Image Analysis

Rasmus R. Paulsen
Tim B. Dyrby

DTU Compute

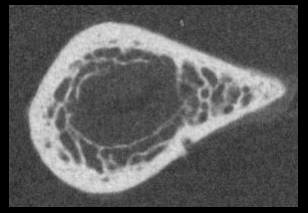
http://compute.dtu.dk/courses/02502

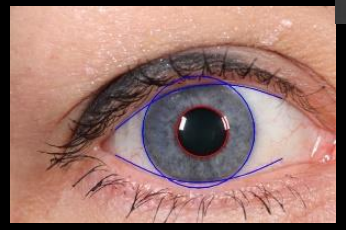
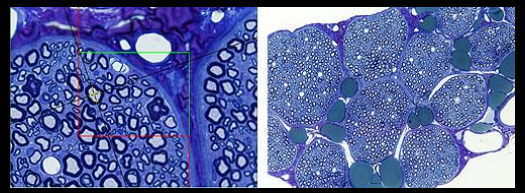
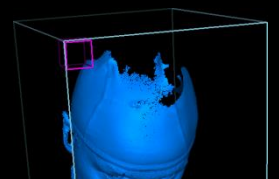
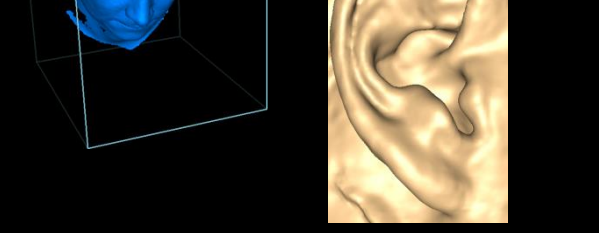
DTU

Week 1 - today

8:00 – 10:00	Exercises
10:00 – 12:00	Introduction and practical matters
	Lecture – Digital Images
	Lecture – A tutorial on Principal Component Analysis (PCA)

Rasmus R. Paulsen


- Master of Science (Eng). DTU 1998
- Industrial PhD with Oticon A/S
- Research and development at Oticon A/S
- Associate Professor DTU Compute

Tim B. Dyrby

- Associate Professor at DTU Compute and Danish Research Centre for Magnetic Resonance (DRCMR)

Teaching Assistants

Mathias Micheelsen Lowes
Mathematical Modelling and Computation

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Mathematical Modelling and Computation

Paula Lopez Diez
Mathematical Modelling and Computation

Practical matters

- 13 days over the DTU 13 week semester
- Flipped class room
  - 8-10 Computer exercises (also on MS Teams)
  - 10-12 Lecture with quizzes

- Lectures are streamed, recorded and made available
  - Links to video on the homepage (under schedule)
  - Courses.compute.dtu.dk/02502

About this course

- Until 2017 the course responsible was Jens Michael Carstensen – CEO of Videometer
  - Now full time at Videometer
  - Will give a guest presentation at the *company presentation day*
- From 2018 Rasmus R. Paulsen is the course responsible
  - Major course revision
  - Other topics and new examples
  - Material from course 02512
- From 2019 Tim B. Dyrby is also teaching the course

New in 2021

- The exercises are now much more related to the exam
- Learning objectives stated in all exercises
- You will be examined in these learning objectives
- You will also be examined in the more theoretical learning objectives from the lectures
- We will expect you can run Matlab during the exam

Very Important!
Do the exercises!

Materials

- Book:
  - Rasmus R. Paulsen and Thomas B. Moeslund: *Introduction to Medical Image Analysis* **(MIA)**
  - Polyteknisk boghandel
  - http://mediabook.compute.dtu.dk

- Notes
  - Notes will be provided during the course

- At the end of the course a complete reading list will be published

DTU Learn and the homepage

- Homepage : The main entry to the course
  - http://courses.compute.dtu.dk/02502
  - Schedule / Exercises / Data
  - Updates happen!

- Course messages will be given through DTU Learn

#	Date	Topic	Video	Material	Exercise
1	31/8	Introduction and digital images. Introduction to Principal Component Analysis (PCA) (Rasmus)		MIA 1, 2, app. A. PCA Note (except Section VI (SVD) and App. A)	1
2	7/9	Image acquisition. Compression and storage (Tim)		MIA 2, 3	1 + 1b
3	14/9	Pixelwise operations, colour images and PCA Analysis on images (Rasmus)		MIA 4, 8 Eigenfaces article (only sections marked with yellow)	2
4	21/9	Neighborhood Processing (Filtering) and Morphology (Rasmus)		MIA 5, 6	3 + 3b
5	28/9	Blob analysis and object classification (Rasmus)		MIA 7	4 + 4b
6	5/10	Pixel classification and advanced classification (Tim)		MIA 9 + notes on DTU Learn	5
7	12/10	Geometric transformations and landmark based registration (Tim)		MIA 10, 11	6 + 6b
8	26/10	Boundary Tracing (Hough Transformation and Dynamic Programming) (Tim)		MIA 12	7
9	2/11	Statistical Models of Shape and Appearance (Rasmus)		Statistical Models of Appearance for Computer Vision (p. 12 - 20 and p. 29 - 33)	8
10	9/11	Advanced registration (Tim)		Notes on DTU Learn	9
11	16/11	Industry presentations		none	10
12	23/11	Active Shape Models (Rasmus)		Statistical Models of Appearance for Computer Vision (p. 34 - 43)	Exercise catch-up
13	30/11	Advanced topics		none	Digital test exam

Book (MIA): Rasmus R. Paulsen og Thomas B. Moeslund. Introduction to Medical Image Analysis. Springer Nature.

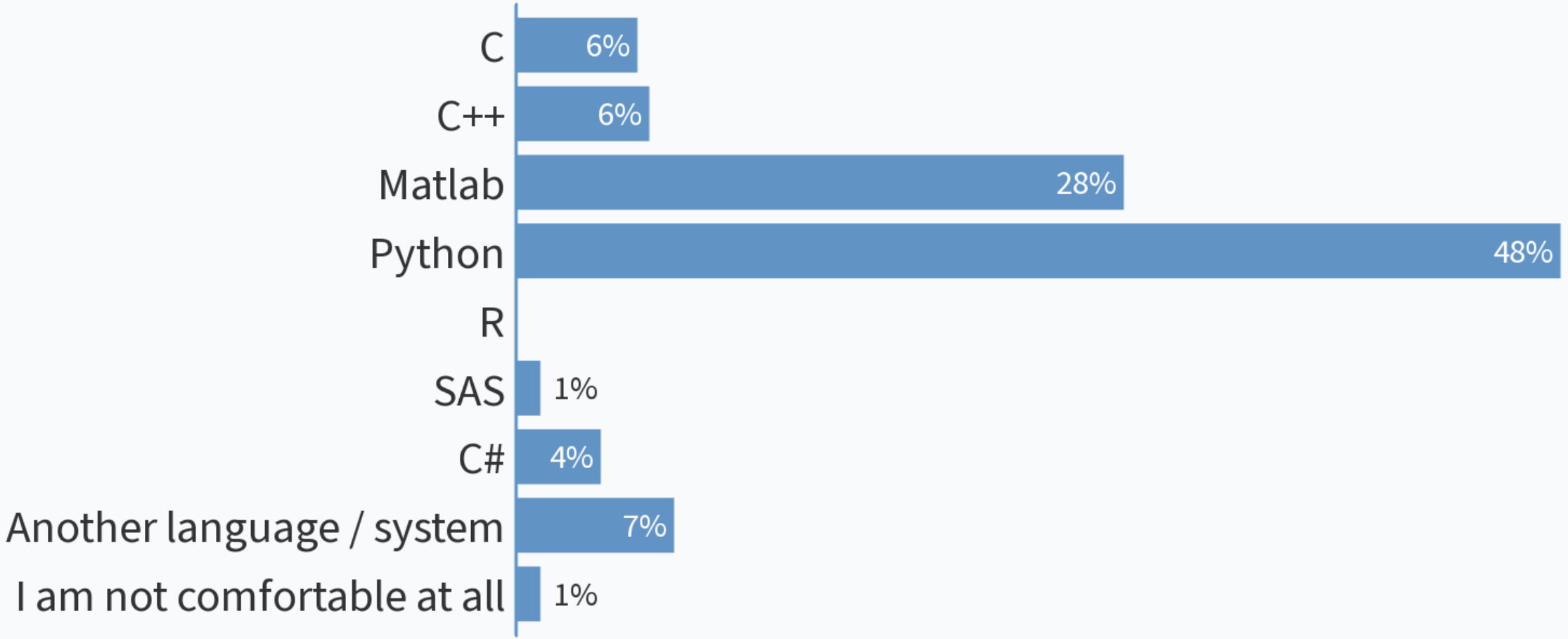
Learning Objectives (Læringsmål)

- A list of learning of objectives for each lecture and exercise
- A learning objective describes what you can do after the lecture/exercise
- If you fulfil all learning objectives you get 12
- Low-level learning objective
  - Apply the Prewitt edge filter to an image
- High-Level learning objective
  - Evaluate and compare the performance of a selection of image analysis algorithms

Exam

- Four hours multiple-choice exam
- Please see details here:
  - http://courses.compute.dtu.dk/02502/exam.html
- Previous exam sets are also available
  - Most relevant is from Spring 2021

What programming language are you most comfortable with?



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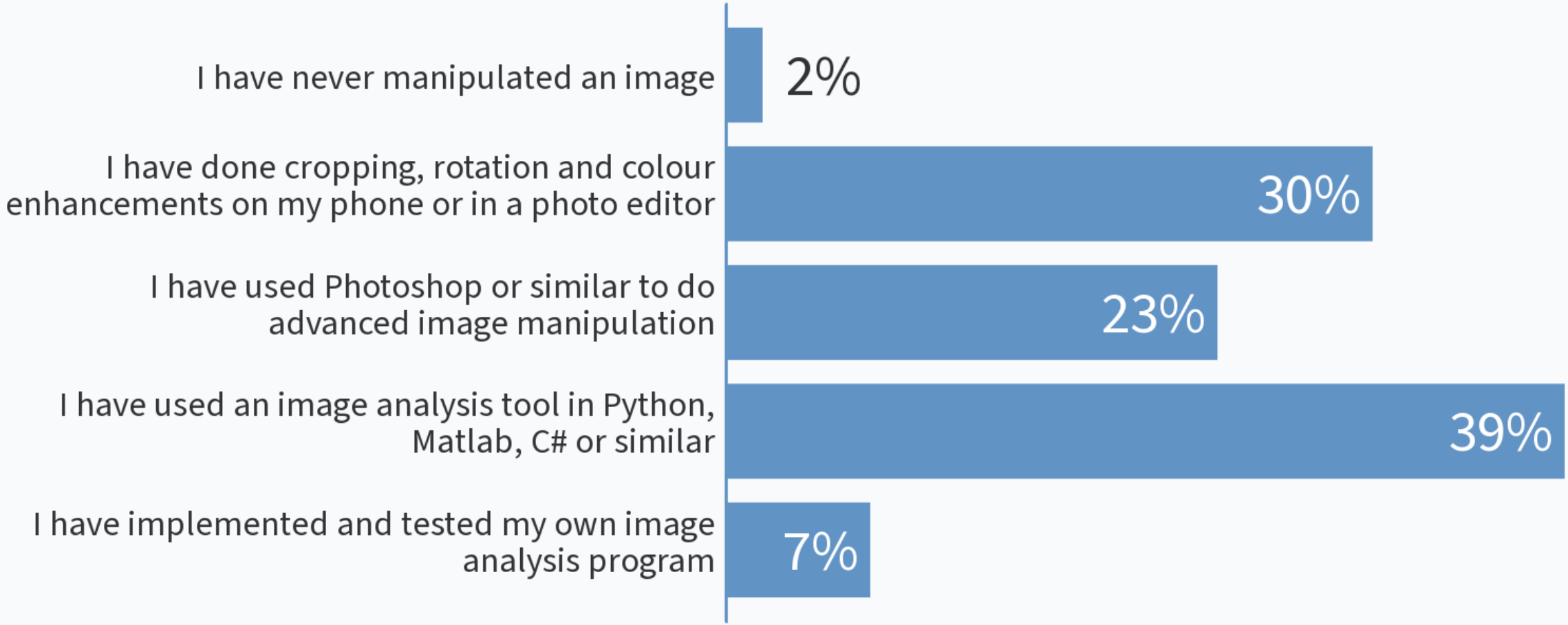
Matlab and computers

- We assume that you can use your own portable computer with Matlab
- Python: Some exercises can potentially be made using Python
  - The TA will help the best they can
- We expect you to be able to run Matlab during exam
- Why Matlab:
  - Requires massive resources to do exercises, TA'ing and exams in several languages
  - Most important to learn the concepts of image analysis – implementation is dependent on the project and company

What is your experience with image manipulation, image processing and image analysis?



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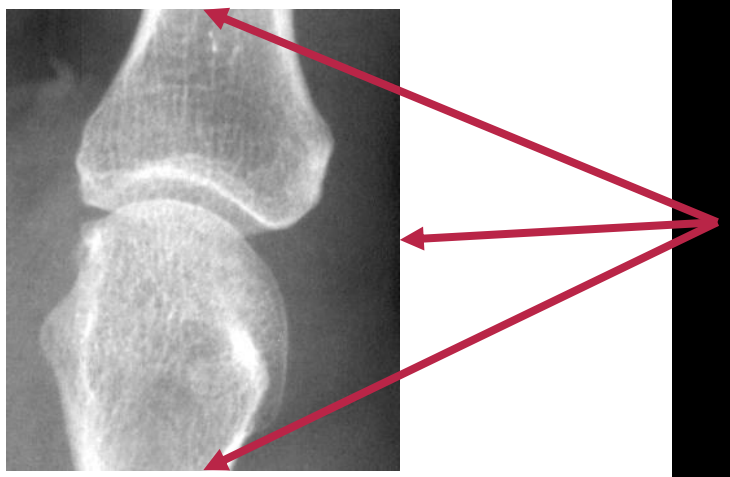
Why are my slides black?

