Image Analysis

Rasmus R. Paulsen
Tim B. Dyrby

DTU Compute

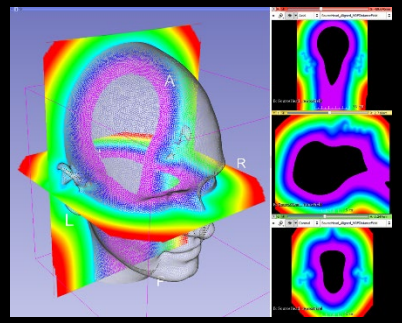
http://compute.dtu.dk/courses/02515

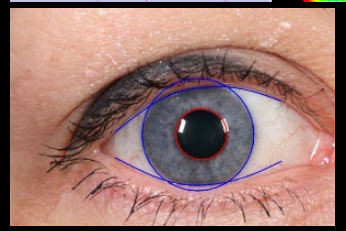
DTU

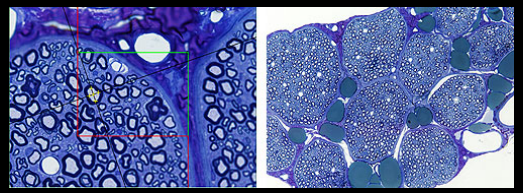
Week 1 - today

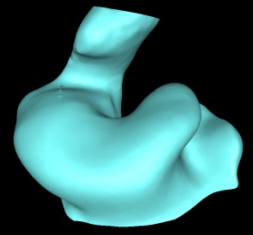
8:00 – 10:00	Exercises
10:00 – 12:00	Introduction and practical matters
	Lecture – An introduction to image analysis
	Lecture – A tutorial on Principal Component Analysis (PCA)

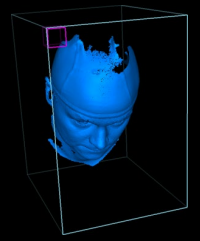
Rasmus R. Paulsen

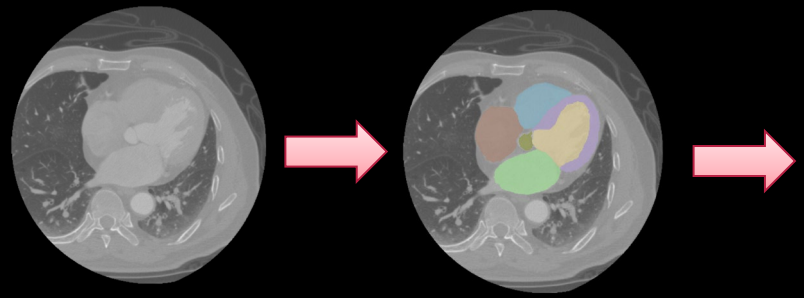


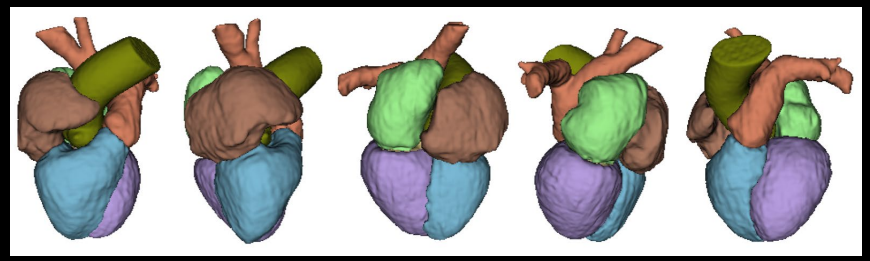












- Master of Science (Eng). DTU 1998
- Industrial PhD with Oticon A/S
- Research and development at Oticon A/S
- Professor DTU Compute

Tim B. Dyrby

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

Teaching Assistant

- Andreas With Aspe

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 the stream will be posted on DTU Learn before the lecture
  - Links to video on the homepage (under schedule)
  - Courses.compute.dtu.dk/02515

The different versions of the image analysis course

- 02502: The previous combined bachelor/master level course
  - Terminated in 2025 since DTU is not allowed to do combine BSc/MSc anymore
- 02503: The bachelor level version of the image analysis course
  - Running from fall 2025
- 02515: The master level version of the image analysis course
  - Running from spring 2026

- The learning objectives and course content is very similar for the three courses. You can only get credits for one of them

The exercises and the exam

- The exercises are very 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 expect that you can run Python during the exam!

Very Important I: Do the exercises!

Very Important II:
We can not help you after the course period!

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/02515
  - Schedule / Exercises / Data
  - Updates happen!

- Course messages will be given through DTU Learn

#	Date	Topic	Video	Material	Exercise
1	3/2	Introduction to image analysis (Rasmus) Introduction to Principal Component Analysis (PCA) (Rasmus)	Stream	MIA 1, 2, app. A. PCA Note (except Section VI (SVD) and App. A)	1
2	10/2	Cameras, lenses, image compression, image storage and change detection in videos (Rasmus)	Stream	MIA 2, 3 + CDV Note	1 + 1b
3	17/2	Pixelwise operations, Colour images. PCA Analysis on images (Rasmus)	Stream	MIA 4, 8 Eigenfaces article (only sections marked with yellow)	2 + 2b
4	24/2	Neighborhood Processing (Filtering) and Morphology (Tim)	Stream Recordings Fall 2023	MIA 5, 6	3 + 8
5	3/3	Blob analysis and object classification (Rasmus)	Stream	MIA 7	4 + 4b
6	10/3	Pixel classification and advanced classification (Tim)	Stream Recordings Fall 2023	MIA 9 + LDA note on Learn	5
7	17/3	Industry presentations: Radiobotics Dalux JLIVision TrackMan Milestone Videometer IHfood Visiopharm	We cannot stream the Industry presentations	none	Exercise catch-up
8	24/3	Geometric transformations and landmark based registration (Tim)	Stream Recordings Fall 2023	MIA 10, 11	6
9	7/4	Boundary Tracing (Hough Transformation and Dynamic Programming) (Tim)	Stream Recordings Fall 2023	MIA 12	6b
10	14/4	Advanced registration (Tim)	Stream Recordings Fall 2023	Elastix manual (5.2.0) chapter 2.	7
11	21/4	Real time face detection using the Viola Jones method (Rasmus)	Stream	Rapid Object Detection using a Boosted Cascade of Simple Features	9
12	28/4	Statistical models of shape and appearance and active shape models (Rasmus)	Stream	Statistical Models of Appearance for Computer Vision (p. 12 - 20 and p. 29 - 43)	Digital test exam and exercise catch-up
13	5/5	Advanced topics (Claes Nøhr Ladefoged)	Stream	none	Digital test exam and exercise catch-up

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/02515/exam.html
- Previous exam sets are also available
  - Most relevant is from Spring 2021 and onwards

AI assisted tools during the course and the exam

- You are allowed to use AI tools like ChatGPT and Copilot
  - Both during the course and at the exam
- It is your responsibility to
  - install and keep your tools up to date
  - Verify if the output of the tools are correct
- The exam can ALSO be solved without the use of AI assisted tools

AI related learning objectives

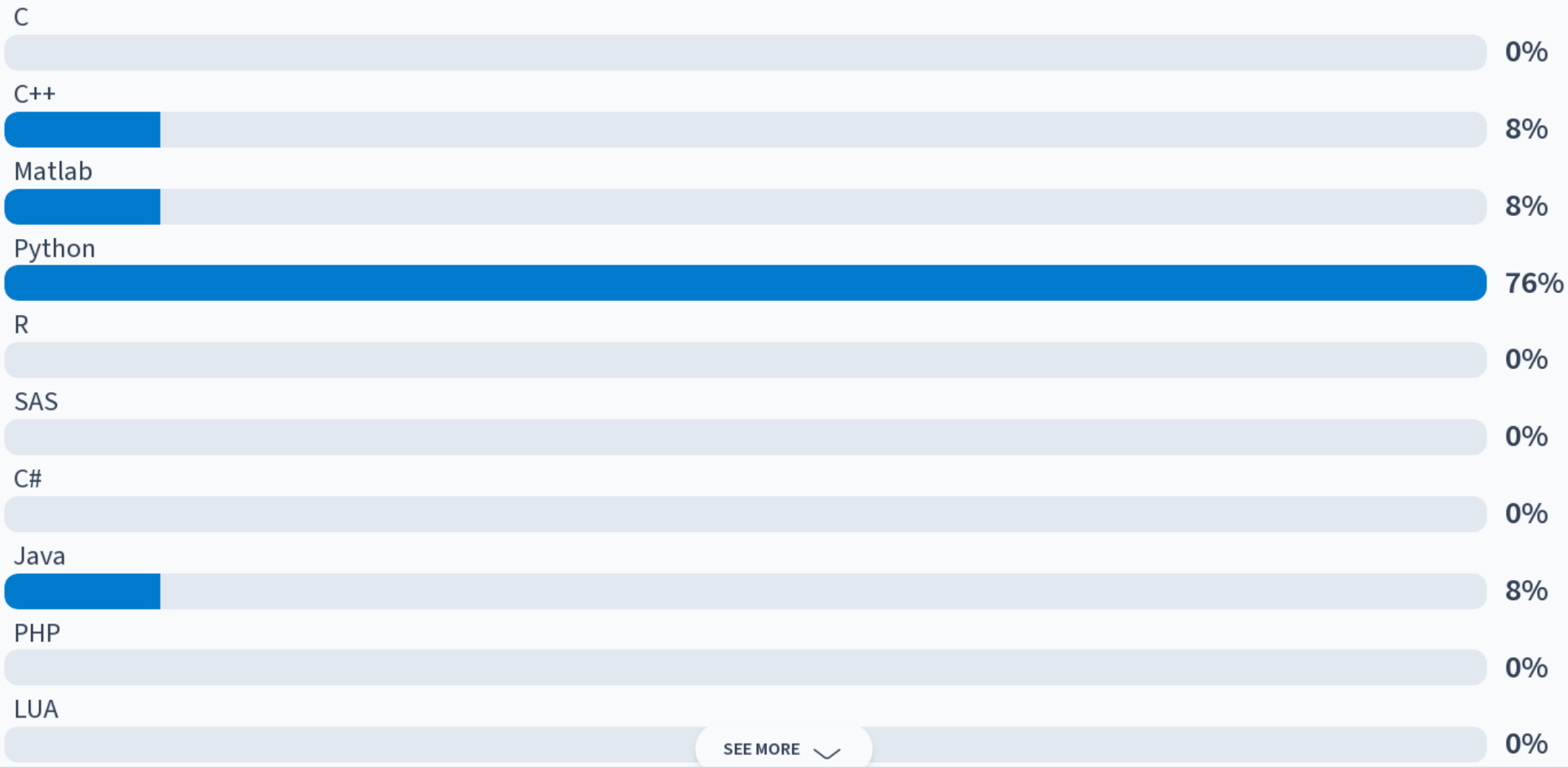
- General 02515 course learning objective:
  - Estimate the correctness of the answer given by an AI assisted tool like ChatGPT and Copilot

- We are gradually adding AI tools related learning objectives to the exercises

PollEverywhere quizzes

https://pollev.com/rasmuspaulse538

What programming language are you most comfortable with?



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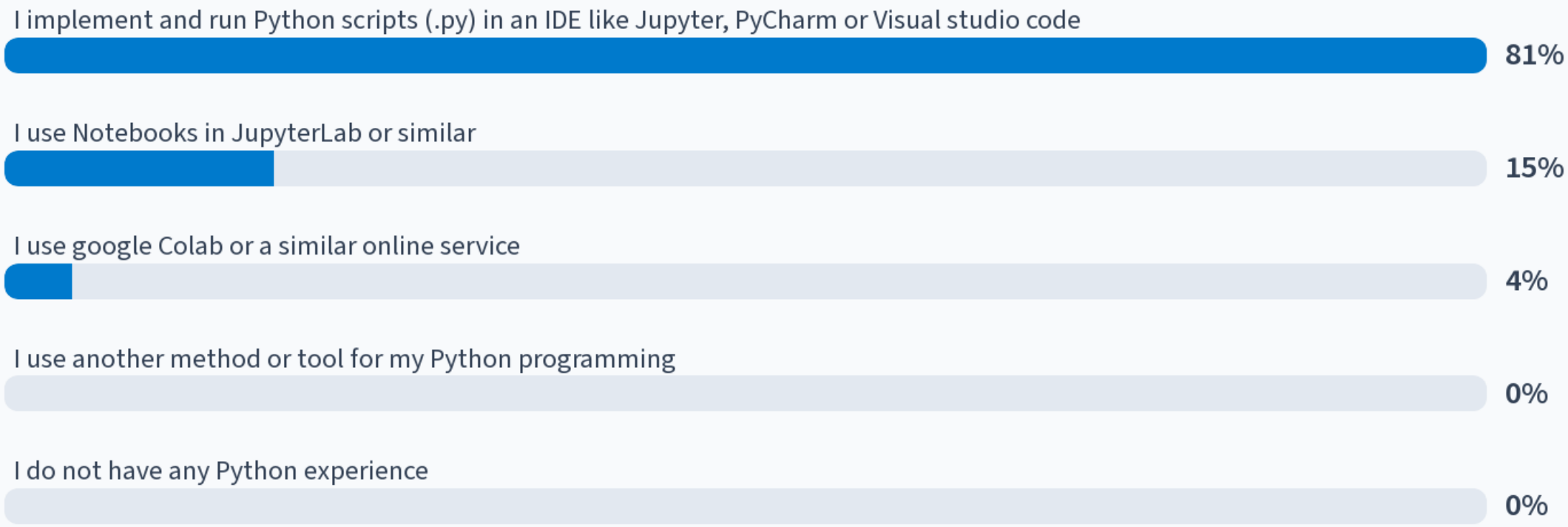
What is your practical experience with Python programming



