Introduction to Medical Image Analysis

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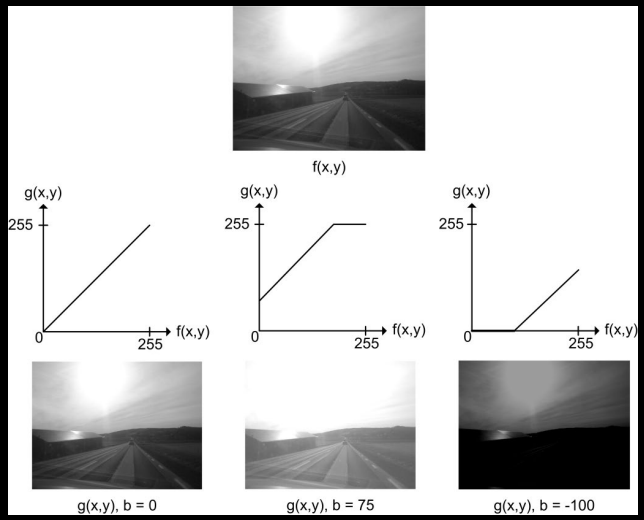
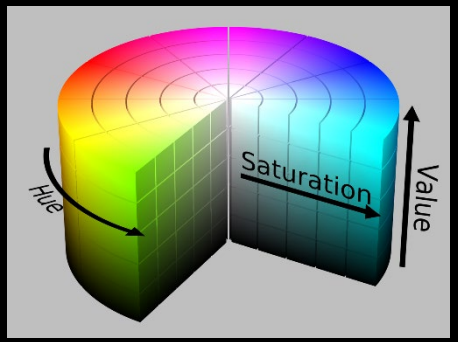
Plenty of slides adapted from Thomas Moeslunds lectures

Week 3
Pixelwise operations and colour images





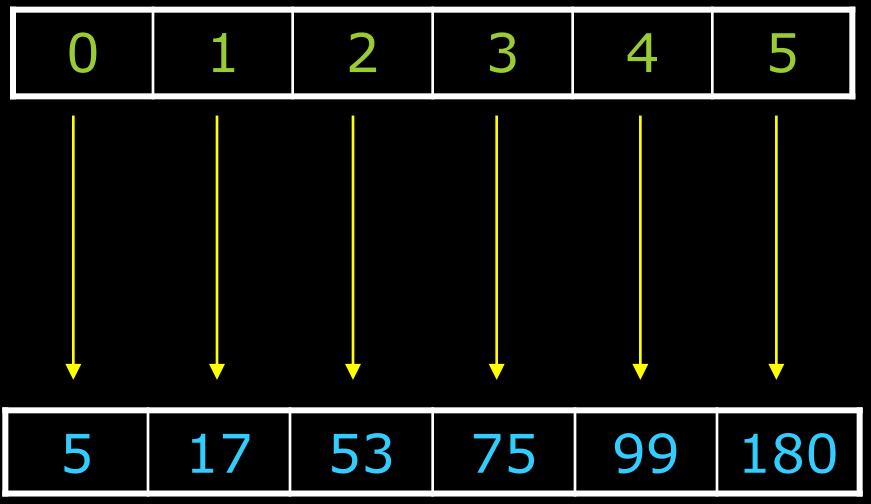
What can you do after today?

- Compute and apply a linear gray transformation
- Describe and compute the image histogram
- Implement and apply histogram stretching
- Implement and apply gamma transformation
- Implement and apply log and exp mappings
- Describe and use thresholding
- Describe and use automatic thresholding
- Perform conversions between bytes and doubles
- Use addition and subtraction of images
- Explain the benefits of bi-modal histograms
- Identify images where global thresholding can be used for object extraction

…and you can even more

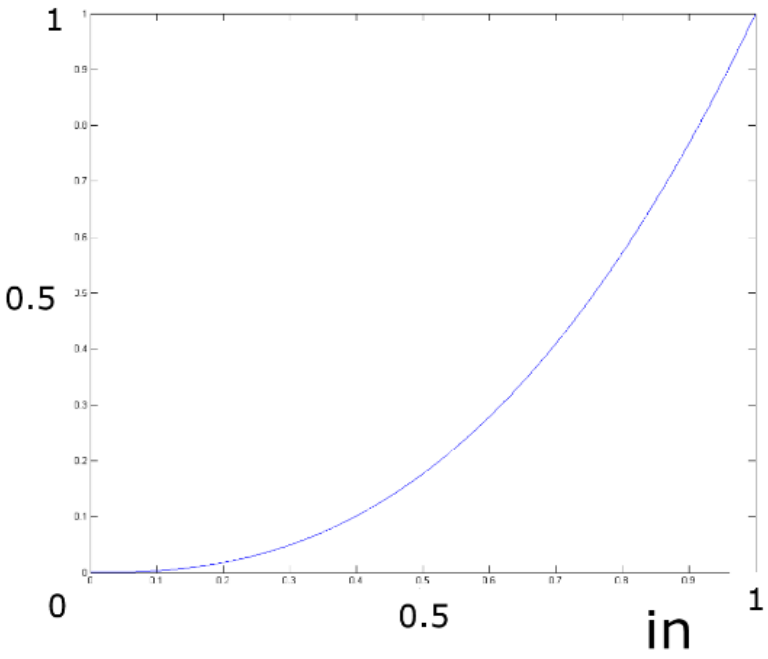
- Describe the basic human visual system including rods and cones
- Describe subtractive colors
- Describe additive colors
- Describe the RGB color space
- Describe the normalised RGB color representation
- Describe the use of the Bayer pattern in digital cameras
- Describe the HSI color space
- Convert from an RGB to a grey level value
- Convert from an RGB value to an HSI value
- Describe the use of different color spaces
- Implement and use color thresholding in RGB space
- Implement and use color thresholding in HSI space

Gray value mappings



- Mapping
  - To make correspondence between two sets of values
- Look-up-table
  - A table of mappings

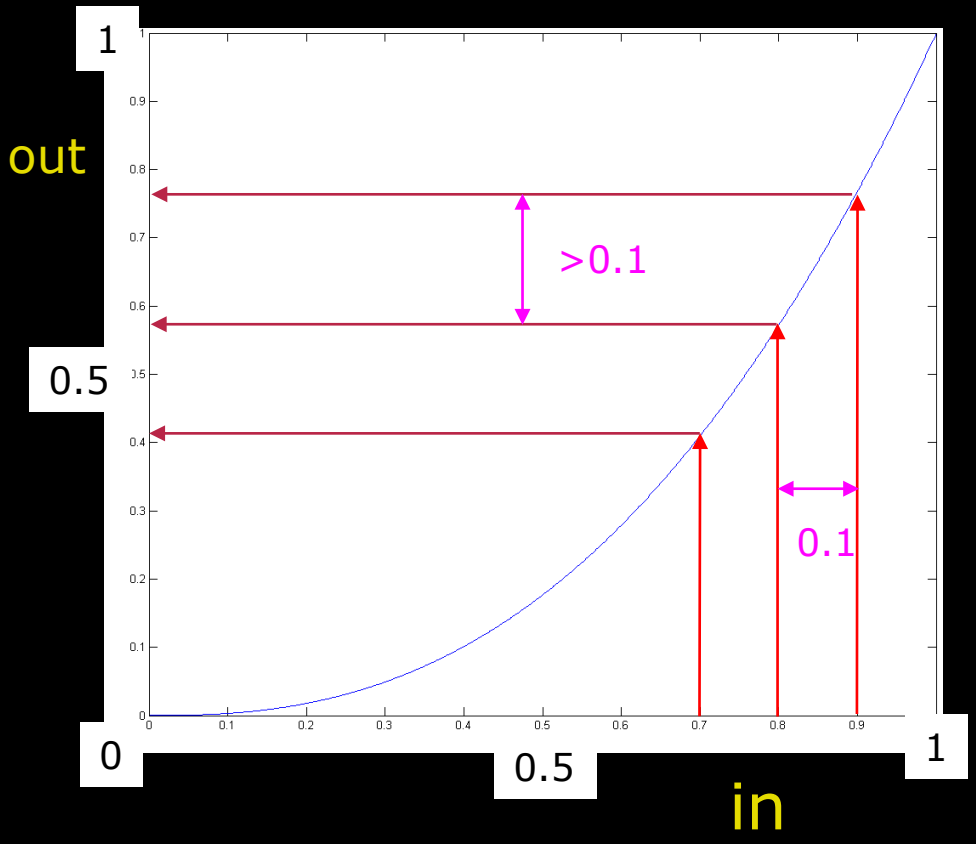
Mapping Function



f(0.5)?

0.1	**A**
0.2	**B**
0.3	**C**
0.4	**D**
0.5	**E**

Gray value mappings

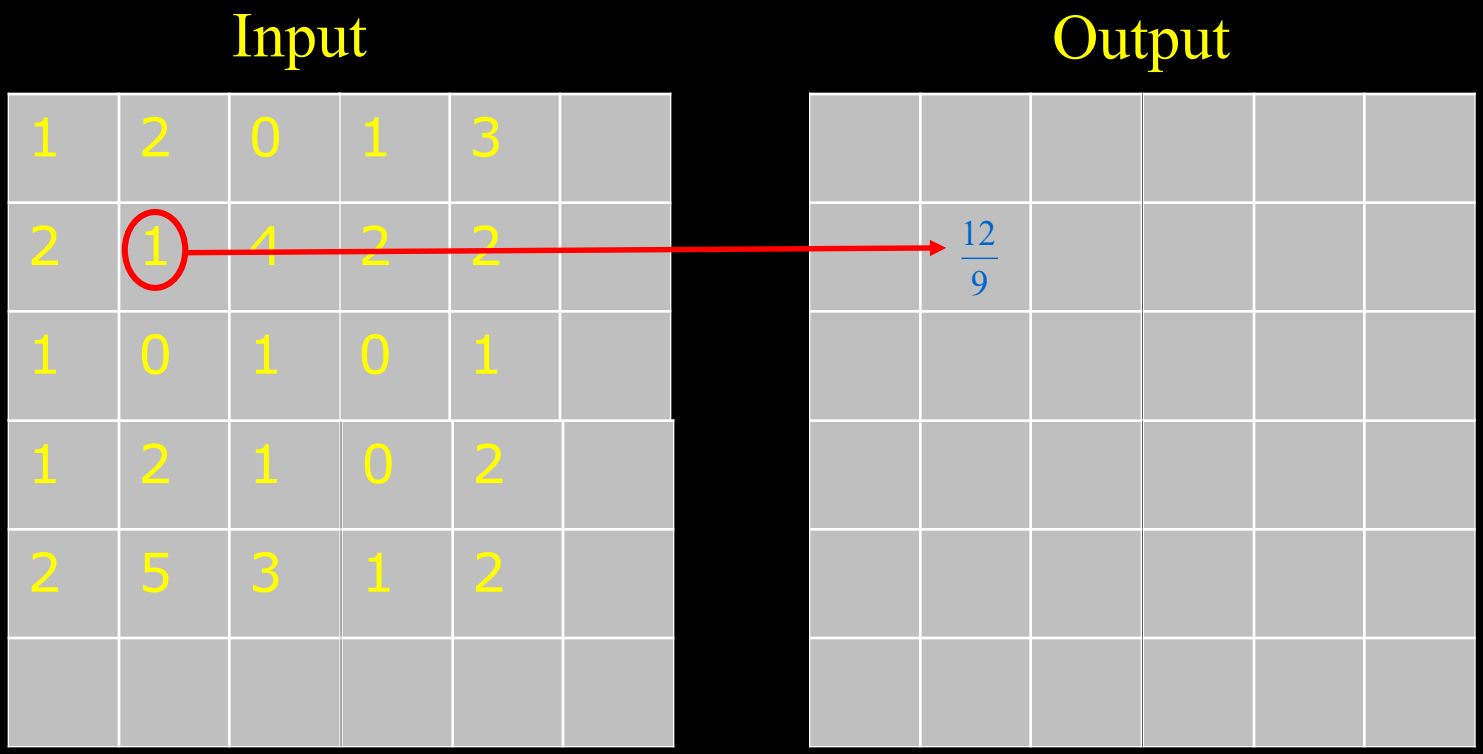


- Mapping
  - To make correspondence between two sets of values
- Mapping function
  - out = f(in)
- What happens with the values?
  - Values with difference 0.1
  - Output values "spread out"

Why change gray level values

- When could it be good to change the gray level values?
  - Lack of contrast
  - Make the image lighter
  - Make the image darker

Point processing



- The value of the output pixel is only dependent on the value of one input pixel
- A global operation – changes all pixels

Point processing

- Grey level enhancement
  - Process one pixel at a time independent of all other pixels
  - For example used to correct Brightness and Contrast
    - Known from the television remote control

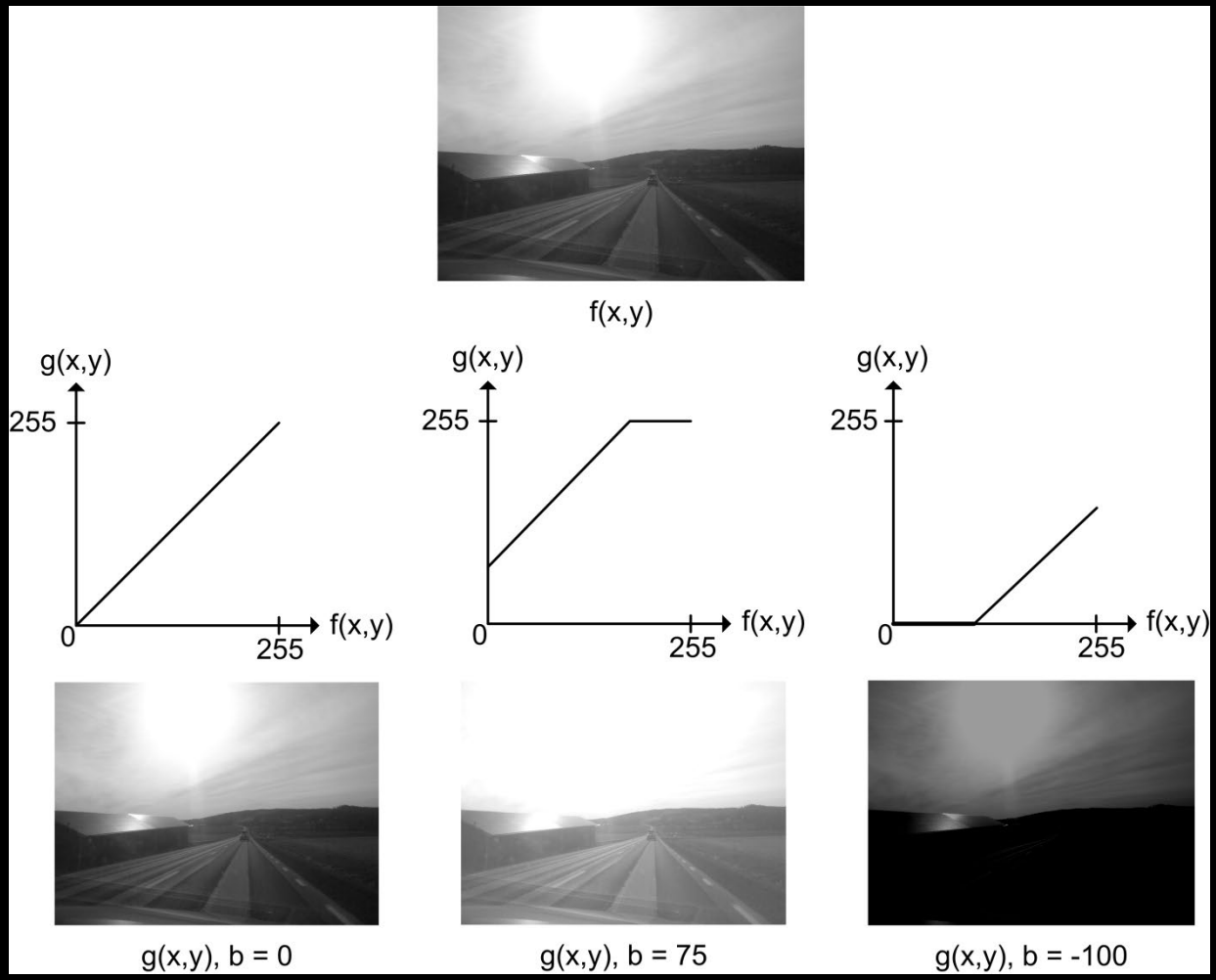
Correct | Too high brightness | Too low brightness | Too high contrast | Too low contrast

Brightness

- The brightness is the intensity
- Change brightness:
  - To each pixel is added the value *b*
  - f(x, y) is the input image
  - g(x, y) is the (enhanced) output image
- If $b>0$: brighter image
- If $b<0$: less bright image

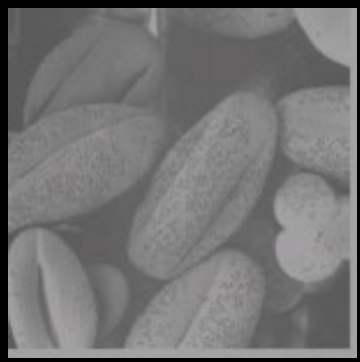
$$g(x,y) = f(x,y) + b$$

Brightness


f(x,y)
g(x,y)
255
0
255
f(x,y)
g(x,y)
255
0
255
f(x,y)
g(x,y)
255
0
255
f(x,y)
g(x,y), b = 0
g(x,y), b = 75
g(x,y), b = -100