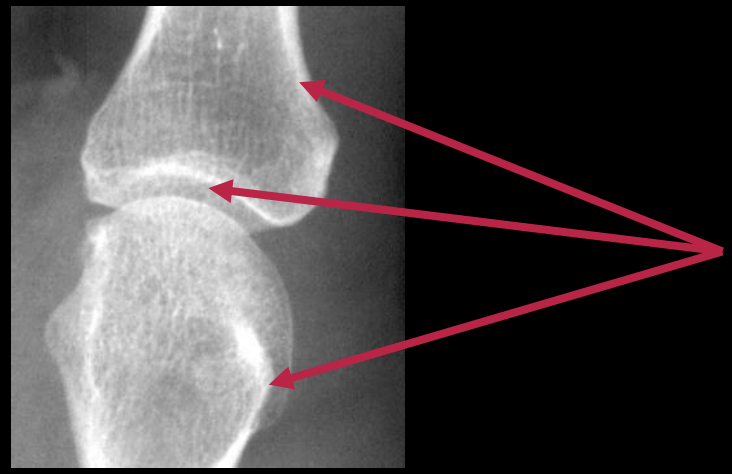
?

Norwegian Black Metal



With a white background, the strongest visual contrast is here

Why are my slides black?



With a dark background, the strongest visual contrast is here

(which I find more important)

What is image analysis

- Automatic extraction of information from images
- A sub-topic within
  - Pattern recognition
  - Machine learning
  - Deep learning

What is image processing

- Changing the information in images – but not necessarily getting any knowledge
  - Photoshopping
  - Changing the visual appearance of photos
  - Cropping / rotating
  - Filters / effects

Classical machine vision

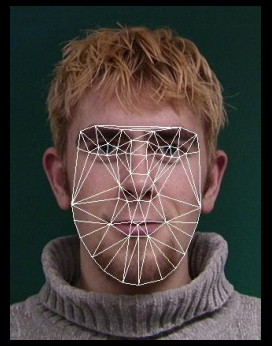
- Tomato sorting machine
  - Good tomatoes vs green/bad tomatoes
- Combination of
  - Very fast cameras
  - Fast classification algorithms
  - Robotics

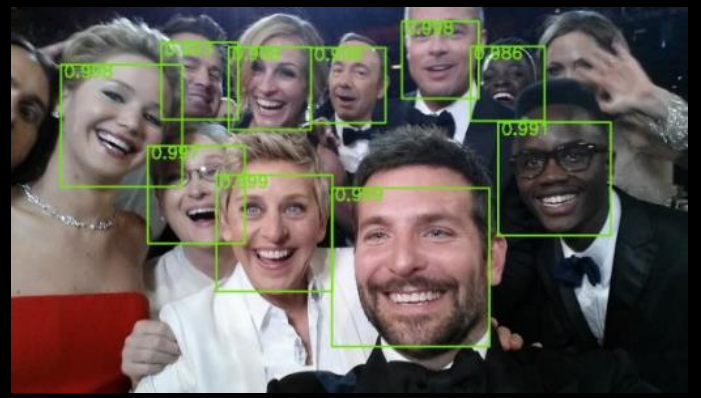
- https://www.youtube.com/watch?v=Lz88nsWL4kw

Local companies (some will be here on the company day):
JLI vision, Videometer, IHfood, Trivision

Face tracking – all features including eyes

- For digital cameras / phones
  - Automatic focus on the face + face beautification
- Tracking and manipulation for apps
  - Messenger / WhatsApp / SnapChat …
- Awareness tracking for car drivers
  - Warning if you fall a sleep





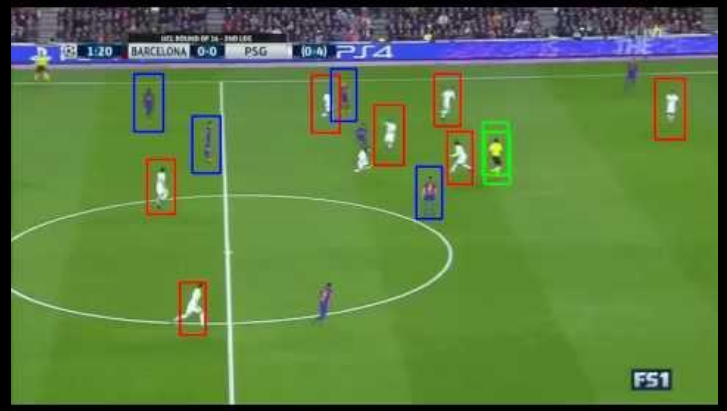
A 100 million $ industry

- This image is worth 100 of millions of dollars!
- Well – perhaps not that exact photo.
- The ability to track faces fast and accurate
  - Including estimates of 3D structure
  - App developers pays buckets of money for that
- It all started in 2001 with:
  P. Viola and M. Jones. "Rapid object detection using a boosted cascade of simple features.". CVPR 2001
- Suddenly you could track faces fast and relatively accurate
- Now it is all deep learning

Self driving cars

- Modern self driving cars rely on many sensors
  - Lidar – radar system
  - GPS
  - Accelerometers, gyroscopes, magnetometers etc.
  - Stereo cameras or multiple cameras
  - Lots of advanced image analysis – sensor fusion

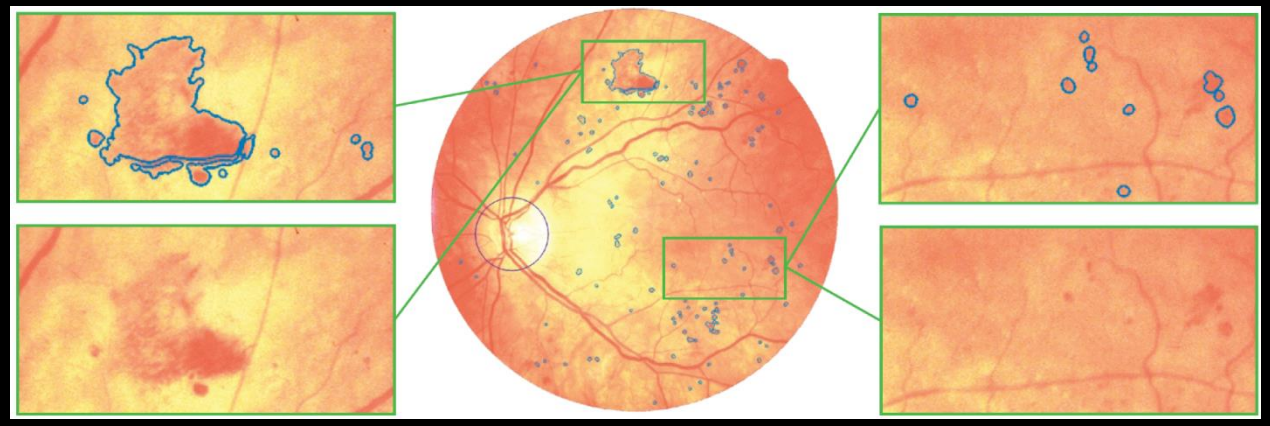
Sports tracking – human body tracking



- Huge commercial impact
- Lots of research in human body tracking
- Personal trainers

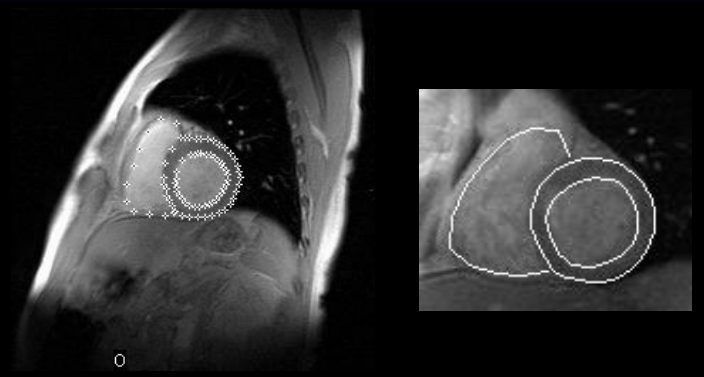
What is medical image analysis?

- Extraction of information from digital images
- Reproduce expert diagnostics
  - More accurate
  - Variation between doctors opinions removed
- Computer aided diagnostics – the doctor has the last word
- Can enhance the signs of diseases
  - Tumours
  - Bleedings



Automatically detected haemorrhages and micro aneurysms in digitized fundus images

Medical image analysis examples



Recognise and track the heart

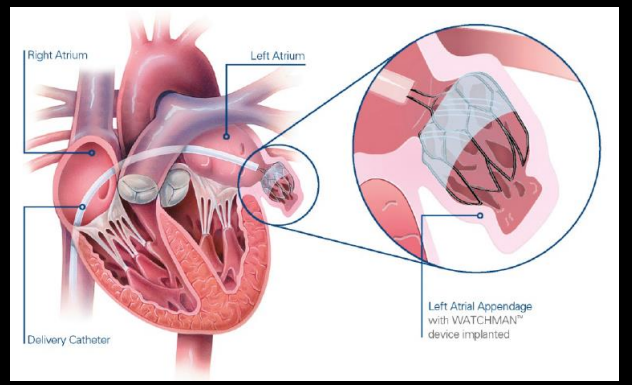
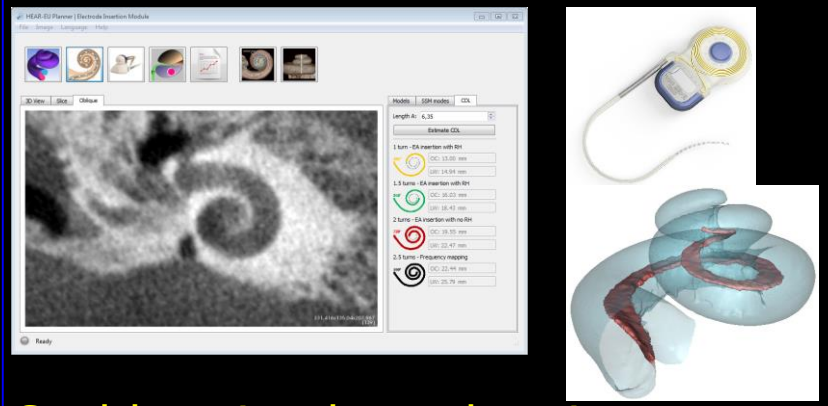
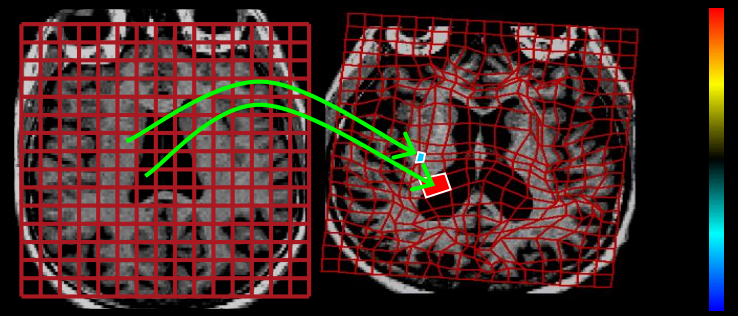


Image based surgery planning

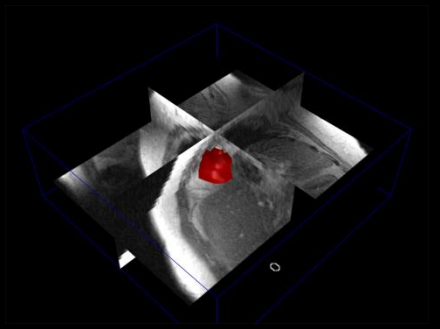


Cochlear implant planning



Shape changes in brain structures

Relevance



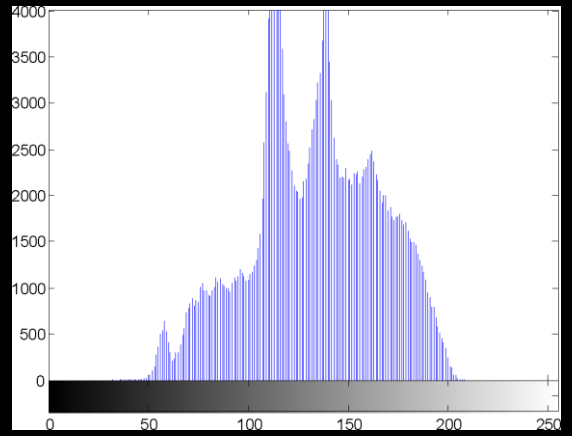
1980
Magnetic
resonance
prototype

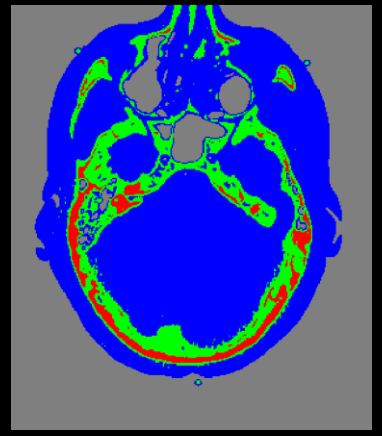
Now – PET/MR

- Images is an important tool in
  - Diagnosis
  - Treatment
  - Follow-up
- Very high-tech!
- New imaging technologies are developed all the time.

Digital Images – Learning Objectives

- Describe the fundamental properties of a digital image
- Read and show an image in Matlab
- Describe the commonly used image coordinate systems
- Describe the binary, the label, the multispectral, and the 16-bit image





A digital image

23	216	120	55
4	89	158	130
65	76	189	34
19	234	7	45

- Consists of pixels (picture elements)
- Each pixel has a value between 0 and 255? Why?

Bits and Bytes!

