 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

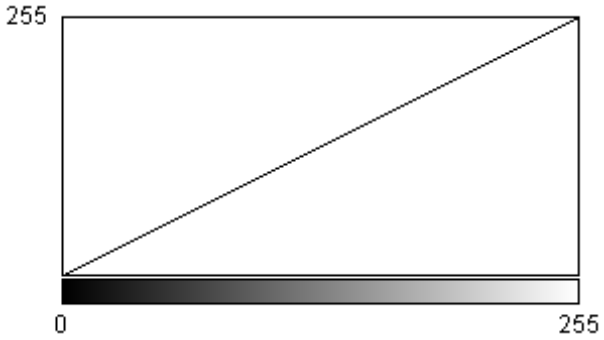
   Compute XYZ values for the RGB colour vector $\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 250 \\ 200 \\ 100 \end{bmatrix}$

3. Define a 9-long RGB colour map specifying red hue of decreasing saturation (from full to zero).

4. The LUT for a grey-scale image is shown below. Define the LUT to change the image into its negative (i.e. black becomes white, white becomes black, dark colours become bright and vice versa).

R	0	32	64	92	128	160	192	224	255
G	0	32	64	92	128	160	192	224	255
B	0	32	64	92	128	160	192	224	255

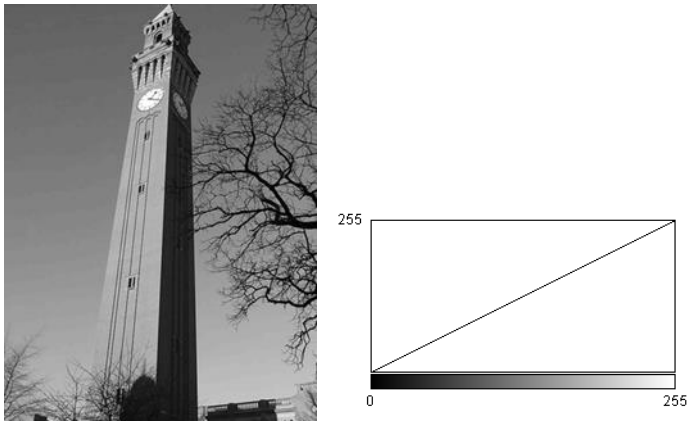
5. The LUT for a grey-scale image can be represented in the form of the graph showing the relationship between image values (x-axis) and shades of grey (y-axis), as below.



Draw a graph representing changing an image into its negative.

6. What is the gamut size for indexed colour images where each of the RGB primaries is represented by 4 bits per pixel and LUT has 256 entries?

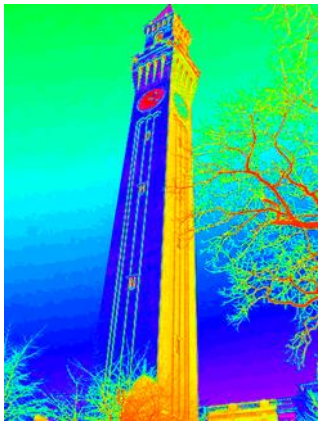
7. The image “Old Joe” and its mapping function are shown below.



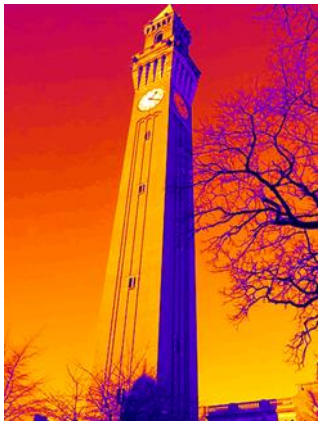
The image was displayed in false colours by changing its colour mapping function.

For the three false colour images A, B,C choose their correct mapping functions M1, M2, M3.

(This question can be difficult / impossible for people affected by “colour blindness”).

