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IMAGE PROCESSING

Image representation, visualization and properties

Agenda

- What is an image?
  - And how is it represented in the computer?
- What is a MEDICAL image?
- Review –Machine Learning (ML) taxonomy
- Computer Vision main tasks

Medical Imaging Usages

Partial list

- Early Detection
- Measurements
- Biomarkers Characterization
- Disease Progression Tracking
- Lesion Segmentation

What is an Image?

(A digital image)

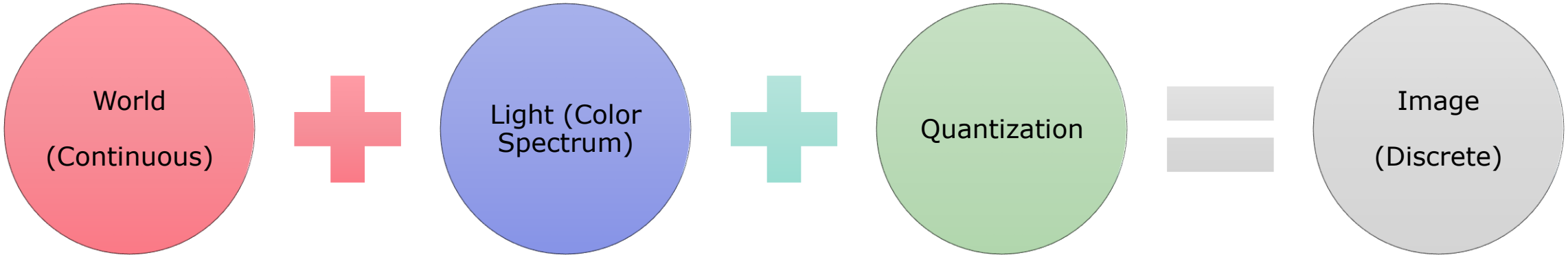
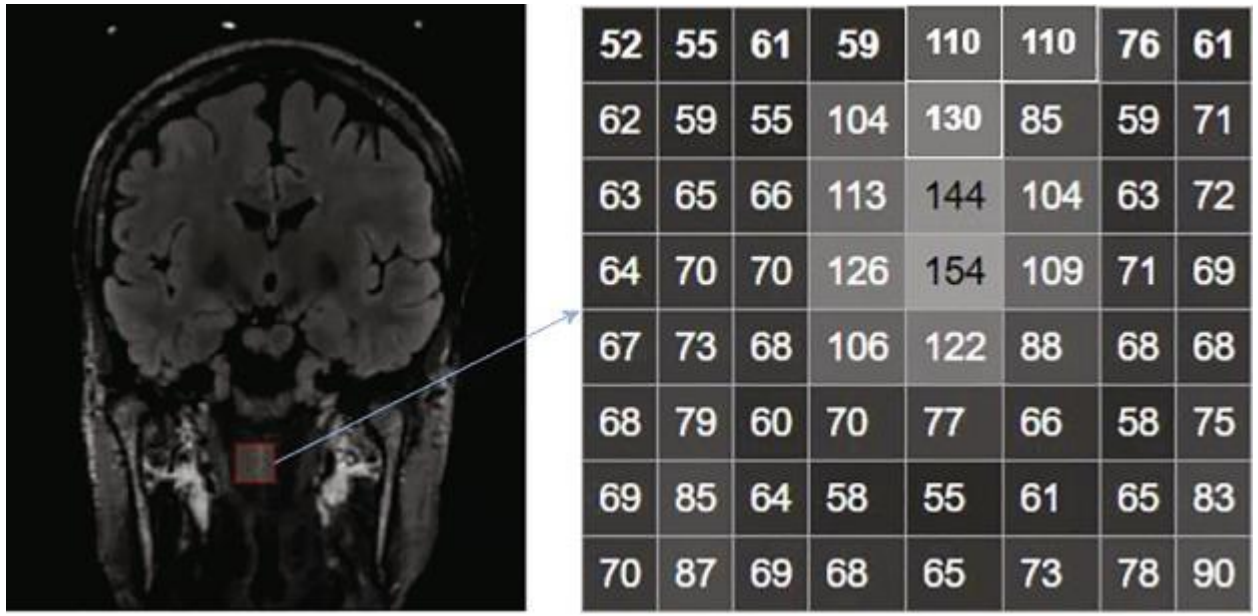


Image Representation

Image as a function

- 2D: I(x, y) = ρ Pixel
- 3D: I(x, y, z) = ρ Voxel
- 4D: I(x, y, z, t) = ρ

...



52	55	61	59	110	110	76	61
62	59	55	104	130	85	59	71
63	65	66	113	144	104	63	72
64	70	70	126	154	109	71	69
67	73	68	106	122	88	68	68
68	79	60	70	77	66	58	75
69	85	64	58	55	61	65	83
70	87	69	68	65	73	78	90

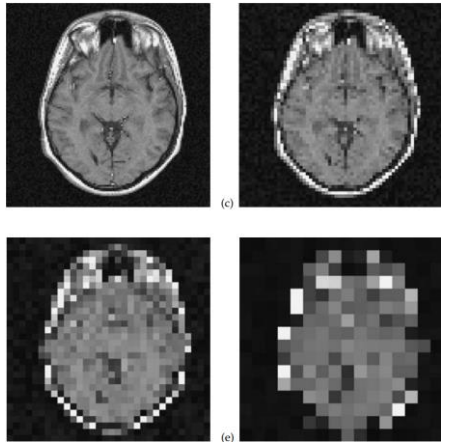
Image Properties

Let’s clear up some terms

- **Image contrast**: Difference in the image pixel values between closely adjacent regions on the image (seen by human or computer)