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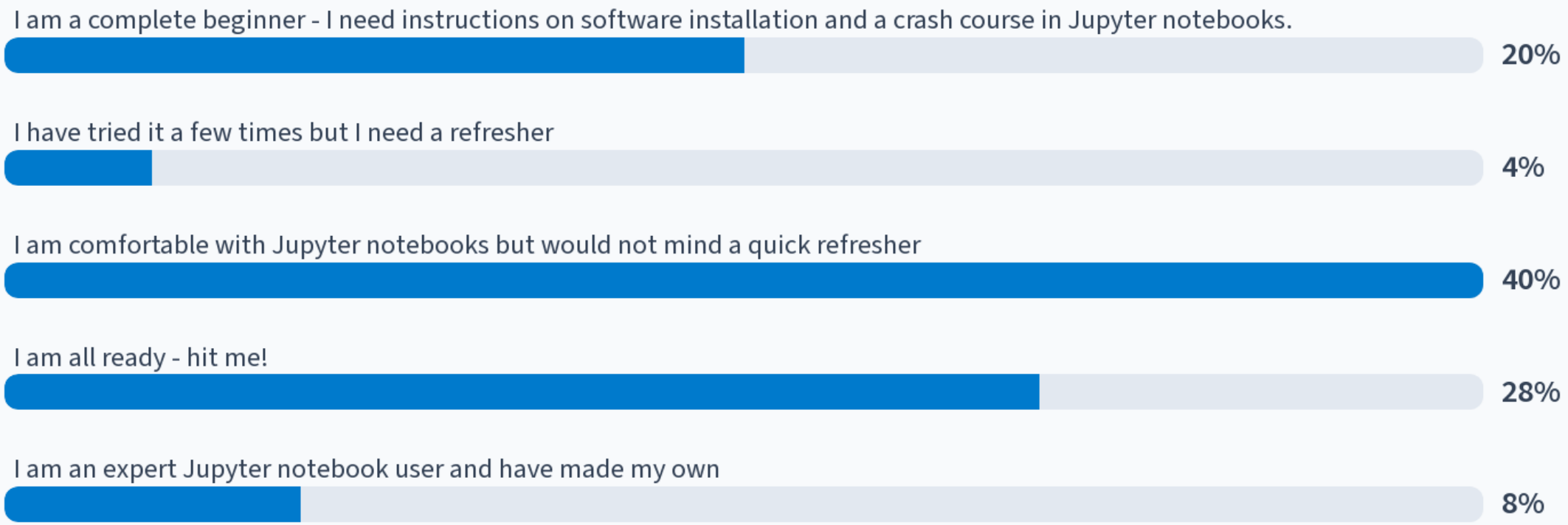
What is your experience with Jupyter Notebooks or JupyterLab



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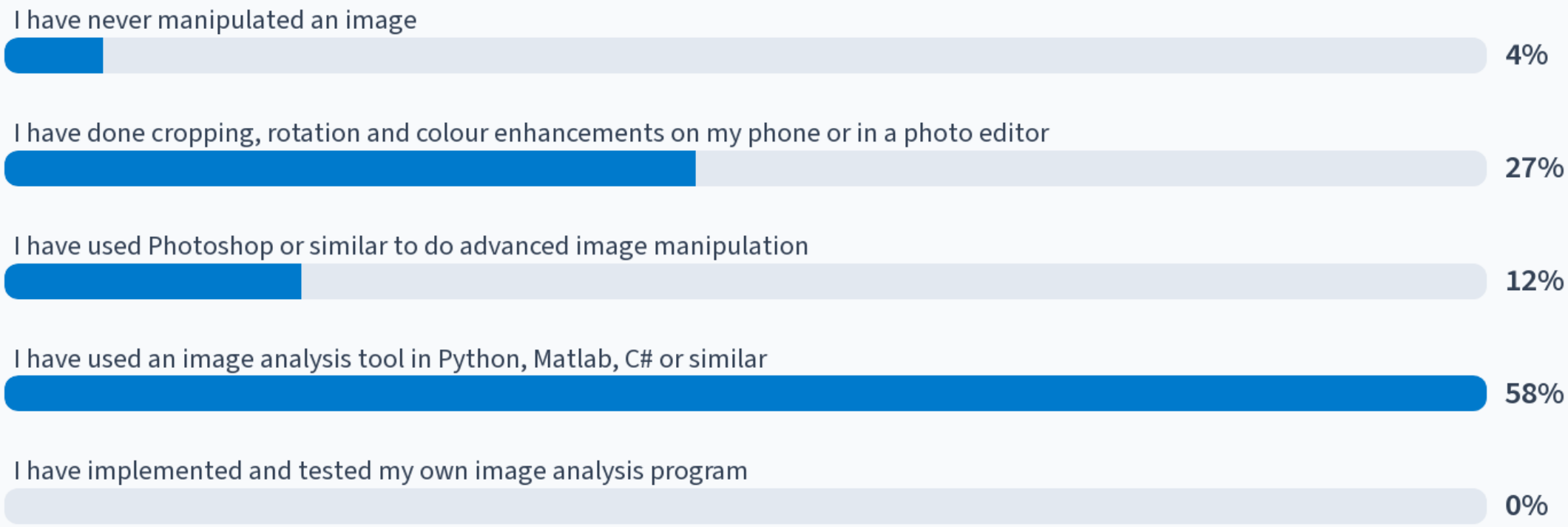
What is your experience with image manipulation, image processing and image analysis?



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To what extent are you currently using AI assisted tools like ChatGPT and Copilot

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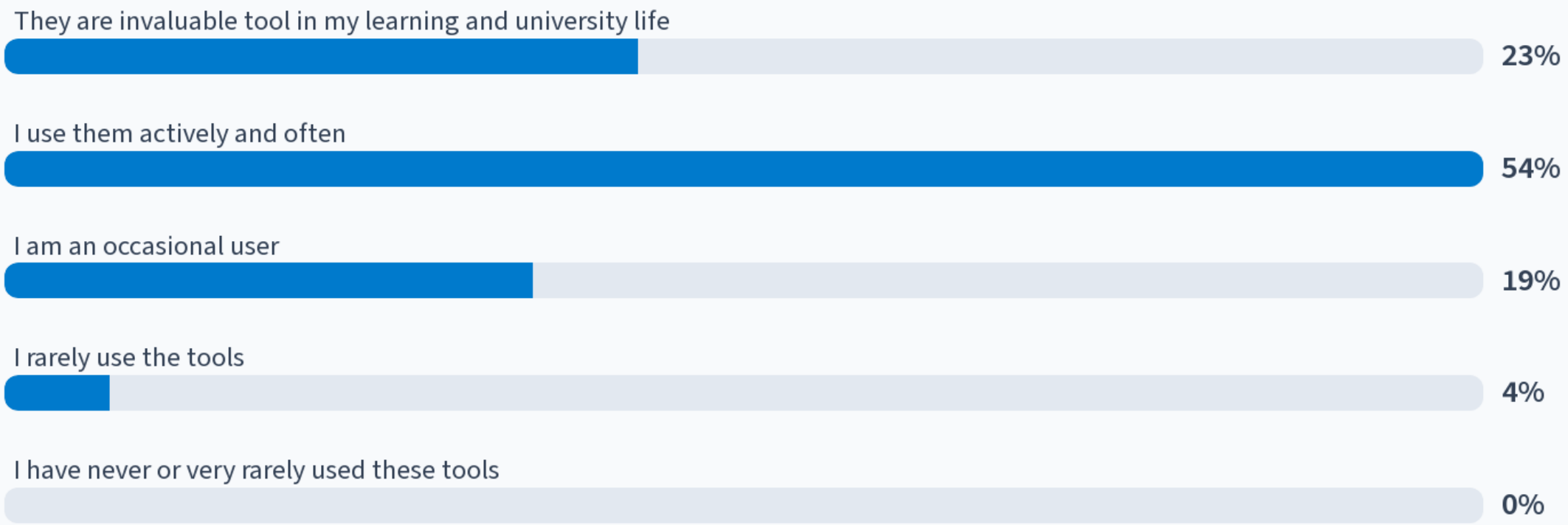

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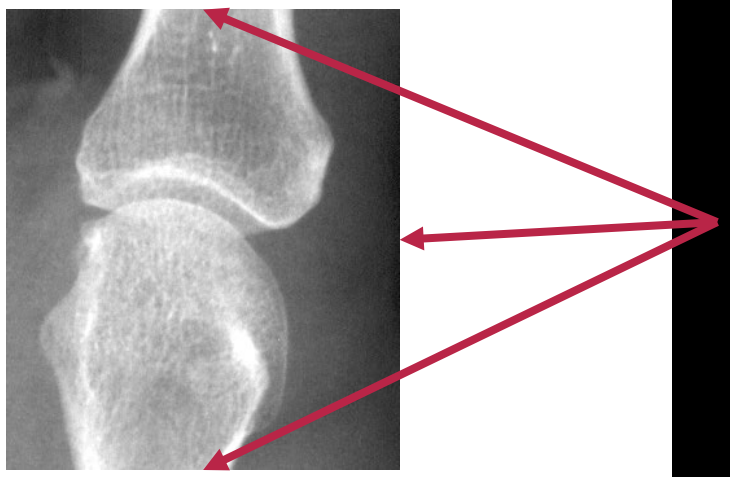
Why are my slides black?

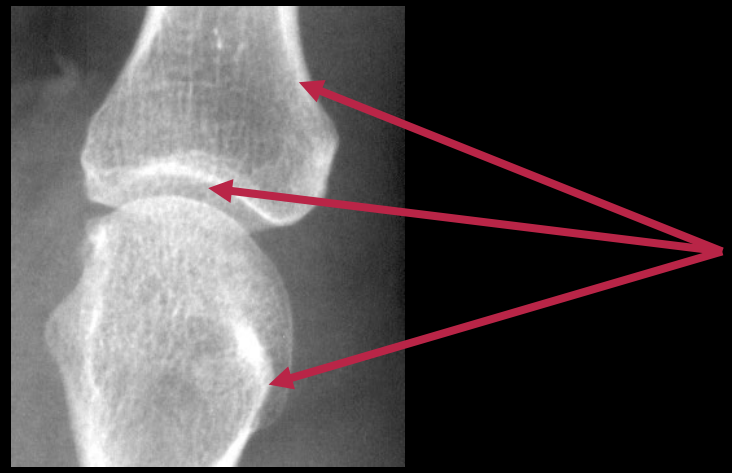
?

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

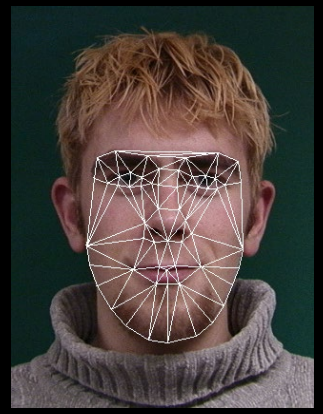
- Automatic extraction of information from images
- A sub-topic within
  - Pattern recognition
  - Machine learning
  - Deep learning

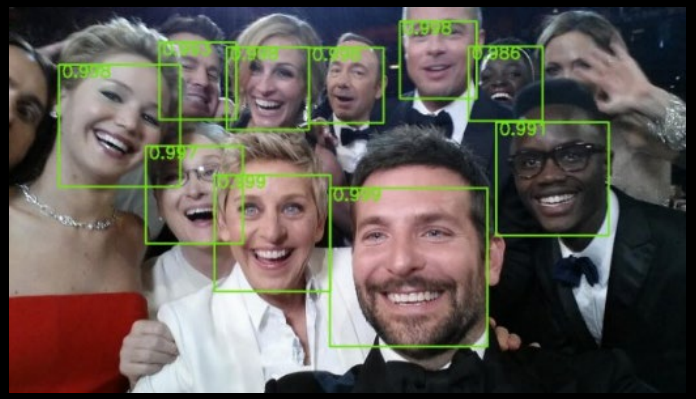
What is image processing

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

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





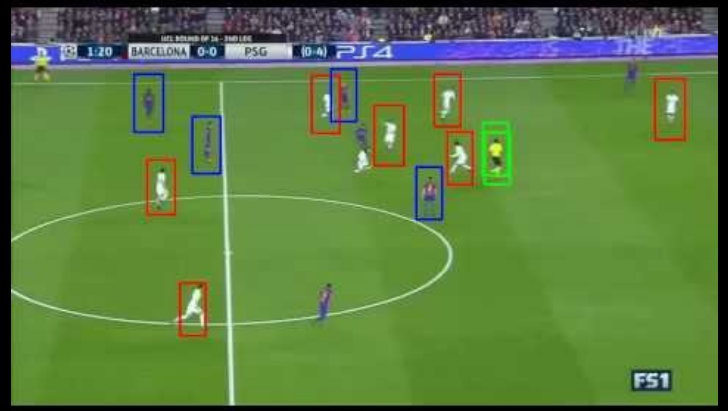
A 100 million $ industry

- 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 a lot of focus on 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

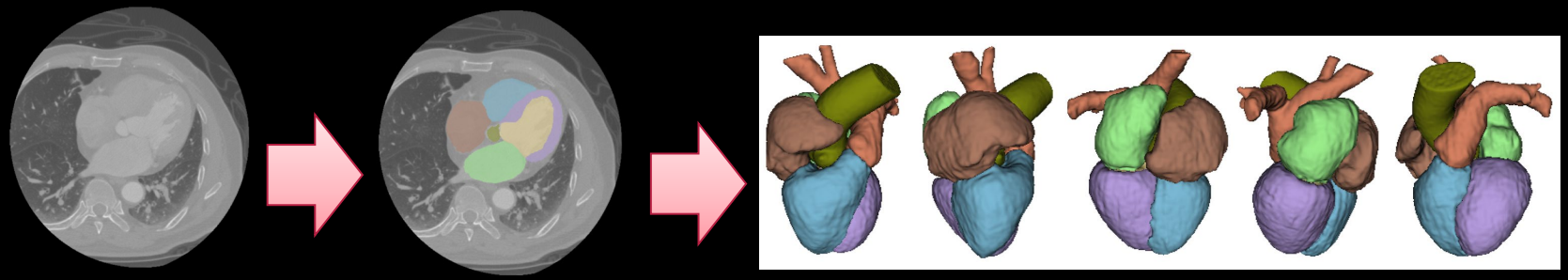


- Huge commercial impact
- Lots of research in human body tracking
- Personal trainers
- TV player tracking and smart overlays

Trackman

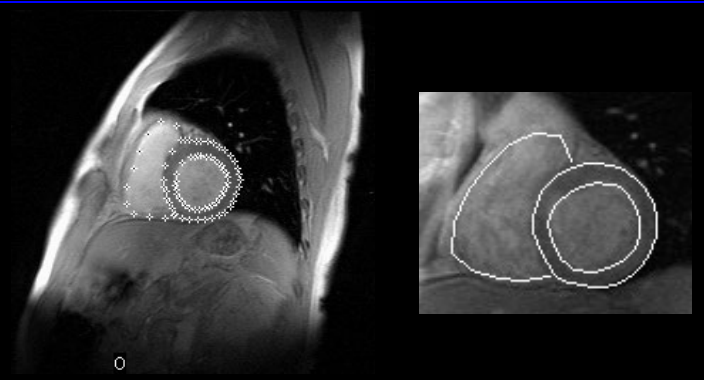
What is medical image analysis?