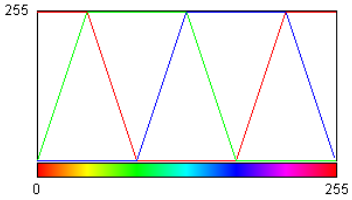


A

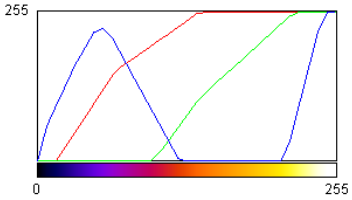


B

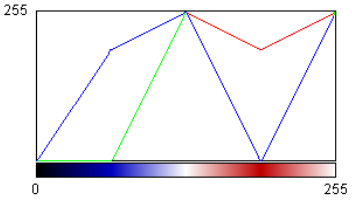
C



M3



M2



M1

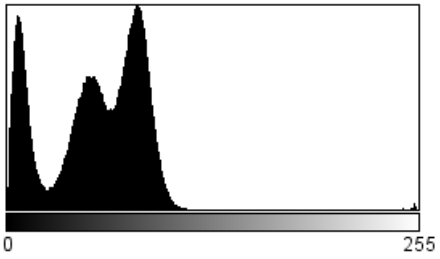
Exercise 5: Image enhancement, part 1

1 February 2018

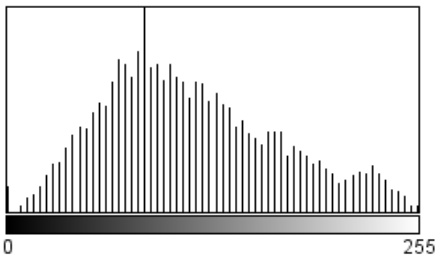
This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

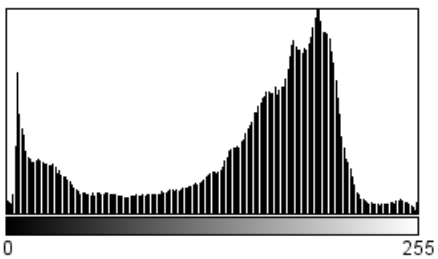
The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. Given a histogram below, characterise its contrast (low - high?) and dynamic range (small - large?). Justify your answer.

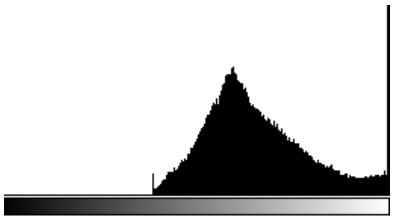


2. Given two histograms below, which one corresponds to an image with a better contrast? Why?

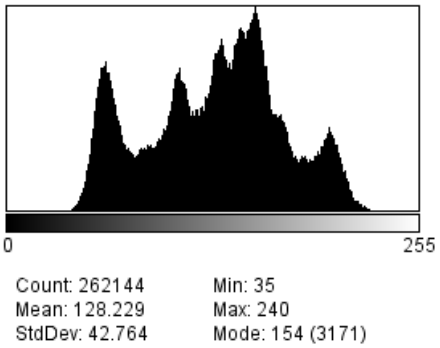




3. What can you say about the image with histogram as below?



4. Given a histogram below suggest mathematical equation(s) that would maximally expand its dynamic range. The equations should include specific numerical parameters.



5. Explain briefly why the mathematical operation(s) that you have specified above improve the dynamic range.

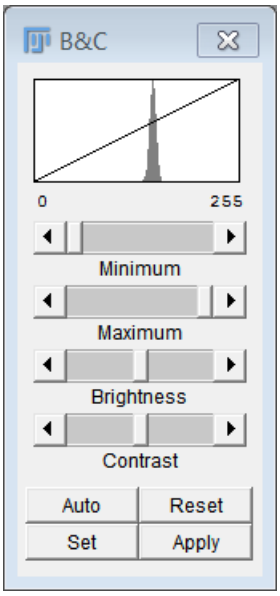
6. How does the histogram equalisation works? In particular, *how* does it spread the image values across the whole range of possible image values?

7. The equation specifying the gamma correction has the form

$$I'(x,y) = C \cdot I(x,y)^{\frac{1}{\gamma}}$$

In the original image γ = 1.0. If you wanted to make dark regions lighter, would you make γ larger or smaller?