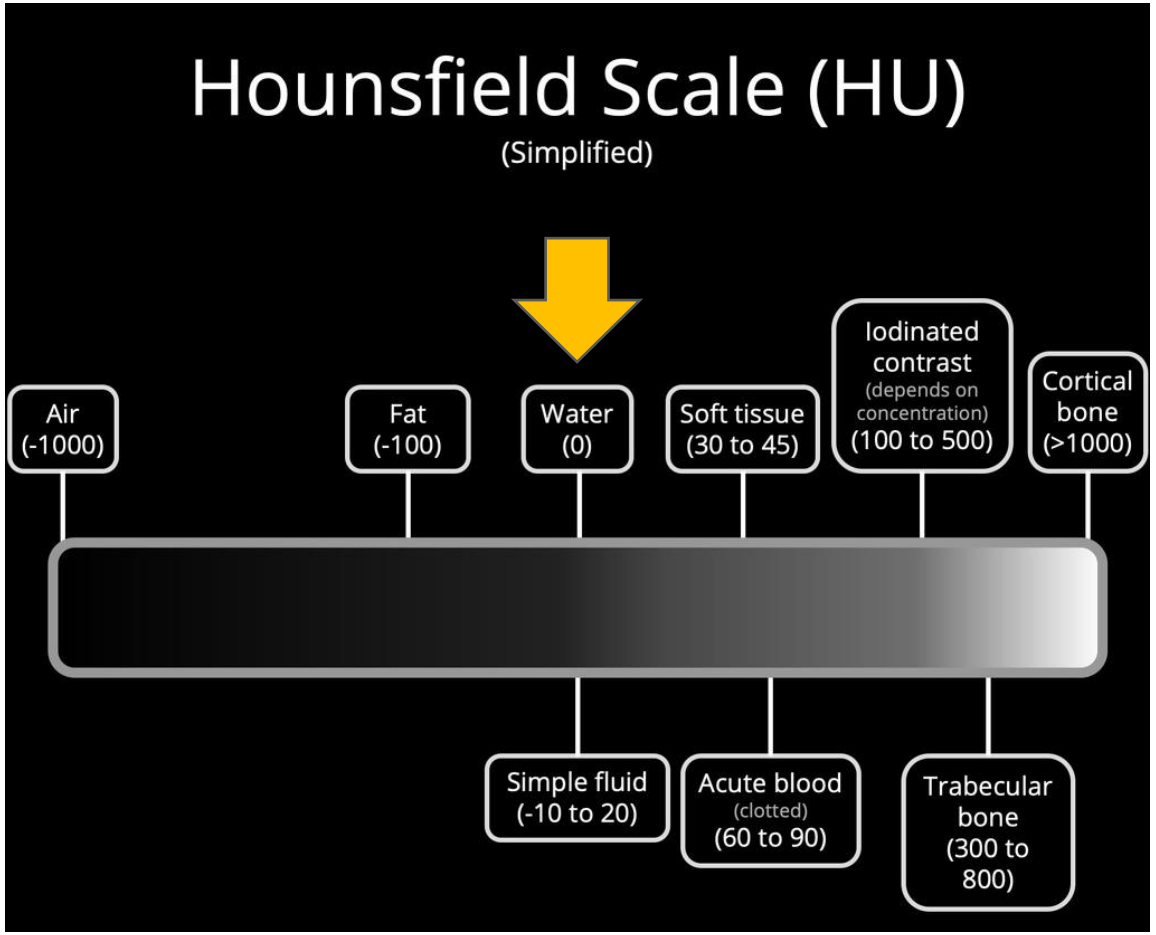
- **Resolution**: the image's level of details.

  Measures the image’s fidelity to the representation of the original scene.