- A bit is a tiny tiny little switch that can be either 0 or 1 – the "memory of a computer" consists of insanely many bits
- One byte is 8 bits together. It is the "basic" unit in a computer.
- With 8 bits how many possible values can be made?
  - (2^8 = 256)

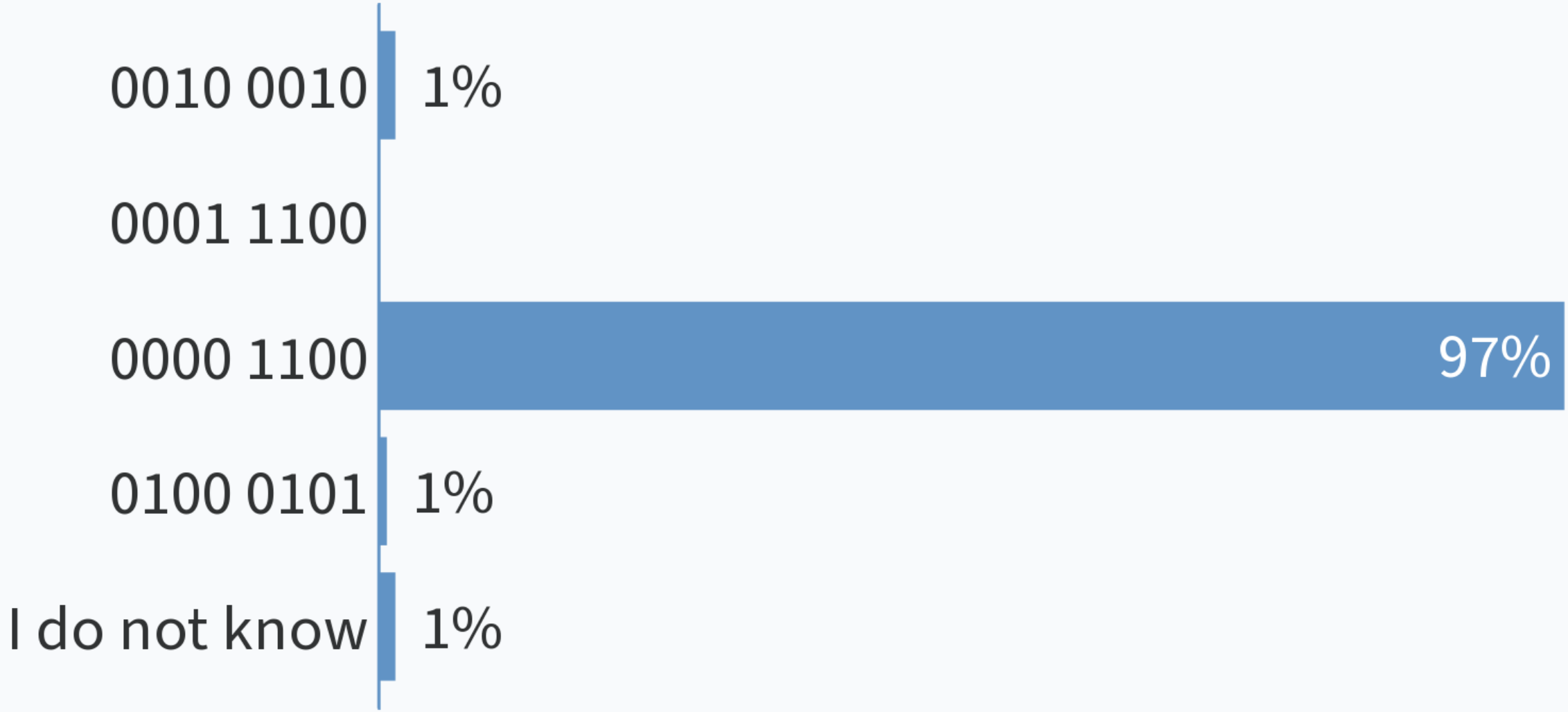
- 00000001 = 1
- 00000010 = 2
- 00000100 = 4
- 00001010 = 10
- 00001111 = 15
- 11111111 = 255

128	64	32	16	8	4	2	1
□	□	□	□	□	□	□	□

What is decimal 12 as a binary number?

- 0010 0010
- 0001 1100
- 0000 1100
- 0100 0101
- I do not know

What is decimal 12 as a binary number?



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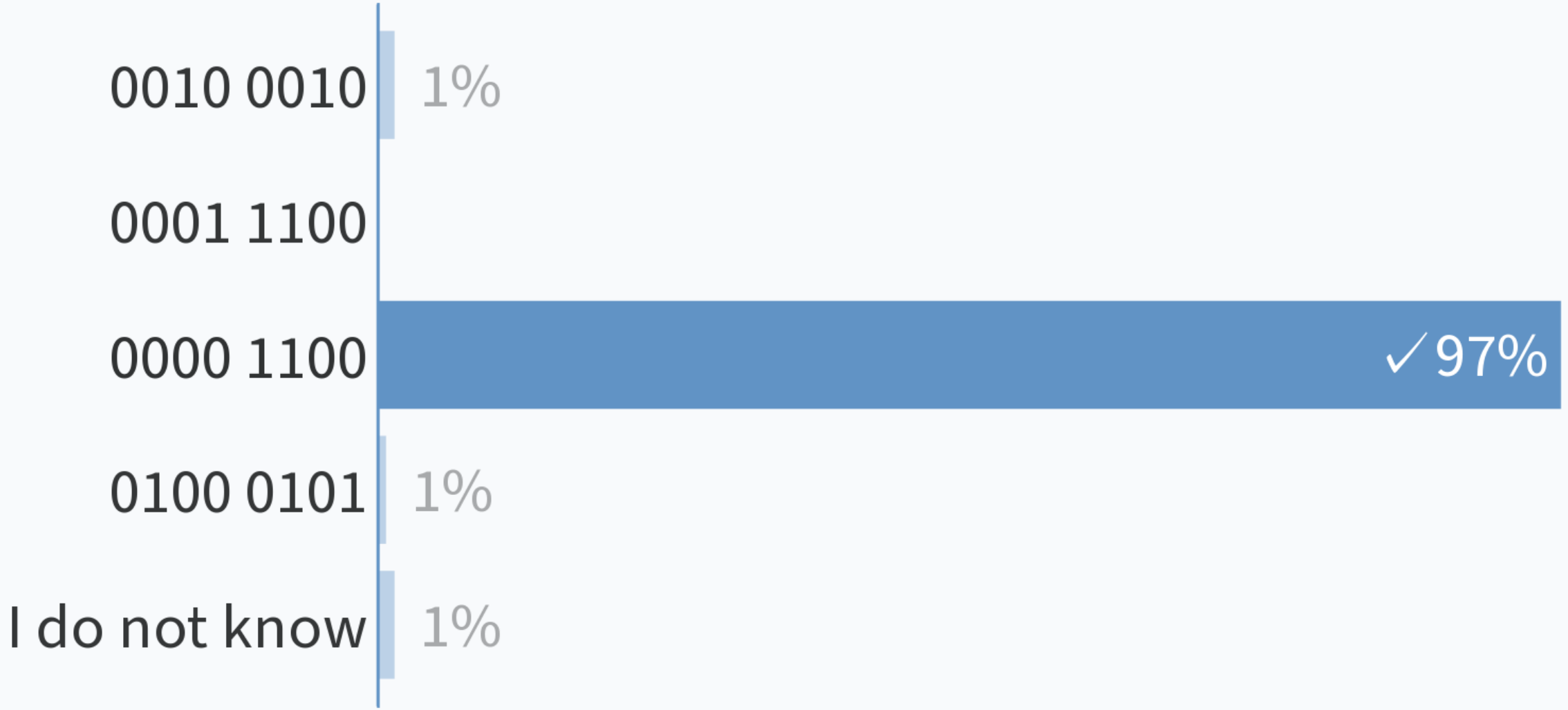
What is decimal 12 as a binary number?



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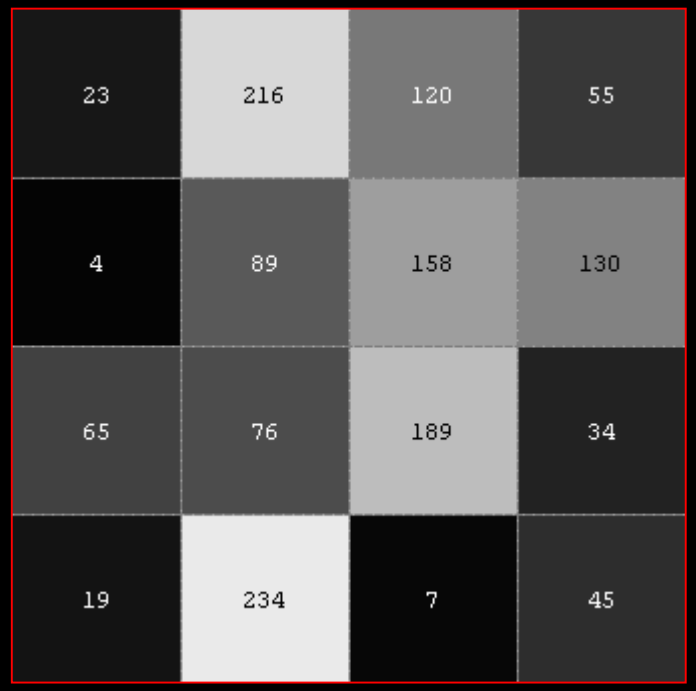
A digital image

23	216	120	55
4	89	158	130
65	76	189	34
19	234	7	45

- between 0 and 255.
- How many bytes do our image take up in the computer memory?
  - 16

Grayscale digital images



- 0 is black and 255 is white!
- The values in between are shown as shades of gray

Typical Grayscale image

- Traditional film X-ray
- Scanned on a flatbed scanner
- Bone is white and air is black
  - The more radiation the darker
- What are they used for?
  - Fractures
  - Arthrisis
  - Osteoporosis

Image Resolution

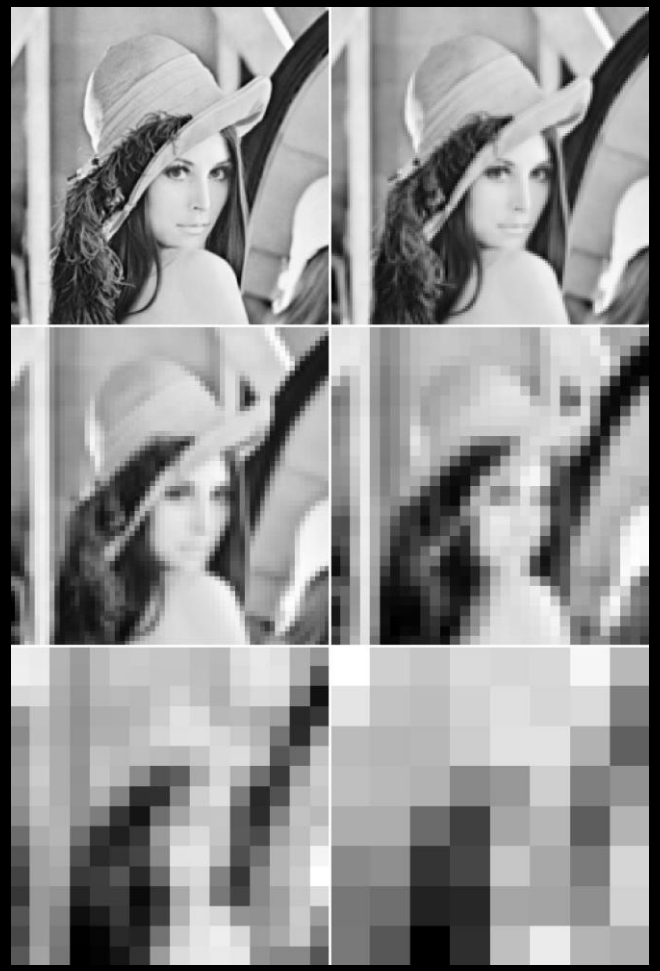
- Determines how much the image fills in the memory and on the hard disk
- Spatial resolution
- Gray level resolution

Spatial?

- Spatial
  - relating to the position, area and size of things
- Example:
  - This task is designed to test the child's *spatial* awareness

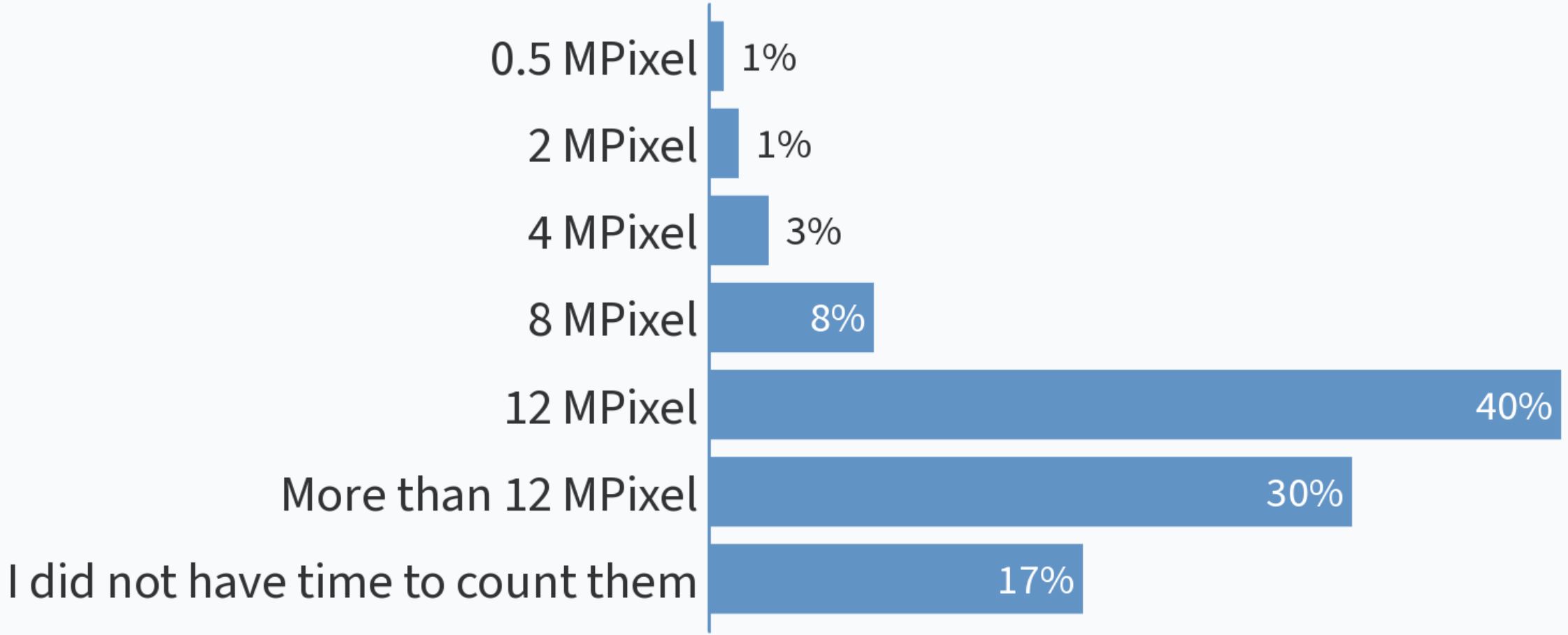
- Danish
  - Rumlig – barnet har en god rumlig forståelse

Spatial resolution



- The number of pixels used to represent the image
- 256 x 256
- 128 x 128
- 64 x 64
- 32 x 32
- 16 x 16
- 8 x 8

How many megapixels (approximately) do the photos you take with your camera or phone have?