8. Image contrast can be improved by either changing image values (e.g. as in question 3 above), or by changing the LUT. Given an image and its current LUT, sketch the shape of the LUT that would improve the image visual appearance.



Original

Exercise 6: Image enhancement, part 2

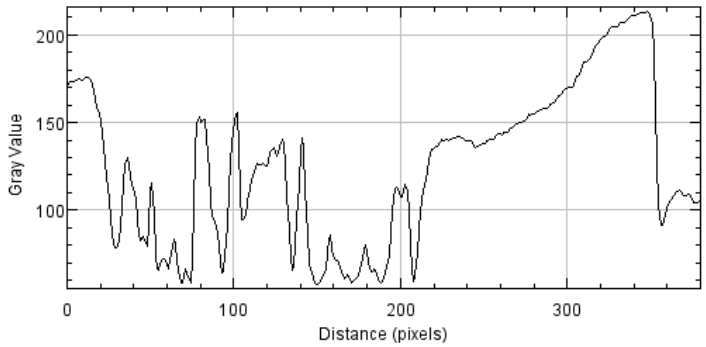
7 February 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. Why images acquired in low-light conditions often have noisy / gritty appearance? How can this problem be rectified by changing image acquisition parameters?
   How can this problem be rectified by image processing?

2. On the image profile below point out regions showing low frequency.



3. In terms of frequency manipulation, what does low-pass filtering do?

4. Given the image fragment $\mathcal{I}$ below compute the result of its convolution with kernel $\mathcal{K}$ for the area highlighted grey in the image grid $\mathcal{J}$.

Image fragment $\mathcal{I}$

84	81	97	80	79
101	111	126	113	87
114	138	116	104	86
61	67	70	85	110
97	83	99	117	112

Convolution kernel $\mathcal{K}$

0.1	0.1	0.1
0.1	0.2	0.1
0.1	0.1	0.1

Image grid $\mathcal{J}$

5. Why is convolution referred to as a “linear transformation”?

6. What are the numerical characteristics of coefficients of a low-pass filter kernel?

7. What is an unwanted effect of low-pass filtering (smoothing)?
   Can you explain this effect in terms of frequency processing?

Exercise 7: Image enhancement, part 3

8 February 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. Name common causes of image blur.

2. In what way blur affects image frequencies?

3. In terms of frequency manipulation, what does high-pass filtering do?

4. Given the image fragment $\mathcal{I}$ below calculate the result of its convolution with kernel $\mathcal{K}$ for the area highlighted grey in the image grid $\mathcal{J}$.

Image fragment $\mathcal{I}$

104	121	136	180	179
101	111	126	113	187
104	138	116	104	86
61	67	70	85	110
97	83	99	97	102

Convolution kernel $\mathcal{K}$

-1	-1	-1
-1	8	-1
-1	-1	-1

Image grid $\mathcal{J}$

(hint: use Excel).

5. What are the numerical characteristics of coefficients of a off-centre on-surround high-pass filter kernel?

6. What is an unwanted effect of high-pass filtering?

   Can you explain this effect in terms of frequency processing?

Exercise 8: Image enhancement, part 4

21 February 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. Explain the principle of difference filters. Write equations for (a) the vertical filter and (b) the left-diagonal filter.

2. What is the difference between an isotropic and an anisotropic edge detection filter? Give one example of each.

3. What does this filter do? What image features give the strongest response (i.e. highest positive value)?

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

4. Given the image fragment $\mathcal{I}$ below calculate the result of its convolution with kernel $\mathcal{K}$ for the area highlighted grey in the image grid $\mathcal{J}$.

Image fragment $\mathcal{I}$

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

Convolution kernel $\mathcal{K}$

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

Image grid $\mathcal{J}$

5. Image fragment $\mathcal{I}$ below contains a bright line on a darker background. Would the filter shown in $\mathcal{K}$ detect the line (i.e. give high response when $\mathcal{I}$ is convolved with $\mathcal{K}$)?