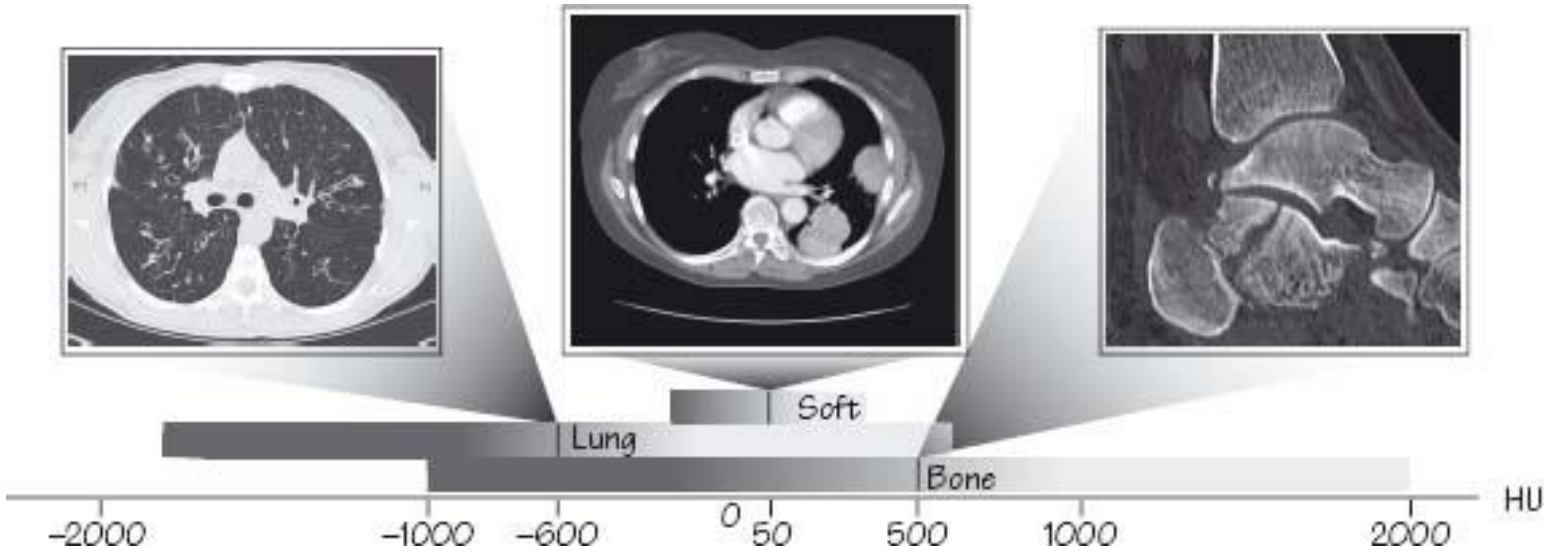
CT Image Pixels

- Each pixel in CT images is assigned a number (Hounsfield Unit).
- HU is related to the *linear attenuation coefficient* (μ) of tissue within each voxel
- Water defined HU=0
- CT Number = $1000\frac{\mu_{object}-\mu_{water}}{\mu_{water}}$



CT Image Pixels

Hounsfield Scale (HU)



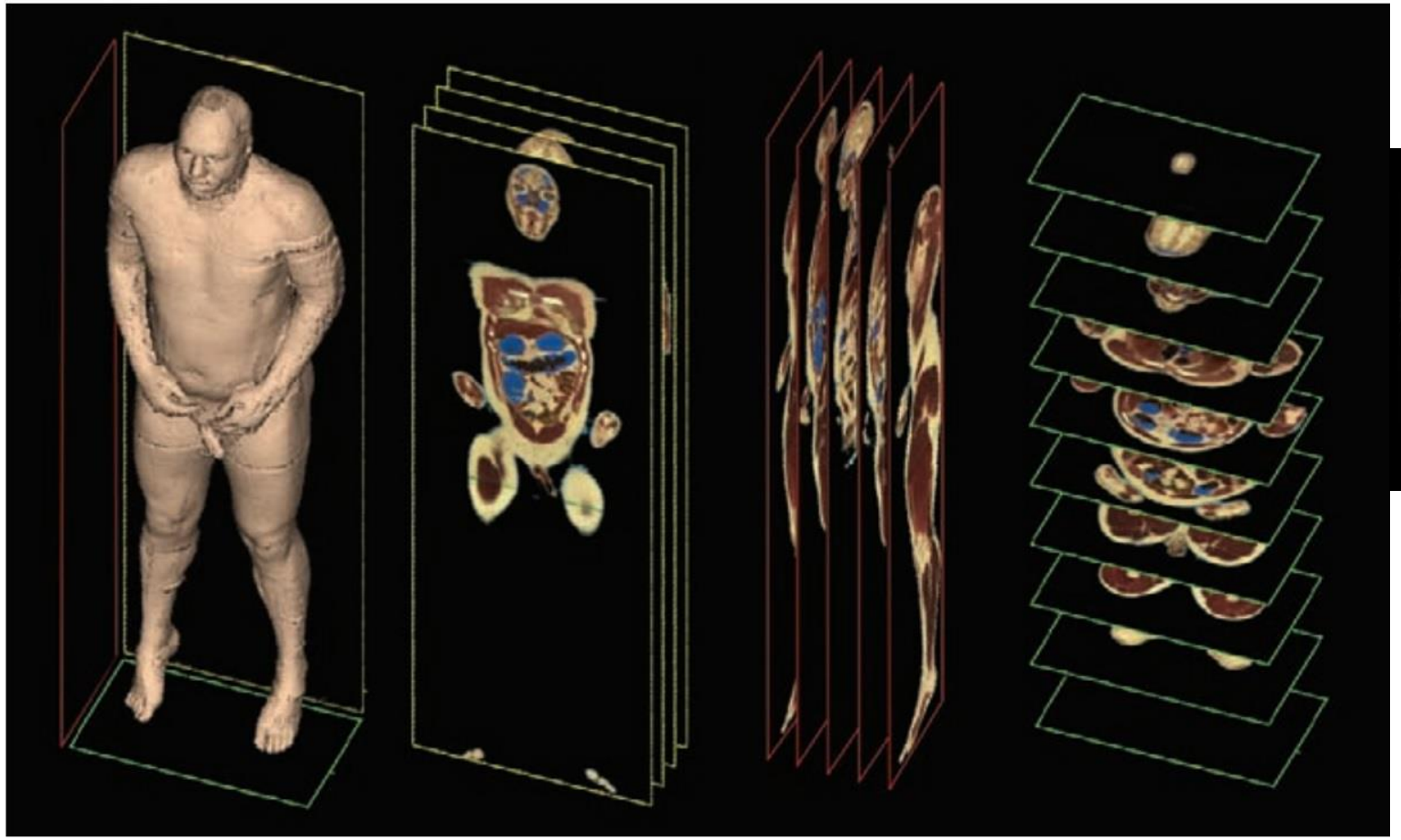
- Large range of HU in CT images
- Human eye cannot appreciate the full range of CT numbers
- Visualized by setting a window width and level