Contrast

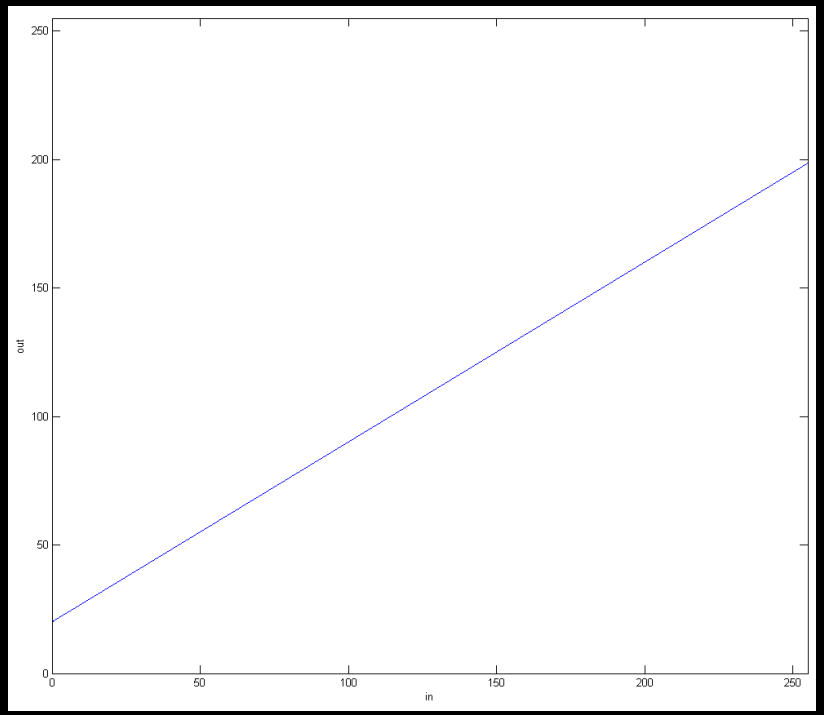
- The contrast describes the level of details we can see
- Change contrast
- Each pixel is multiplied by *a*
  - f(x, y) is the input image
  - g(x, y) is the (enhanced) output image
- If *a*>1 => more contrast
- If *a*<1 => less contrast



$$g(x,y) = a * f(x,y)$$

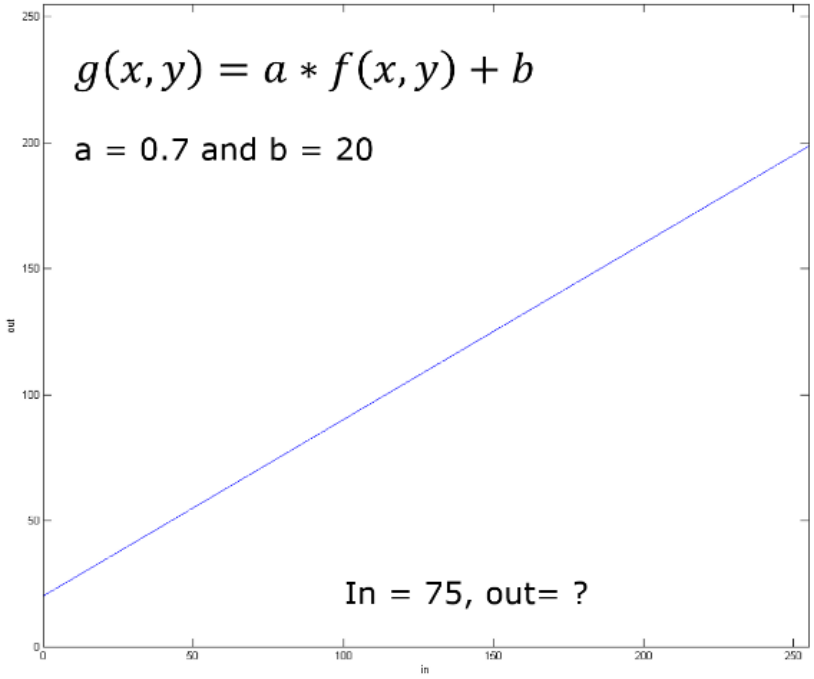
Combining brightness and contrast

- A straight line
- Called a *linear transformation*
- Here a = 0.7 and b = 20



$$g(x,y) = a * f(x,y) + b$$

Linear Transformation



20

45

72

103

230

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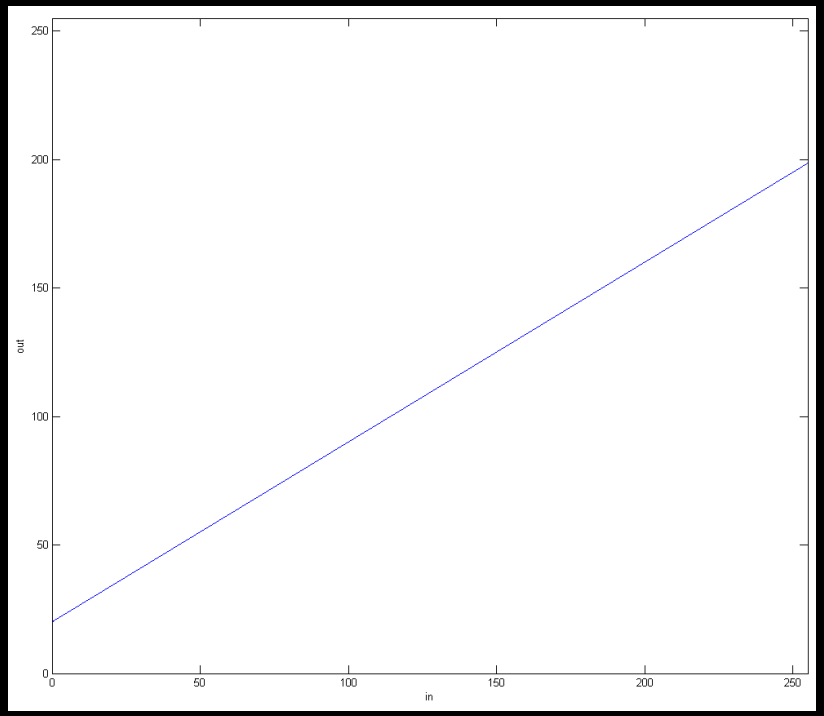
Combining brightness and contrast

- A straight line
- Called a *linear transformation*
- Here a = 0.7 and b = 20
- What will the result be on the output image?
  - More bright (b > 0)
  - Less contrast (a < 1)

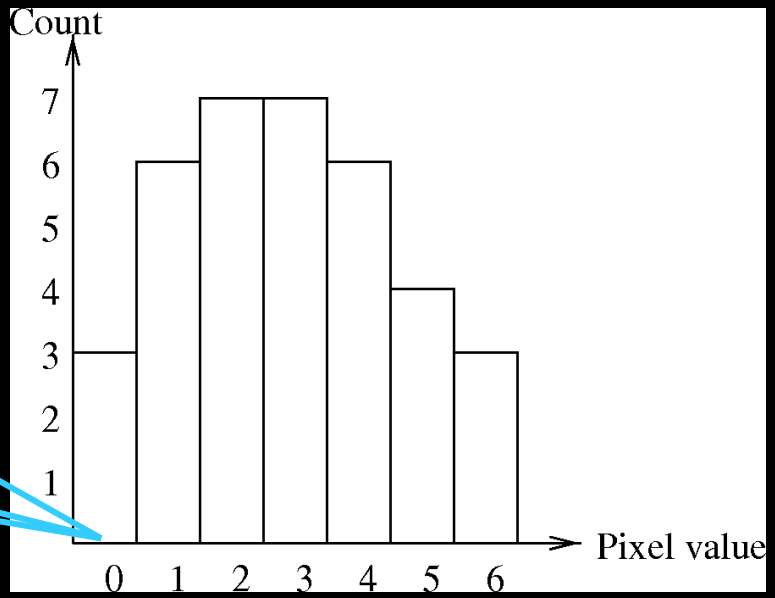


$$g(x,y) = a * f(x,y) + b$$

Histogram Reminder

- A histogram normally contains the same number of "bins" as the possible pixel values
- A bin stores the number of pixel with that value

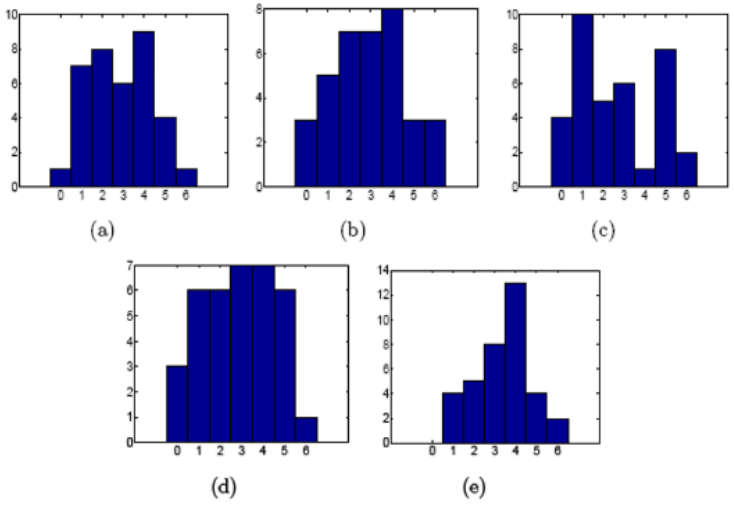
0	2	6	6	3	3
1	4	3	4	4	4
3	2	5	1	5	2
1	4	2	1	3	1
2	5	3	0	2	0
4	2	5	6	3	1



Choose the histogram that represents the image

0	5	3	5	2	1
3	5	5	3	3	1
1	1	1	3	2	3
6	2	2	1	0	0
0	2	1	5	1	5
5	5	1	4	1	6

Figur 6: Grayscale billede.



A

B

C

D

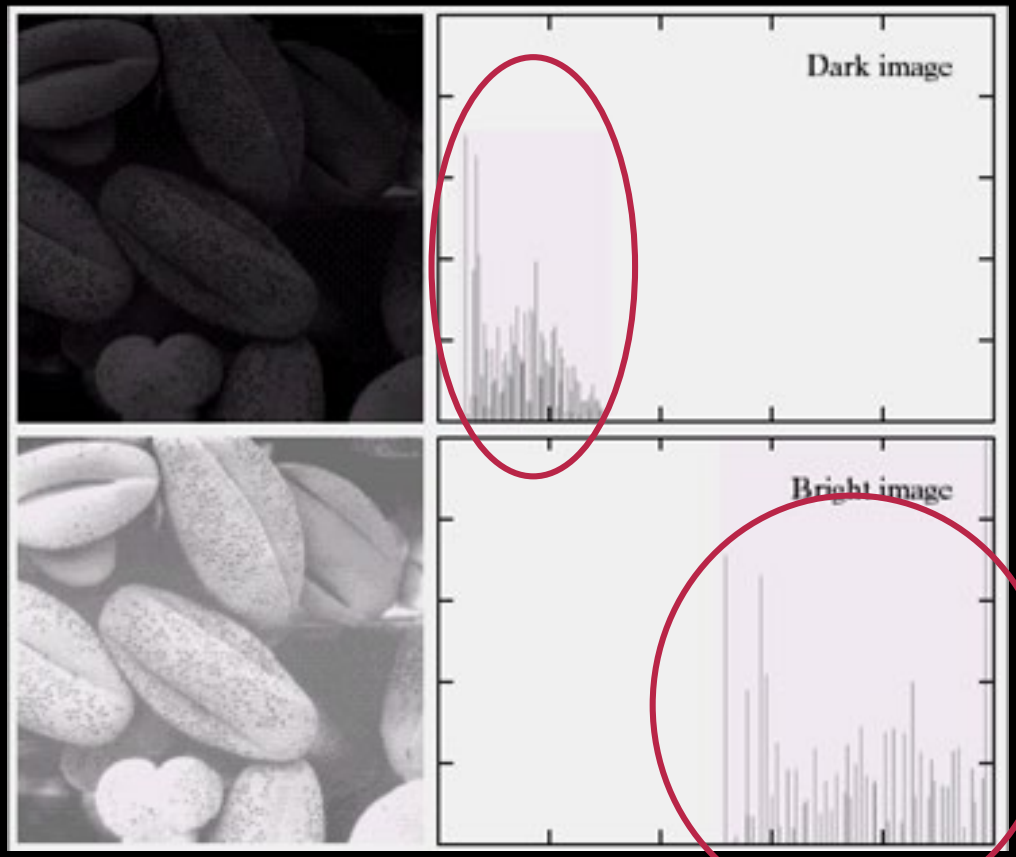
None of the above

Start the presentation to see live content. Still no live content? Install the app or get help at PollEv.com/app

Back to the histogram

- The shape of the histogram tells us a lot!

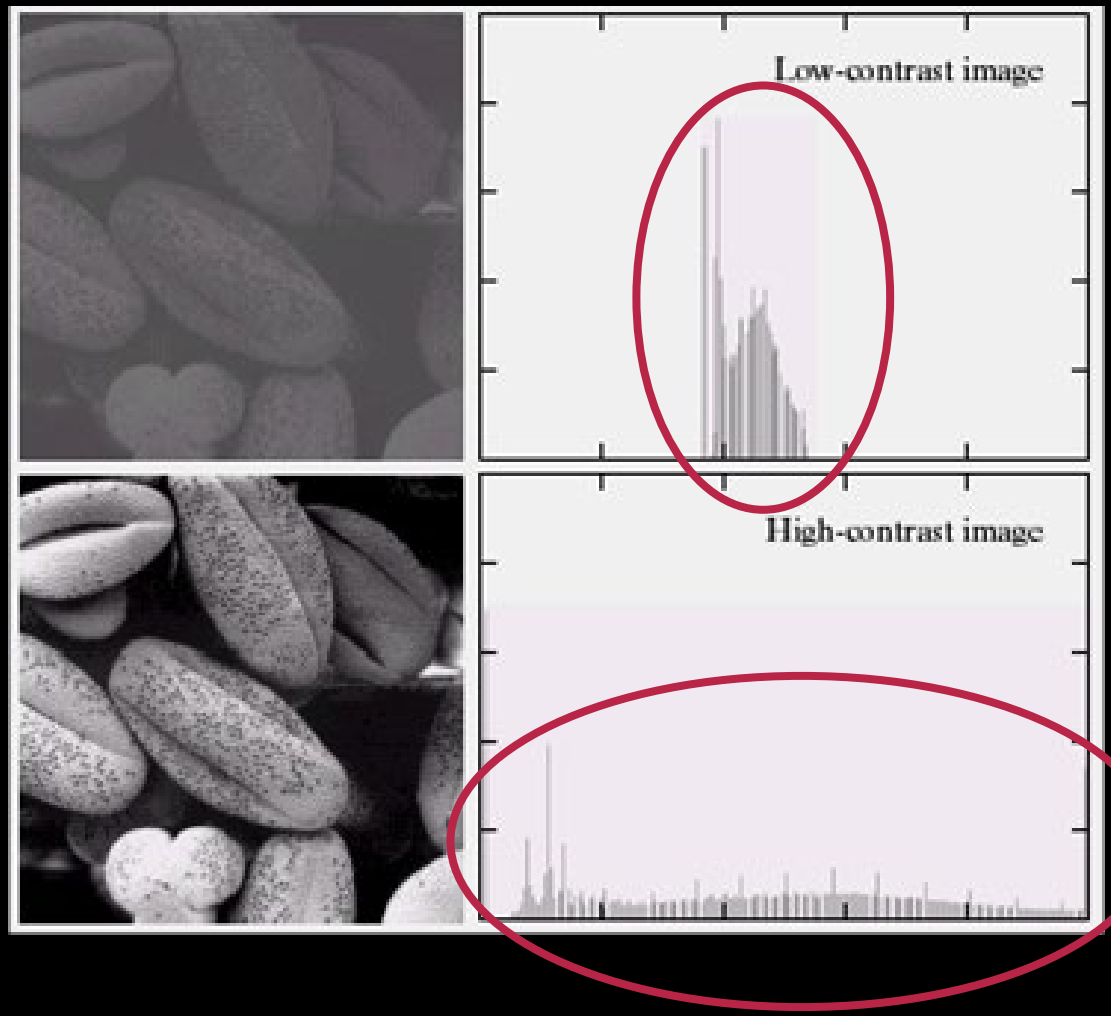
Histogram inspection



Dark image

Bright image

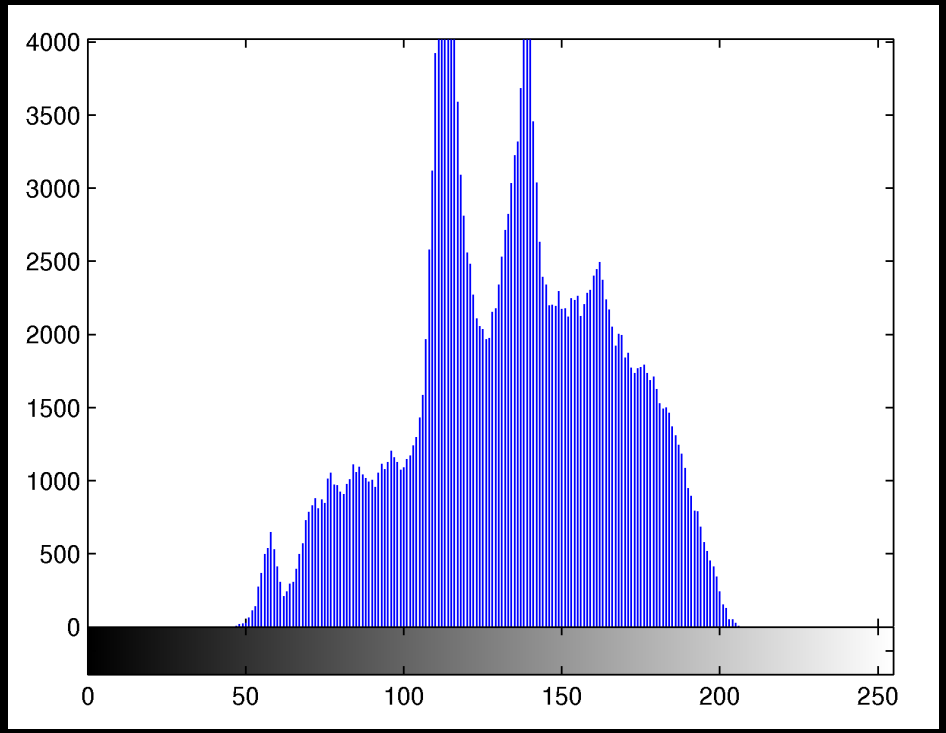
Histogram inspection



Low contrast

High contrast

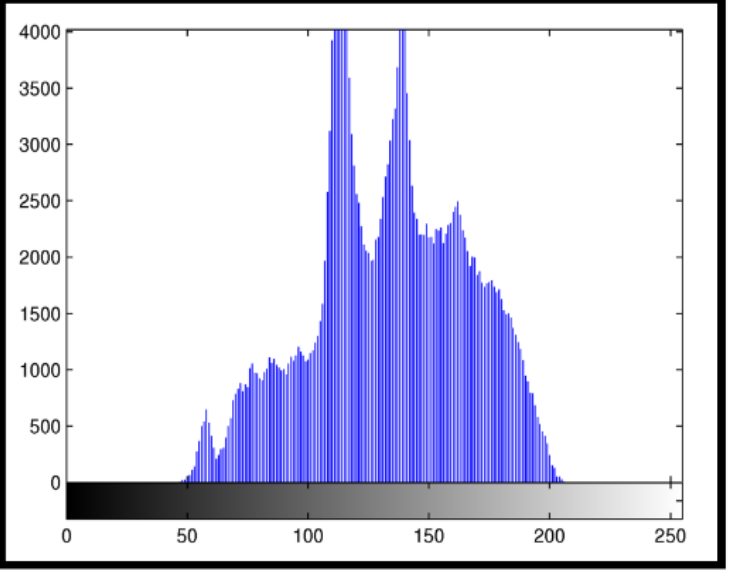
Histogram stretching



- How do we optimise the image using the histogram?
  - Minimum and maximum values?
  - Stretch it so new minimum = 0 and new maximum = 255

Histogram stretching

- We want
  - Min = 0
  - Max = 255
- We have
  - Min = 32
  - Max = 208



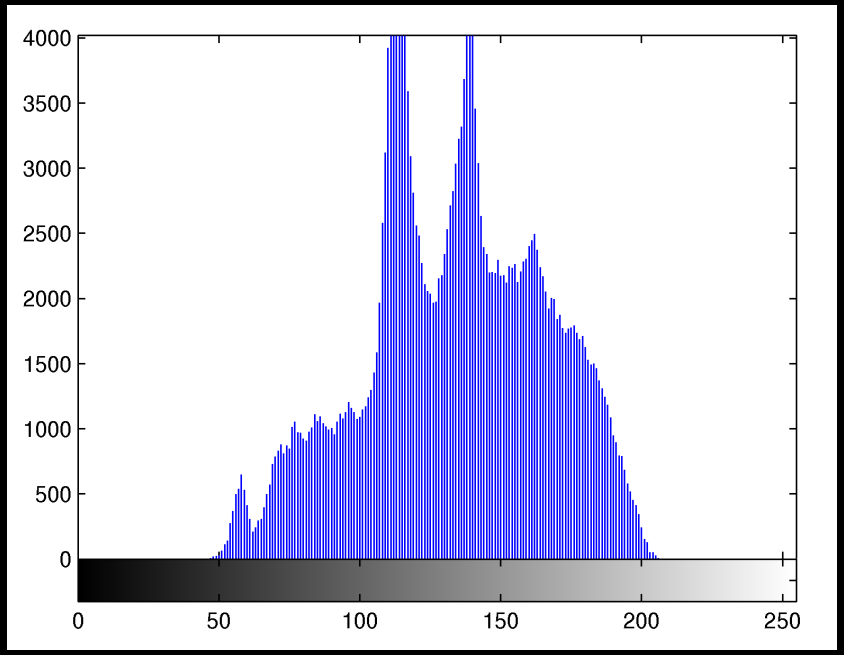
Jsing brightness

Using contrast

Jsing brightness and contrast

None of the above

Histogram stretching



- We want
  - Min = 0
  - Max = 255
- We have
  - Min = 32
  - Max = 208

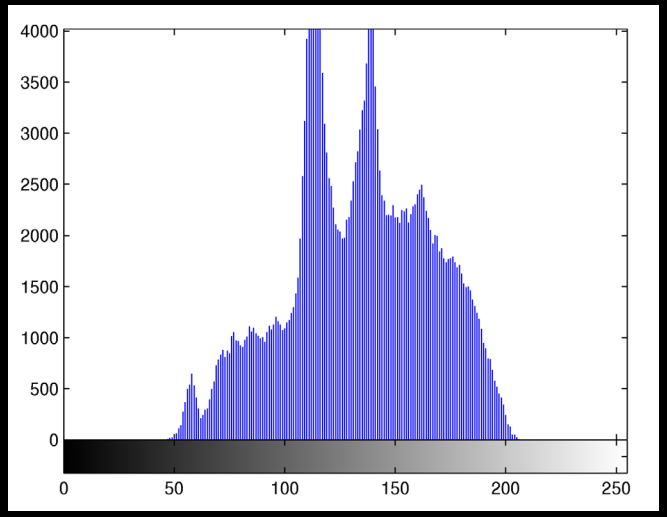
$$g(x,y) = \frac{v_{max,d} - v_{min,d}}{v_{max} - v_{min}} (f(x,y) - v_{min}) + v_{min,d}$$