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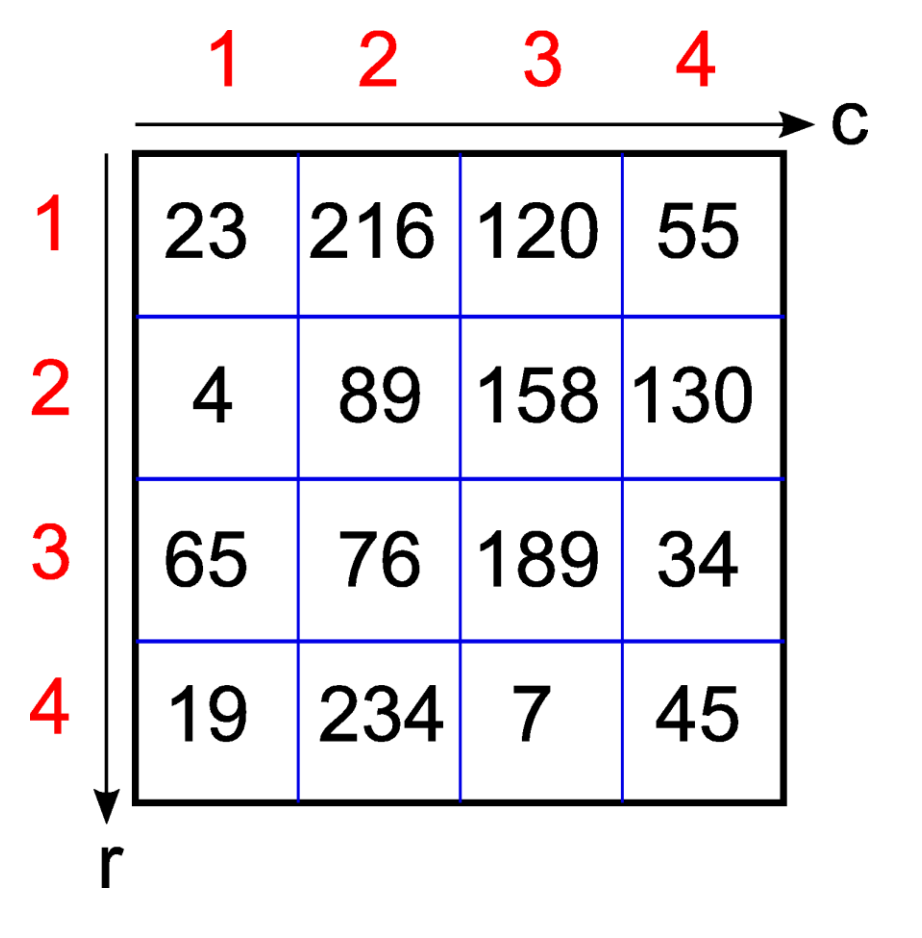
How many pixels?

Width	Height	Pixels	Mega-pixels	Camera
320	240	10.000	0.01	Prototype 1975
1600	1200	1.920.000	2	Nikon Coolpix 950
4032	3024	12.192.768	12	Samsung Galaxy S7 edge
6240	4160	26.000.000	26	Canon EOS 6D M2
8984	6732	60.480.288	60.5	Phase One P65+

Gray level resolution

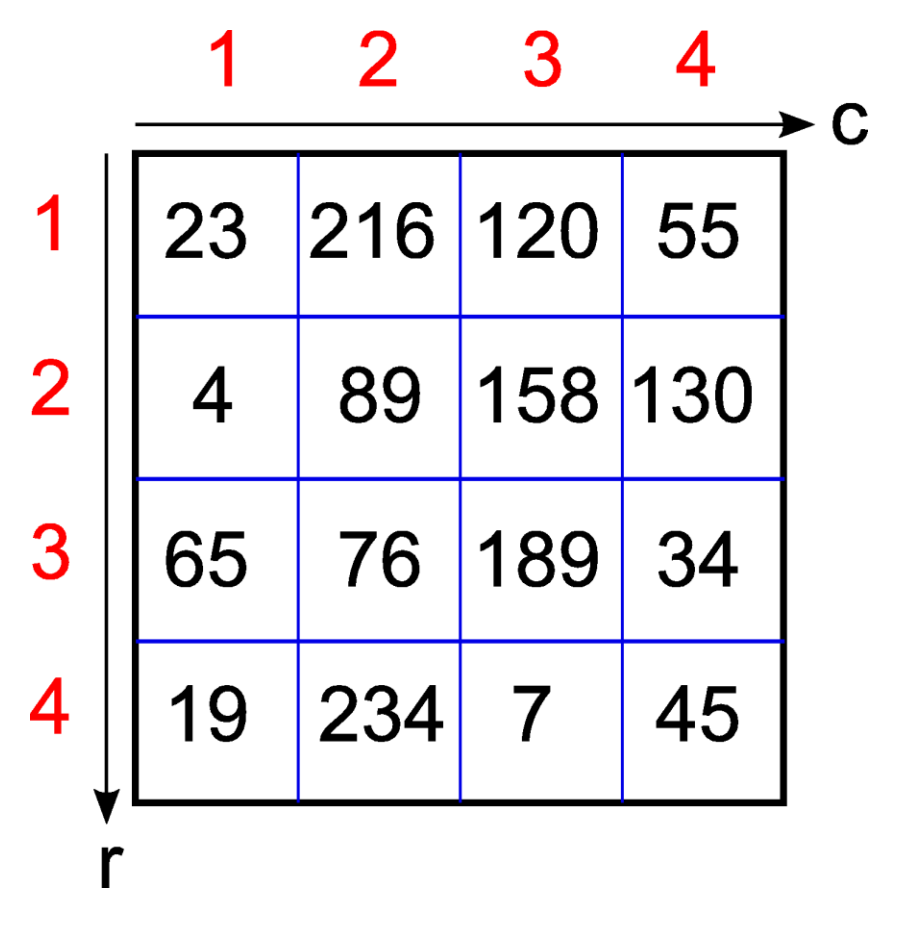
- The number of gray levels in the image
- 256
- 64
- 16
- 8
- 4
- 2

Image as a matrix



- An image is stored in the computer memory as a 2 dimensional matrix
- 4 rows and 4 columns
- Matlab image I – what is I(2,3) ?
- Can also be seen as a discrete function f(r, c)
- In Matlab a pixel is stored as an UINT8!
- UINT8 = Unsigned 8-bit integer = 1 byte

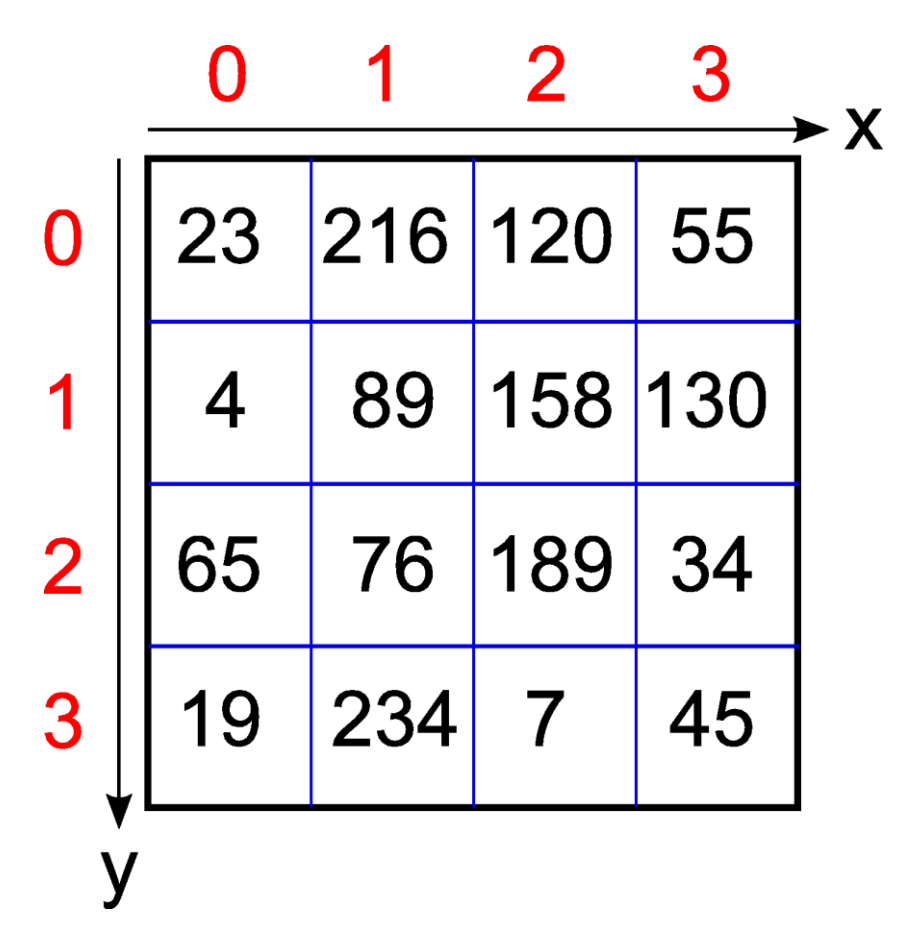
Pixel coordinates – Matlab matrix



- Used in Matlab
- Origin is in upper left corner
- 1-based
- (row, column) system
- M rows and N columns

- What is the coordinates of the pixel with value 34?

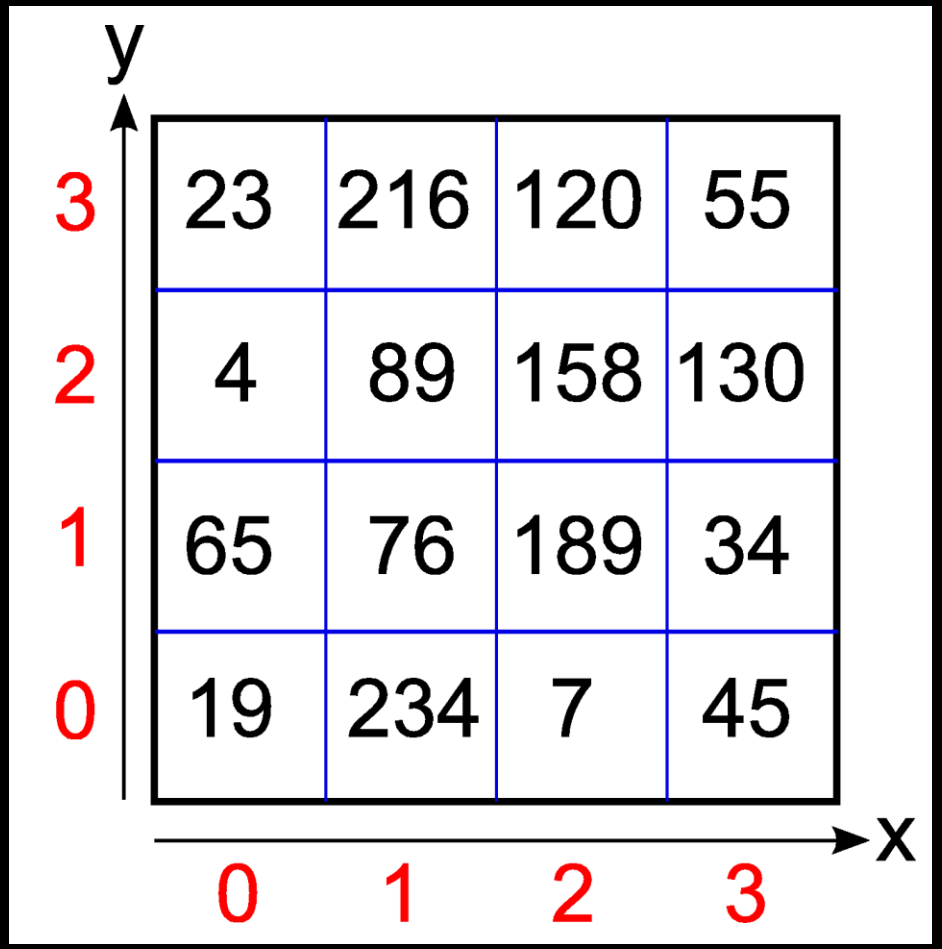
Pixel coordinates – Photoshop etc.



- Used in many graphics programs
- Origin in upper left corner
- 0-based
- (X,Y) system

- What is the coordinates of the pixel with value 34?