MRI Contrast

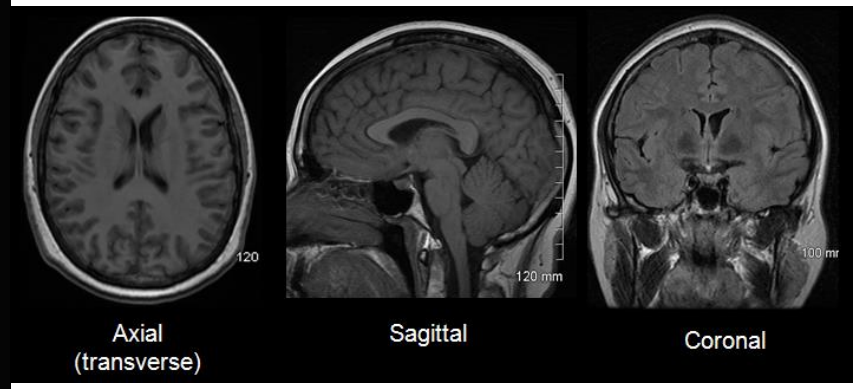
- Basis for imaging: radio waves emitted from the patient
- Superb and varied soft-tissue contrast
- Any scan plane
- Excellent depiction of the musculoskeletal system and bone marrow
- Used to characterize pathology seen on ultrasound or CT

- Different pulse sequences can create different imaging:
  Proton Density (PD), T1, T2, and more.
- Demo: MRI sequences (overview) | Radiology Reference Article | Radiopaedia.org

Imaging Planes



Coronal Sagittal Transverse (Axial)



Medical Image Formats

- DICOM - https://www.dicomstandard.org/
  - Digital Imaging and Communications in Medicine
  - Contains both images and patient data (key-value)

- NIfTI - NIfTI: — Neuroimaging Informatics Technology Initiative (nih.gov)
  - Combines multiple DICOM images
  - Nii files

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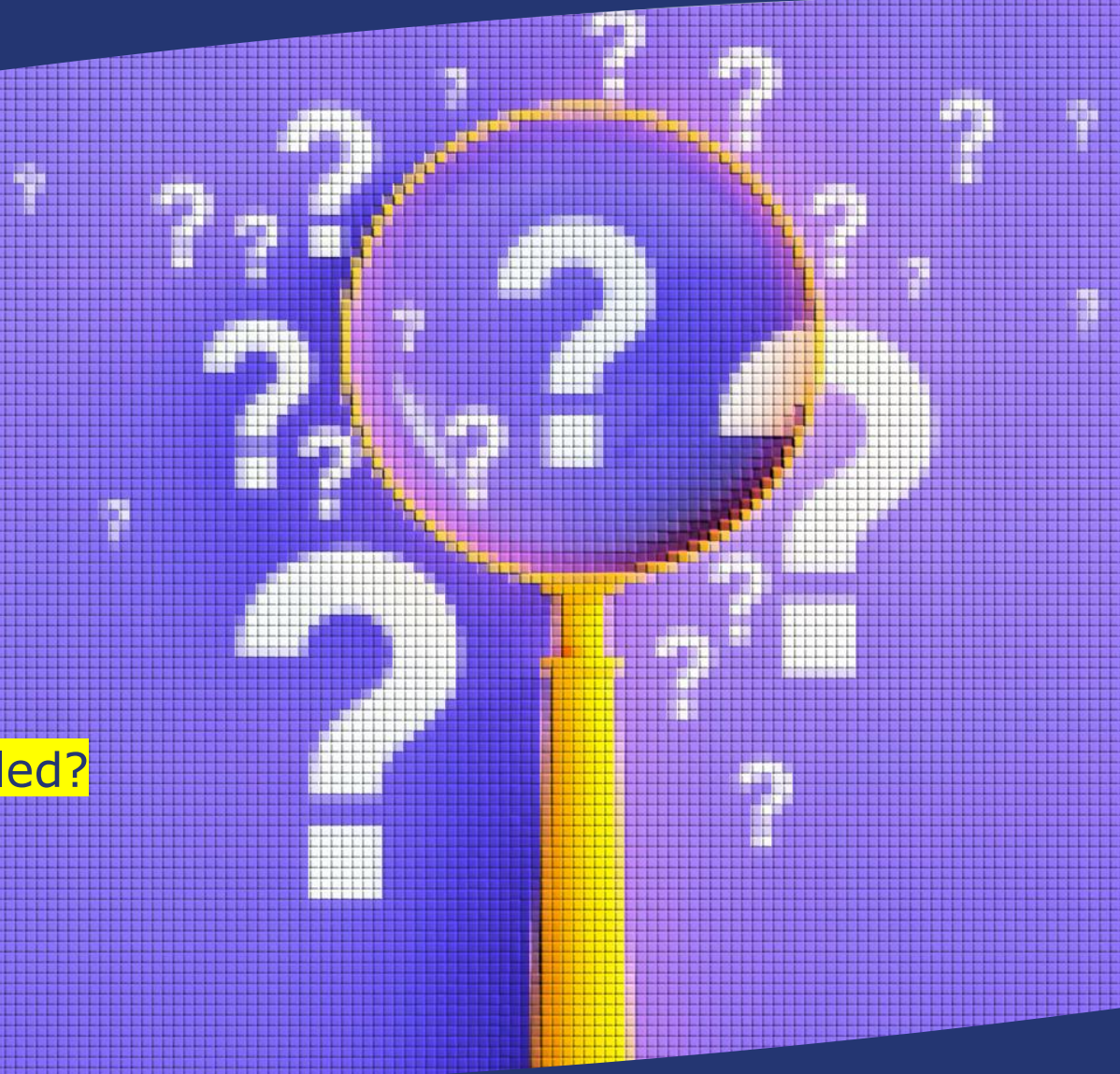
POP QUIZ

How is a 3D pixel called?