- Extraction of information from digital images
- Find unknown connections between diseases and what can be seen in images
- Can enhance the signs of diseases
  - Tumours / heart diseases / brain diseases / bone fractures
- Reproduce expert diagnostics
  - More accurate
  - Variation between doctors opinions removed
- Computer aided diagnostics



Automatic localization of the heart and its major substructures

Medical image analysis examples



Recognise and track the heart

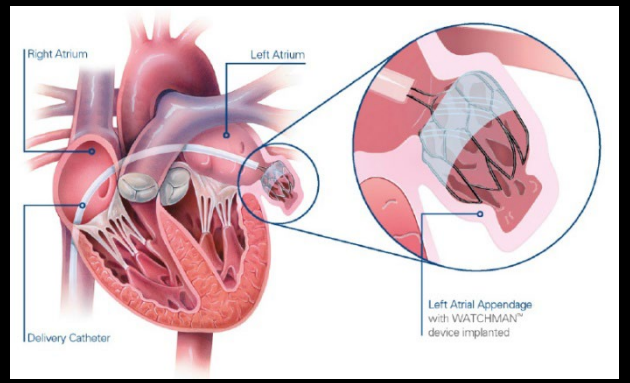
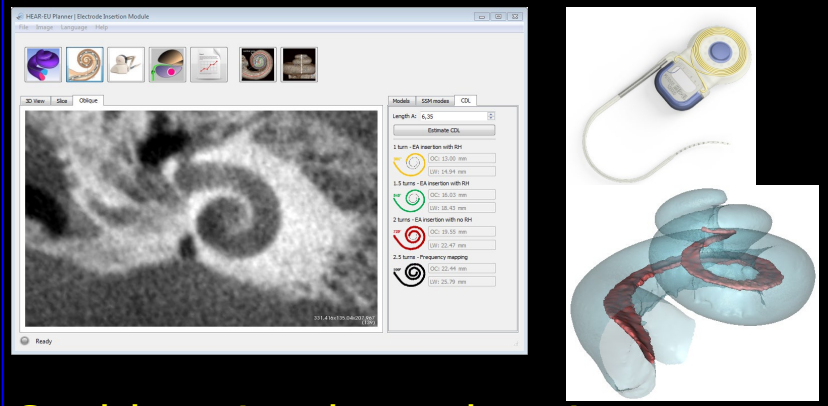
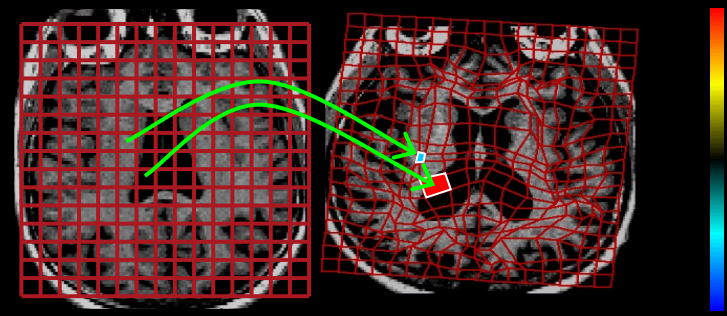


Image based surgery planning



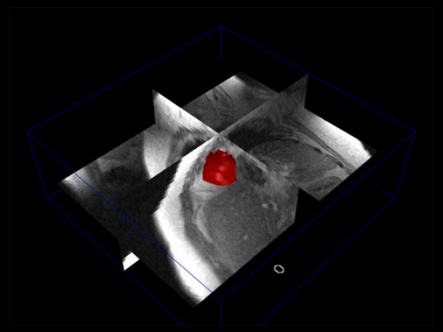
Cochlear implant planning



Shape changes in brain structures

Relevance

1980
Magnetic
resonance
prototype

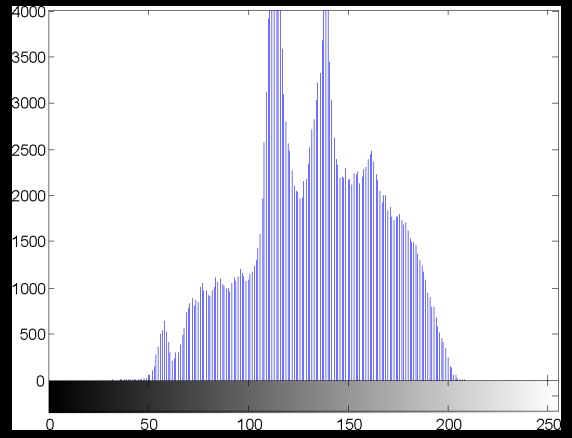


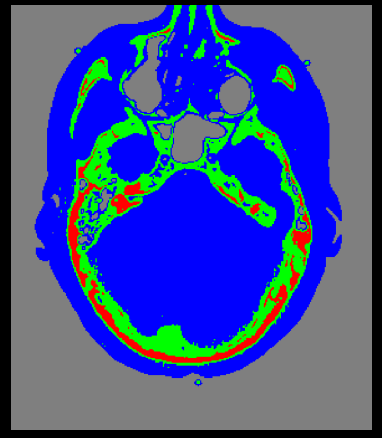
Now – PET/MR

- 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
- Describe and use the commonly used image coordinate systems
- Describe pixel types
- Describe the binary, the color, the label, the multispectral, the floating point, 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 67 as a binary number?

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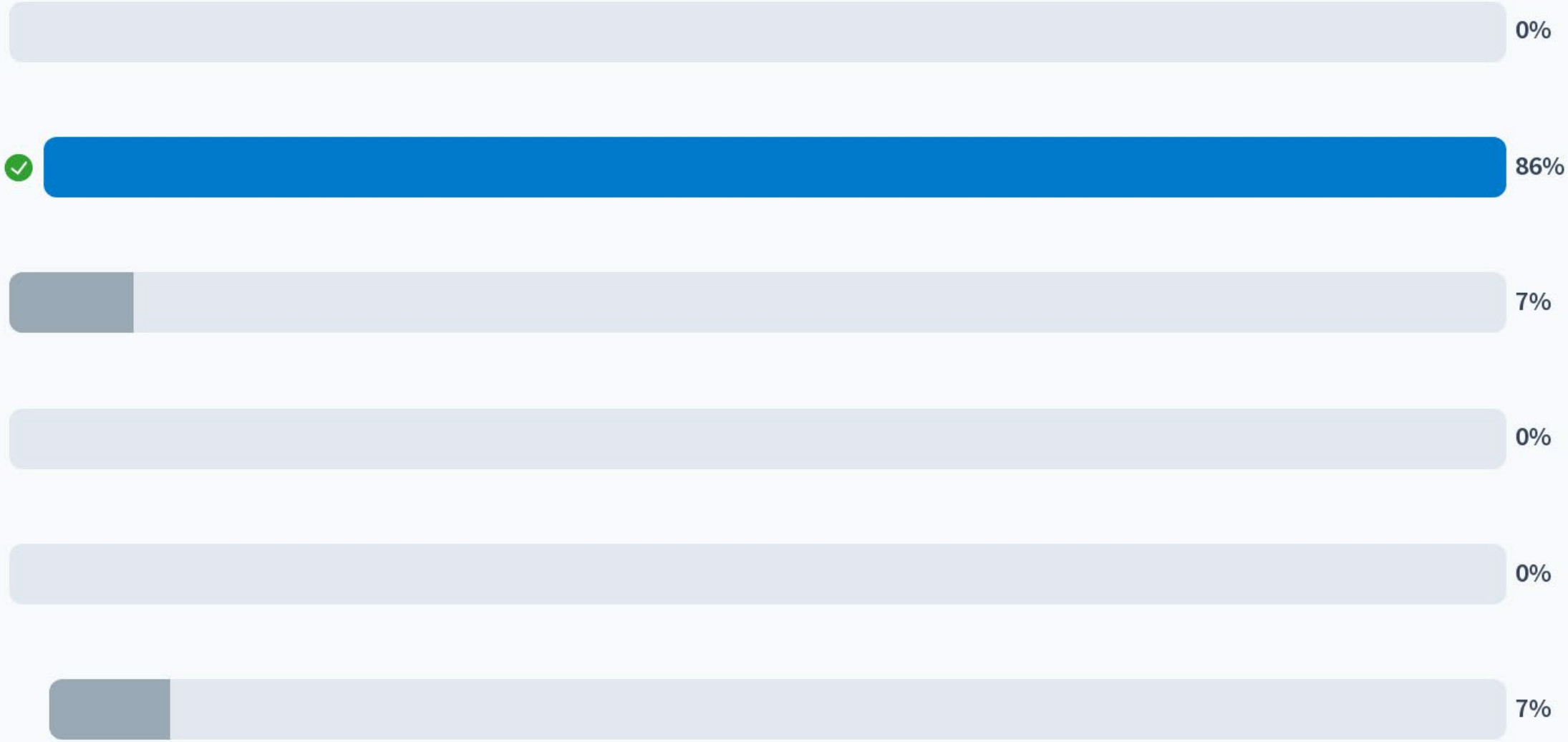
What is decimal 67 as a binary number?



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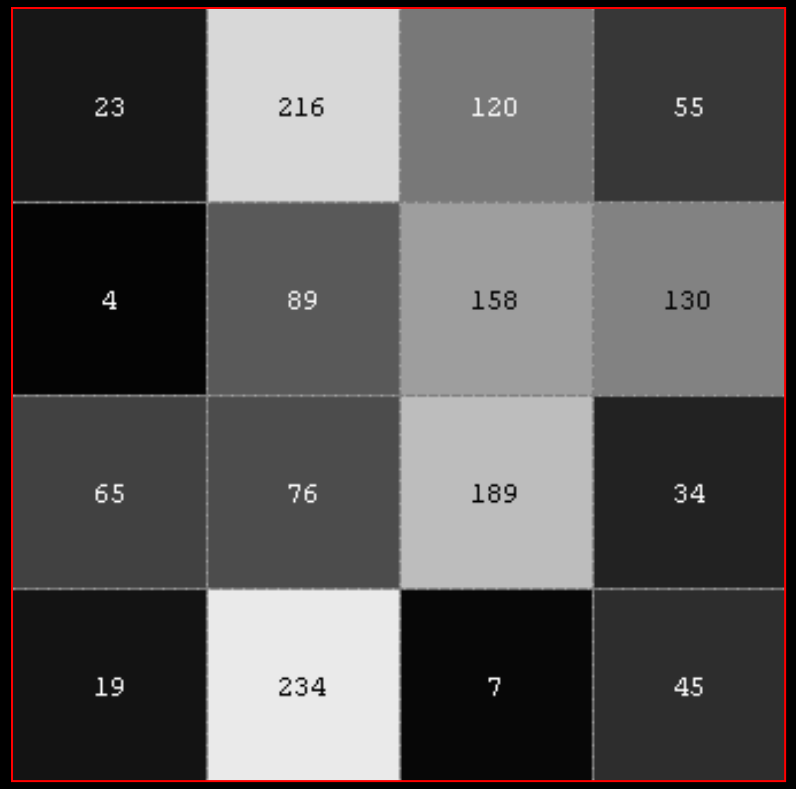
A digital image

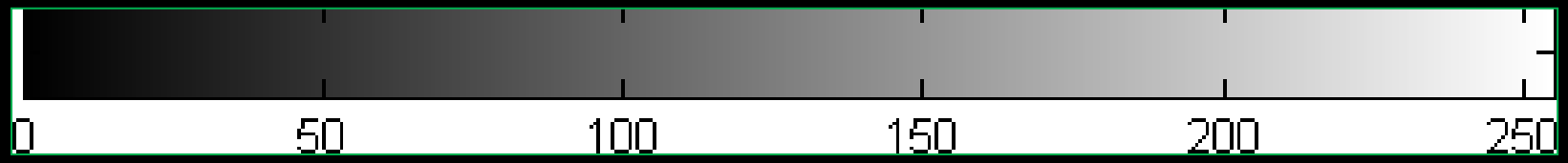
23	216	120	55
4	89	158	130
65	76	189	34
19	234	7	45

- between 0 and 255.
- The pure image data takes up 16 bytes of computer memory

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

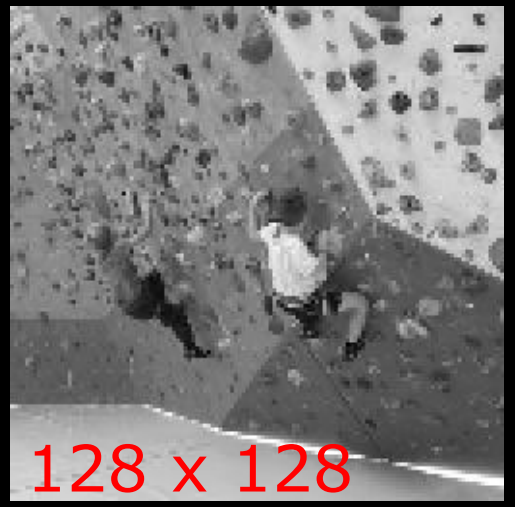
Spatial?