Image fragment $\mathcal{I}$

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

Convolution kernel $\mathcal{K}$

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

6. Given the image fragment $\mathcal{I}$ below predict the result of applying a 3 x 3 median filter for the area highlighted grey in the image grid $\mathcal{J}$. Confirm your prediction by carrying out the calculations.

Image fragment $\mathcal{I}$

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

Image grid $\mathcal{J}$

7. Briefly explain the principle and the method of the edge preserving smoothing.

Exercise 9: Image segmentation

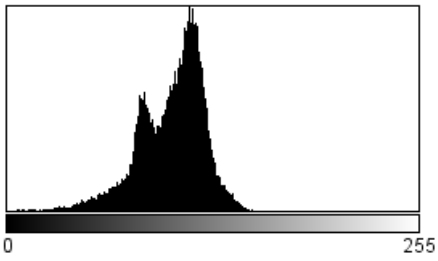
22 February 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. Why is it said that image segmentation by extracting object boundaries and by extracting regions is equivalent?

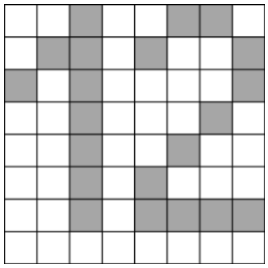
2. Given the image histogram below, indicate the location of the threshold value you would choose to separate object(s) from the background. Justify your choice.



3. How is image segmentation computed for dark objects on a bright background?

4. One of the outputs of image segmentation can be a "label image". What is represented by pixel values in the label image?

5. In the grid below mark all clusters of pixels that are 4-connected but not 8-connected.



6. Otsu thresholding is one of the most commonly used methods for automatic threshold selection. Briefly explain its principle.

7. What is the key difference between global and local segmentation methods?

Exercise 10: Post-processing

1 March 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

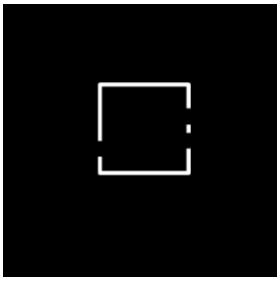
The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. Erosion and dilations are the basic operations of mathematical morphology. Explain how they work and what effect they have on a binary image.

2. After thresholding, the image regions belonging to objects ended up having "holes" due to image noise. How would you remove the holes using mathematical morphology methods? Object pixels have value one, background pixels have value zero.

3. What is the mathematical morphology operation "opening"? What is it useful for?

4. Due to noise in the image edge detection filter produced gaps in the edge outline. Can you repair the gaps (without upsetting the rest of the outline) by using mathematical morphology methods?



5. You were given an image of a car registration plate as below. Your task is to extract just the edges of the plate using only thresholding and the basic methods of mathematical morphology.

Exercise 11: Object properties: counting, measuring and localisation

7 March 2018

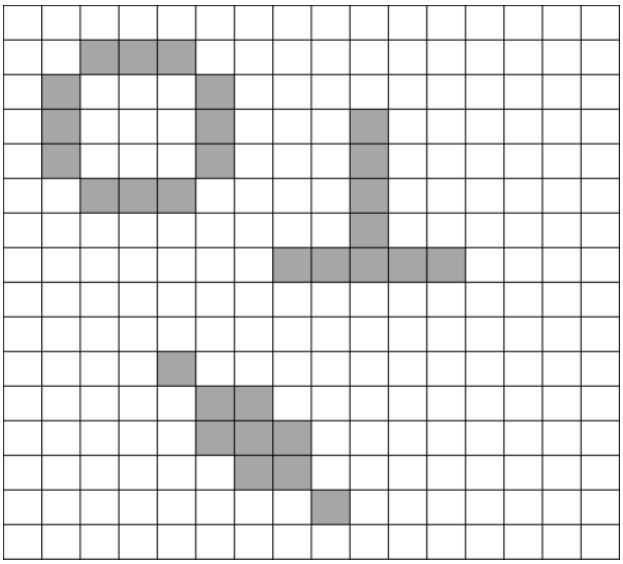
This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