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POP QUIZ

What is Axial?

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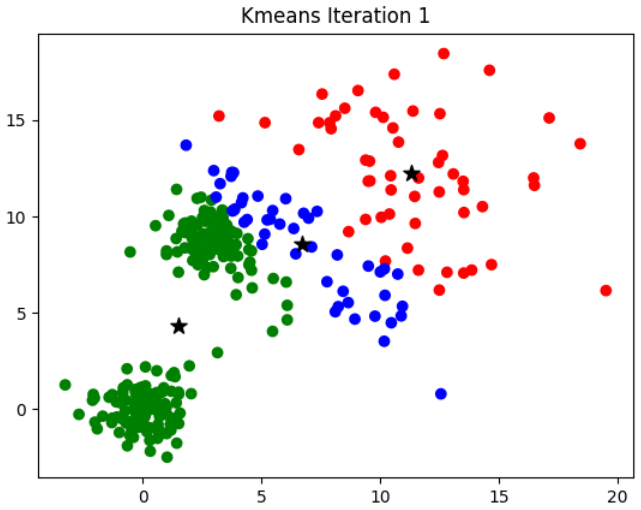
POP QUIZ #2

What is Sagittal?

Review: Machine Learning



Machine Learning Types

- Supervised Learning
  - **Classification**:
    Learn a (mapping) function $f(x) = y$ given a set of matched (= labeled) samples $(x, y) \in X, Y$
  - **Regression**: Learn a mapping function - $f(x) = y \quad y \in \mathbb{R}$
- Unsupervised Learning
  - **Clustering**:
    Finds clusters automatically by minimizing a distance function
  - **Dimension Reduction**

Review: Machine Learning

Machine Learning Types

Supervised Learning

- Classification
  - Random-Forest
  - Support Vector Machine (SVM)
  - KNN
  - Deep-Learning
- Regression
  - Linear Regression

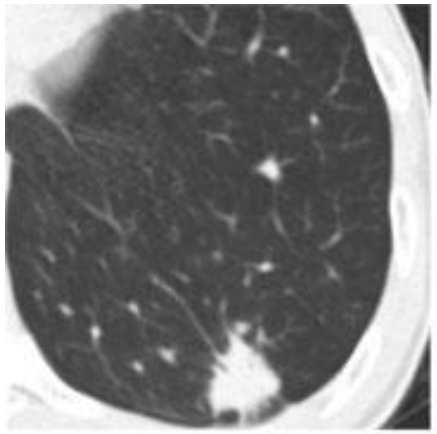
Unsupervised Learning

- Clustering
  - K-Means
  - DBScan
- Dimension Reduction
  - PCA
  - T-SNE
  - U-MAP

Reinforcement Learning

ML Imaging Tasks

Classification **Detection** **Segmentation**



Adenocarcinoma

Adenoma

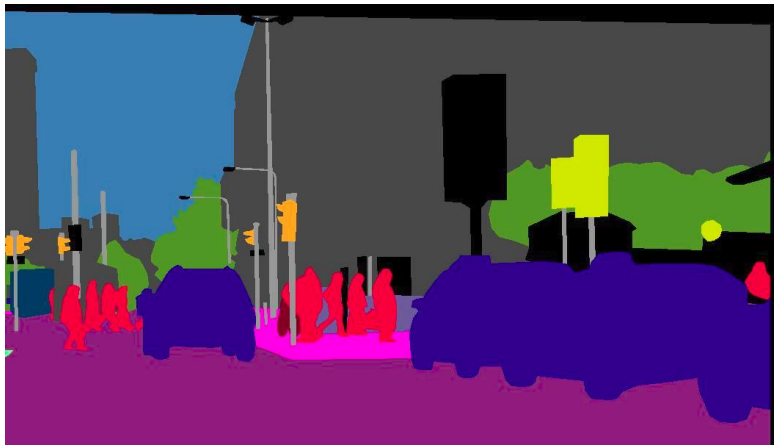
Mesothelioma

…

Segmentation

Semantic Segmentation

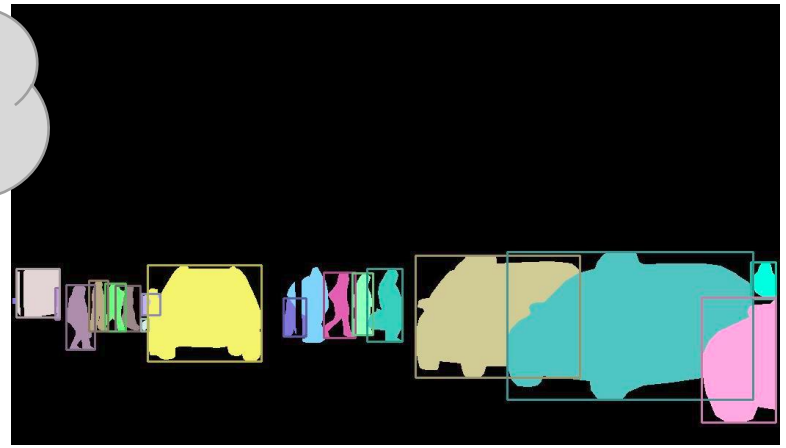
Similar objects belong to the same class



More Relevant for Medical Imaging

Instance Segmentation

Every class instance stands on its own



The 5 Classes of Image Processing

Image Enhancement

- (Examples in a few slides)