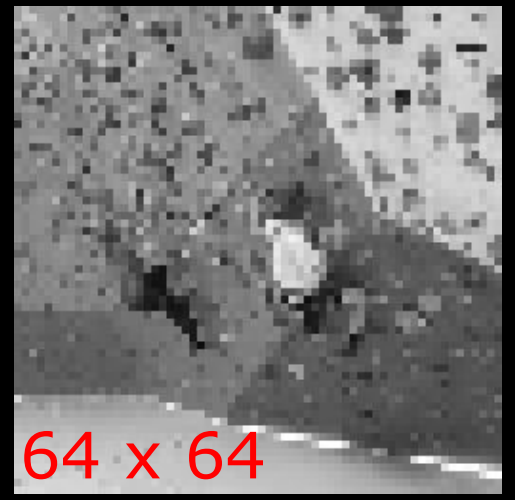
- Spatial
  - relating to the position, area and size of things
- Example:
  - This task is designed to test the child's *spatial* awareness

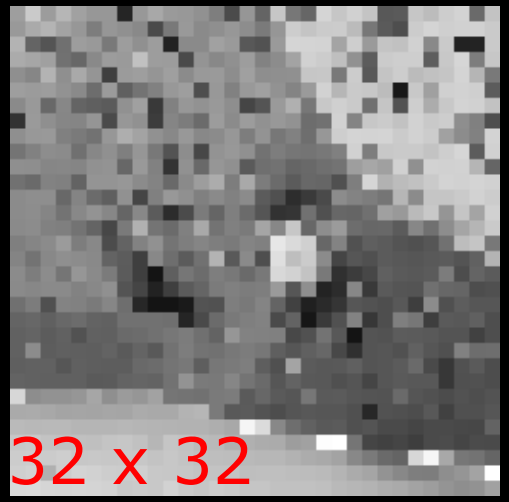
- Danish
  - Rumlig – jeg har en god rumlig forståelse

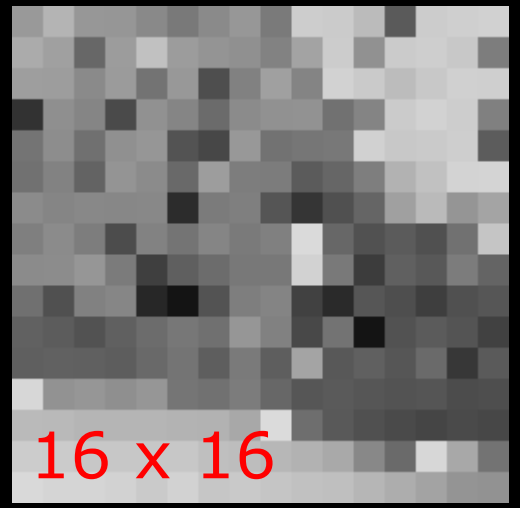
Spatial resolution

The number of pixels used to represent the image

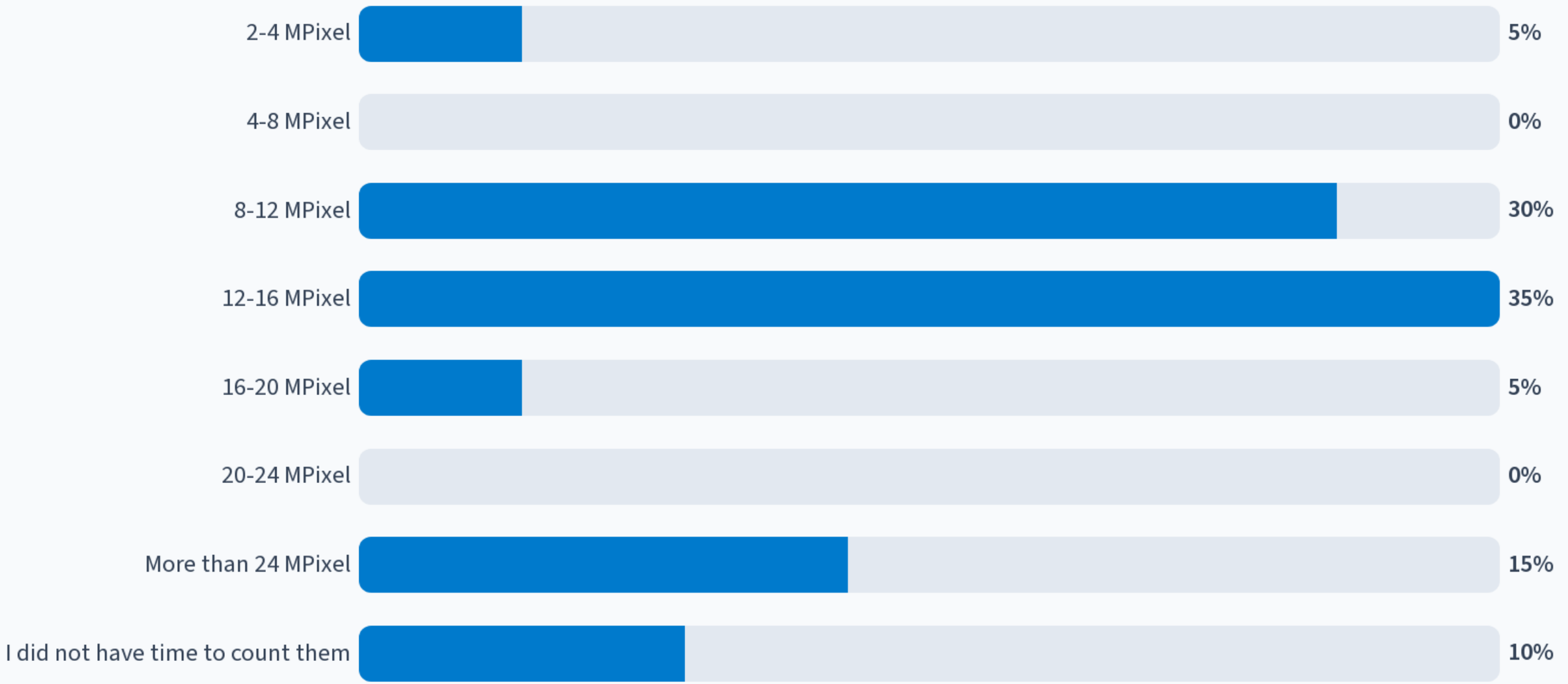








How many megapixels (approximately) do the photos you take with your camera or phone have?



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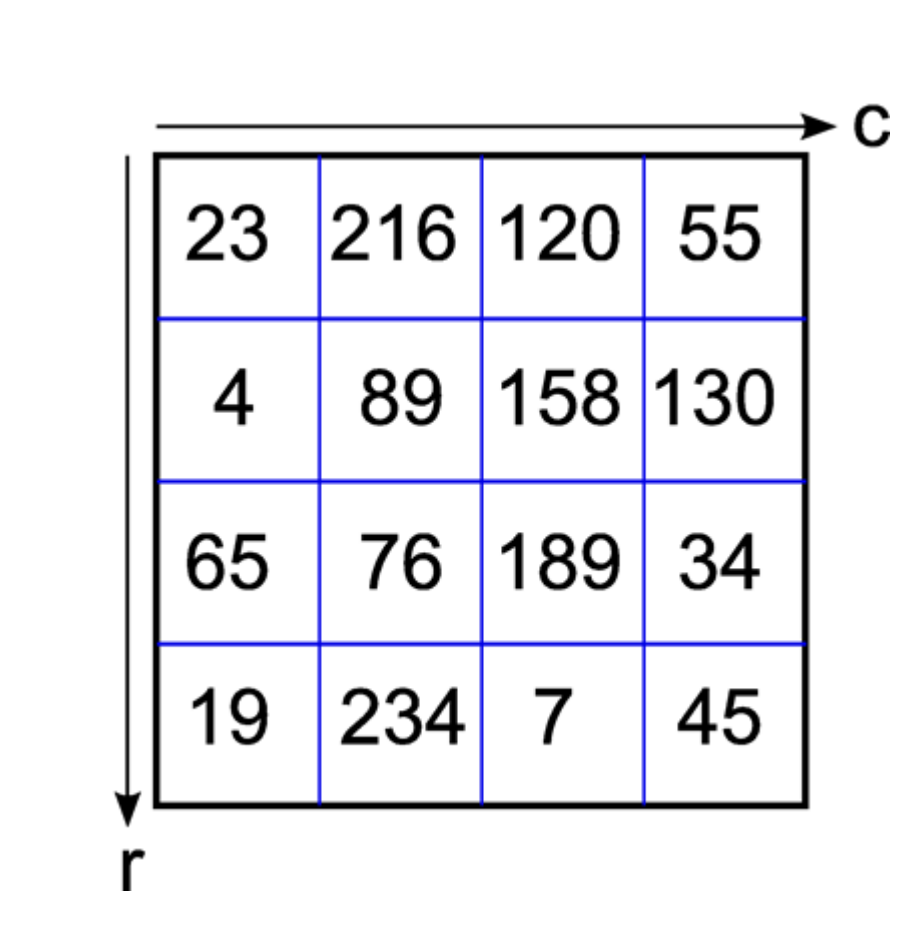
How many pixels?

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+

Grey level resolution

The number of grey levels in an image

An image as a matrix



- An image is stored in the computer memory as a 2 dimensional matrix
- 4 rows and 4 columns
- Can also be seen as a discrete function f(r, c)
- In Python a pixel can be stored as an uint8
- uint8 = Unsigned 8-bit integer = 1 byte

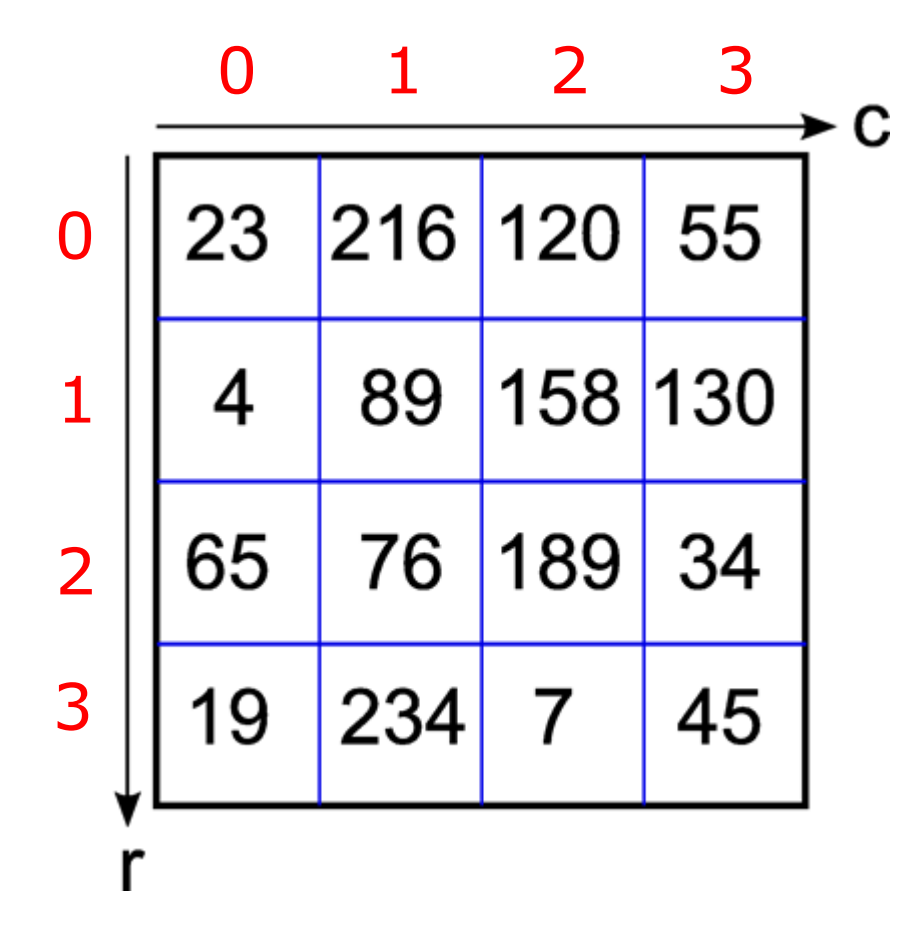
Pixel types and their ranges

Data type	Range
uint8	0 to 255
uint16	0 to 65535
uint32	0 to 2^{32} - 1
float	-1 to 1 or 0 to 1
int8	-128 to 127
int16	-32768 to 32767
int32	-2^{31} to 2^{31} - 1

- A pixel can be processed and stored as different *types*
- The uint8 is the most common type
- For processing a pixel is often transformed to a float
- When processing speed and memory space is an issue you should be careful about the pixel type – more about that later in the course.

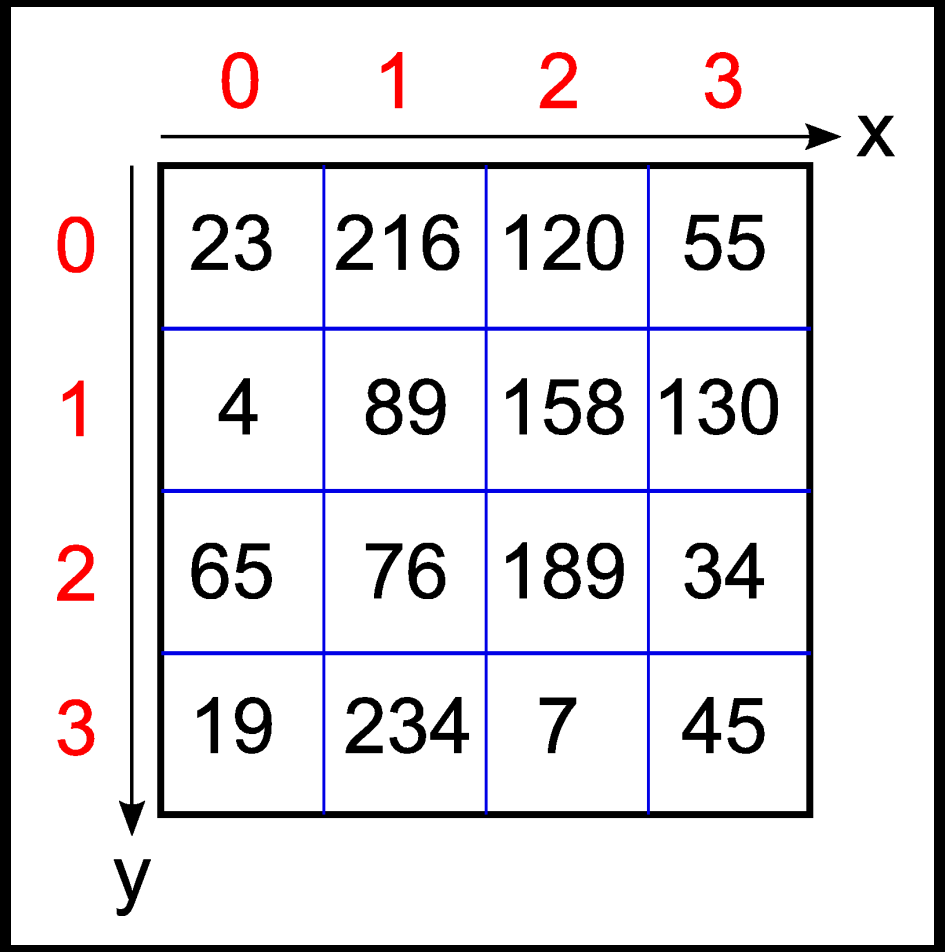
https://scikit-image.org/docs/stable/user_guide/data_types.html