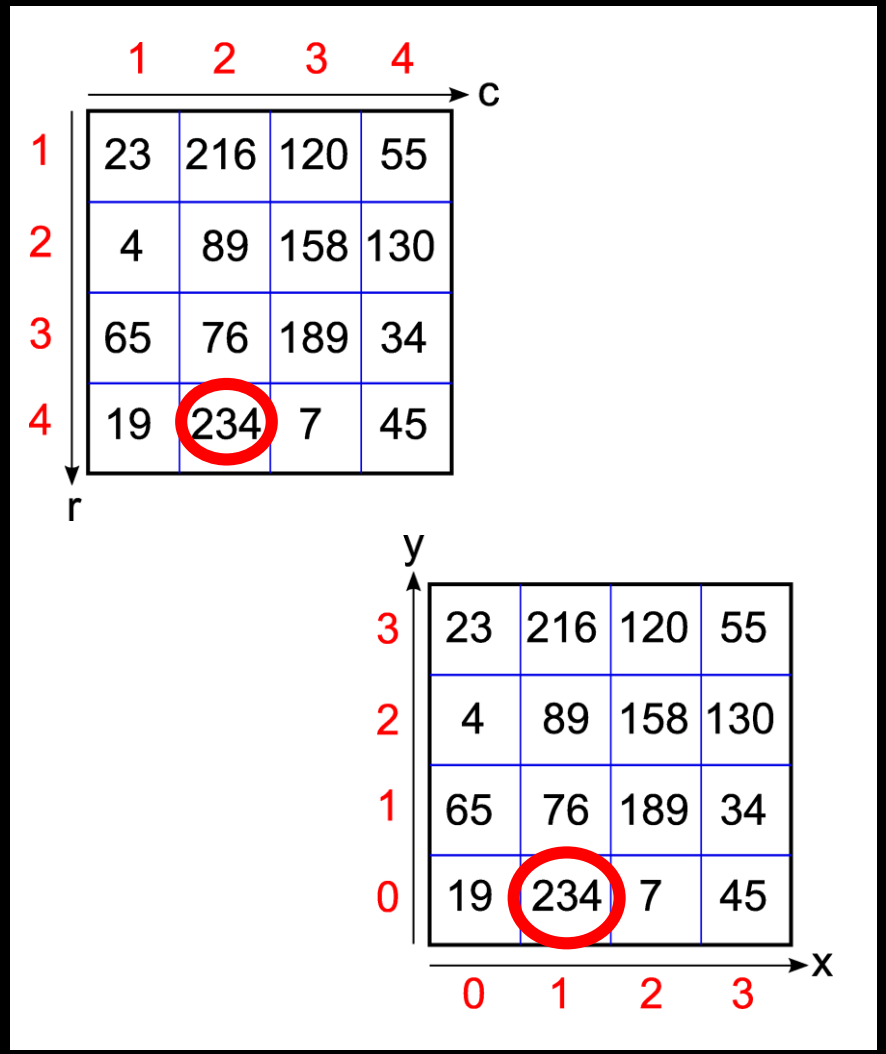
Pixel coordinates – Matlab plots



- Used when plotting – known from mathematics
- Origin in lower left corner
- 0-based
- (X,Y) system

- What is the coordinates of the pixel with value 34?

Why should I care?



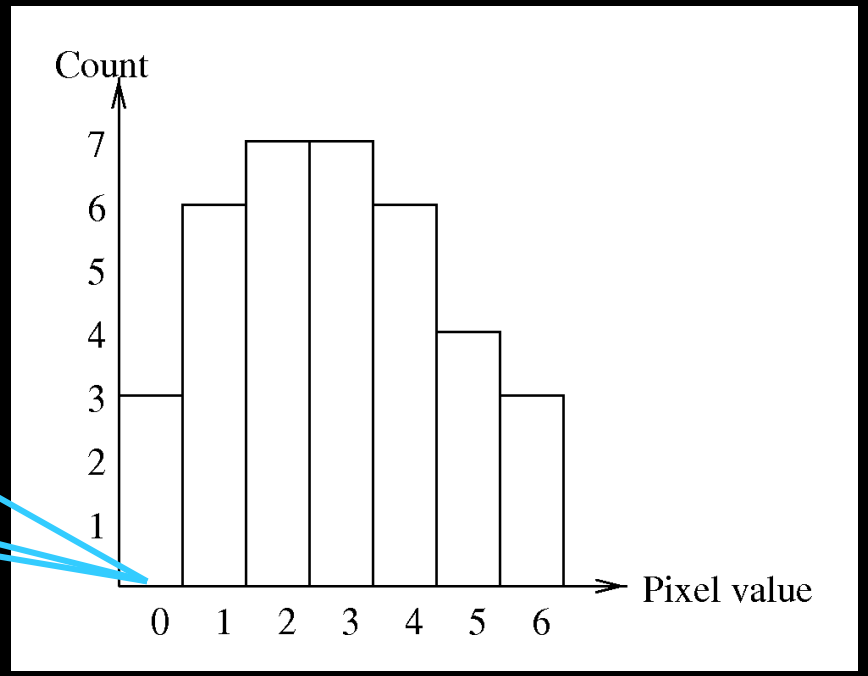
- You have a Matlab image in the matrix system
- Found the pixel with the maximum value
- Want to plot a red circle on top of it
- Plotting is done in the Matlab plot system
- How is this done in this image?
  - Max = 234 at (r,c) = (4,2)
  - Plot circle at (x,y) = (1,0)
- General conversion
  - x = c-1
  - y = M-r

The Image Histogram

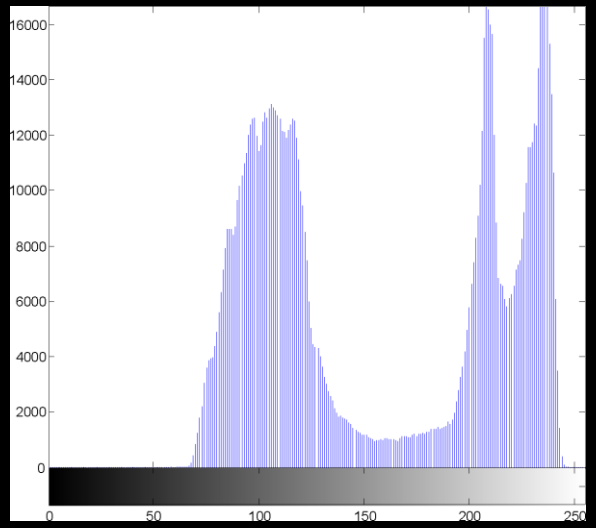
- A histogram normally contains the same number of "bins" as the possible pixel values
- A bin stores the number of pixel with that value

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

3



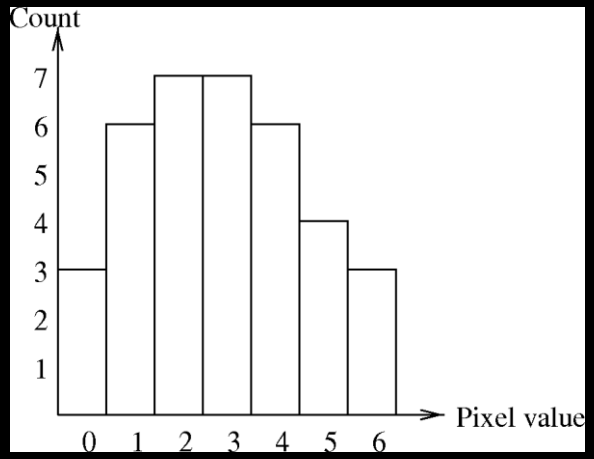
A real grayscale image histogram



- 256 gray levels in the image = 256 bins in the histogram
- The shape of the histogram tells us something about the image
- Can you "recognise" the flower in the histogram?
- What "colors" are missing?

The histogram function

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

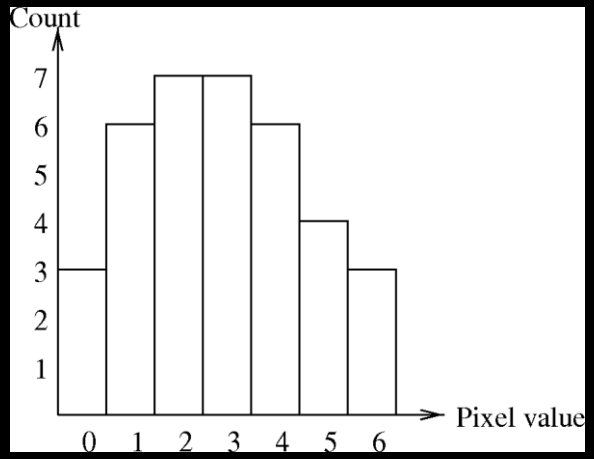


- Can be seen as a function h(v)
- v is the pixel value
- h(2) = 7
- h(5) = 4

- Total number of pixels is the sum of all h

Pixel value statistics

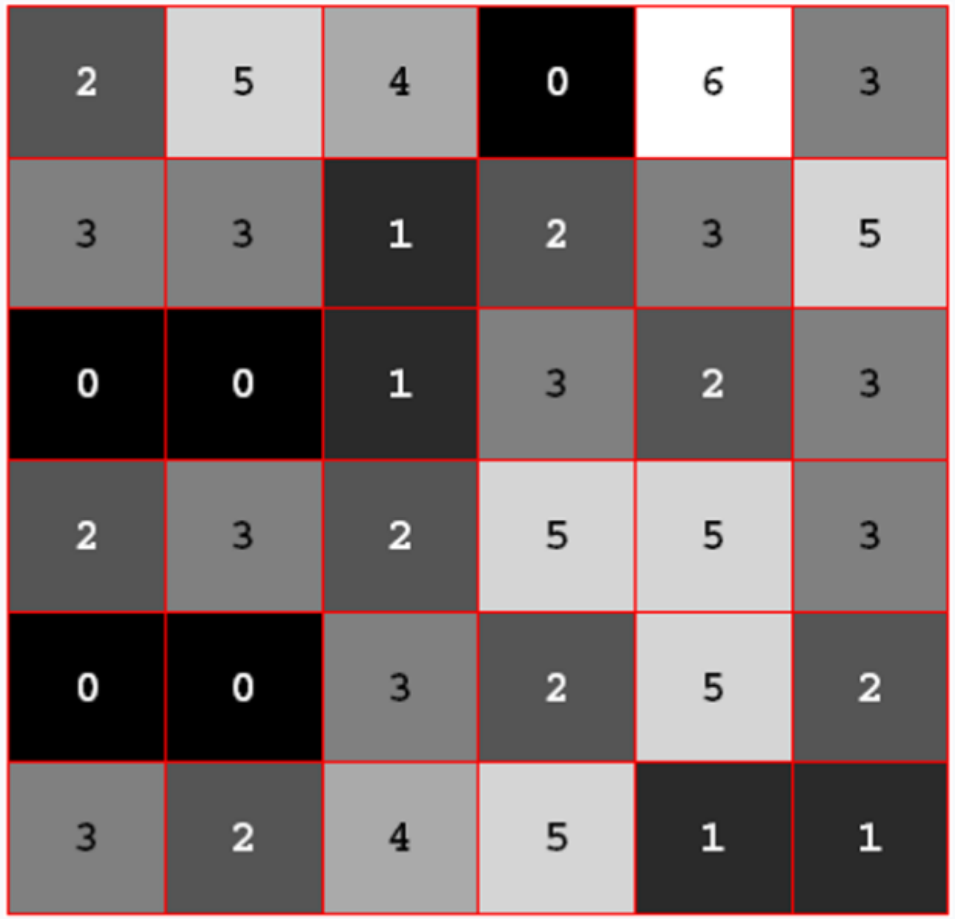
0	2	6	6	3	3
1	4	3	4	4	4
3	2	5	1	5	2
1	4	2	1	3	1
2	5	3	0	2	0
4	2	5	6	3	1



- Pick a random pixel in the image
- What is the probability of it having value 3? P(v=3)

- h(3) = 7
- Np = 36
- P(v=3) = 7/36 * 100%

A random pixel is chosen in the image. What is the probability that the value of the pixel is 3?