Image Restoration (geometric correction)

Image Analysis (Classification, segmentation)

Image Compression

Image synthesis (registration, visualization, 3D-rendering)

ML on Unstructured Data

Extracting quantitative image features

- Two approaches for deriving structure from images:
  - Extract pre-defined (hand-crafted) features
  - Unsupervised feature learning (data-driven)

- N.B.: Image classification with deep learning is an example of deriving structure from images

Radiomics

Crafting features

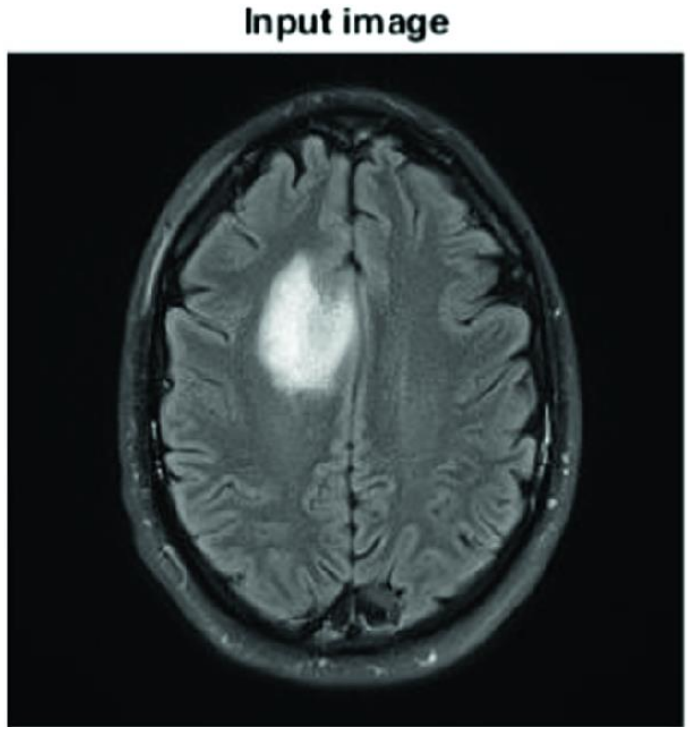
- “a field of medical study that aims to extract a large number of quantitative features from medical images using data characterization algorithms”

- Preprocessing:
  - Contrast & edge enhancement

- Image segmentation and ROI determination
  - Geometric features: volume, shape, surface, density

Image Histogram

Count pixels by their value (color).



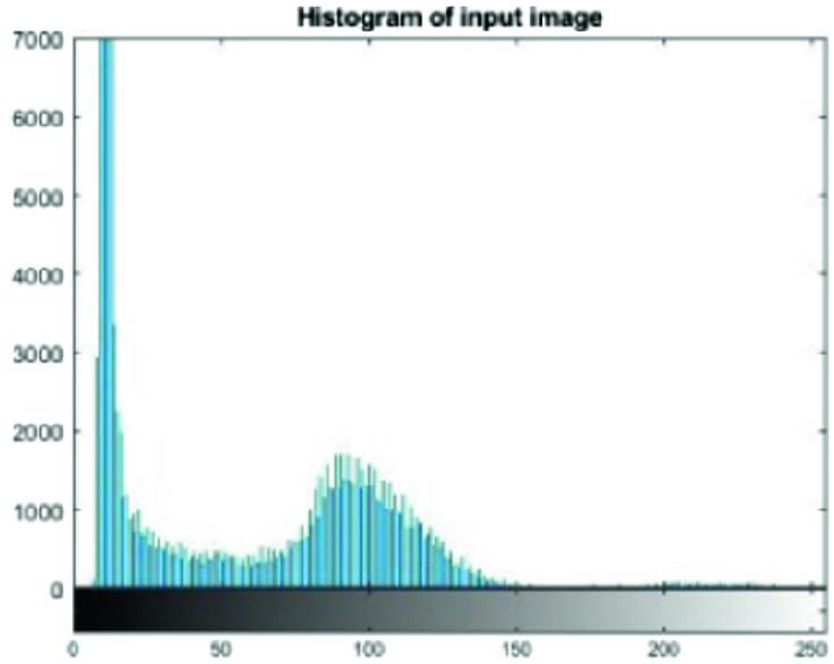
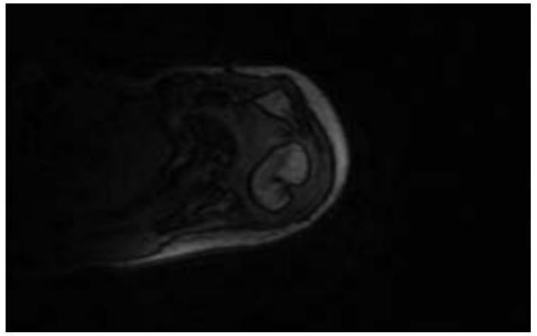