Pixel coordinates – Python matrix



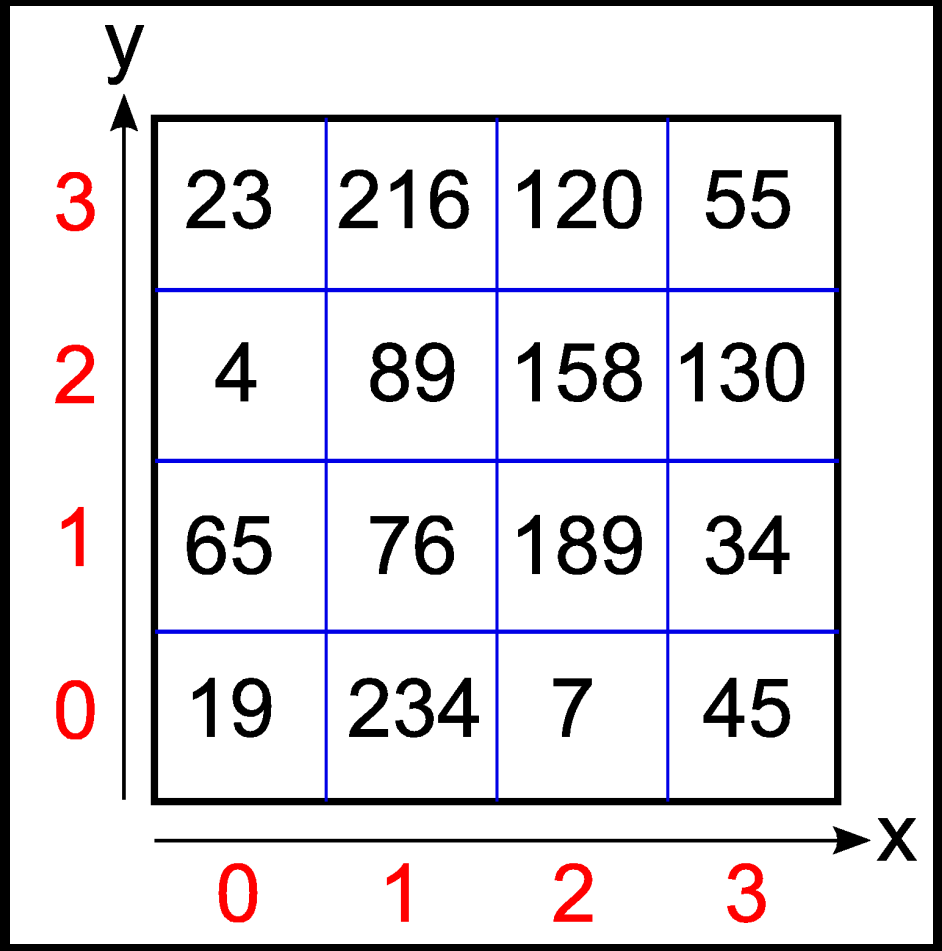
- Origin is in upper left corner
- 0-based
- (row, column) system
  - Vertical axis is the first axis
- M rows and N columns
- Row range [0, M-1]
- Column range [0, N-1]

Pixel coordinates – Photoshop etc.



- Used in many graphics programs
- Origin in upper left corner
- 0-based
- (X,Y) system
  - Horizontal axis is the first coordinate
- Often width (W) and height (H) are used to denote image dimensions
- X range [0, W-1]
- Y range [0, H-1]

Plot coordinates



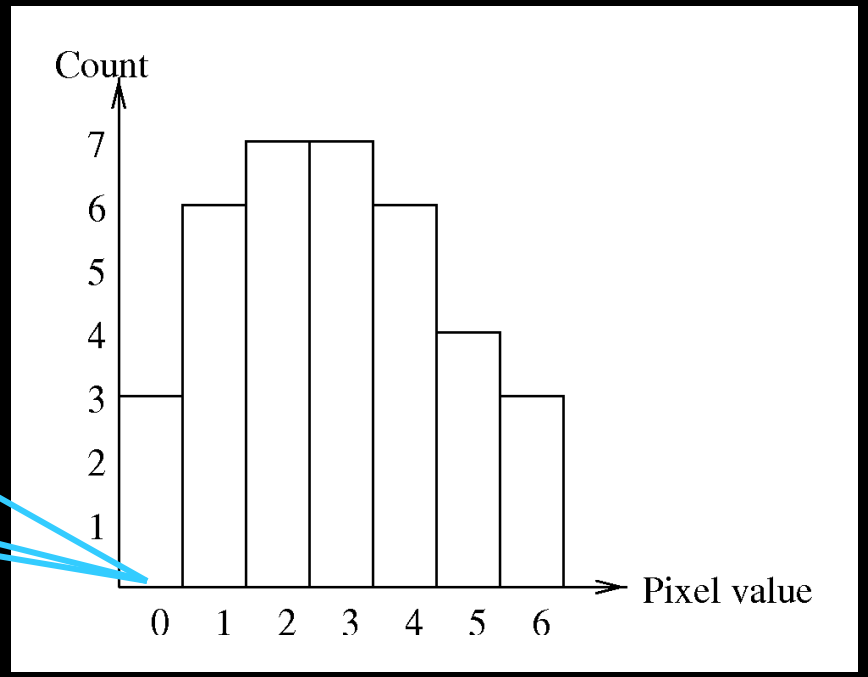
- Used when plotting – known from mathematics
- Origin in lower left corner
- 0-based
- (X,Y) system
  - Horizontal axis is the first axis

The Image Histogram

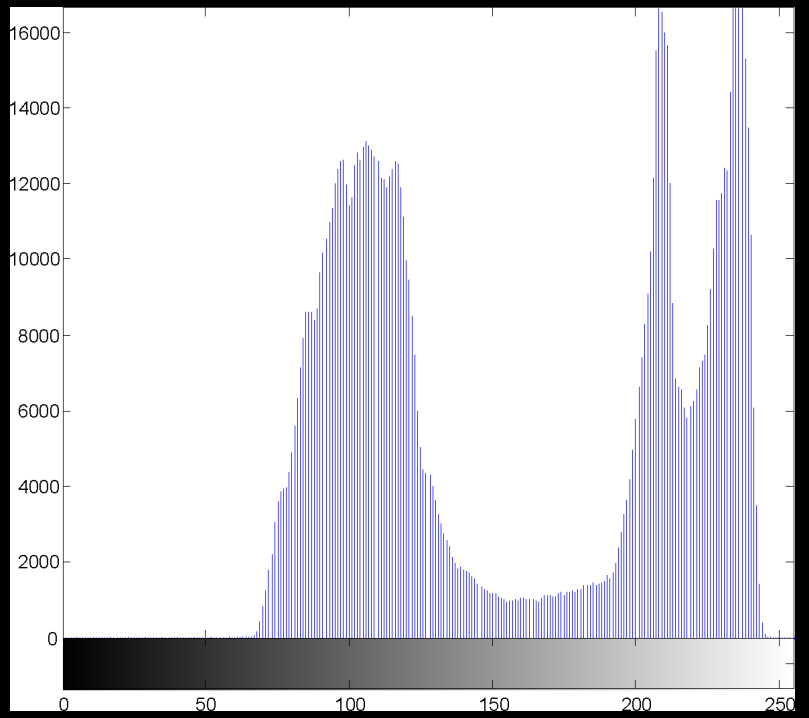
- A histogram normally contains the same number of “bins” as the possible pixel values
- A bin stores the number of pixel with that value

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

Where are the flower leaves in the histogram?

Range 1

Range 2

Range 3

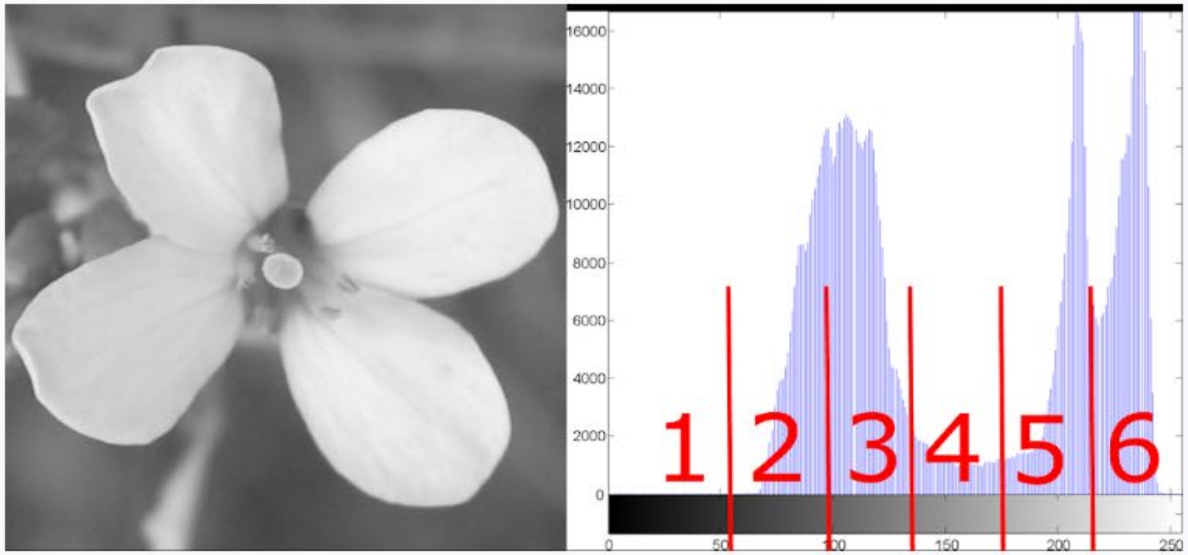
Range 4

Range 5

Range 6

Oh bugger - my flower allergy has been triggered

Where are the flower leaves in the histogram?



Range 1	0%
Range 2	8%
Range 3	0%
Range 4	0%
Range 5 ✓	8%
Range 6 ✓	83%
Oh bugger - my flower allergy has been triggered	0%

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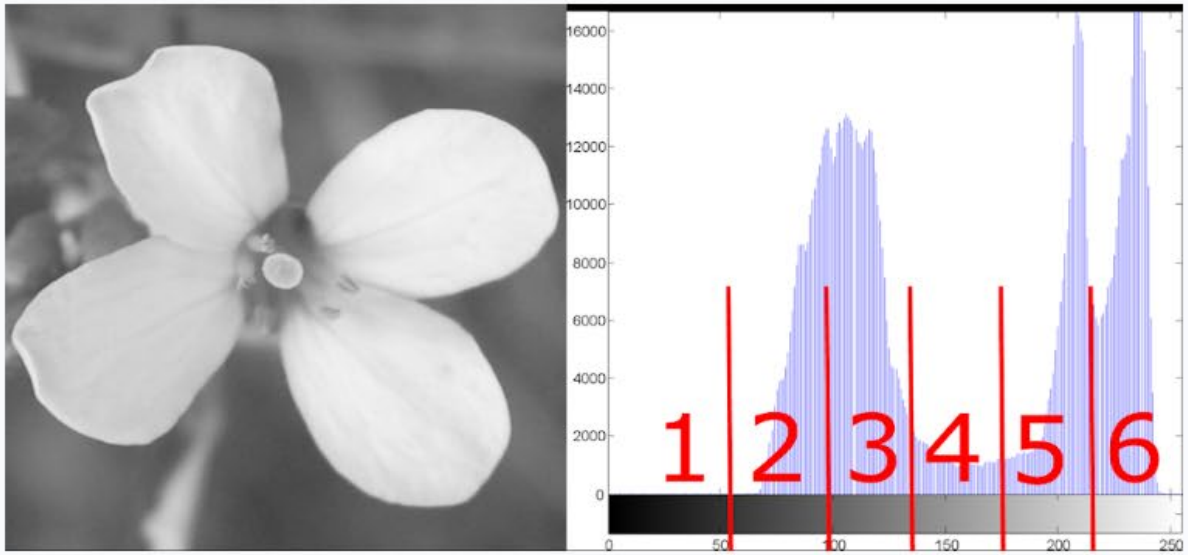
Where are the flower leaves in the histogram?



Range 1	0%
Range 2	8%
Range 3	0%
Range 4	0%
Range 5 ✓	8%
Range 6 ✓	83%
Oh bugger - my flower allergy has been triggered	0%

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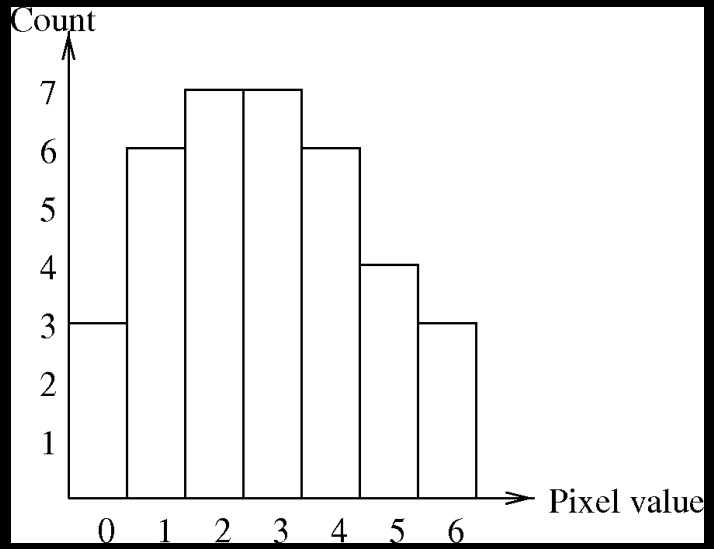
Pixel value statistics