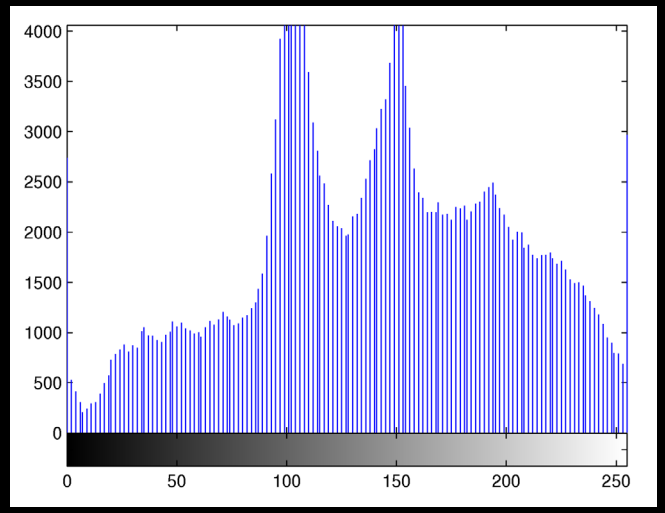
Histogram stretching formula

$$g(x,y) = \frac{v_{max,d} - v_{min,d}}{v_{max} - v_{min}} (f(x,y) - v_{min}) + v_{min,d}$$

- Desired min value $v_{min,d} = 0$
- Desired max value $v_{max,d} = 255$
- Current min value $v_{min} = 32$
- Current max value $v_{max} = 208$

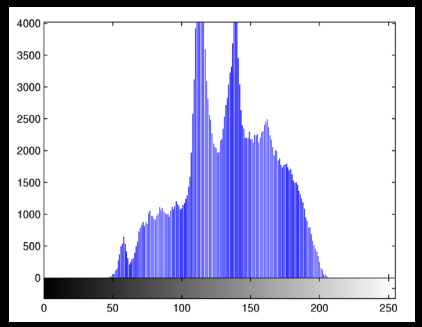
Histogram stretching





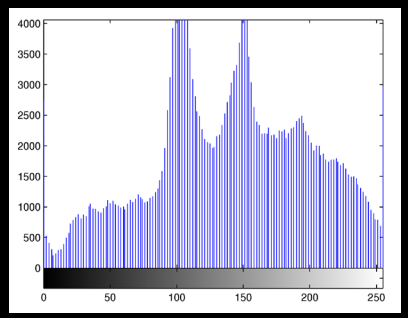
$$g(x,y) = \frac{255}{176}(f(x,y) - 32)$$

Effect of histogram stretching



32

208



0

255

Histogram stretching – weaknesses

- A single pixel value of 0 or 255 ruins it
- Sometimes you want
  - To stretch only the high pixel values
  - While "compressing" the low pixel values
  - Non-linear mapping

Linear mapping on an image

Der udføres en *linear mapping* på billedet i Figur 16 hvor resultatet er et ny grayscale billede med maksimum værdi 255 og minimum værdi 0. Hvad er den nye værdi af den pixel, der har værdi 108?

1. 95
2. 111
3. 98
4. 119
5. 101
6. Ved ikke

208	25	40	36	167
231	71	23	108	18
32	139	244	234	217
233	244	124	202	238
161	245	204	245	173

Figur 16: Grayscale billede.

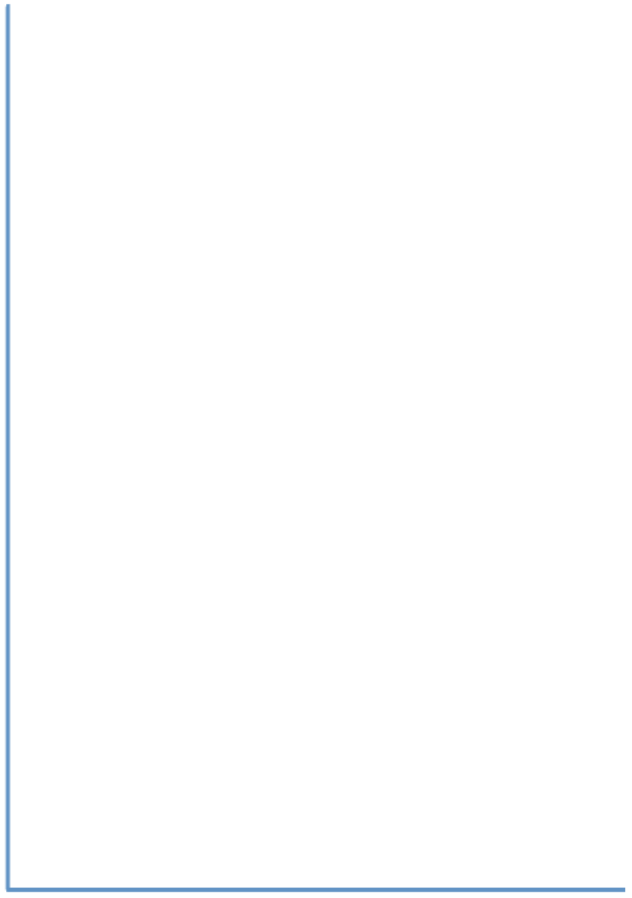
95

111

98

119

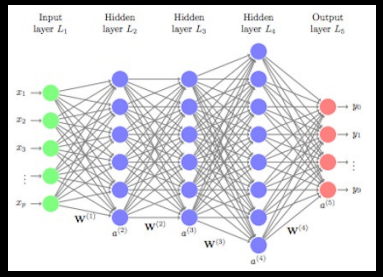
101



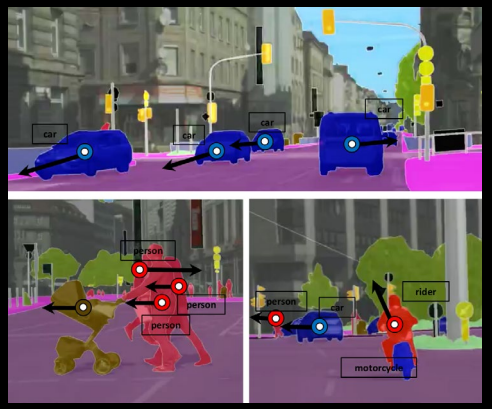
Deep learning and color/gray scale transformations

- Deep learning needs training data
  - Input image
  - Ground truth labels or classes

- When you lack data you can *augment* your data
  - Create artificial versions
  - Adding variation
  - Changing gray / color levels in the image
  - Point wise operations



http://uc-r.github.io/feedforward_DNN

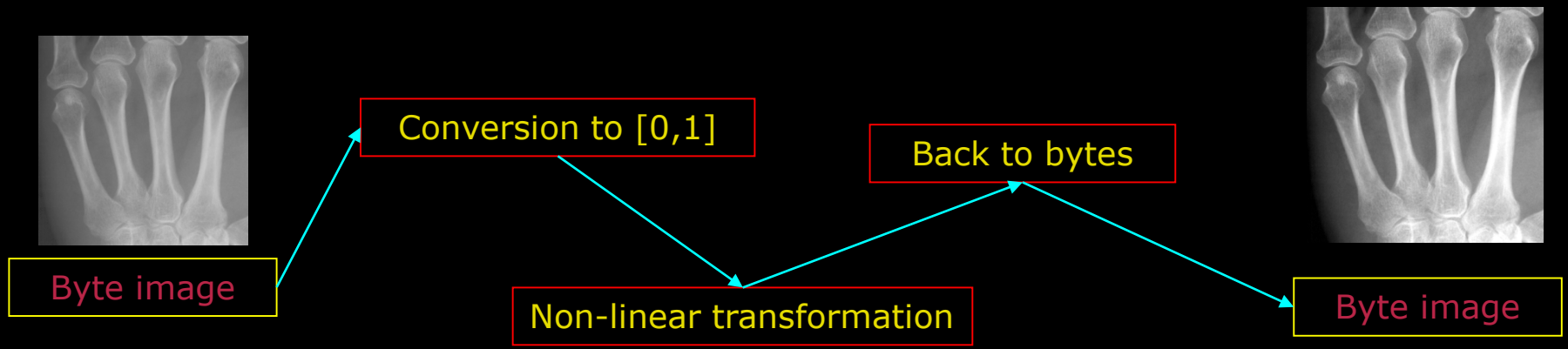


Luc, Pauline, et al. "Predicting deeper into the future of semantic segmentation." IEEE International Conference on Computer Vision (ICCV). Vol. 1. 2017.

https://www.quora.com/What-does-the-term-semantic-segmentation-mean-in-the-context-of-Deep-Learning

Other mappings

- Non-linear mappings
- Not always nice to work with byte images
  - Better to work with image with values in [0,1]



Working with bytes and doubles

- A byte contains integer values [0,255]
  - A byte can not store 127.4232
- A value of type *double* can contain "all numbers"
- Why not use doubles always?
  - One double = 8 bytes in the memory
  - Images become very large!
  - Many things can be done with bytes

Map pixels to [0,1]

- In Matlab it is easiest to create a new image of type double
  - Itemp = double(I);
  - (temp means temporary and is used by many programmers for variables that quickly are thrown away)
- Conversion to [0,1]

$$g(x,y) = \frac{1}{255} f(x,y)$$

Pixels back to bytes

- Input pixels are [0,1]
- We want them to be [0,255]
- Simple linear transformation equal to
  - Contrast?
  - Brightness?

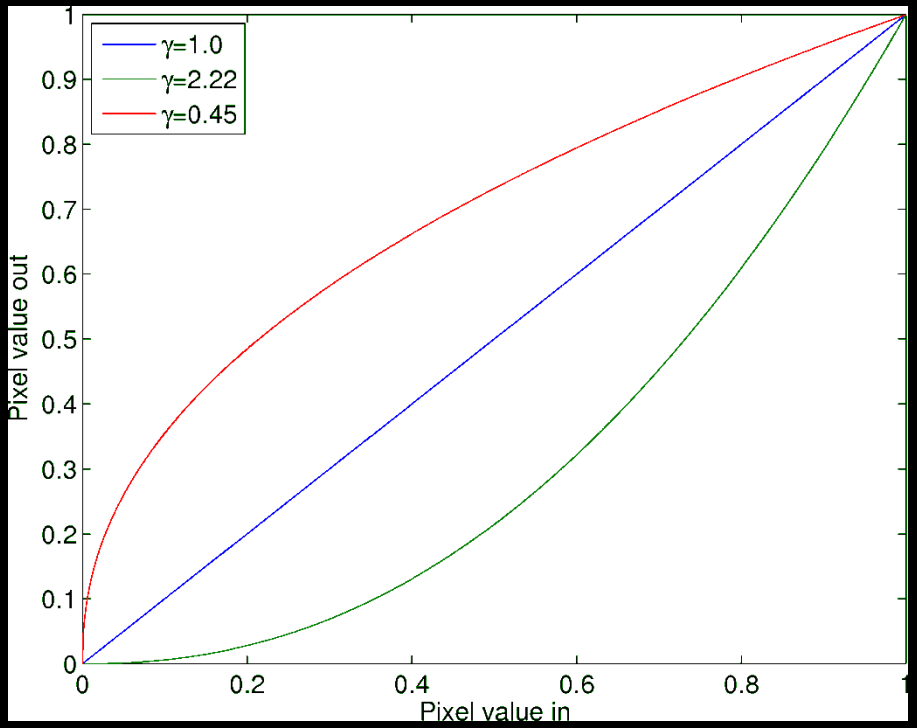
$$g(x,y) = 255 * f(x,y)$$

- Back to bytes
  - Ifinal = uint8(Itemp);

Gamma mapping

- Gamma mapping is used in televisions and flat panels
- Can increase the contrast (dynamics) in more selected part of the histogram
- Many games have a possibility for a gamma correction

Gamma curves



- Named after the Greek letter gamma
- What happens to the dark areas
  - With 0.45?
  - With 2.22?

$$g(x,y) = f(x,y)^{\gamma}$$

Perform the gamma mapping

Byte image

Conversion to [0,1]

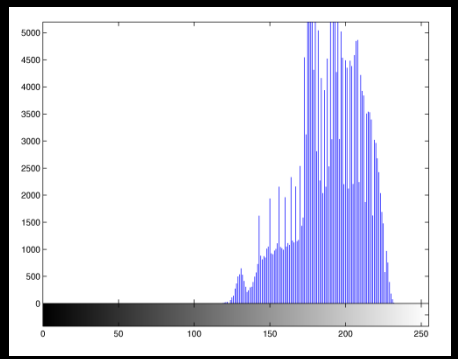
Gamma mapping

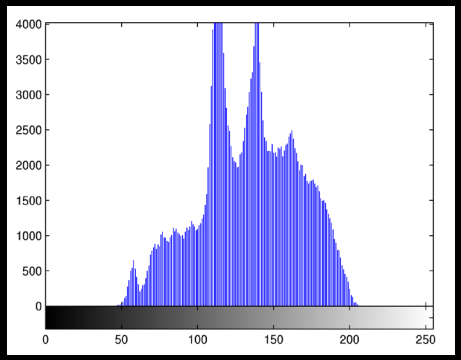
Back to bytes

Byte image

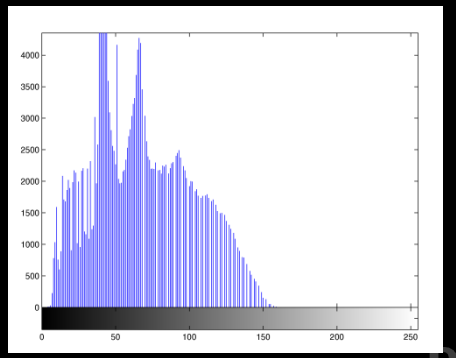
Results of gamma mapping

0.45





2.22



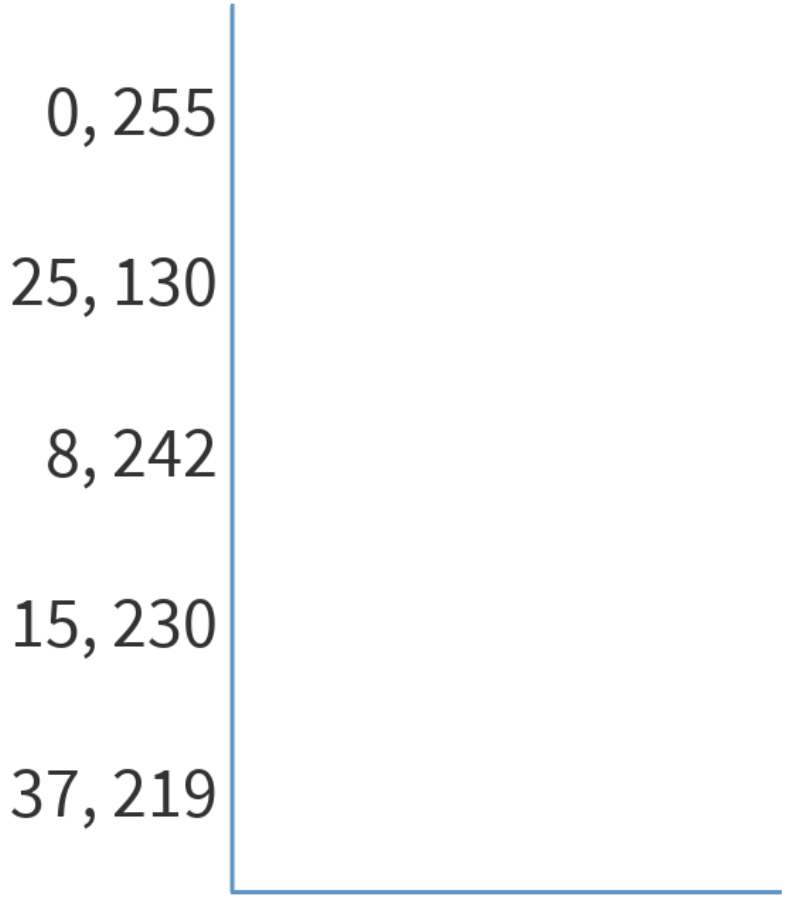
Gamma mapping on an image

Der udføres en *gamma mapping* med $\gamma = 1.3$ på billedet i Figur 3. Resultatet er et ny grayscale billede. Hvad er den mindste og største pixelværdi i det nye billede?

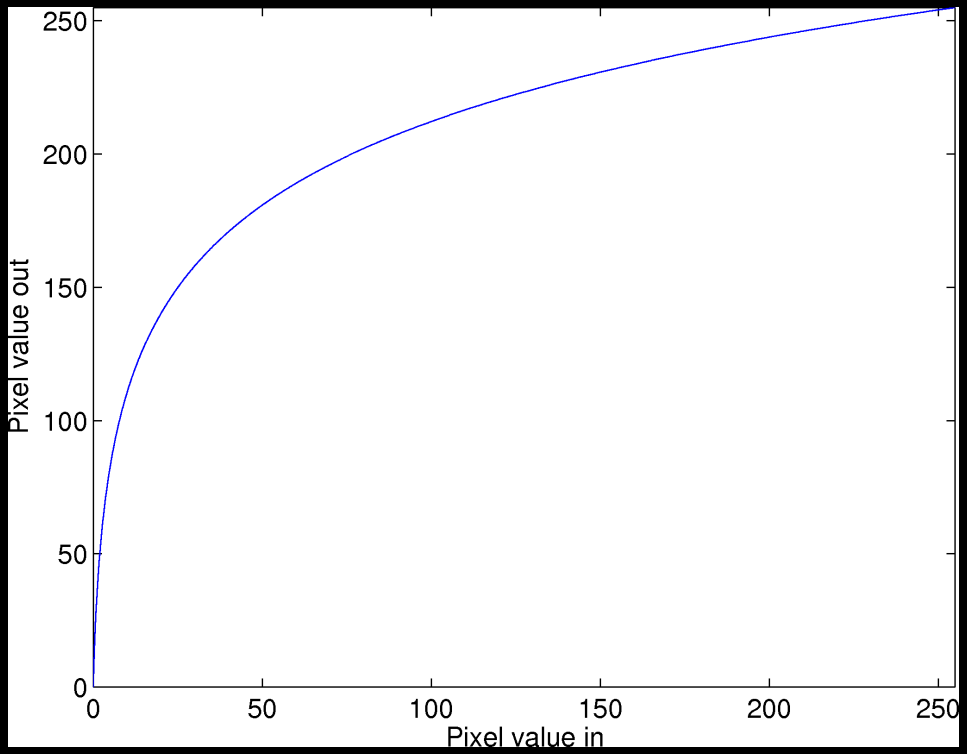
1. 0 og 255
2. 25 og 130
3. 8 og 242
4. 15 og 230
5. 37 og 219
6. Ved ikke

208	25	40	36	167
231	71	23	108	18
32	139	244	234	217
233	244	124	202	238
161	245	204	245	173

Figur 3: Grayscale billede.



Logarithmic mapping



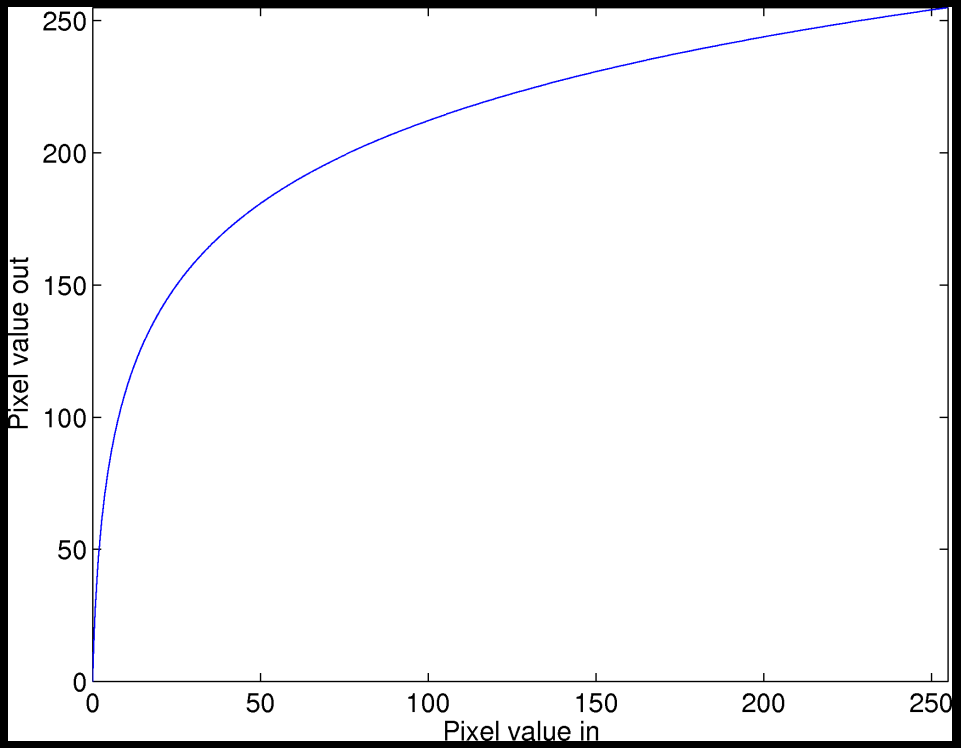
Maps from [0,255] to [0,255]

Why?