Image Histogram

Low-Contrast image



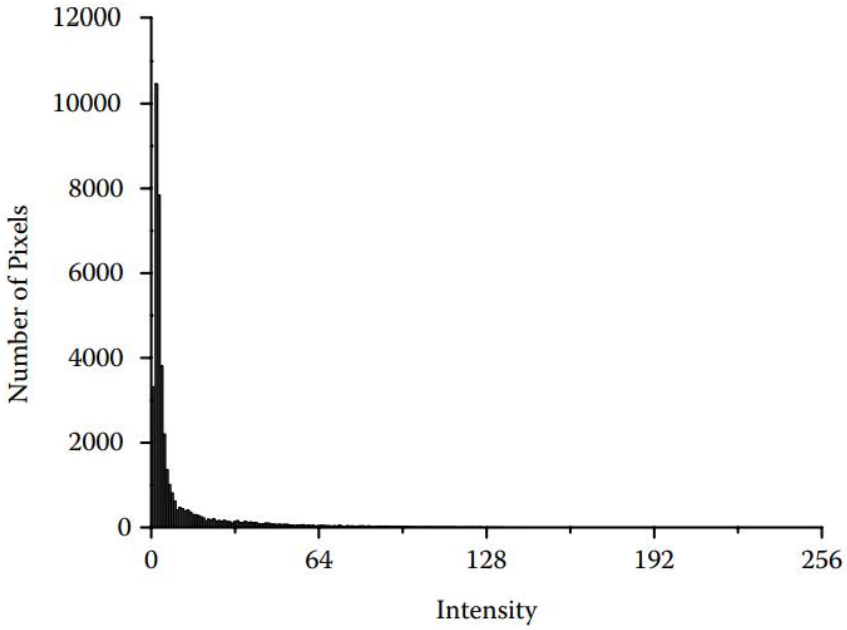
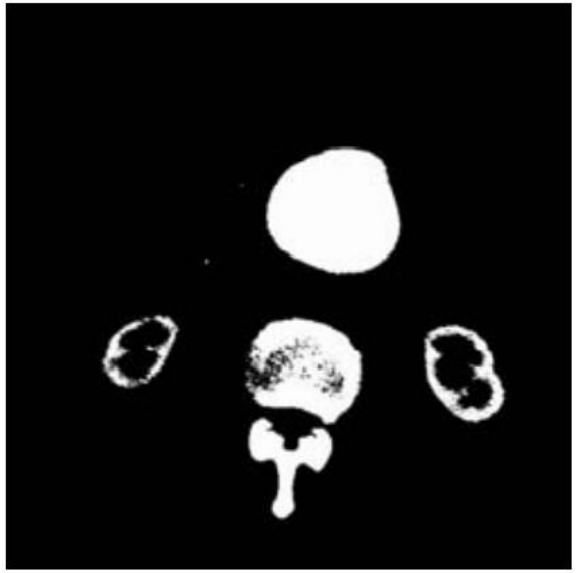


Image Histogram

High-Contrast Image



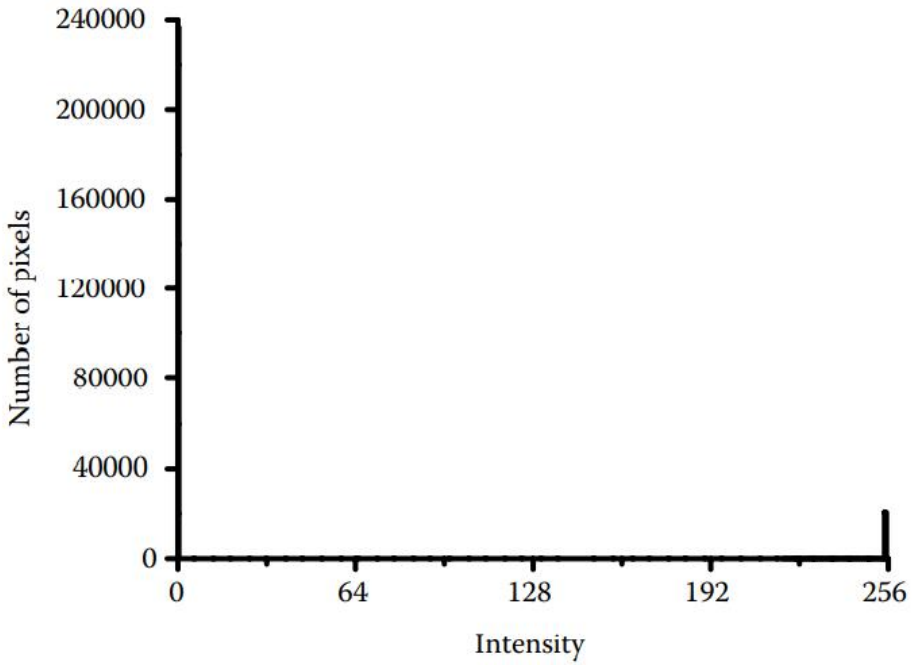
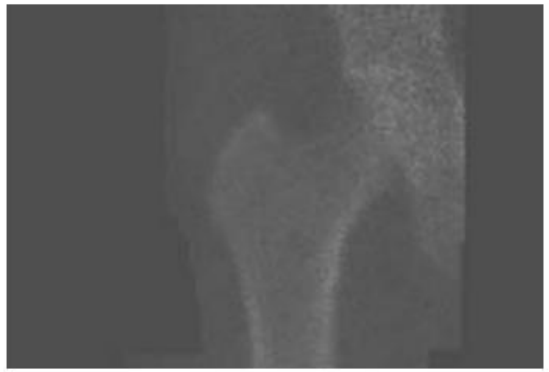
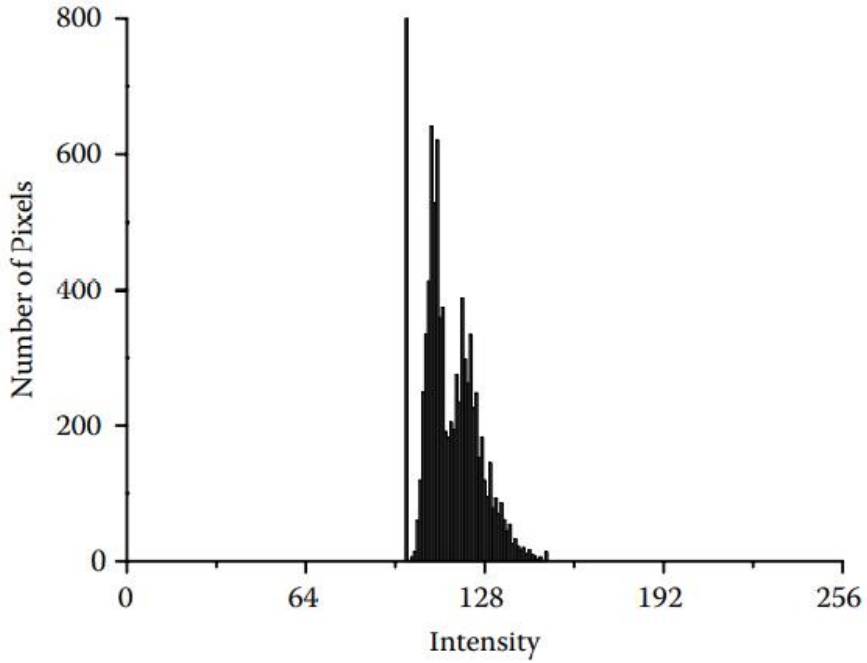