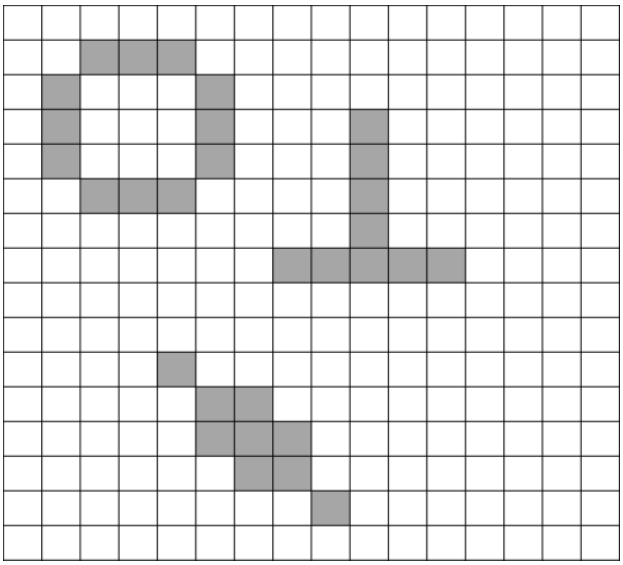
1. The "hand-on-the-wall" algorithm is a simple method for outlining binary images. Is it suitable for outlining inner edges of objects with holes, such as the one below? Why?

2. After segmentation a labelling operation was applied to a binary image, generating a "label image". What is represented by pixel values in the label image?

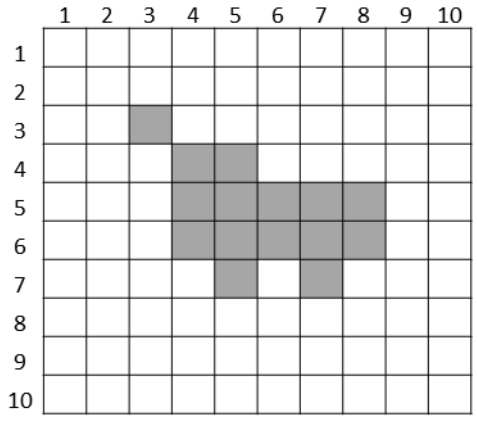
3. For a binary image fragment below enter the region ID for each pixel as it would be assigned after the ***first pass*** of the row-by-row labelling algorithm. Object pixels are indicated by a grey shade, background by white.



4. For the same image fragment enter now the region ID-s resulting from the ***second pass*** of the row-by-row labelling algorithm.



5. Compute the ***centre of mass*** for the object in the figure below. The numbers above and to the left of the grid are pixel coordinates.



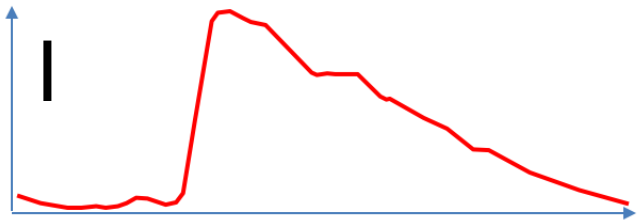
Exercise 12: Object properties: shape and texture

8 March 2018

This unassessed exercise gives you an opportunity to test your understanding of the material covered in the lectures and to encourage you to look at the materials suggested in further reading and exploration. You do not need to submit it, but you should write down the answers and keep them for future revisions.

The exercise will not be marked, instead the outline solutions, answers and pointers to external sources will be provided one week after the exercise has been issued.

1. The curve below reproduces a red curve from slide 6, lecture 11. The minimum width of the bounding box (tolerance band) is shown as a vertical black bar. Show the steps leading to approximating this curve by a polyline according to the tolerance band.



2. Sketch Ψ-s curve for

   (a) Square

   (b) Ellipse

3. Compute the co-ocurrence matrix at one pixel distance in **vertical** direction.

1	0	0	0
1	0	3	3
1	2	3	1
1	3	1	3

4. What is the size of a co-occurrence matrix for an image with radiometric resolution of 8 bits per pixel?