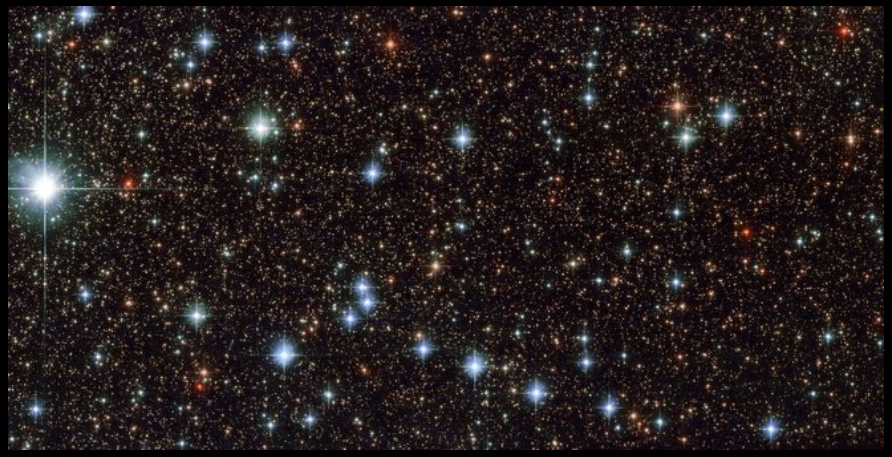
$$g(x,y) = c \log(1 + \mathrm{f}(\mathrm{x},\mathrm{y}))$$

$$c = \frac{255}{\log(1 + v_{max})}$$

Logarithmic mapping – when?



- For images with very bright spots
- Low intensity pixel values are enhanced

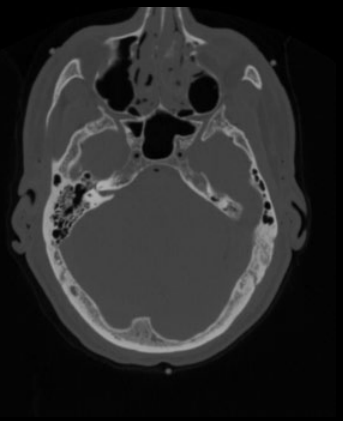


What do we get out of pixel mappings

- Spreading out or compressing pixel values
  - Better for humans to see
  - New information – no!

Now for something different

- Until now image processing
  - Input image transformed to output image
- Now for something more like image analysis
- Segmentation
  - Segment the image into regions
    - Background and objects for example

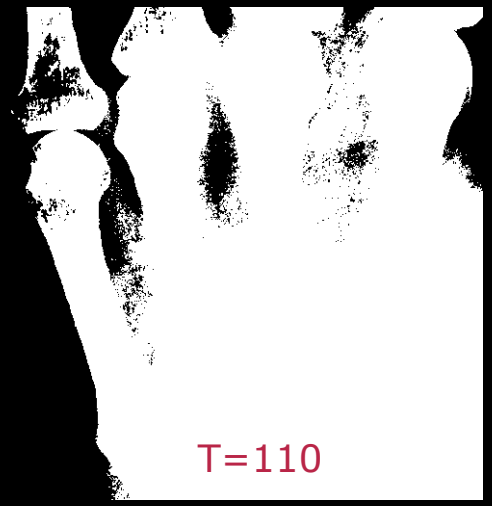
Thresholding

- A threshold T is a value
  - Pixels below that value is set to 0 (background)
  - Pixels equal or above is set to 1 (object)
- One threshold value for the entire image
  - Difficult to choose!

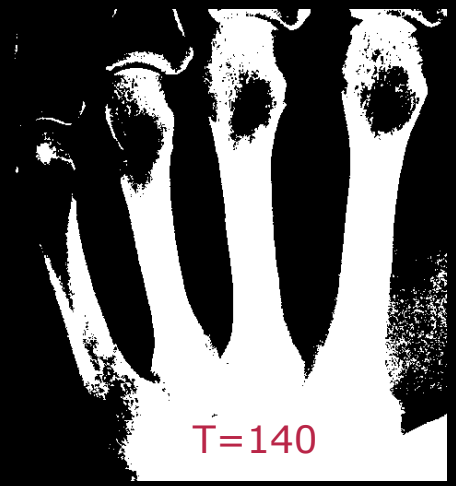
$$\text{if } f(x,y) \leq T \text{ then } g(x,y) = 0$$

$$\text{if } f(x,y) > T \text{ then } g(x,y) = 255$$

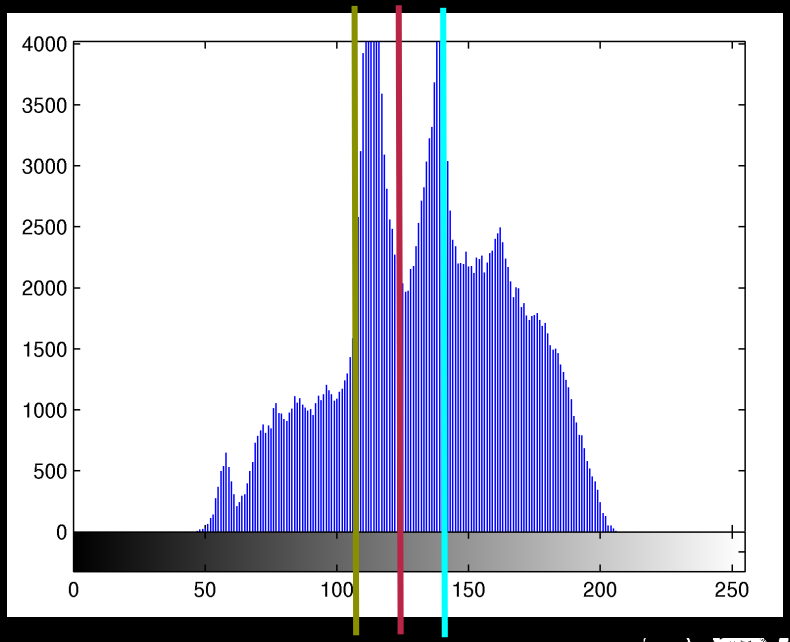
Thresholding



Background and bone have same value!

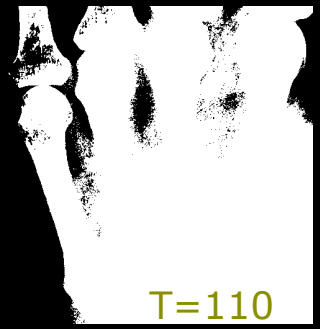


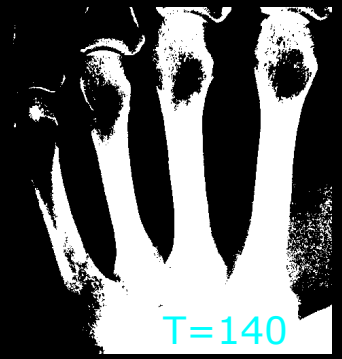
Thresholding based on the histogram



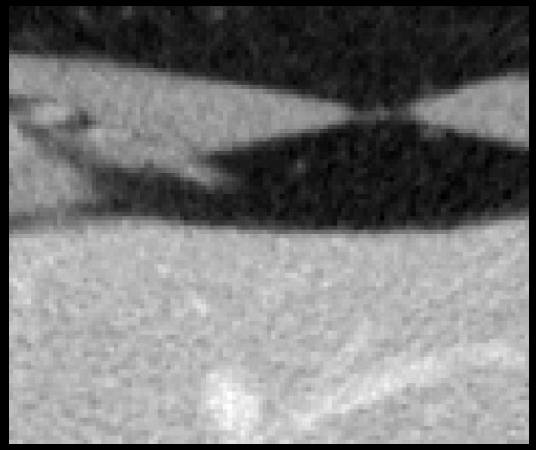
The bones are visible in the histogram!

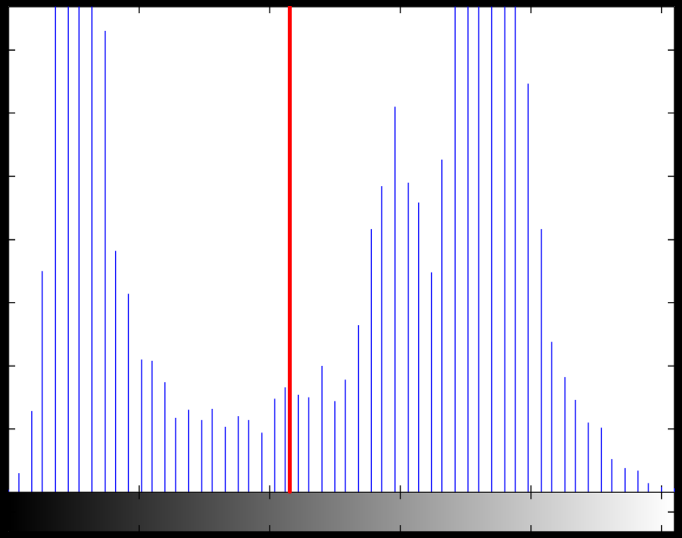
But mixed with soft-tissue





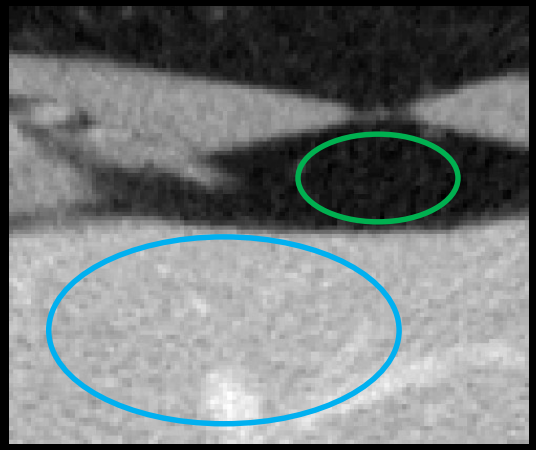
Automatic Tresholding

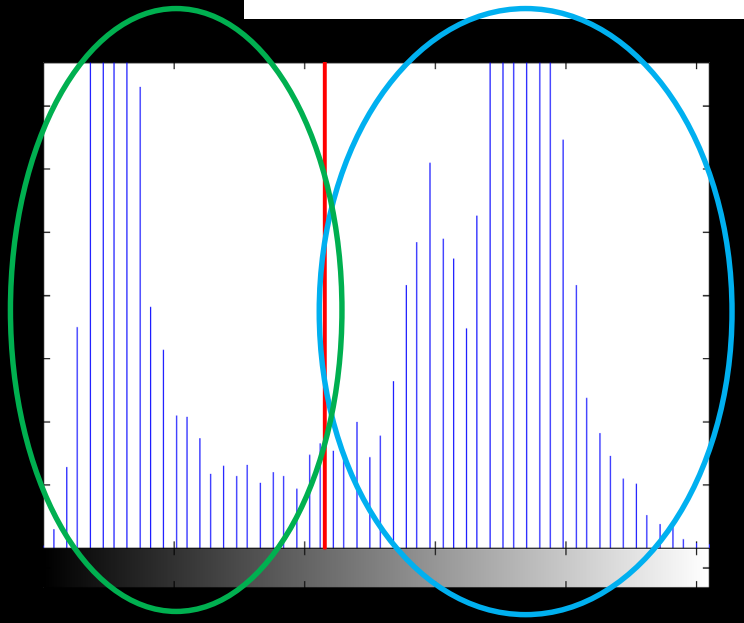




Otsu, Nobuyuki. "A threshold selection method from gray-level histograms." IEEE transactions on systems, man, and cybernetics 9.1 (1979): 62-66.

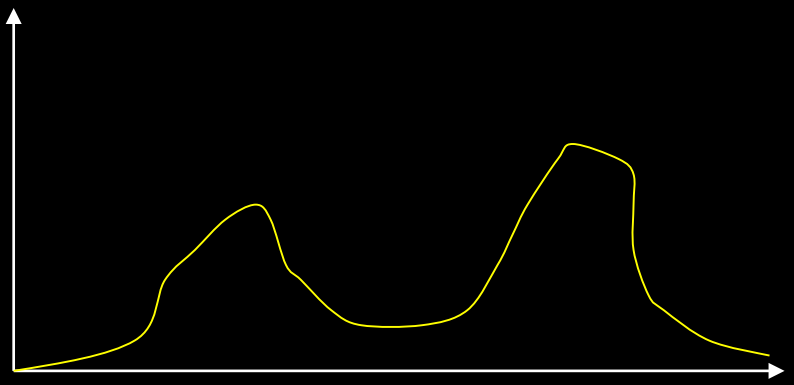
Automatic Tresholding Otsu's method

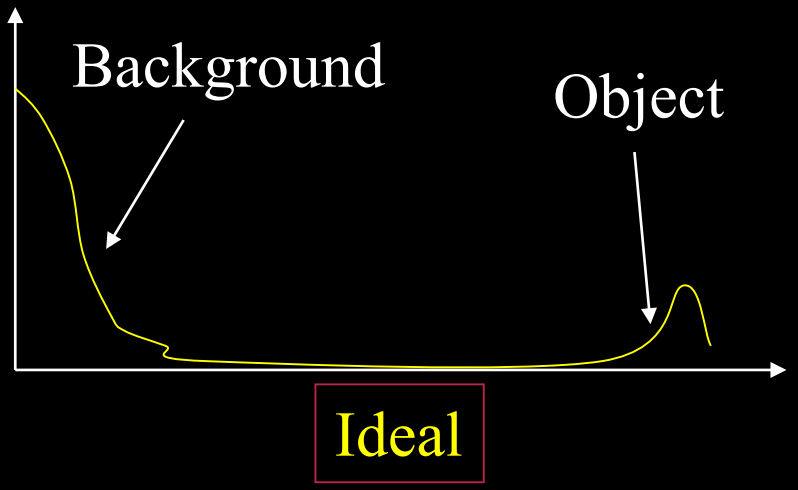




- Two classes: background and object
- T divides pixels into object and background
- Compute pixel value variance in each class
- Find T that minimises combined variance

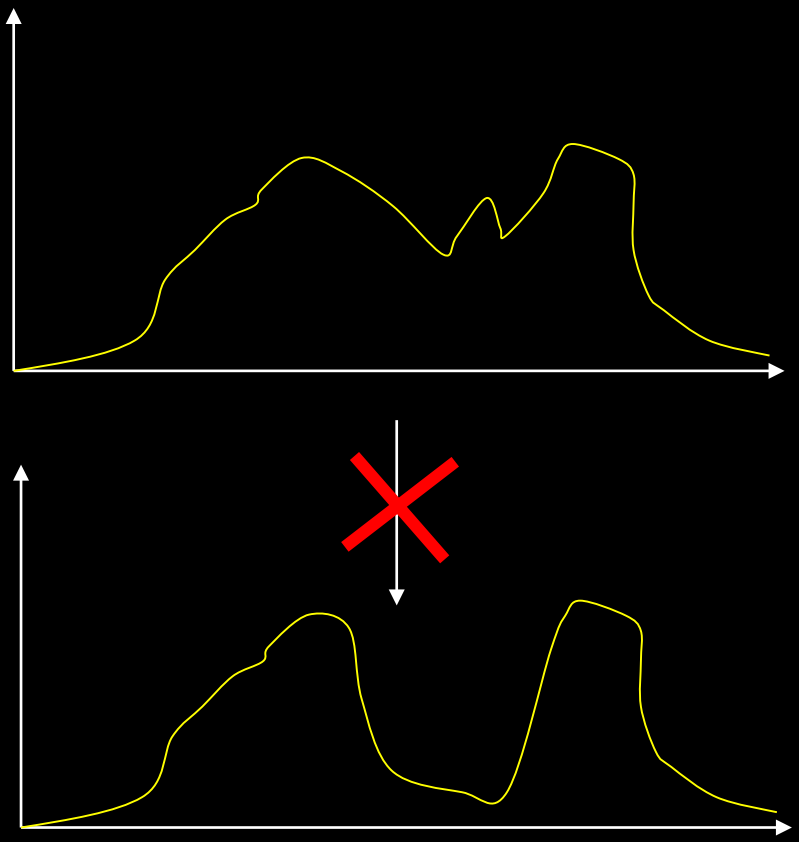
Segmentation – histogram shaping





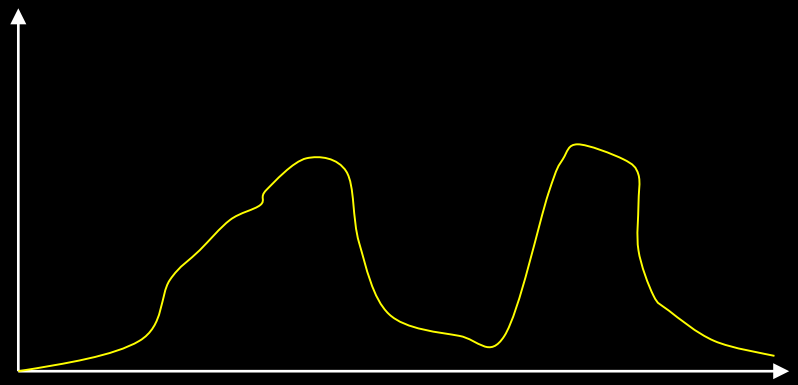
- With a threshold you want a histogram with two peaks
  - *Bimodal*
- An ideal histogram has well separated peaks
- Obtaining a bi-modal histogram is very important in the image acquisition

Histogram shaping



- It is not possible to "unmix" using gray level transformations

How to obtain good histograms



- With cameras
  - Light
  - Setup
  - Camera
  - Lens
  - Backlight?

Gamma mapping and threshold on an image

Der udføres en *gamma mapping* med $\gamma = 1.1$ på billedet i Figur 12 og herefter sættes der et *threshold* på 120. Pixels over threshold sættes til forgrund og resten til baggrund. Hvor mange forgrundspixler er der i resultatbilledet?

1. 5
2. 2
3. 10
4. 7
5. 12
6. Ved ikke

108	245	217
234	167	238
202	9	173

Figur 12: Grayscale billede.