- 6%
- 28%
- 39%
- 51%
- 72%
- I do not know

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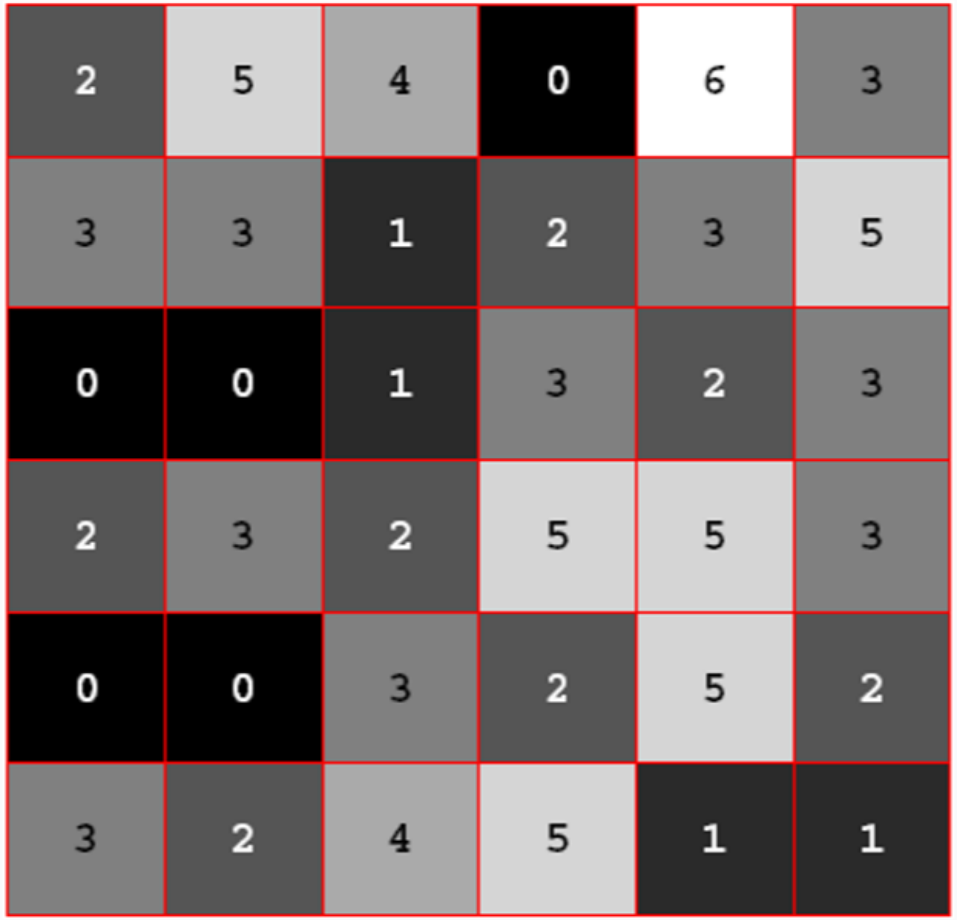
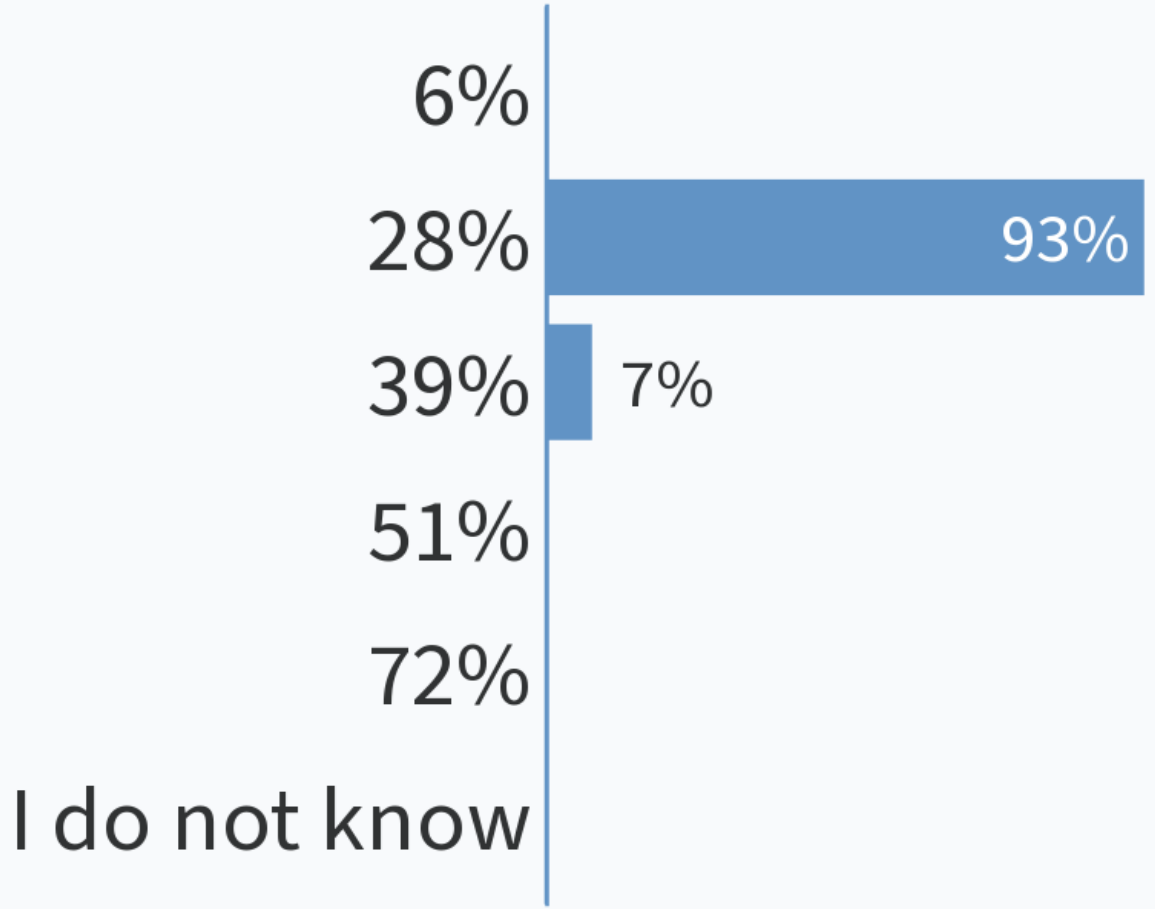
A random pixel is chosen in the image. What is the probability that the value of the pixel is 3?





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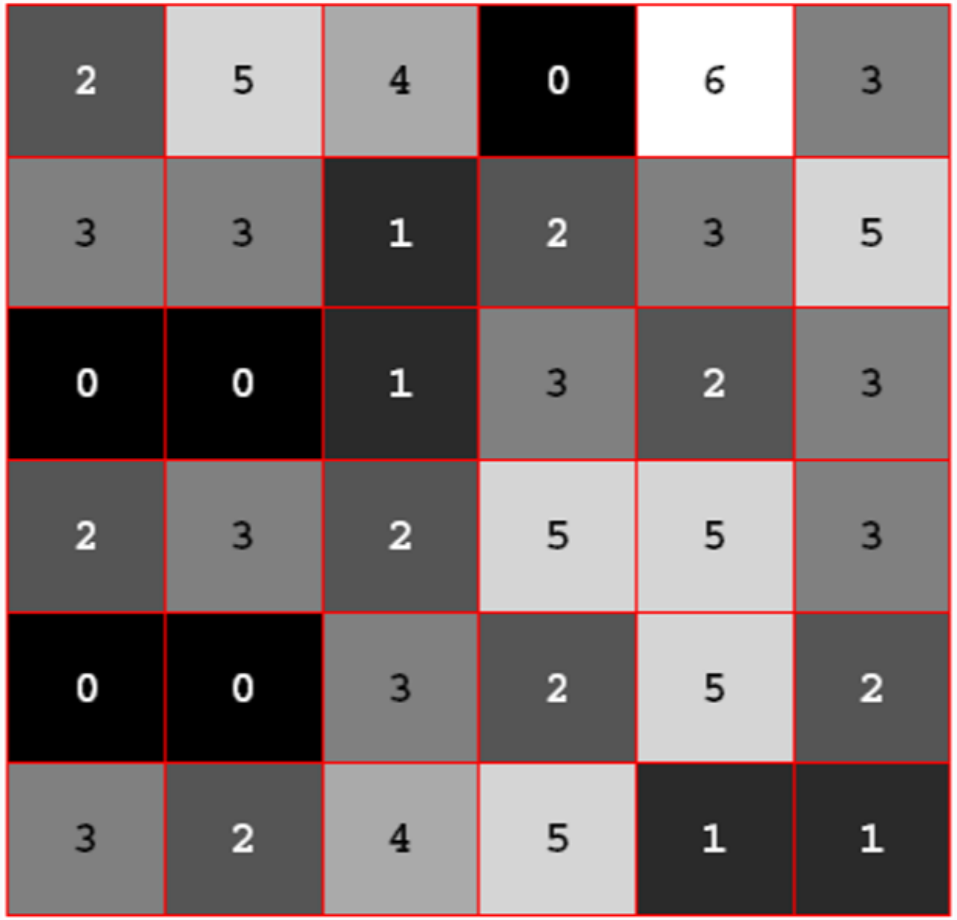
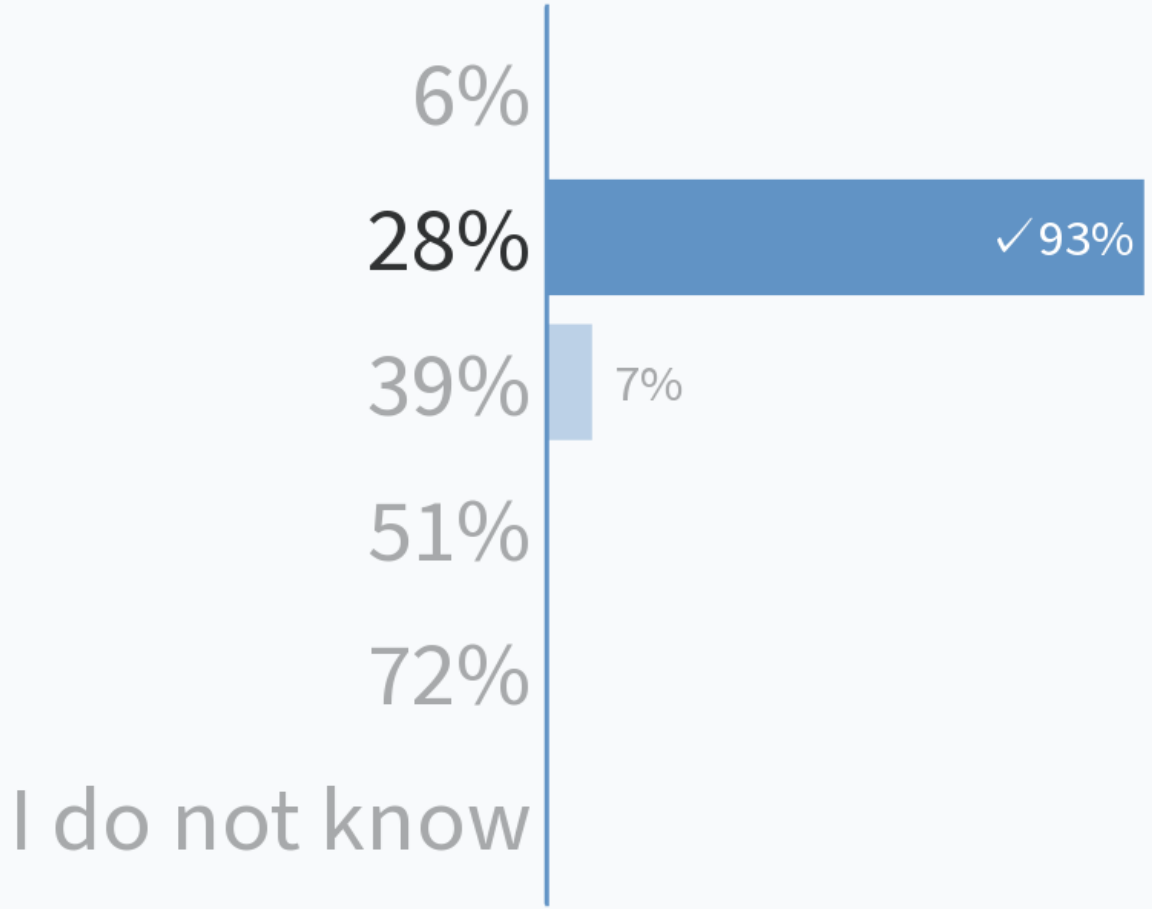
A random pixel is chosen in the image. What is the probability that the value of the pixel is 3?





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Normalised histogram

- A normalised histogram is made by dividing each bin count with the total number of pixels
- H(v) is the normalised histogram function
- H(v) is the probability that a random pixel has value v

- Equal to a probability density function

Other Image Types

- Colour images
- Binary Images
- Label Images
- 16-bit images

Colour images

- RGB = Red, Green, and Blue
- Television, computers, digital cameras use the “RGB color space”
- Additive colours: Final colour is made by mixing red, green, and blue
- Typically the values of R, G, and B lie between 0 and 255 (total 3 bytes)!

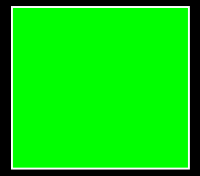
RGB Colours

RGB = (0,0,0)

RGB = (255,255,255)

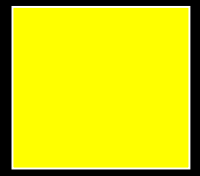
- When alle three “Lamps” are turned of we get black
- When all three “lamps” are on what do we get?

(255,0,0)



(0,255,0)

(0,0,255)

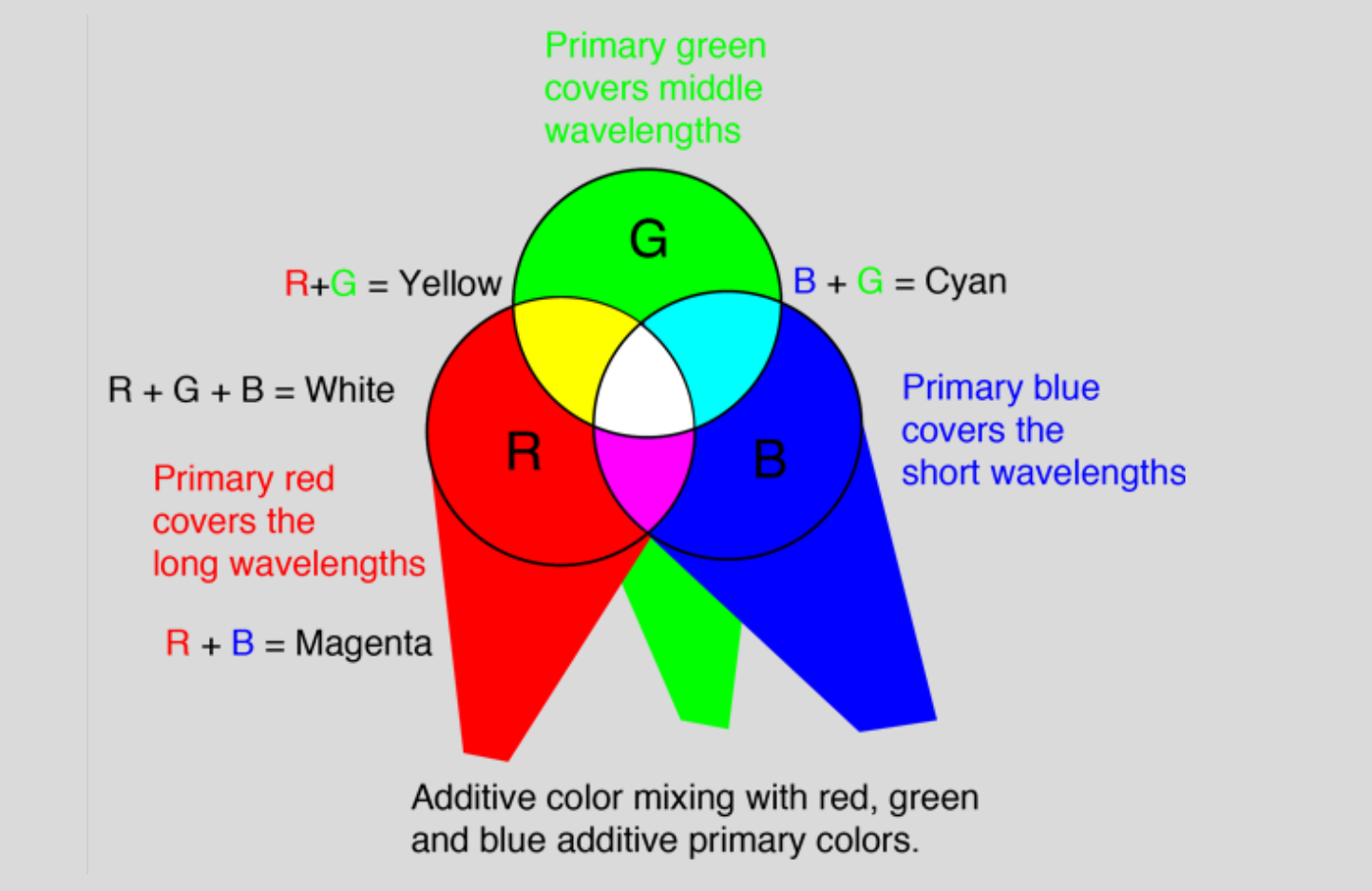


(255,255,0)