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

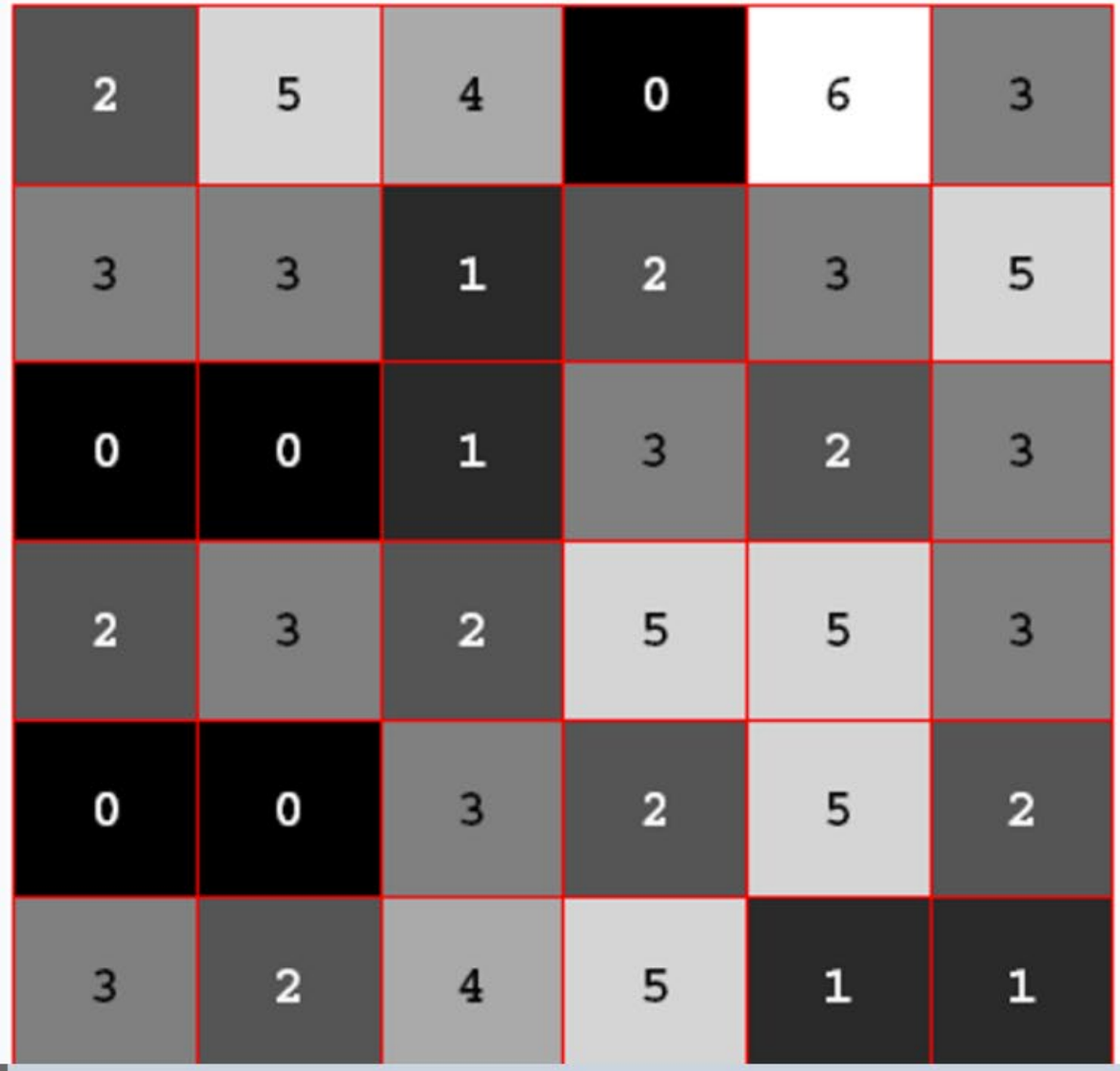


- Pick a random pixel in the image
- What is the probability of it having value 3? P(v=3)

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

- The histogram divided by the total pixel count can be seen as a probability density function

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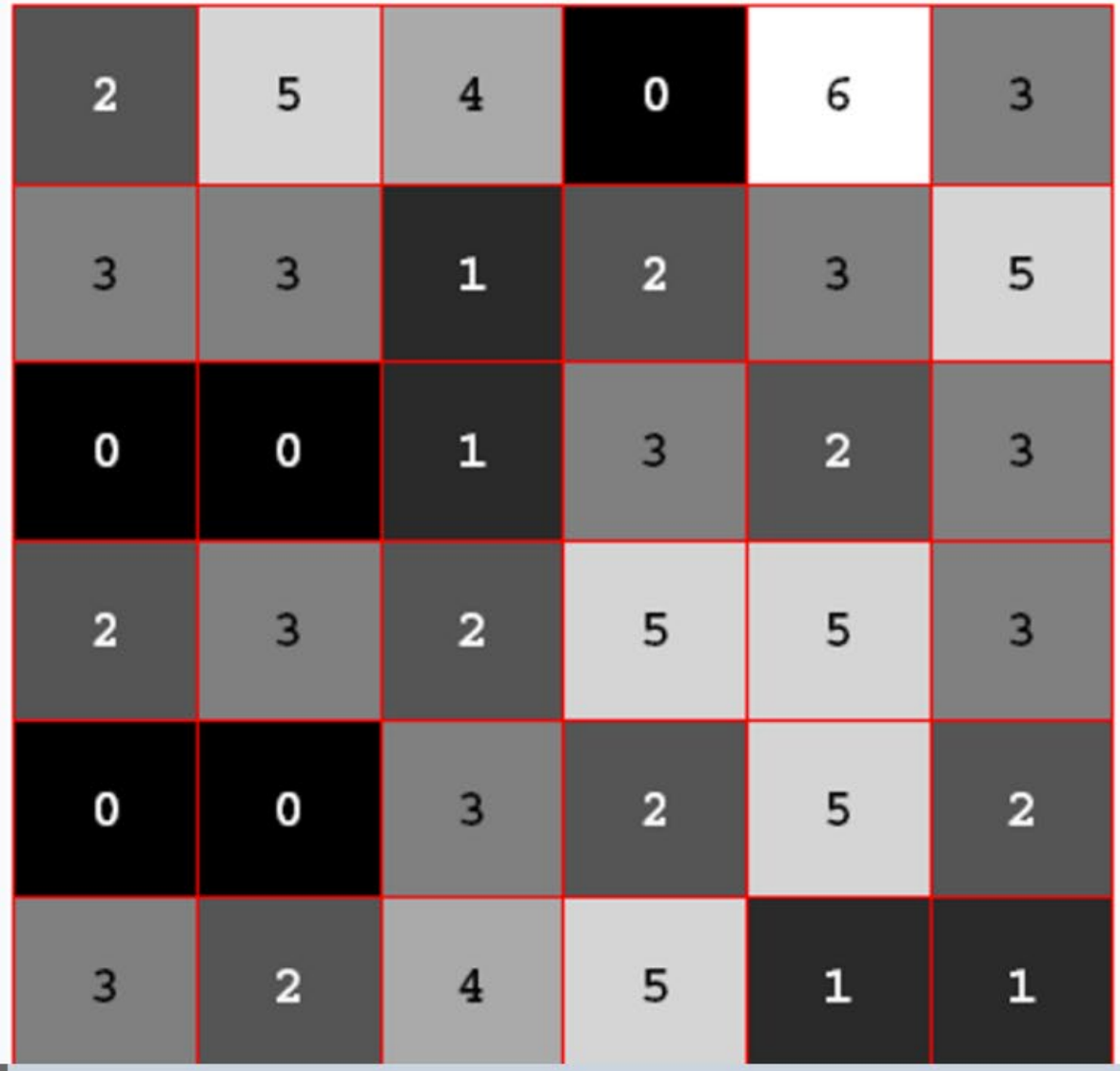
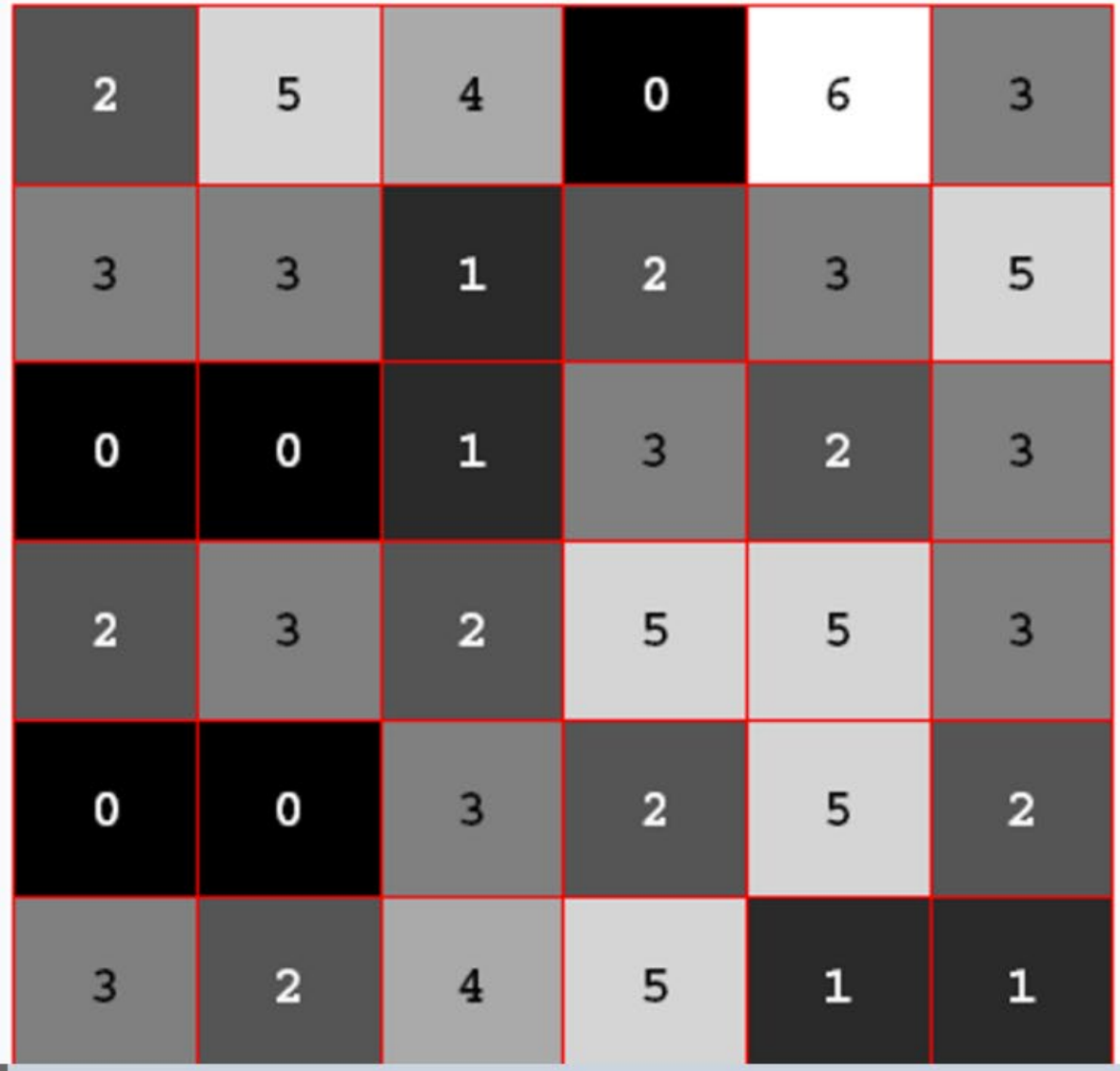
A random pixel is chosen in the image. What is the probability that the value of the pixel is 3?



6%		0%
28% ✓		79%
39%		21%
51%		0%
72%		0%
I do not know		0%

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

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



6%	0%
28% ✓	79%
39%	21%
51%	0%
72%	0%
I do not know	0%

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

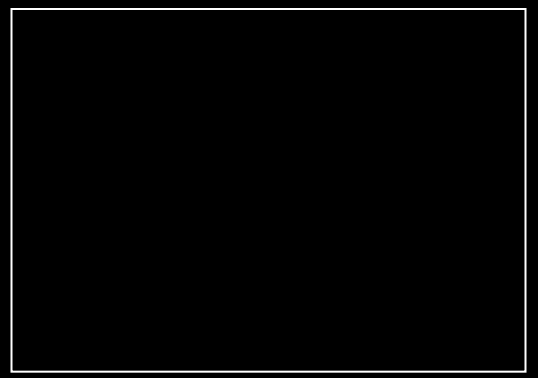
Other Image Types

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

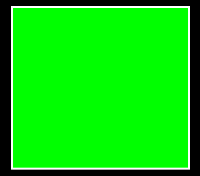


RGB = (0,0,0)

RGB = (255,255,255)

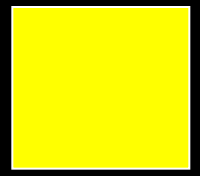
- When alle three “Lamps” are turned of we get black
- When all three “lamps” are on what do we get?

(255,0,0)



(0,255,0)

(0,0,255)

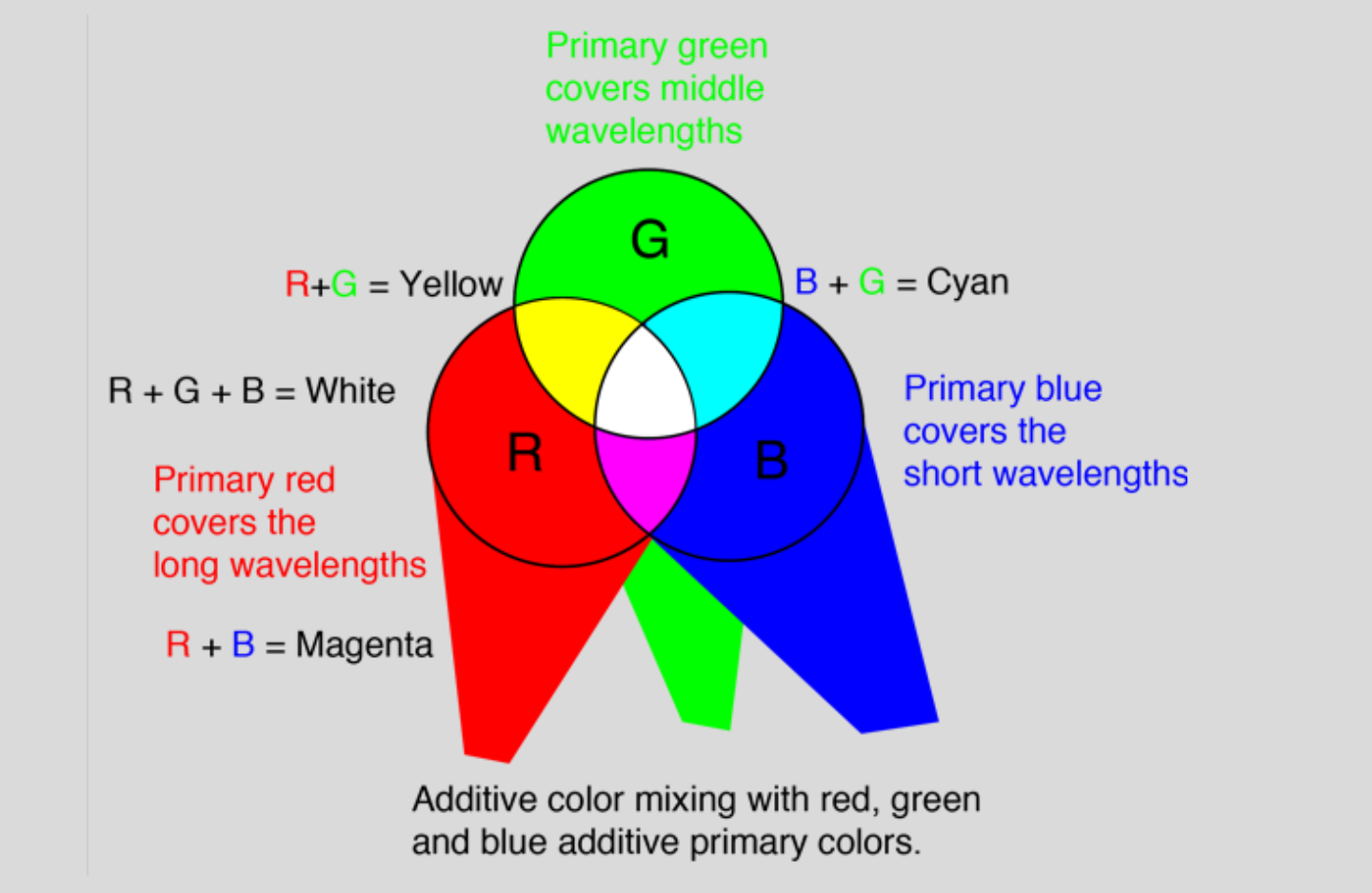


(255,255,0)