5

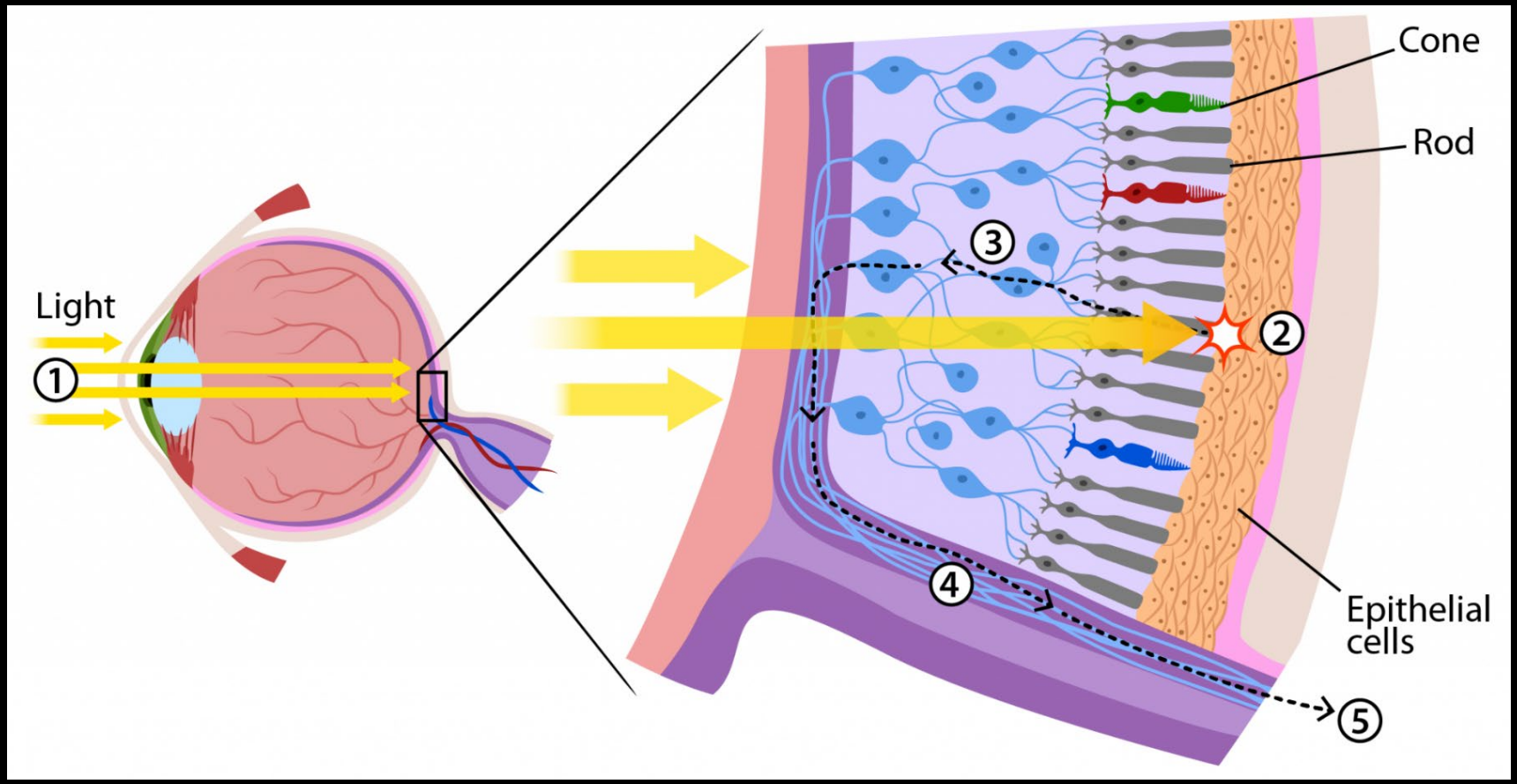
2

10

7

12

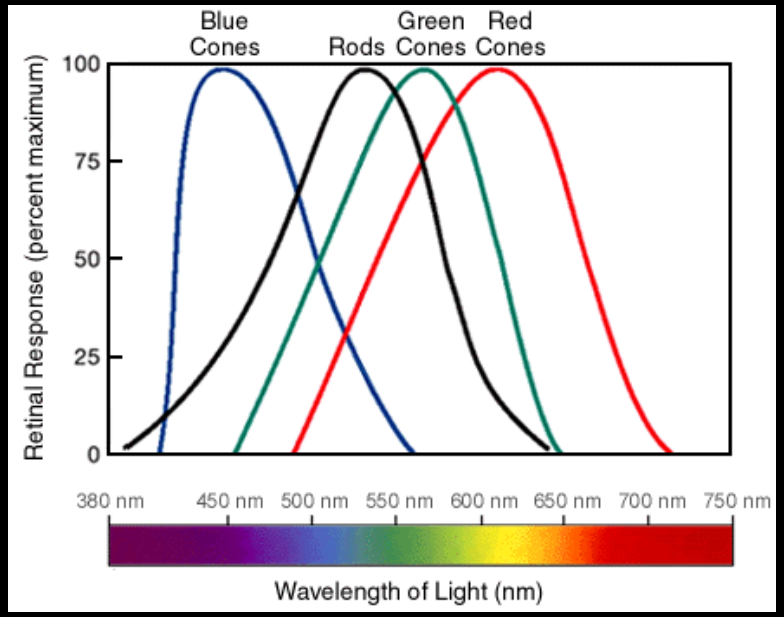
Colour images and colour perception
The Human Eye



https://askabiologist.asu.edu/rods-and-cones

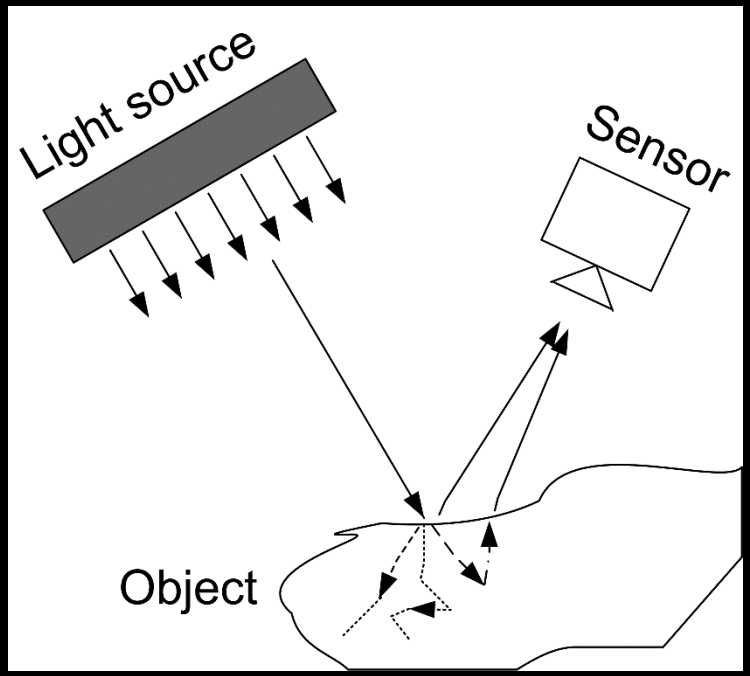
Color sensitivity

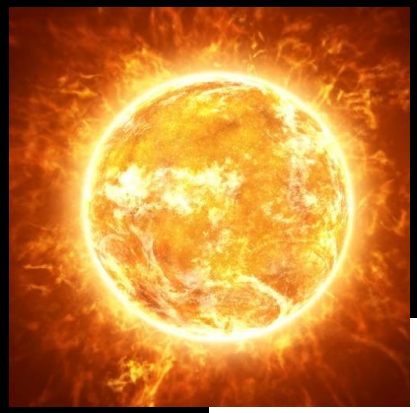
Photoreceptor cell	Wavelength in nanometers (nm)	Peak response in nanometer (nm)	Interpretation by the human brain
Cones (type L)	[400-680]	564	Red
Cones (type M)	[400-650]	534	Green
Cones (type S)	[370-530]	420	Blue
Rods	[400-600]	498	Shade of gray

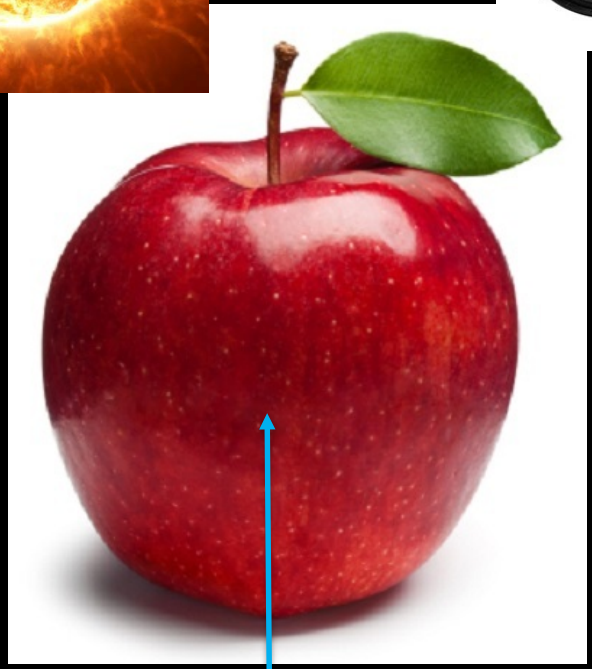


https://askabiologist.asu.edu/rods-and-cones

Object colors
Subtractive colors







All other colors than red absorbed

Object colors
Additive colors

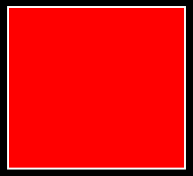
- Additive colours: Final colour is made by mixing red, green, and blue
- RGB = Red, Green, and Blue
- Television, computers, digital cameras use the “RGB color space”
- Typically the values of R, G, and B lie between 0 and 255

RGB Colours

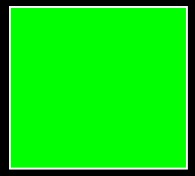
RGB = (0,0,0)

RGB = (255,255,255)

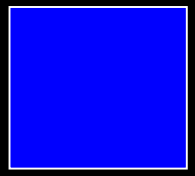
- When alle three “Lamps” are turned of we get black
- When all three “lamps” are on what do we get?



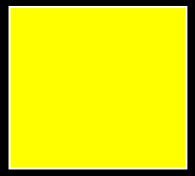
(255,0,0)



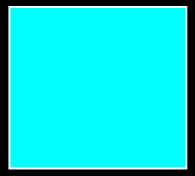
(0,255,0)



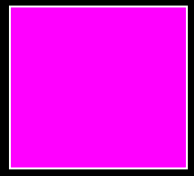
(0,0,255)



(255,255,0)

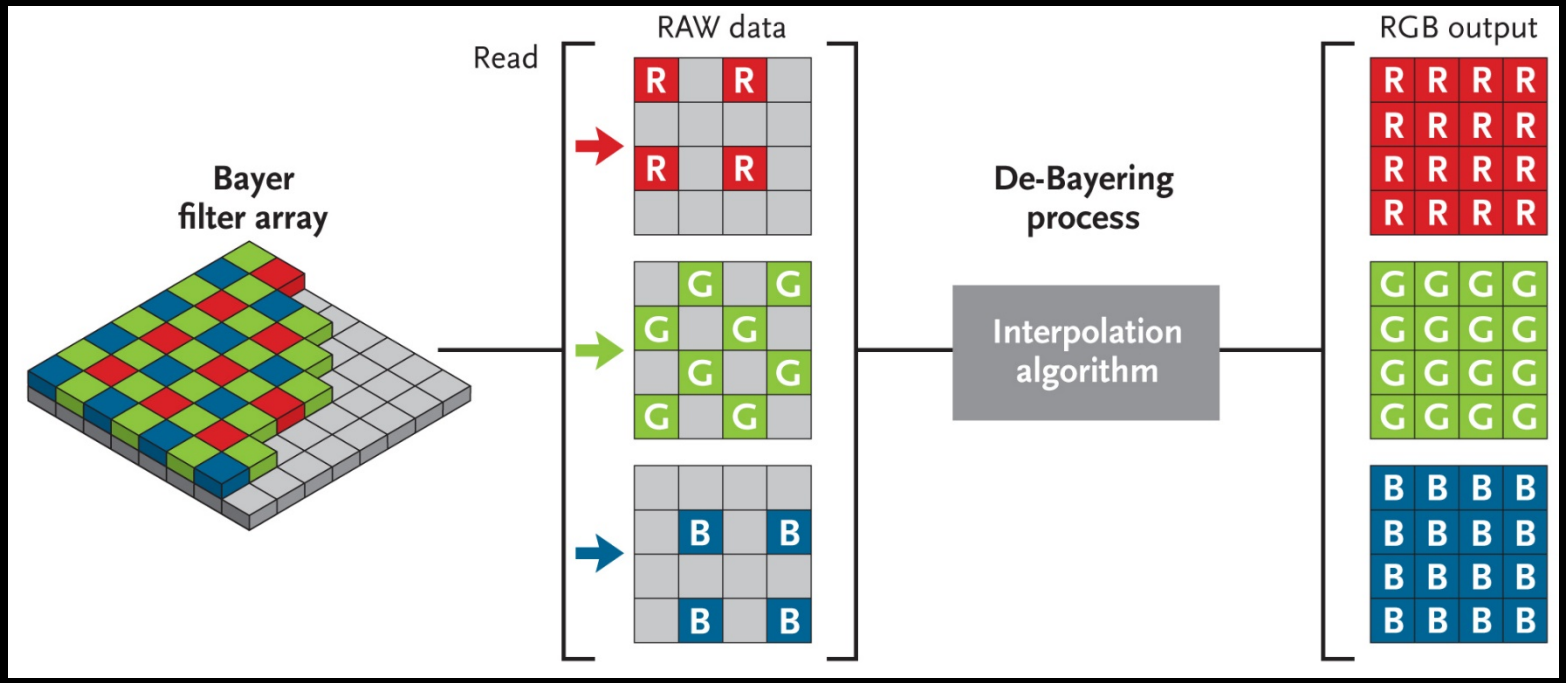


(0,255,255)



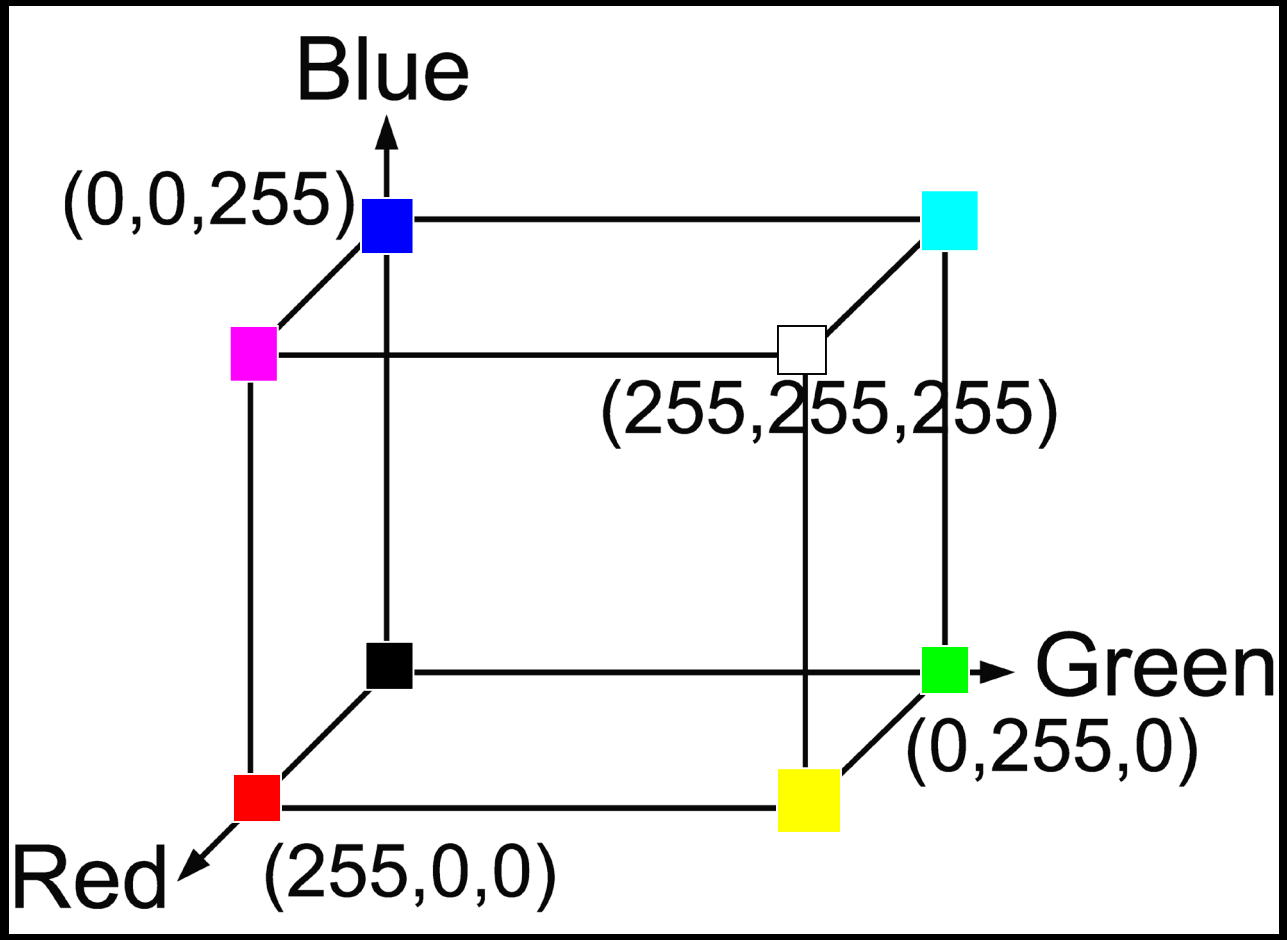
(255,0,255)

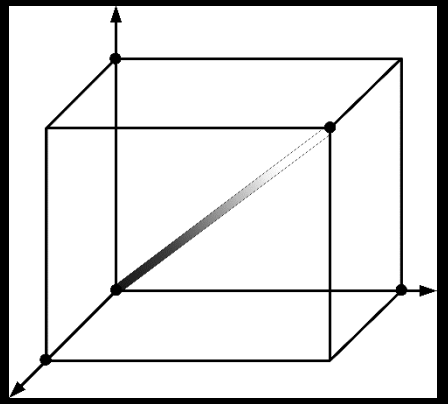
Color camera with one sensor



http://www.skyandtelescope.com/astronomy-resources/astrophotography-tips/redeeming-color-planetary-cameras/