(0,255,255)

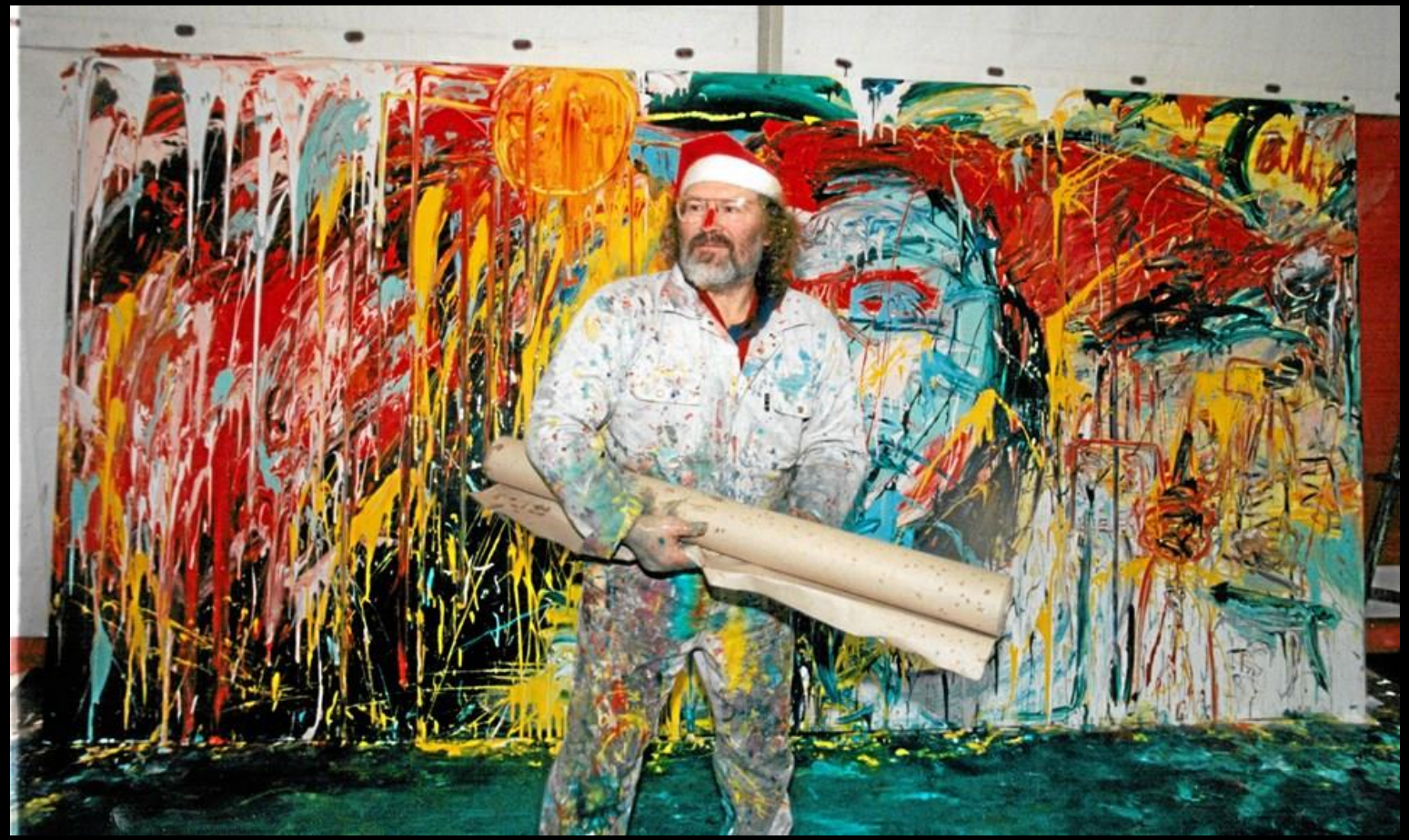
(255,0,255)

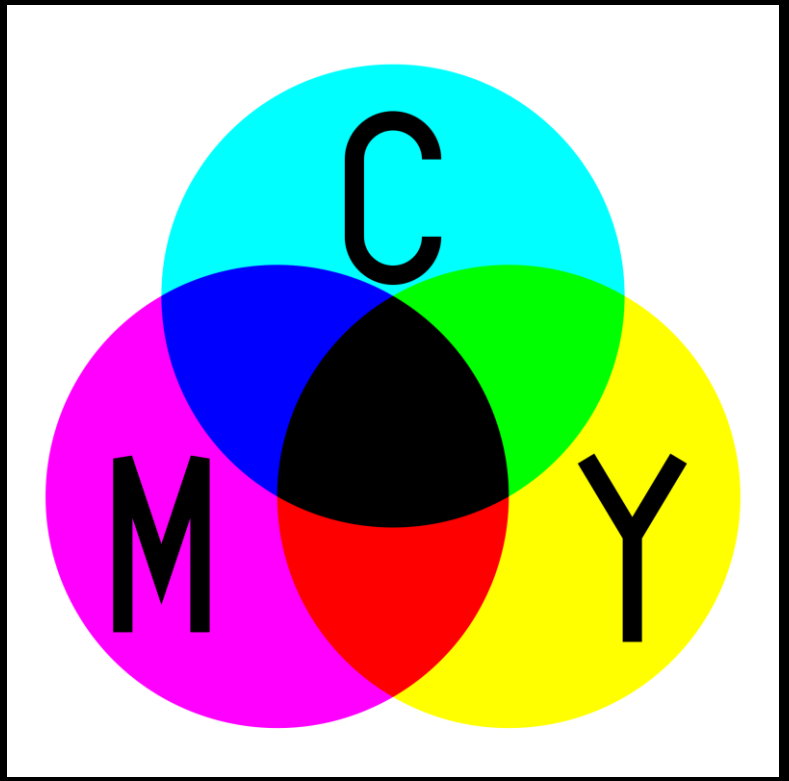
Additive color mixing



http://hyperphysics.phy-astr.gsu.edu/hbase/vision/addcol.html

Subtractive color mixing





Wikipedia

Processing RGB images

- Each pixel in a colour image contains 3 values
- Equal to a “vector function” in mathematics
- More complicated to analyse
- Medical images are typically grayscale
  - Why?
- Often images are converted from colours to grayscale before the analysis

Converting colour to grayscale

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

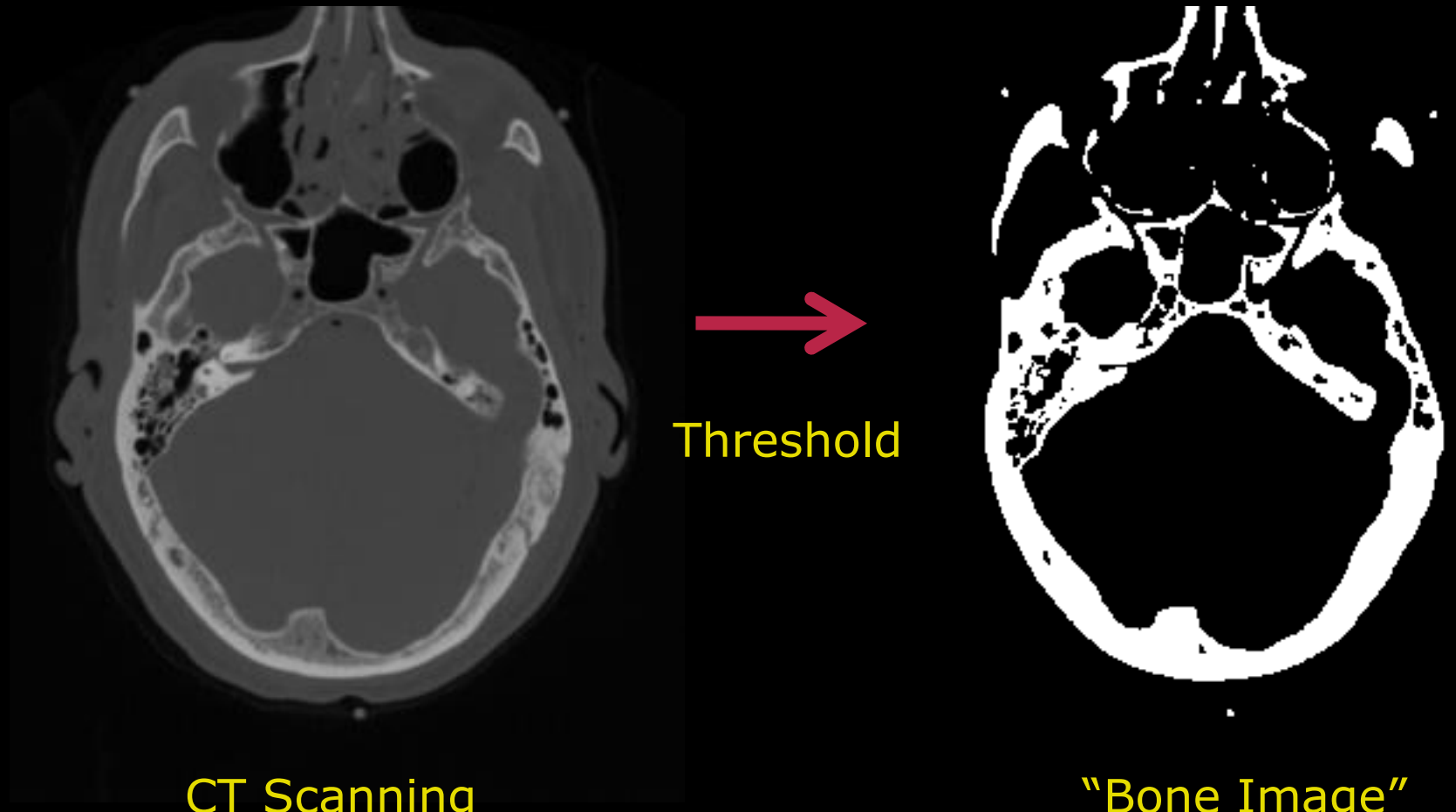
Is it possible to convert a grayscale image back to a color image?

Binary images

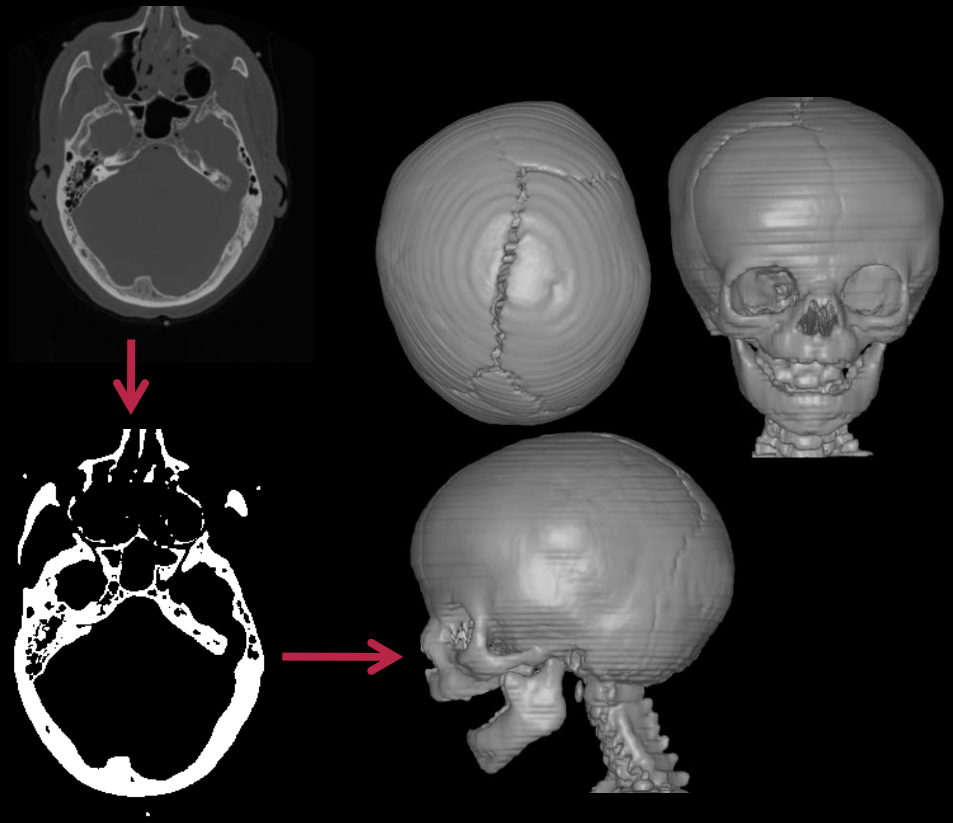
- Binary – means on or off
- Binary image – only two colors
- Background (0 = black)
- Foreground (1 = white)

- Simple representation of CT scanning of the head

Gray scale to Binary Image



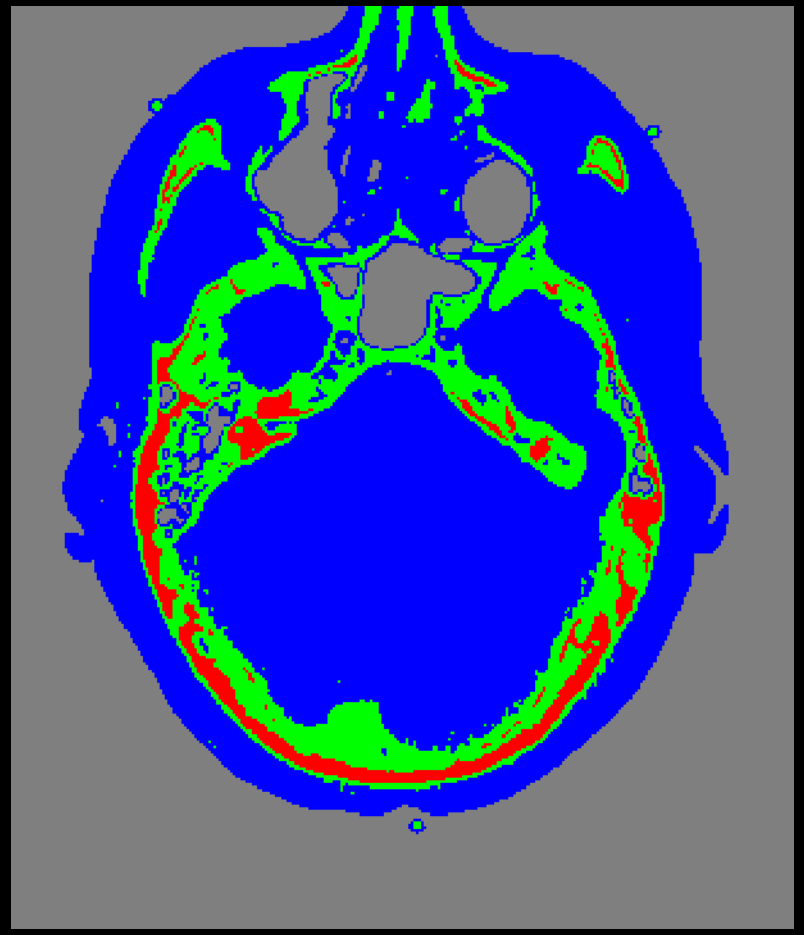
Binary image – why?