(0,255,255)

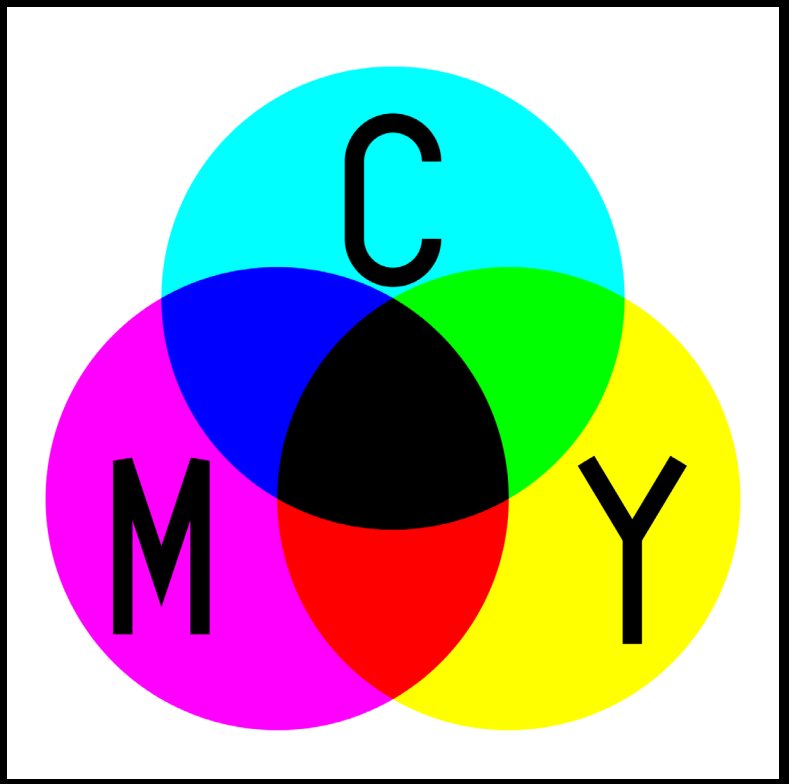
(255,0,255)

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

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

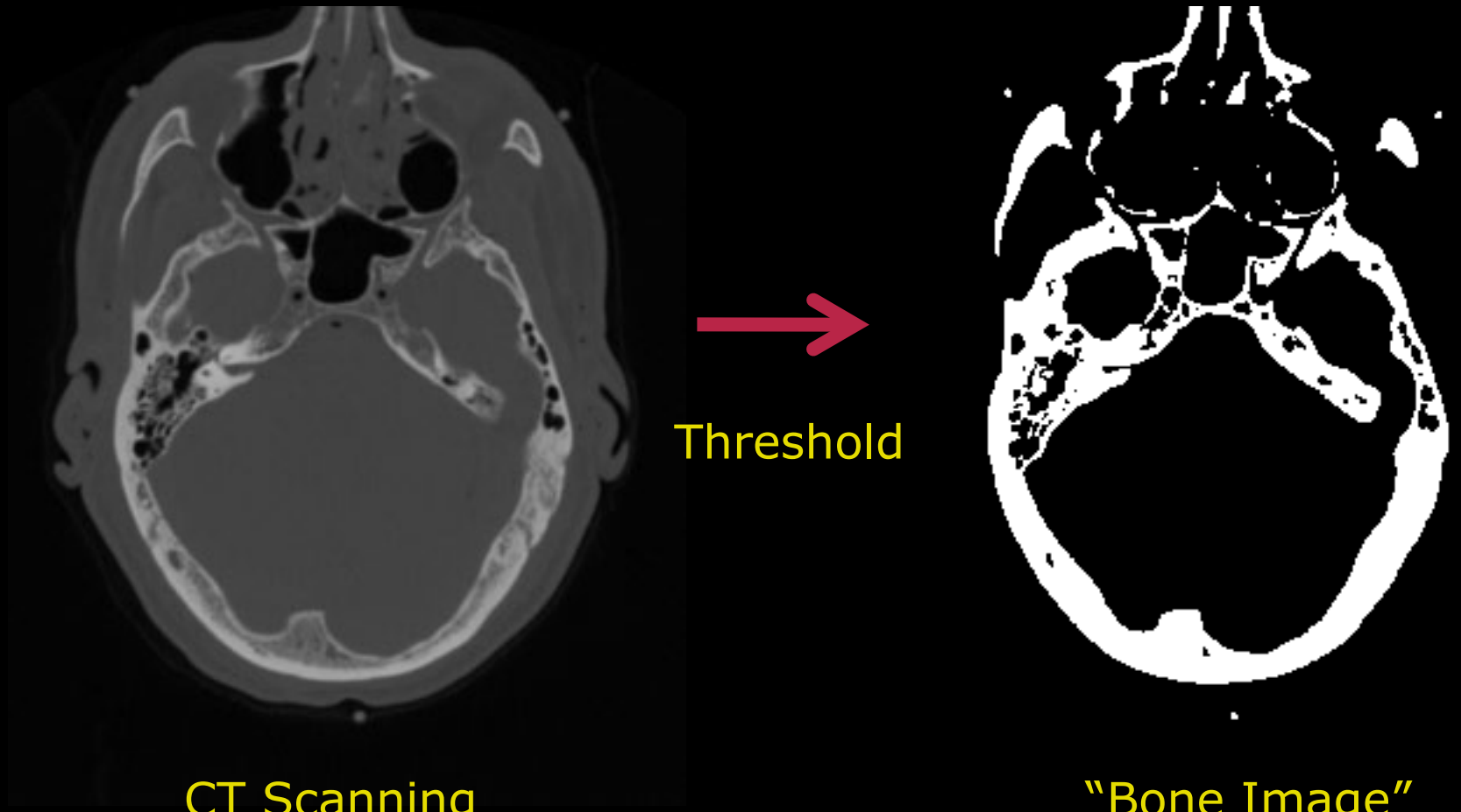
Is it possible to convert a grayscale image back to a color image?

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?

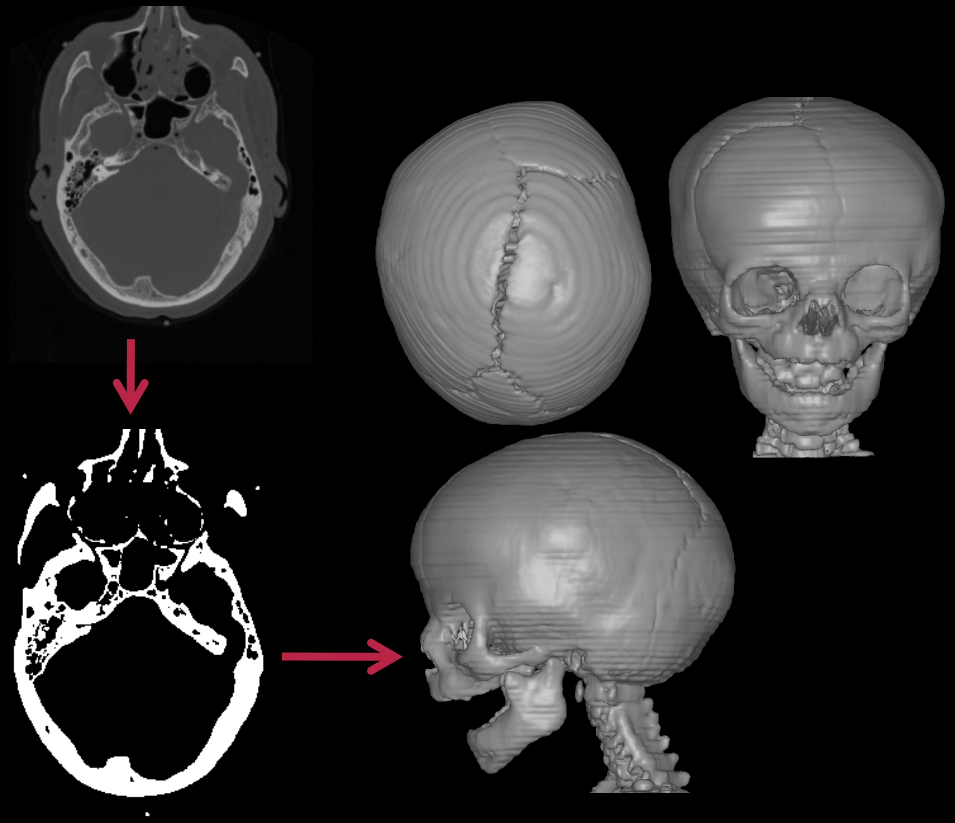
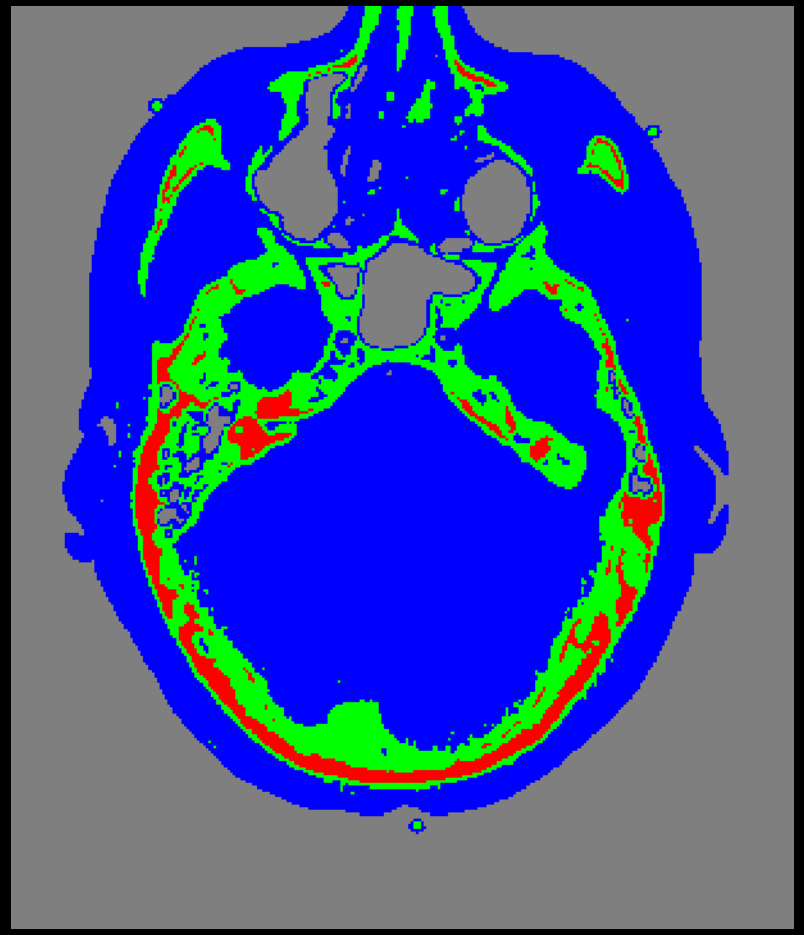


Image from 3D laboratory

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

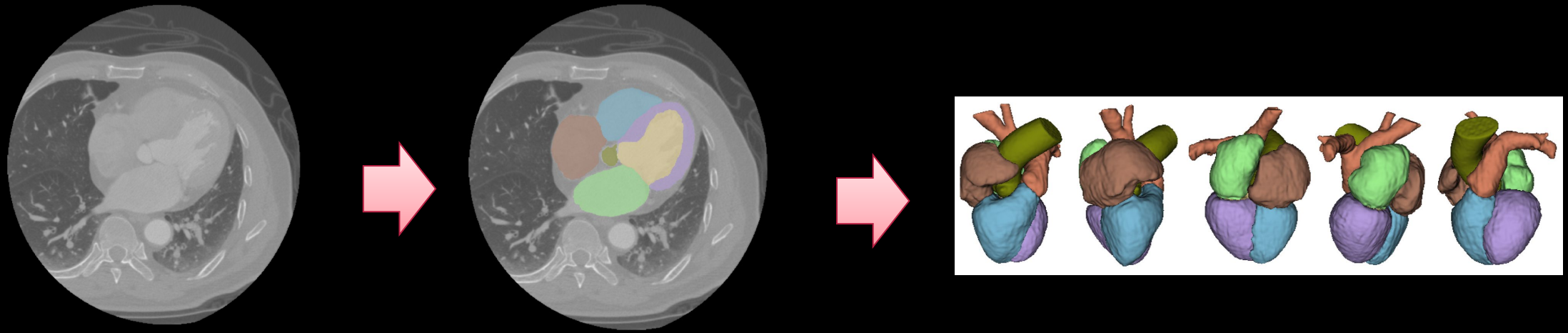
Label Image



- 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?

- Segment images into regions
- Example: Recognize the major structures of the human heart as seen in a computed tomography image. Construct a 3D model of a given patient heart. Use the 3D model for diagnostics and surgery planning.