RGB color space



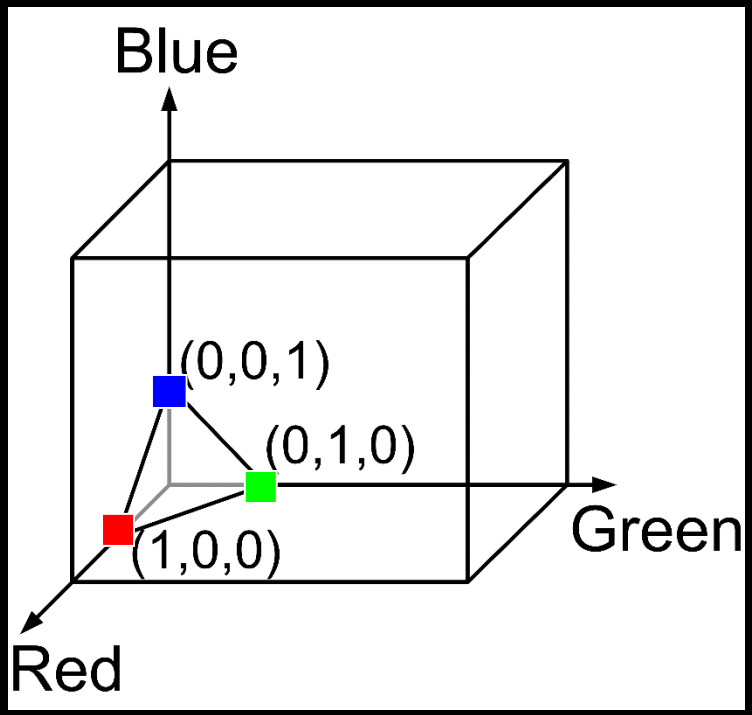


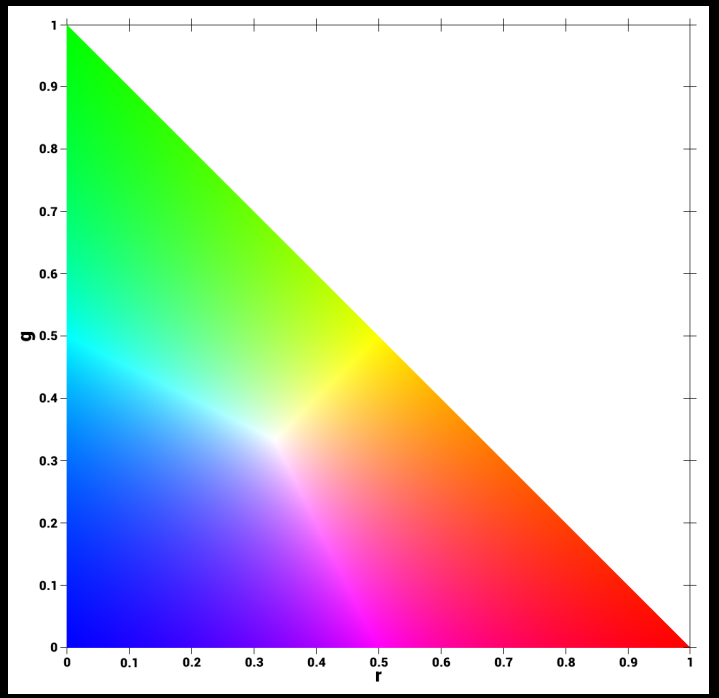
Converting colour to grayscale

$$v = 0.2989 * R + 0.5870 * G + 0.1140 * B$$

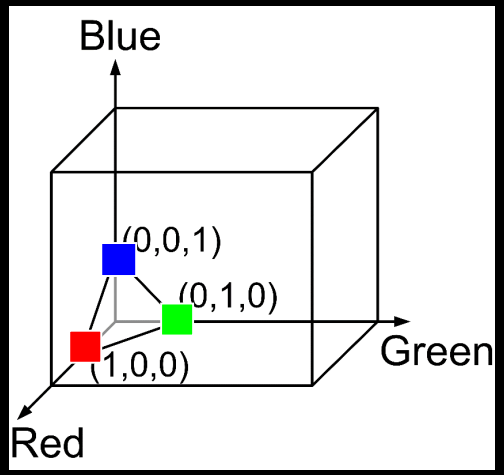
Normalised RGB colors

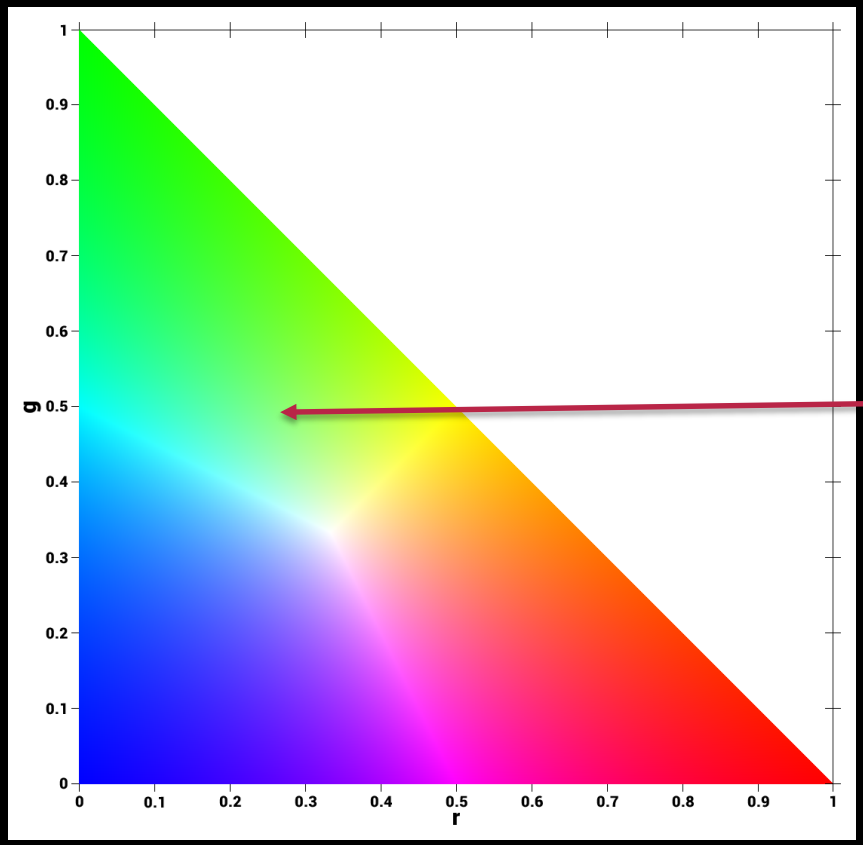
$$(r,g,b) = \left(\frac{R}{R+G+B}, \frac{G}{R+G+B}, \frac{B}{R+G+B}\right)$$





Another RGB representation



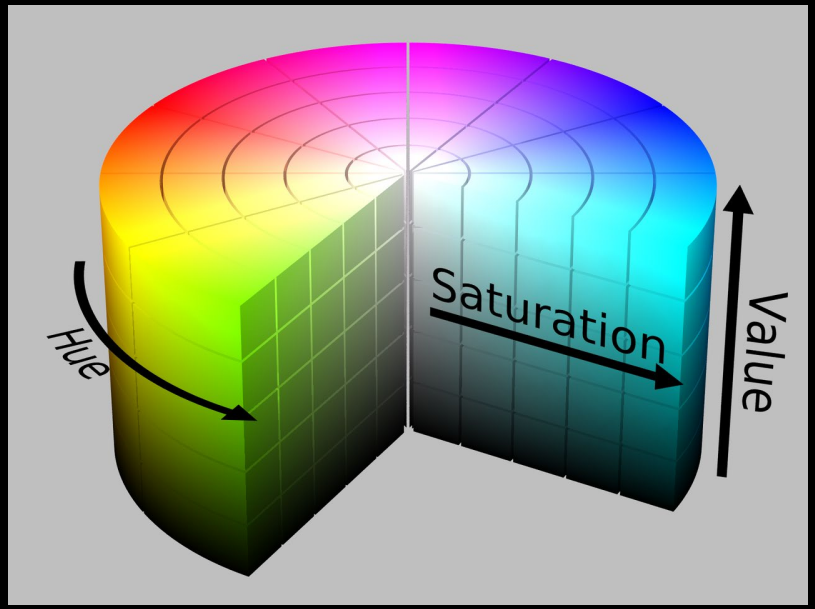


(r,g,I)

$$I = \frac{R+G+B}{3}.$$

HSI Color Reprentation

- Hue – the dominant wave length in the perceived light (the pure color)
- Saturation – the purity of the color
- Intensity – the brightness of the color (sometimes called the value)



Converting between RGB and HSI

- You have an RGB value
- You want the corresponding HSI value

$$H = \begin{cases} \cos^{-1}\left(1/2 \cdot \frac{(R-G)+(R-B)}{\sqrt{(R-G)(R-G)+(R-B)(G-B)}}\right), & \text{if } G \geq B; \\ 360^\circ - \cos^{-1}\left(1/2 \cdot \frac{(R-G)+(R-B)}{\sqrt{(R-G)(R-G)+(R-B)(G-B)}}\right), & \text{Otherwise.} \end{cases} \quad (8.8)$$

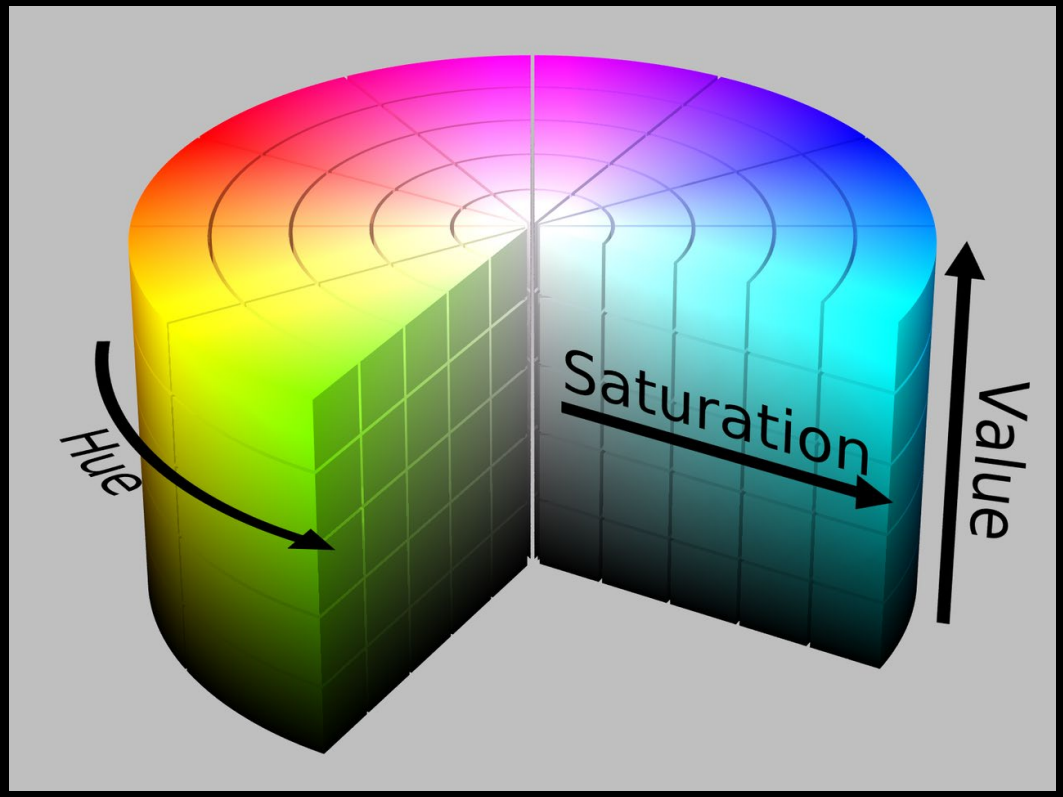
$$H \in [0, 360[$$

$$S = 1 - 3 \cdot \frac{\min\{R, G, B\}}{R+G+B} \qquad S \in [0, 1] \quad (8.9)$$

$$I = \frac{R+G+B}{3} \qquad I \in [0, 255] \ , \quad (8.10)$$

Why other colorspaces

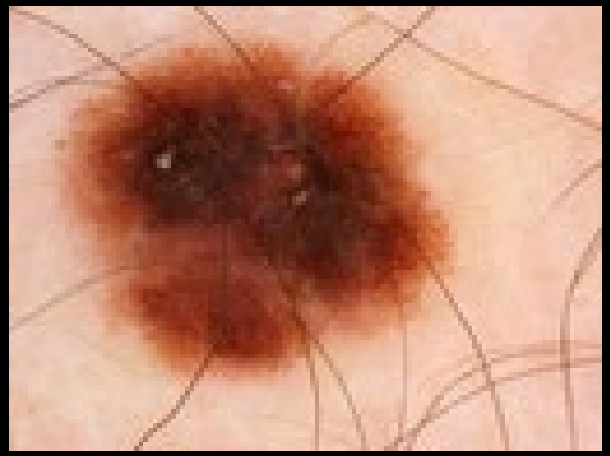
- Why should we use for example HSI ?



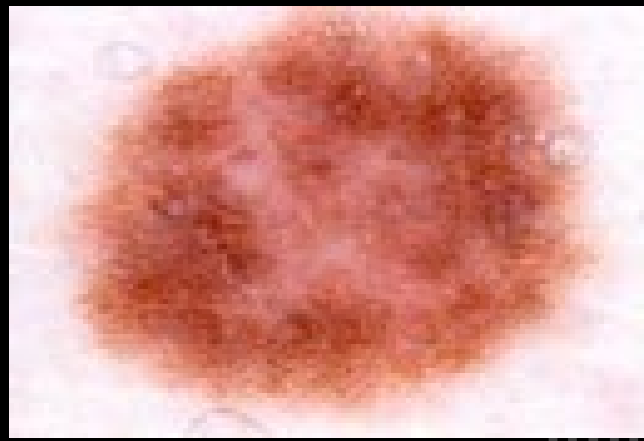
Melanoma segmentation

- An algorithm that can do pixelwise classification
  - Background / skin
  - Melanoma
- Use the colors

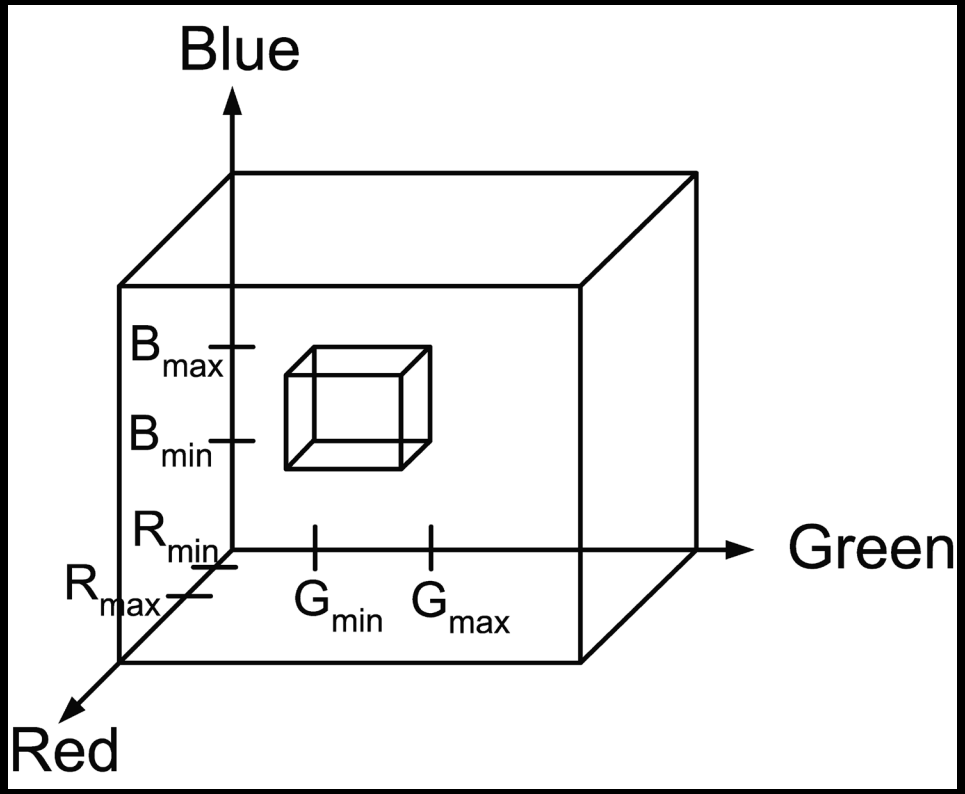
Melanoma segmentation – color variation





Color thresholding



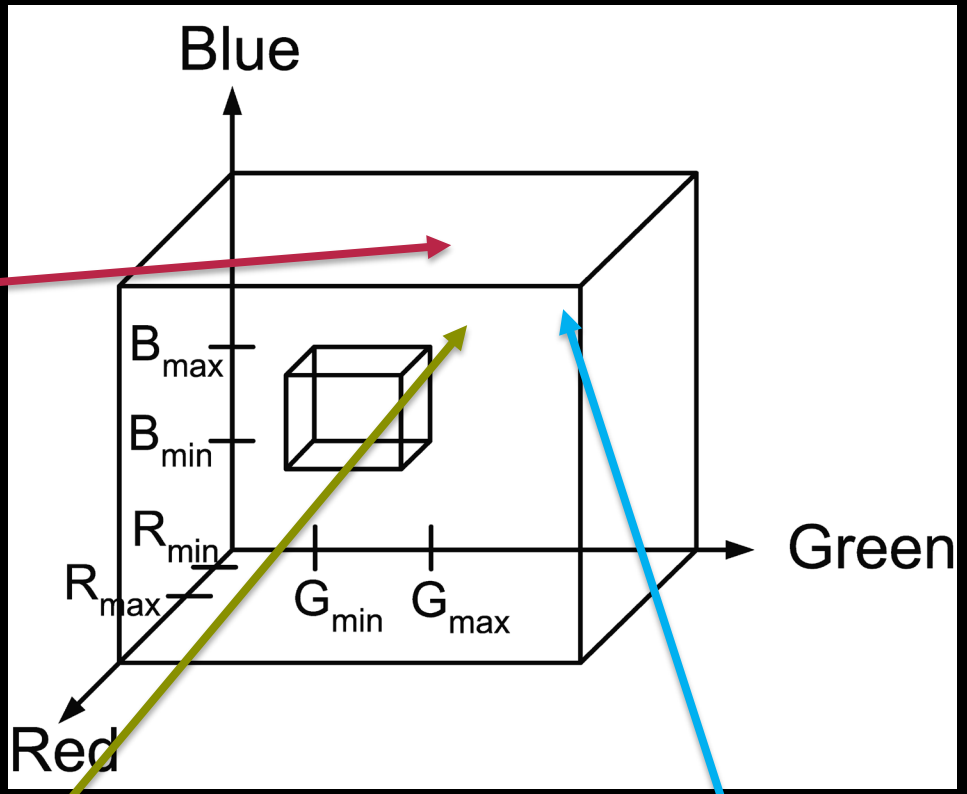
If

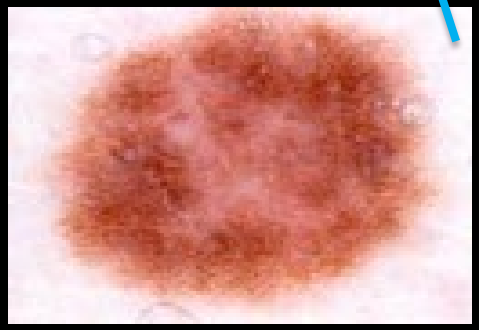
$$R > R_{min} \text{ and } R < R_{max} \text{ and}$$
$$G > G_{min} \text{ and } G < G_{max} \text{ and}$$
$$B > B_{min} \text{ and } B < B_{max}$$

Then $g(x, y) = 255$

Else $g(x, y) = 0$

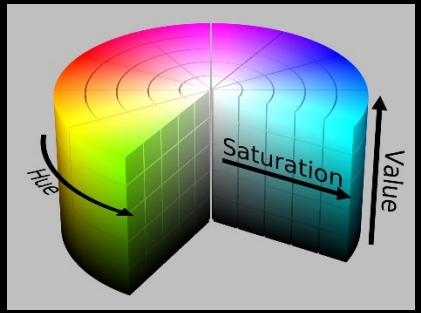
Color thresholding

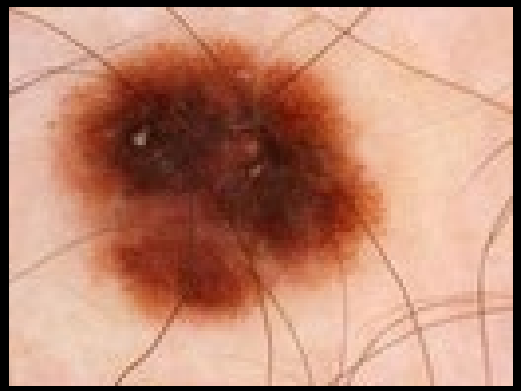


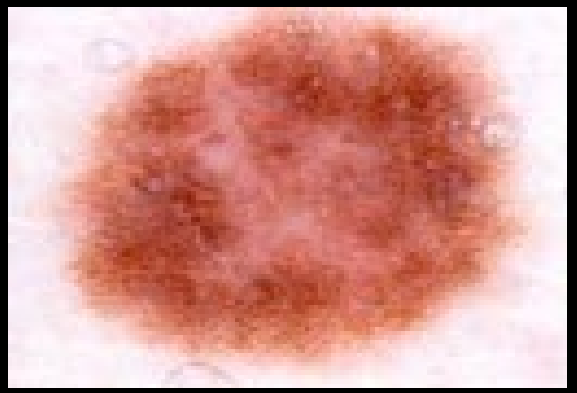


Color variation

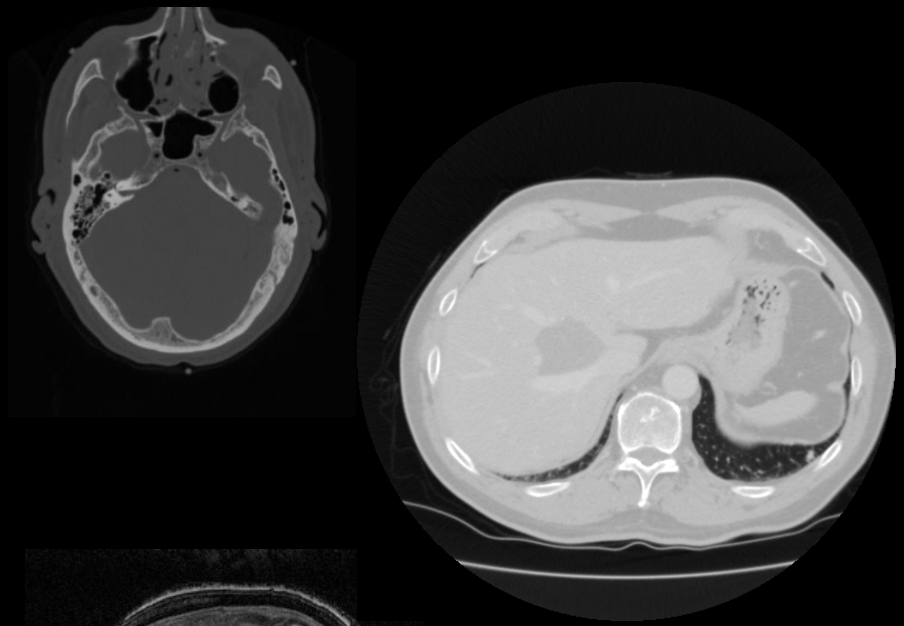
- The major variation is in the brightness
  - This will spread out the values in RGB space
- The Hue is rather constant
- HSI Space
  - HUE and saturation rather stable
  - Only variation in intensity / value