- Separating objects from background
- Count the number of the objects
- Measure the size and shape of objects
- Advanced 3D visualisations

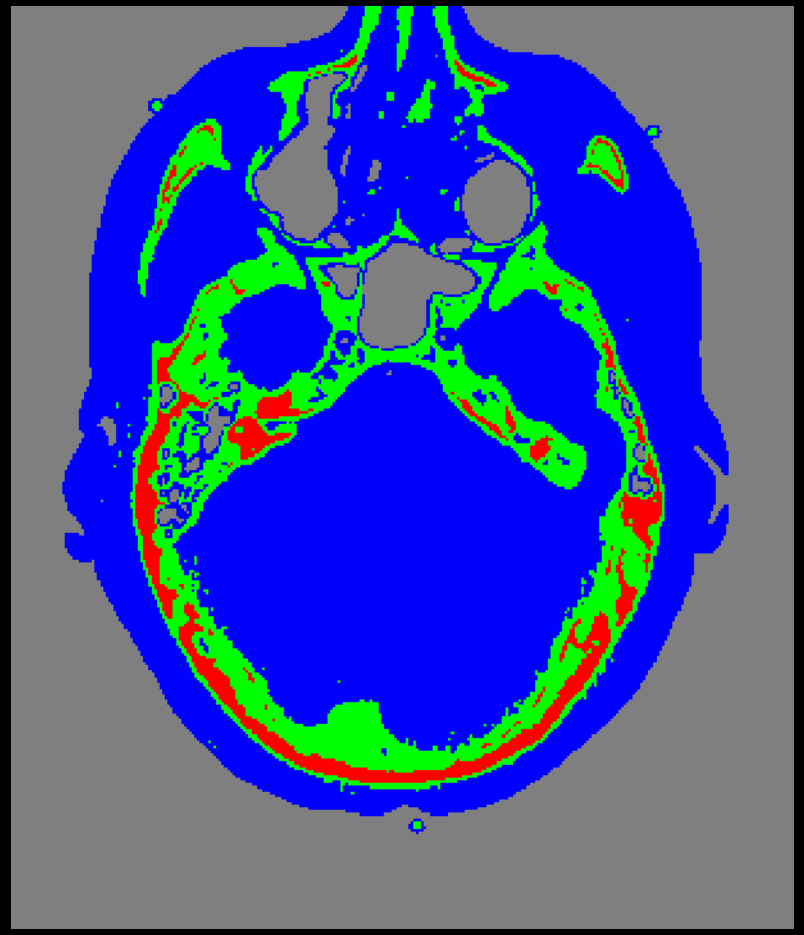
Image from 3D laboratory

Label Image



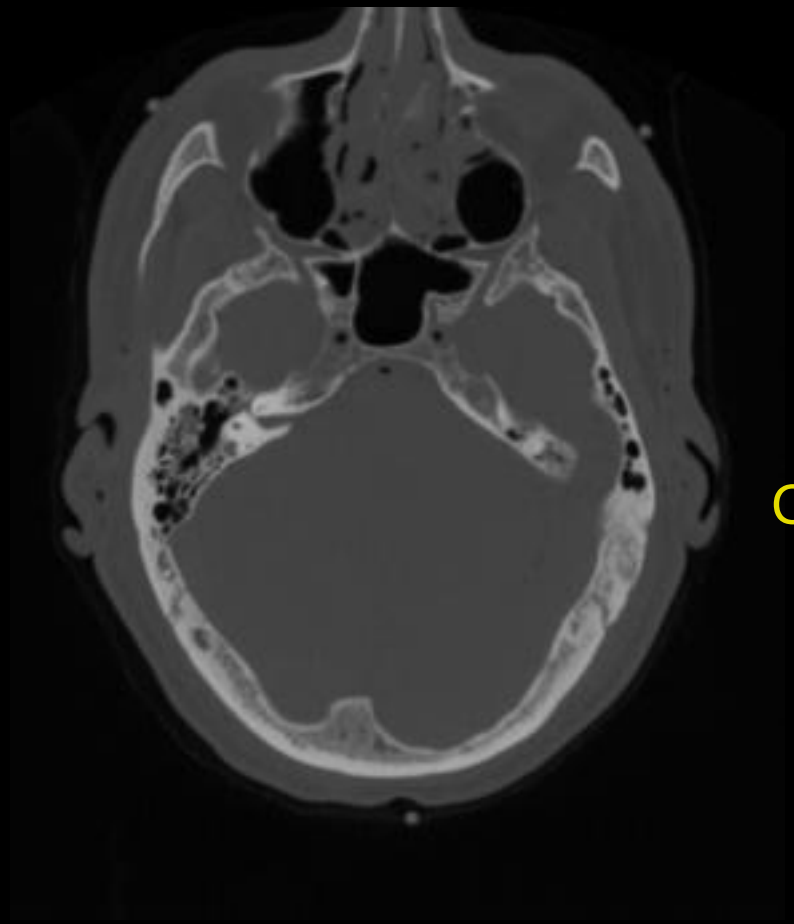
- The pixel value tells the *type* of the pixel
  - (0) Gray – background
  - (1) Blue – soft tissue
  - (2) Green – hard bone
  - (3) Red – spongy bone
- Only 4 different pixel values
- Colours made using a *look-up-table*

Label Image –why?

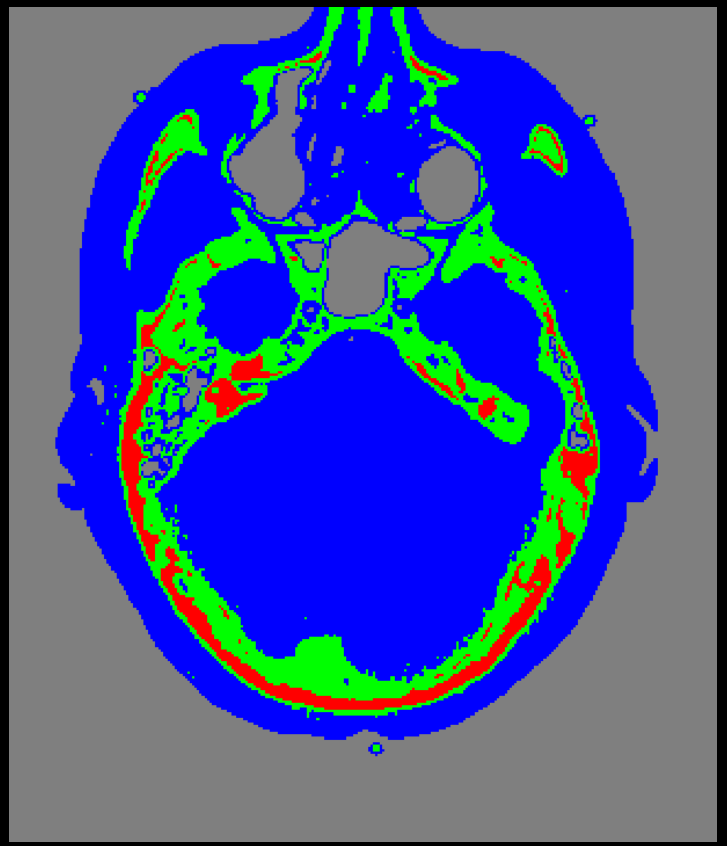


- How big is a tumour? (volume / percent)
- Bone density
- General anatomy recognition
  - Blood vessels
  - Calcifications

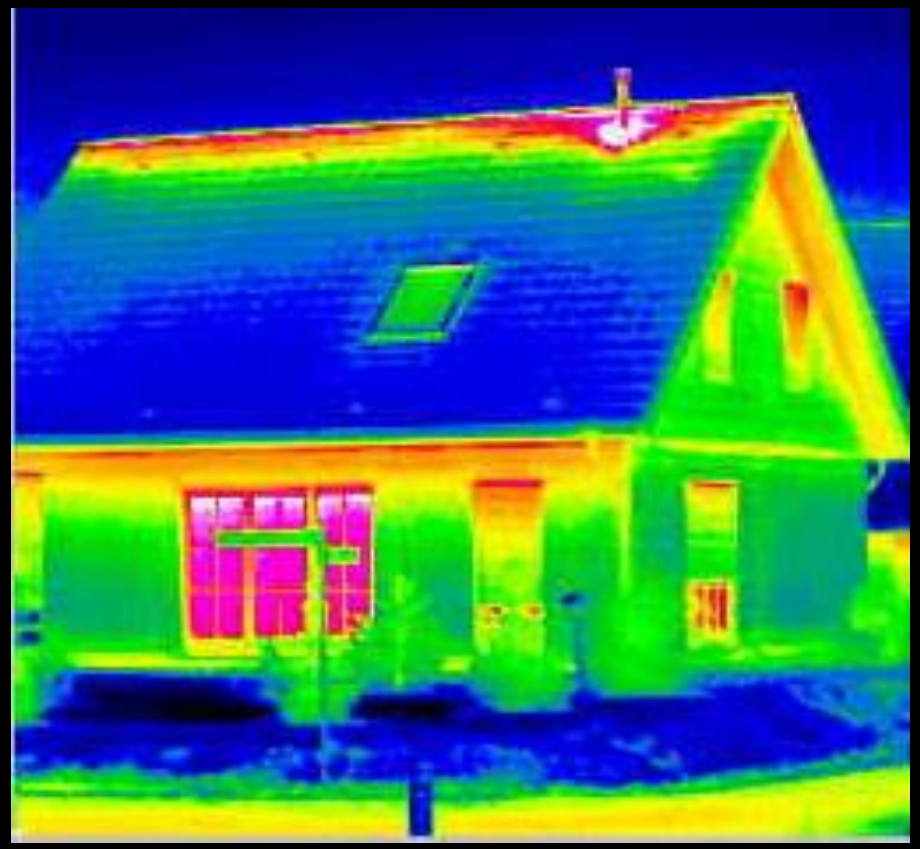
Label Image – how?



Classification



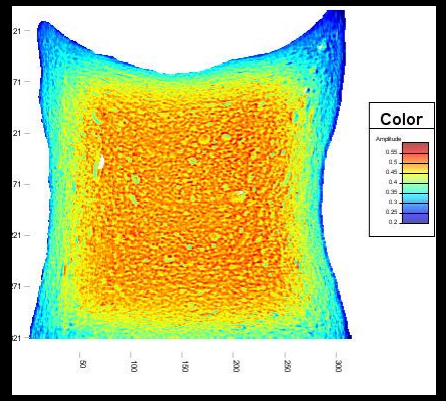
Multispectral images

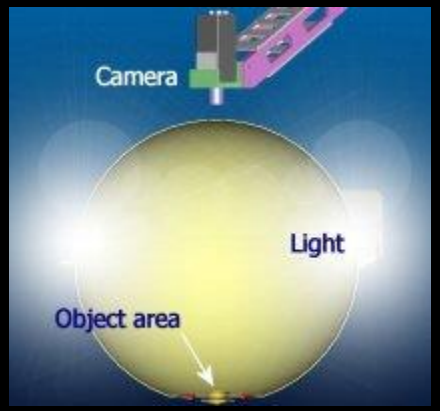


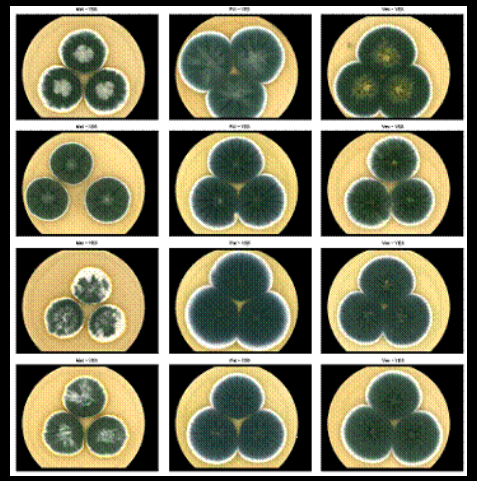
Infrared

- There are more visual information than what can be seen with the human eye
- Standard cameras captures the red, green, blue colours
- Capture systems that capture more bands and other frequencies exist
- Creates multispectral images
  - Each pixel contains perhaps 20 values from different spectral bands

Multispectral System - VideometerLab







- Integrating sphere
- Light emitting diodes with different wavelengths
  - From near infrared to ultraviolet
- High resolution camera
- Water in bread
- Classification of fungi
- Skin diseases

16-bit images

- 256 values fine for the human eye
- Pixel values not only for display
  - Physical meaning
- Computed Tomography
  - X-ray attenuation
- Hounsfield units
  - 0 water
  - -1000 air
  - -120 fat
  - 400+ bone

PCA Analysis

Next week:
Image acquisition, digital cameras, compression and storage