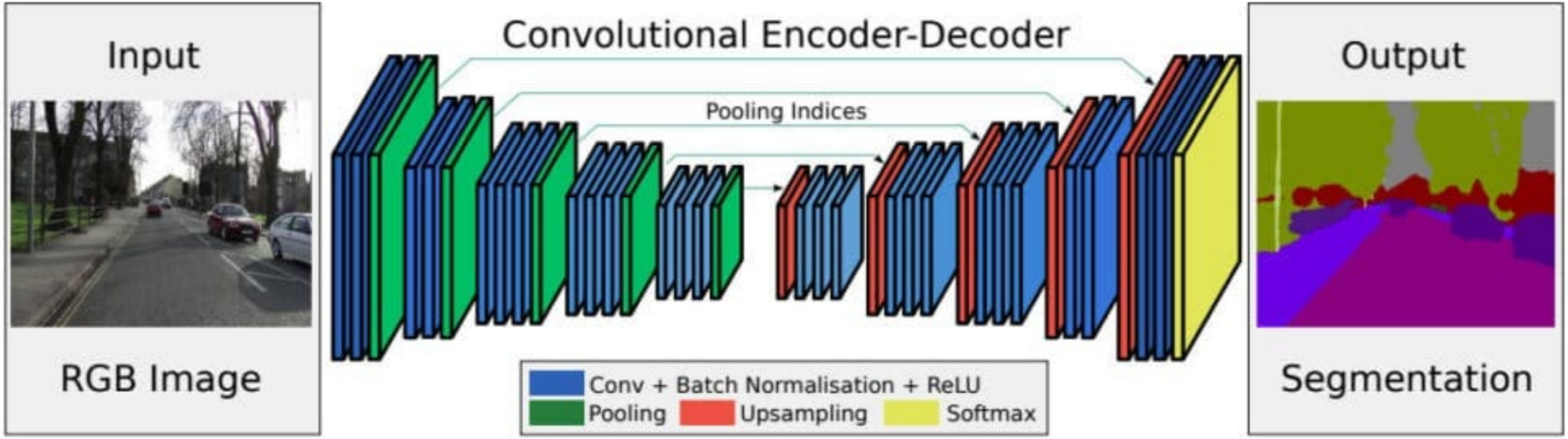


Label image from semantic segmentation

- Scene understanding for self navigating vehicles

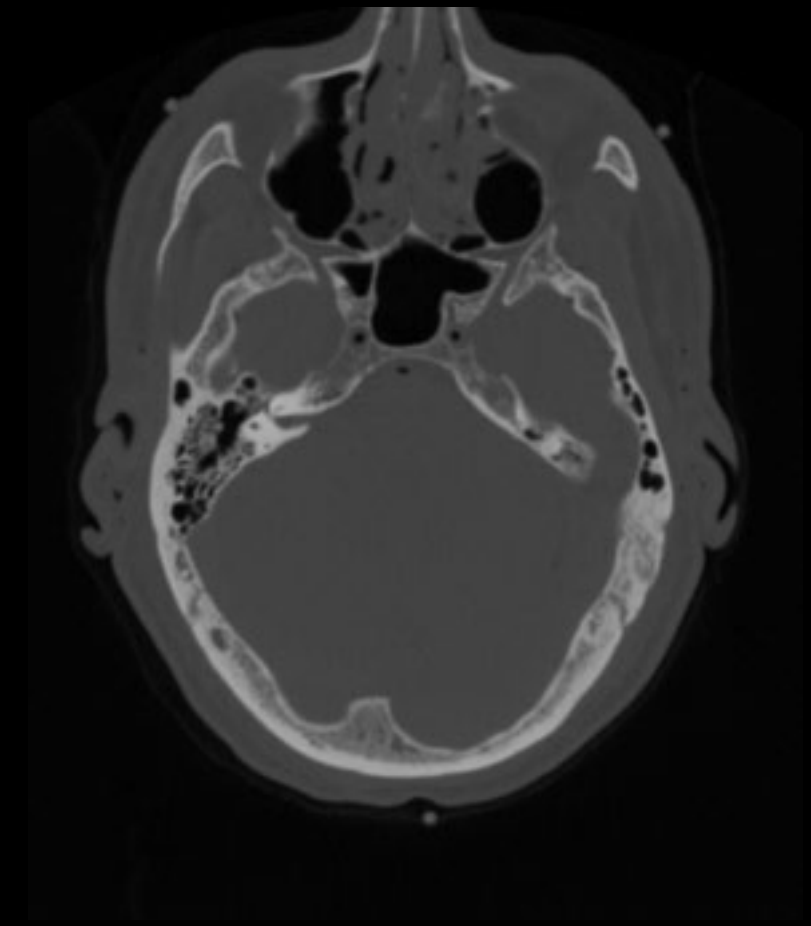
https://towardsdatascience.com/semantic-segmentation-of-150-classes-of-objects-with-5-lines-of-code-7f244fa96b6c

Deep learning for semantic segmentation



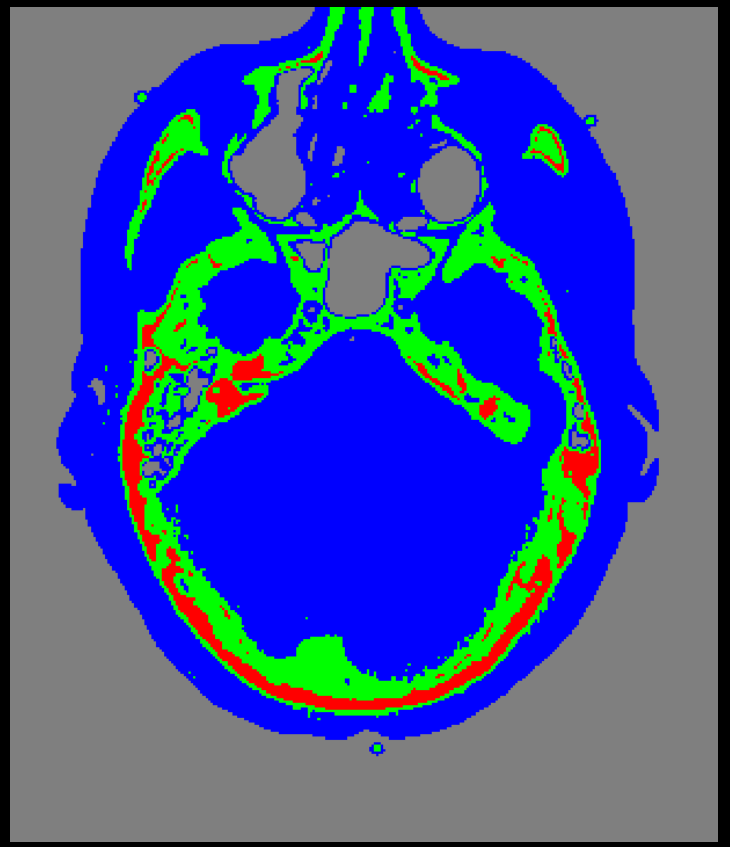
Badrinarayanan, Vijay, Alex Kendall, and Roberto Cipolla. "Segnet: A deep convolutional encoder-decoder architecture for image segmentation." IEEE transactions on pattern analysis and machine intelligence 39.12 (2017): 2481-2495.

Label images in this course

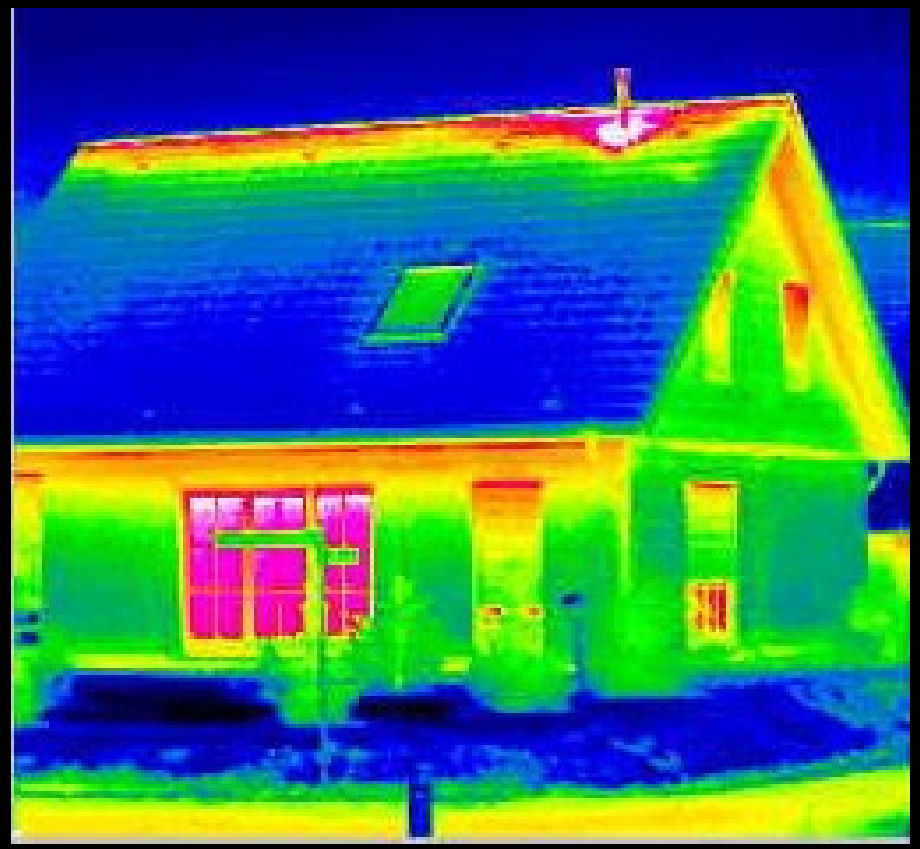


Pixel Classification

BLOB analysis and classification



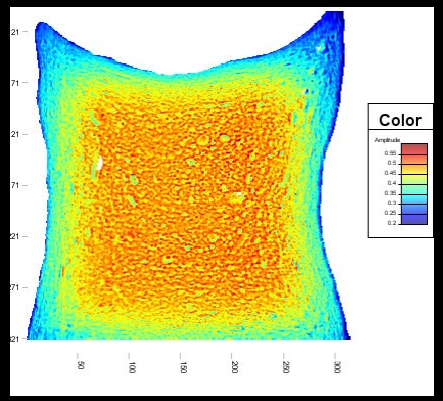
Multispectral images

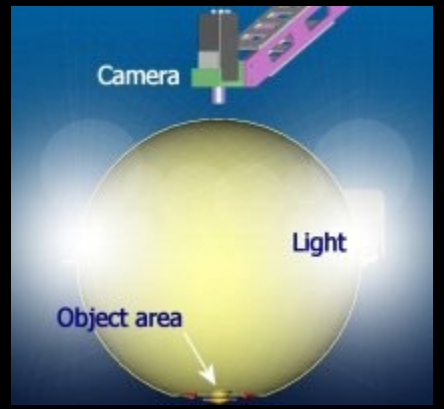


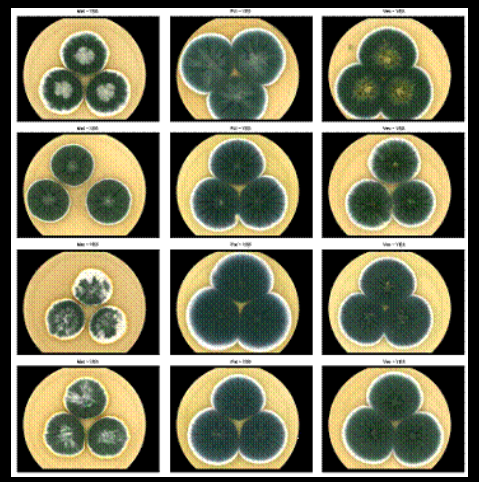
Infrared

- 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

Floating point images

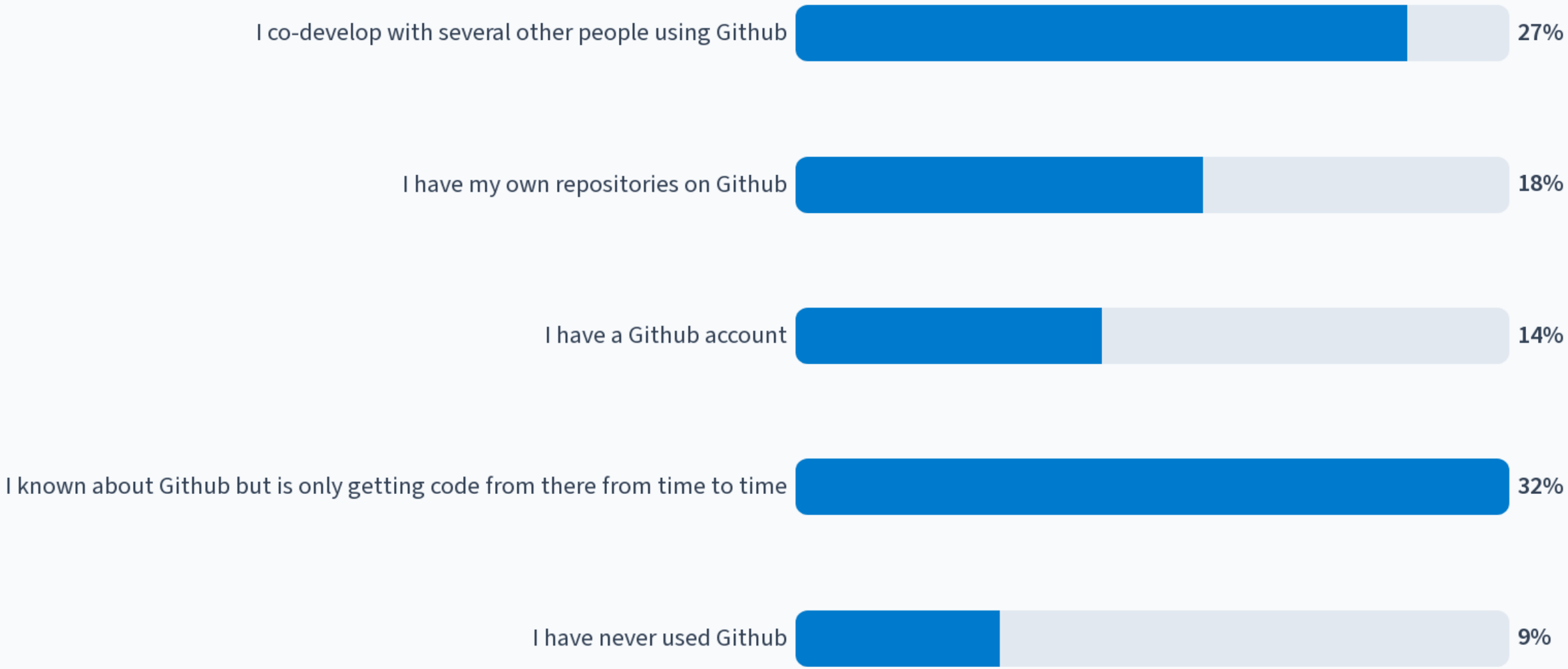
- The pixel type is often changed when applying image processing functions
- For example when scaling an image, the output will be a floating point image:

```
image_rescaled = rescale(im_org, 0.25, anti_aliasing=True, channel_axis=2)
print(image_rescaled.shape)
print(image_rescaled.dtype)
```

Python scripts vs. Jupyter Notebooks

- In this course, you can do the exercises and the exam in both Jupyter Notebooks or as Python scripts
- Strengths and benefits of both approaches

What is your experience with Github?



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PCA Analysis

Next week:
Image acquisition, digital cameras, compression and storage and real-time image analysis