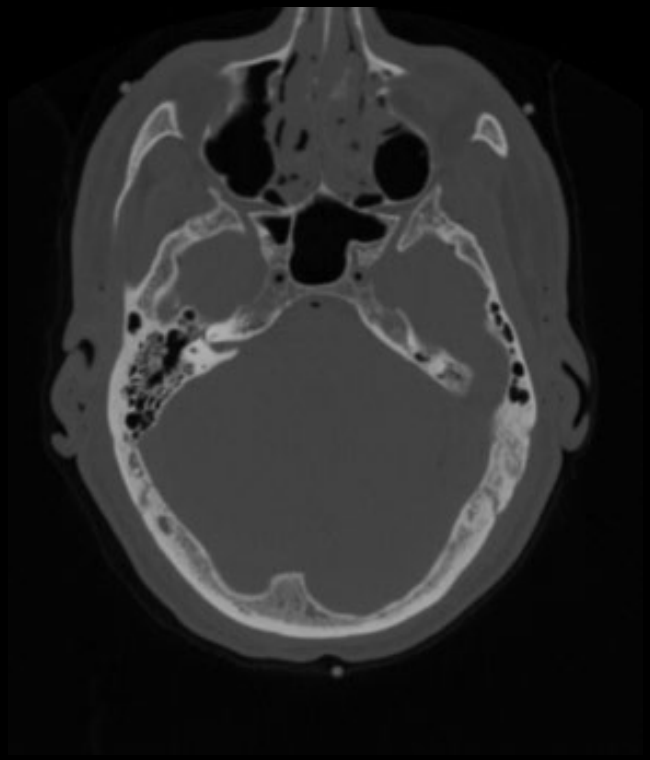


Contrast in medical images



- How do we optimise image acquisition when we want to look at
  - Bones
  - Brain structures
  - Cancer

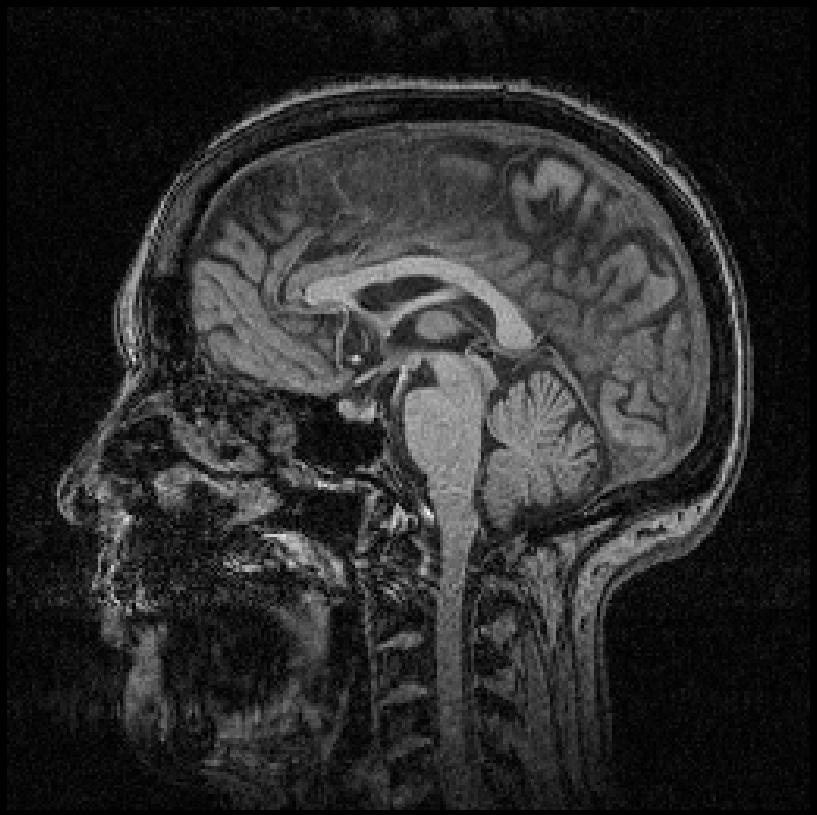
Image acquisition - bone



- X-rays
  - goes through soft tissue with little loss
  - are attenuated in bone
- CT scanners use X-rays
  - Good for imaging bones
- A simple threshold can often extract the bones
- Areas with only bone and soft-tissue will have a bimodal histogram

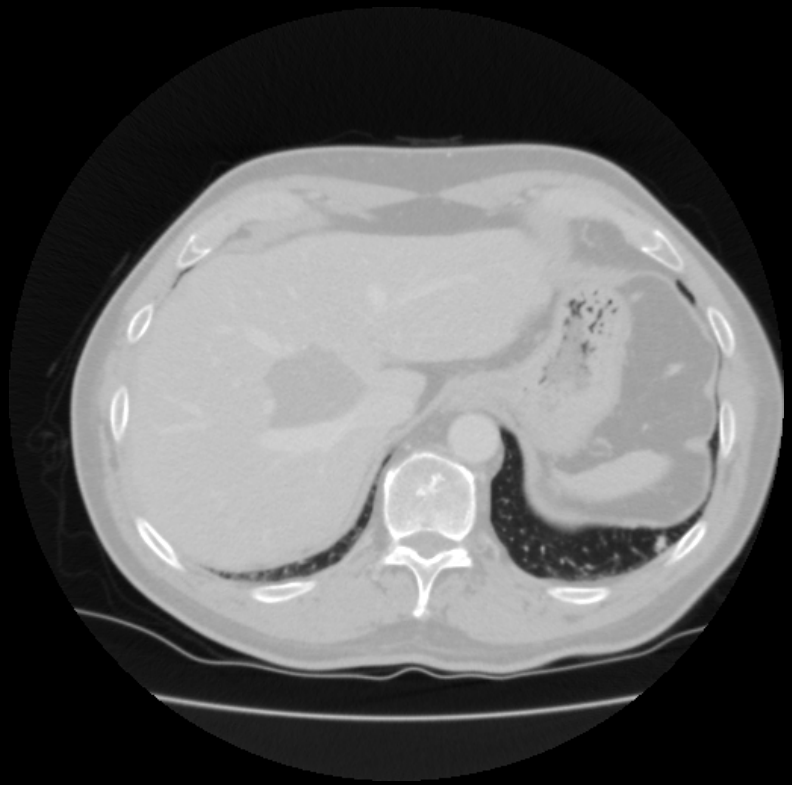
Attenuation - the gradual loss in intensity

Image acquisition – brain structures



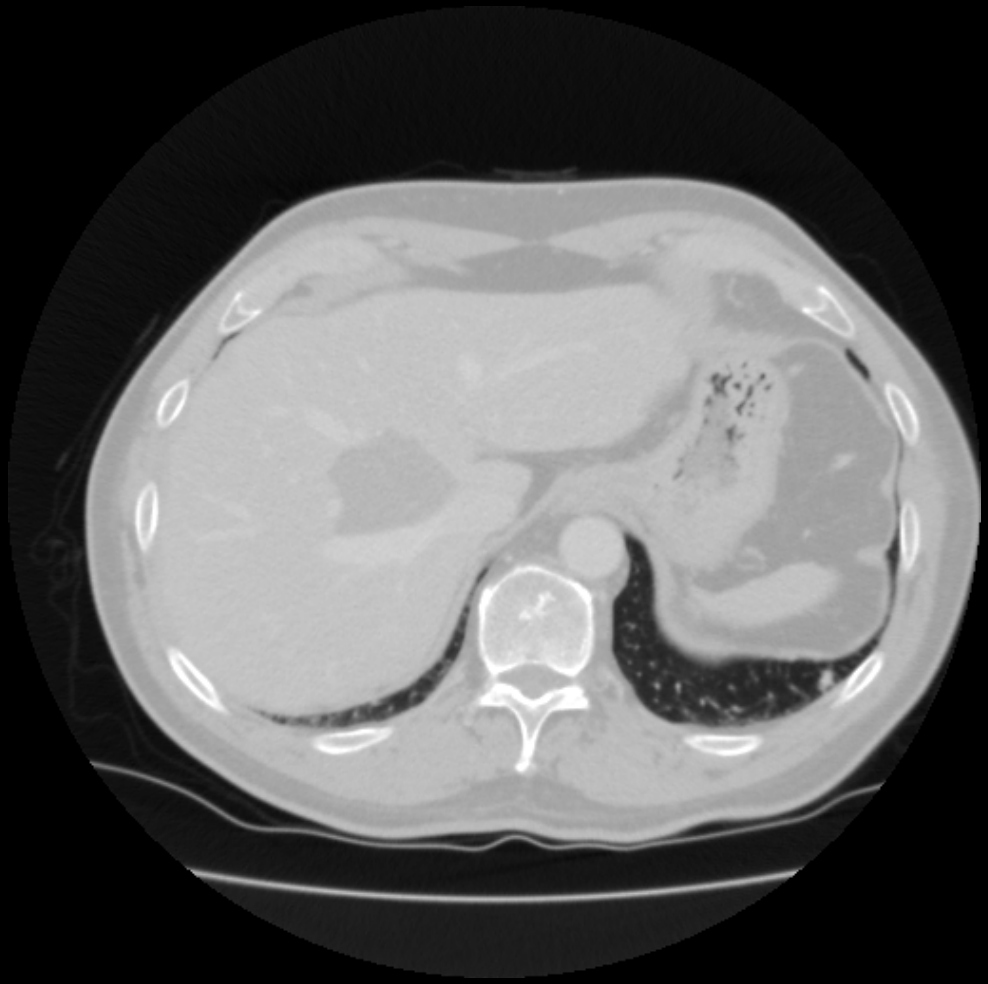
- Magnetic Resonance Imaging (MRI) is often used
- Much more difficult to explain!
  - Based on very powerful magnetic fields and radio waves
- Needs water molecules!
- Bone is black!

Image acquisition - cancer

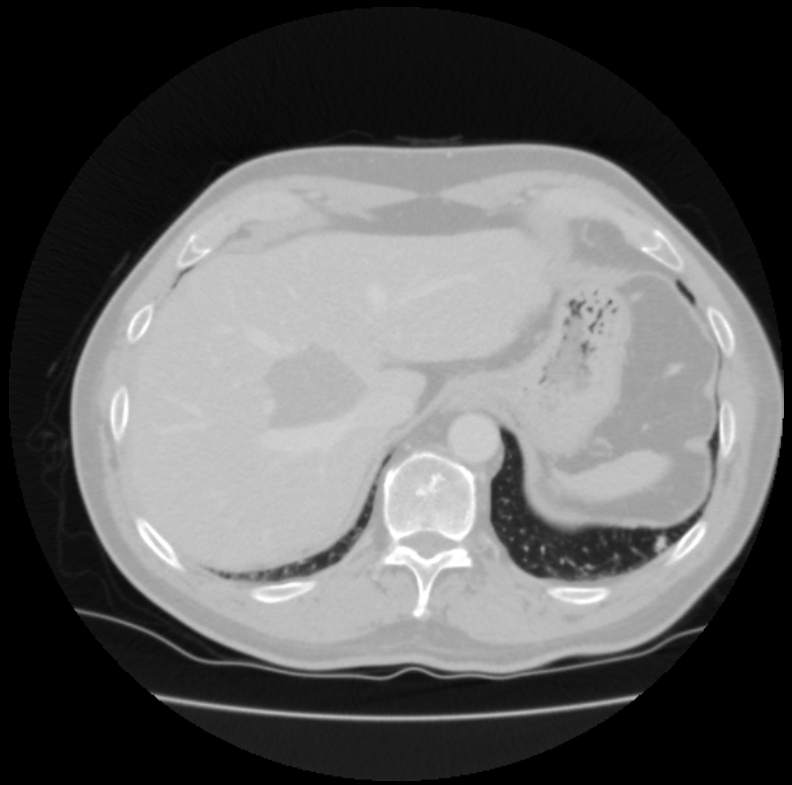


- CT scan
- Liver cancer
  - Very difficult to see

What makes cancer cells special?

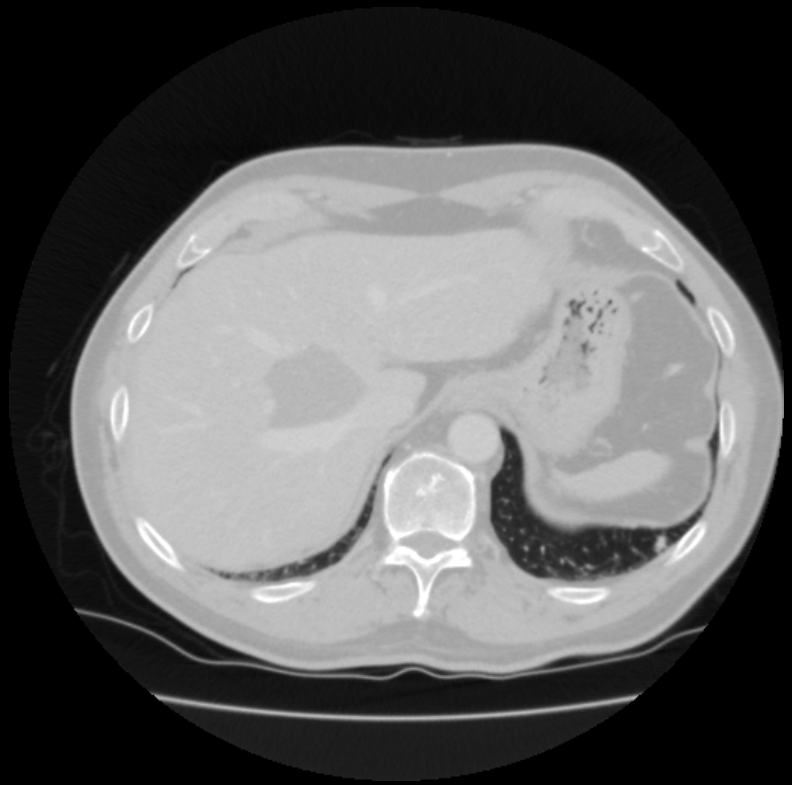


Cancer metabolism



- Cancer cells typically have a high metabolism
  - They eat more!
- Some substances are easier to see on different scanners
  - Bone on CT

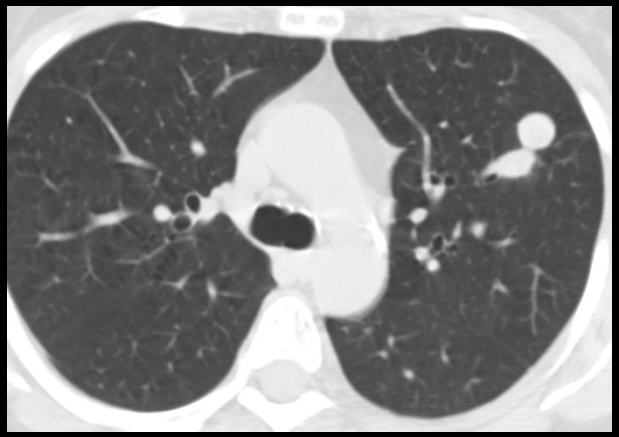
Using the cancer metabolism



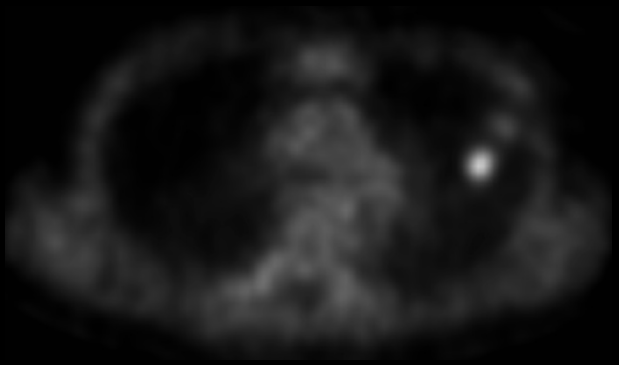
- Something that is to see
  +
- Something that is being eaten by the cancer

- A tracer

Contrast using tracers



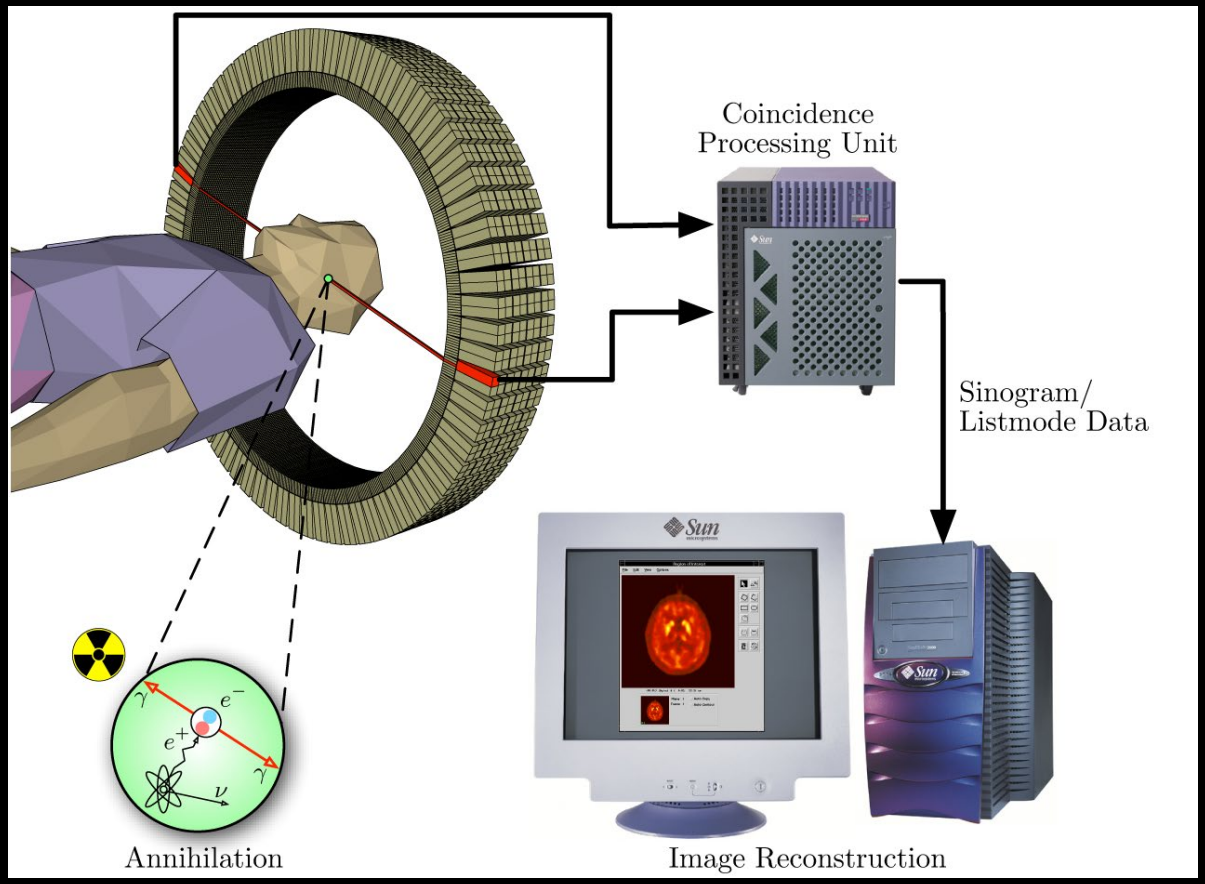
CT image



PET-FDG image

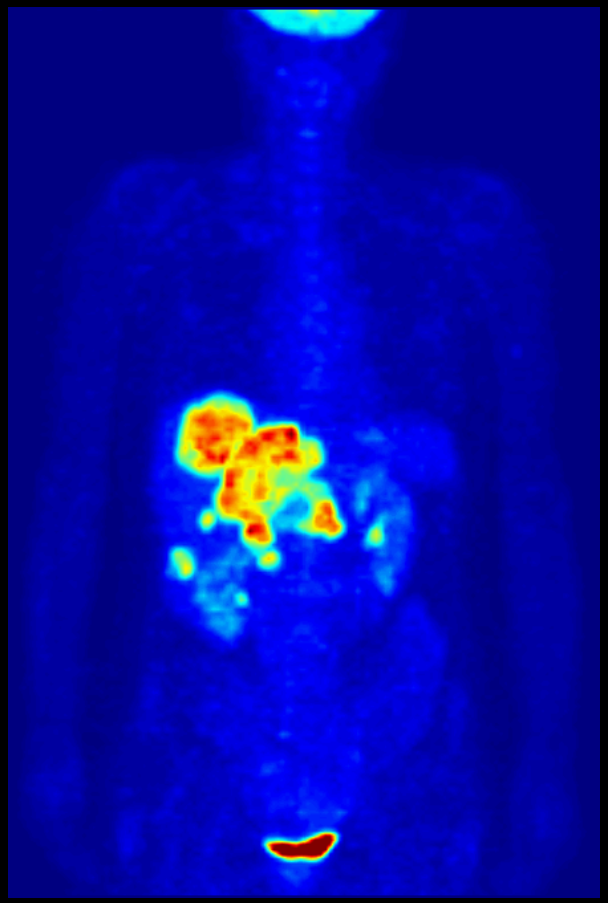
- A commonly used tracer is
  - 18F-FDG = 18F-fluorodeoxyglucose
- Used in *oncological PET*
  - *Oncology : Cancer*
  - *PET: positron emission tomography*
- Positron-emitting radioactive isotope fluorine-18
- Glucose is a “sugar”

PET



Wikipedia

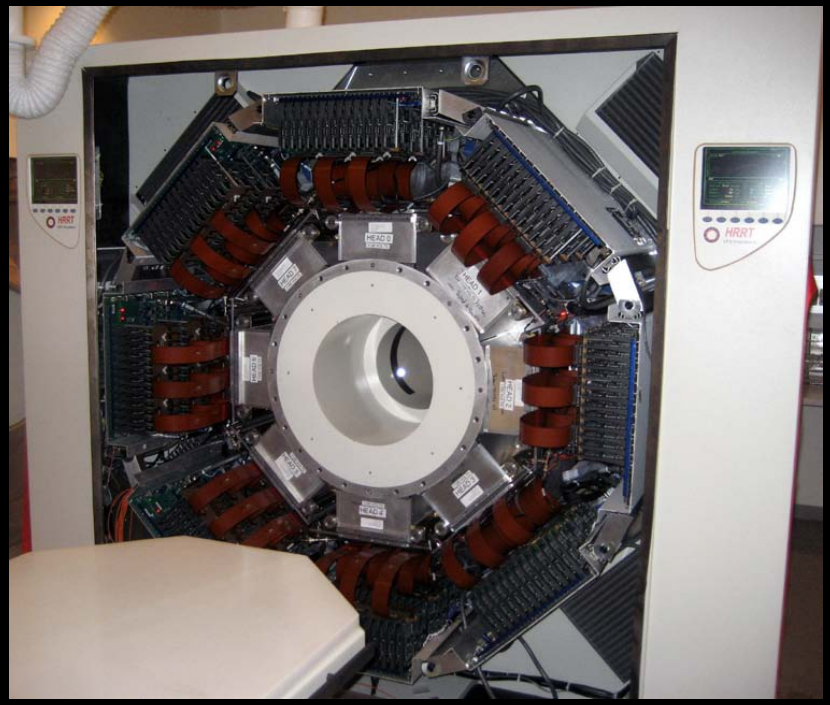
PET Image

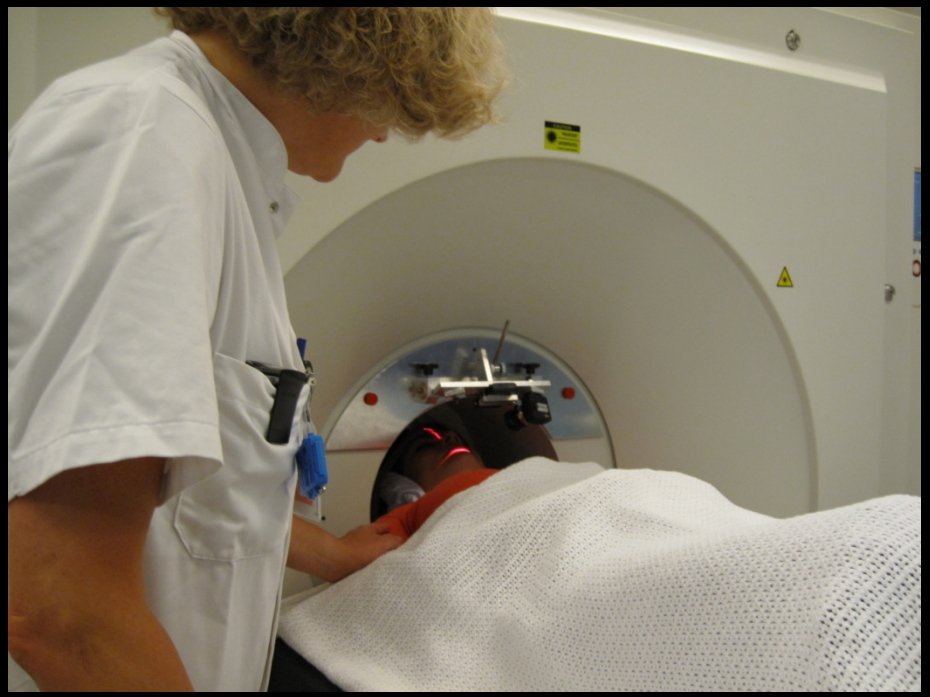


Wikipedia

- Areas with high glucose intake will be brighter
  - Higher intake of radioactive molecules
- Bimodal histograms in areas with cancer cells
- Big research topic

High-Resolution PET scanner at Rigshospitalet

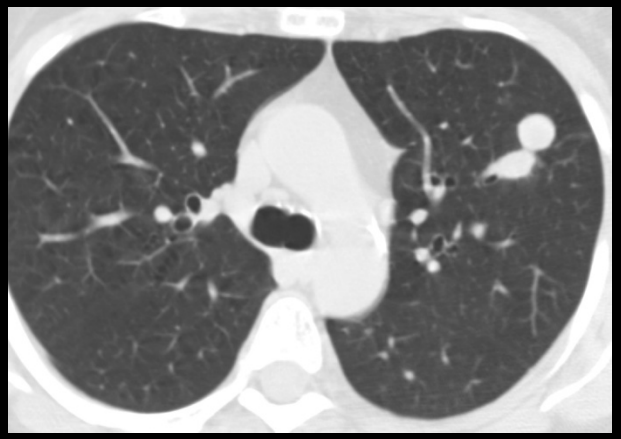


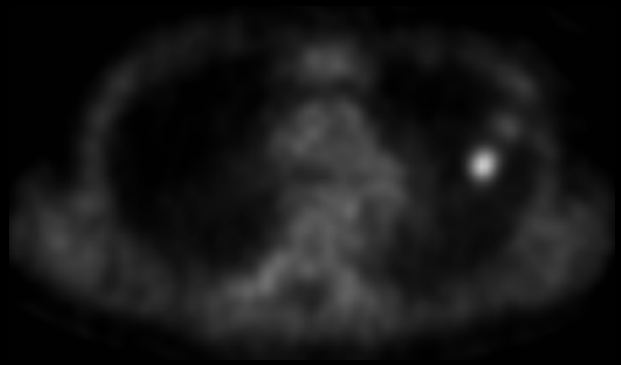


PhD project by Oline Vinter Olesen –

now startup

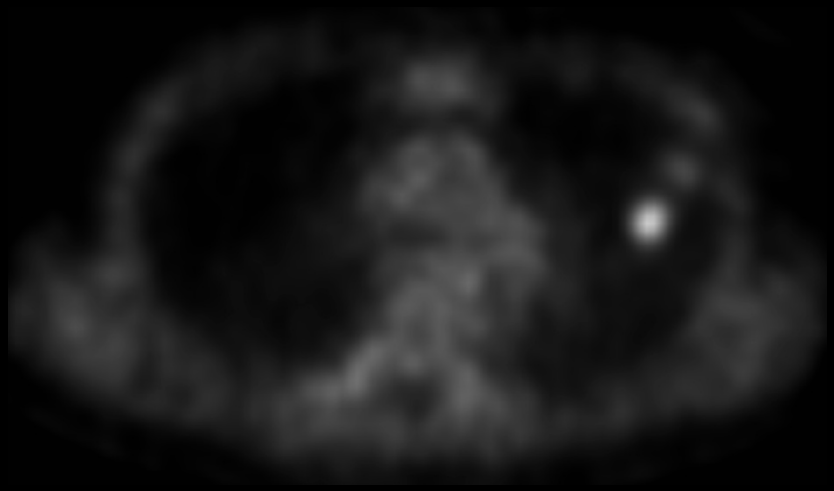
Combining Images





- CT is good for bone
- PET is good for cancer
- What if I want to see both?
- PET/CT scanner
  - Patient scanned in both a CT and a PET scanner
- Image registration
  - Take two or more separate images
  - Combine them using image registration
  - More about that later

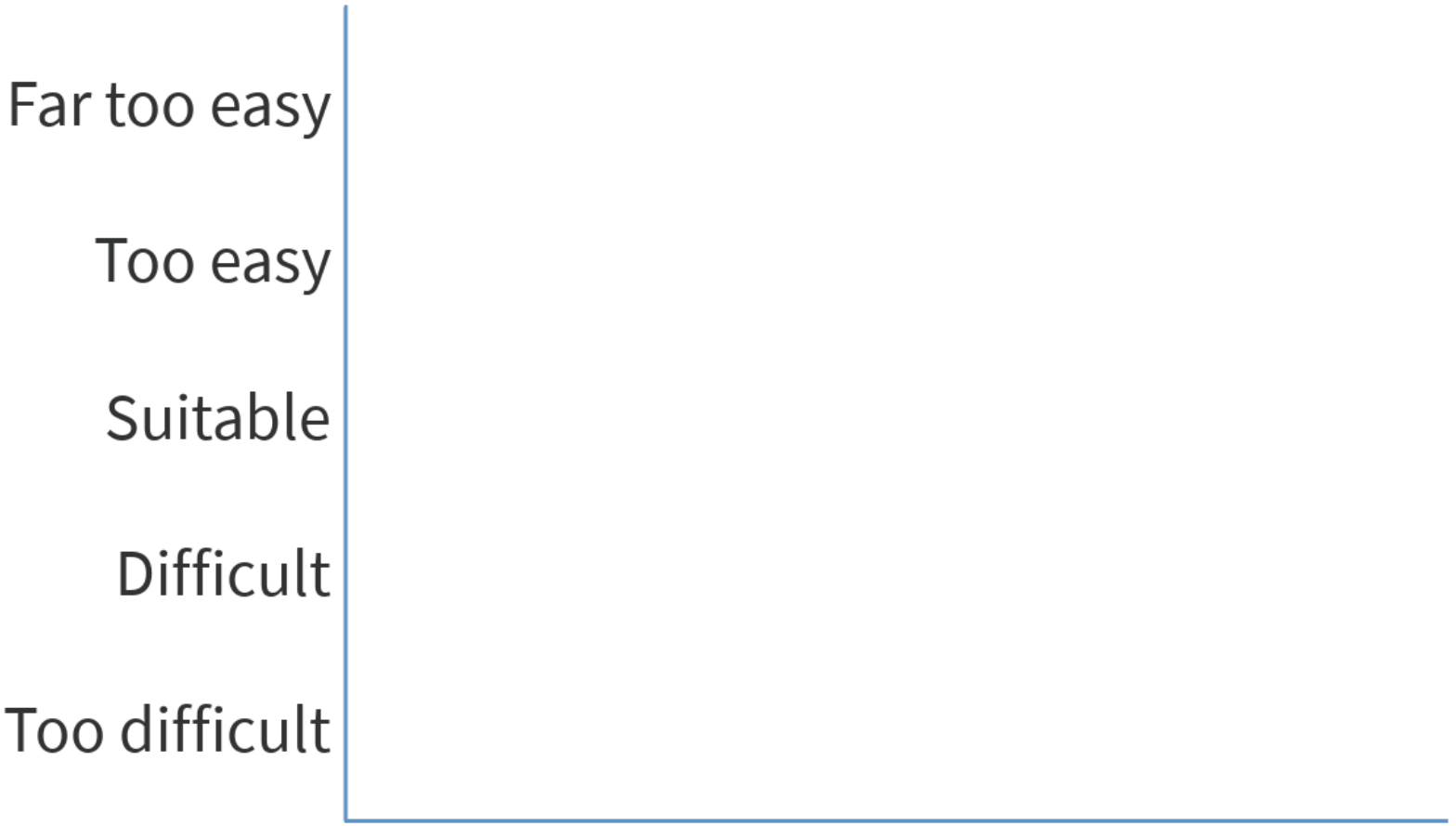
Thresholds visited



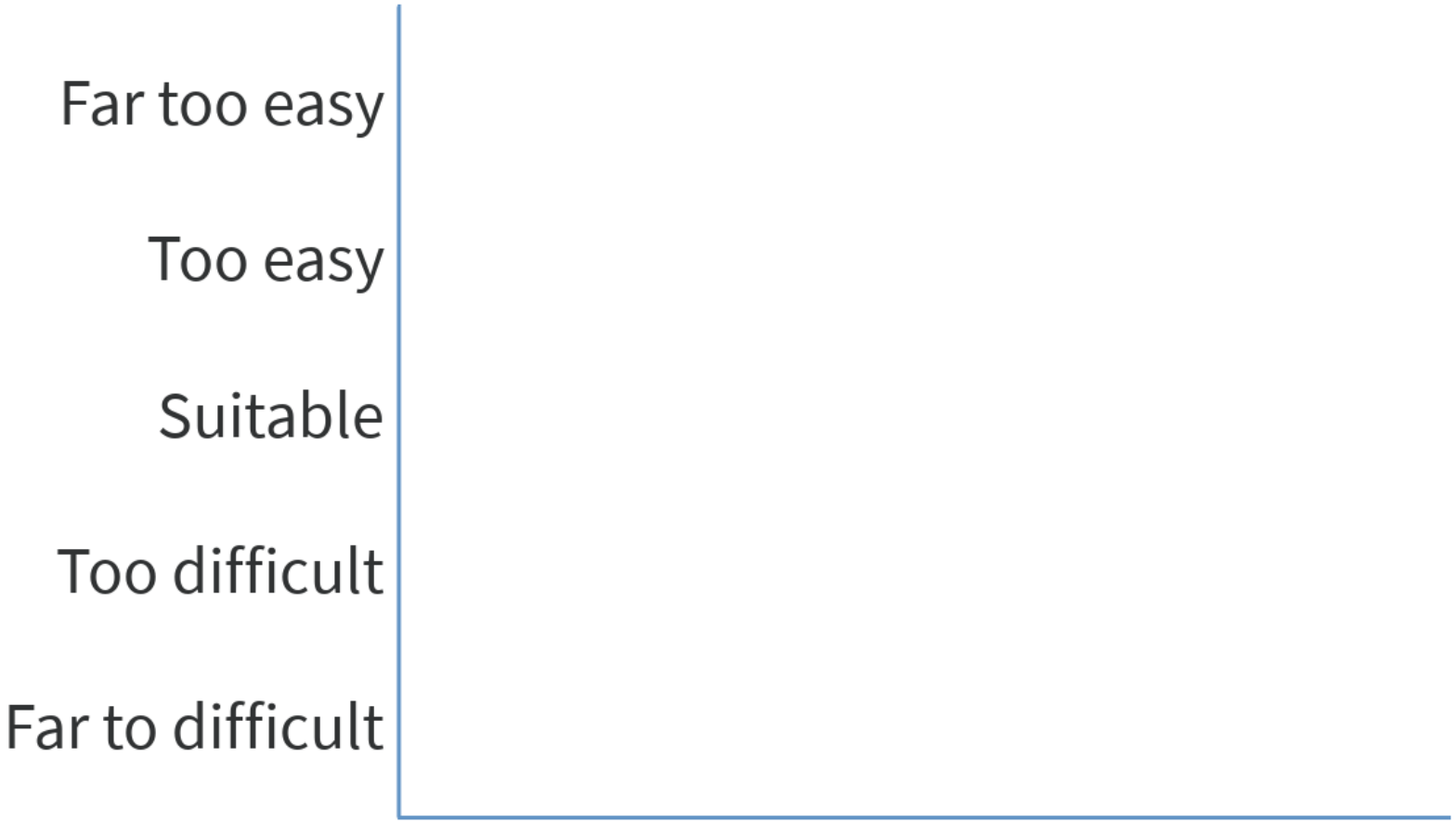
- The tumour became much more separated from the background
- Perhaps a simple threshold is enough now?
- The best solution
  - Clever imaging techniques

    and
  - Intelligent image analysis

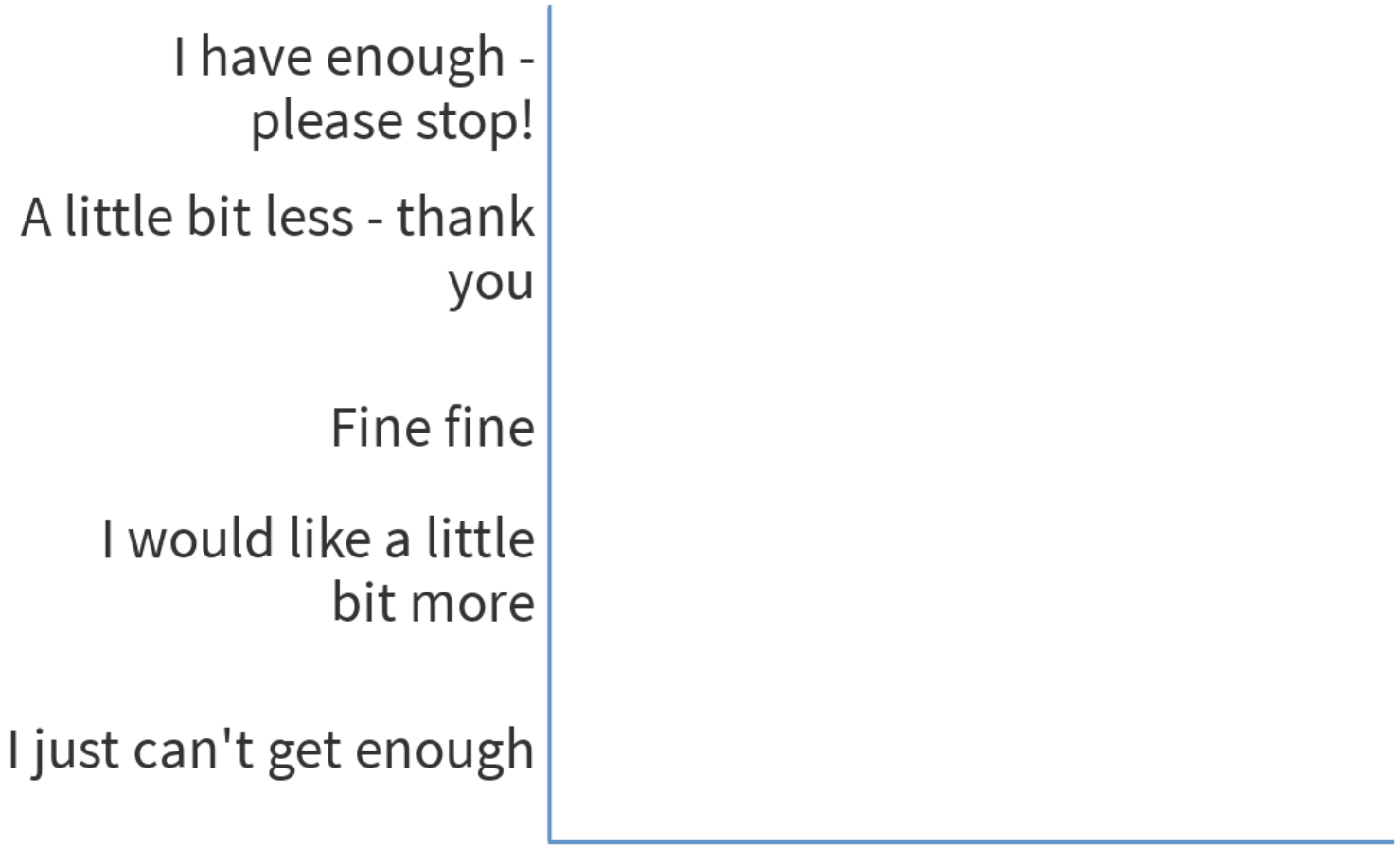
Level of the lectures



Level of the exercises



Use of PollAnywhere



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Next week

- Neighbourhood processing
  - Filtering