Image Histogram

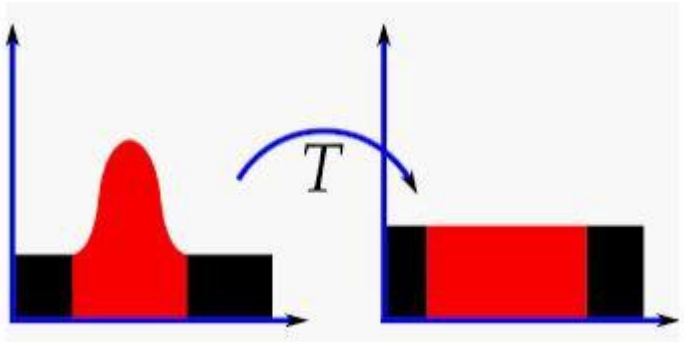
Small **actual dynamic range**



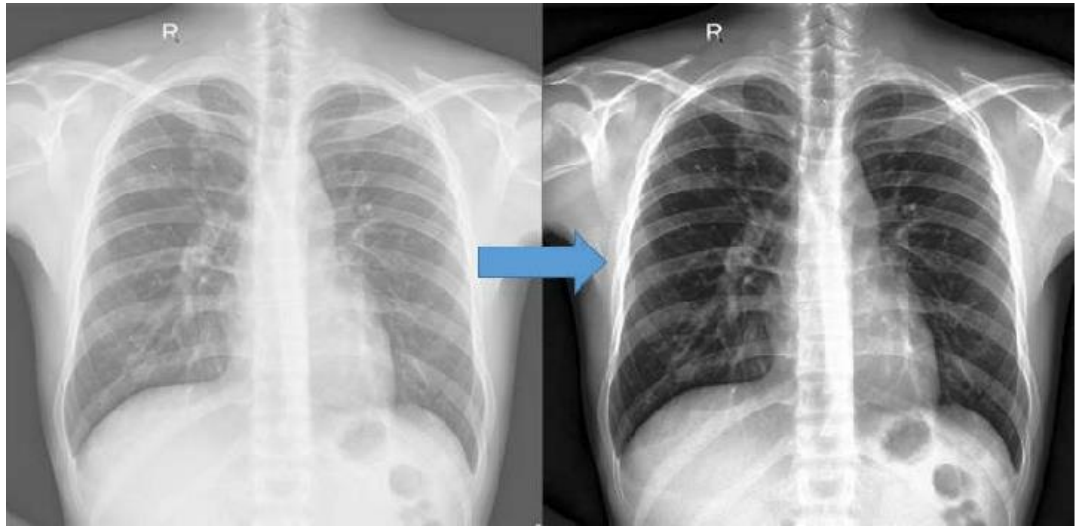


Histogram Equalization

Adjusts (increases) the contrast

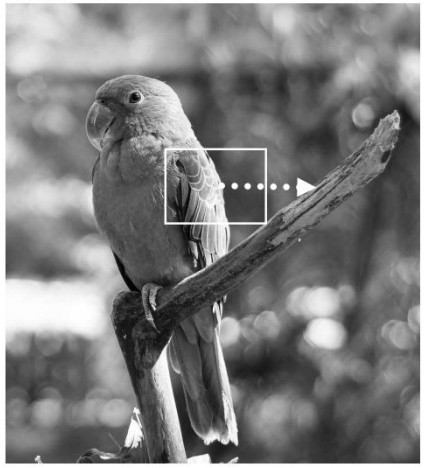


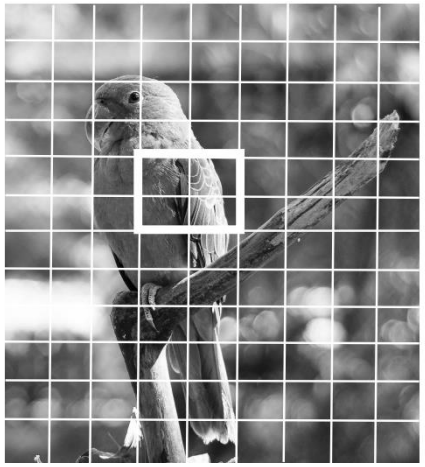
- Spreads pixel values evenly across the range.
- Cumulative Distribution Function

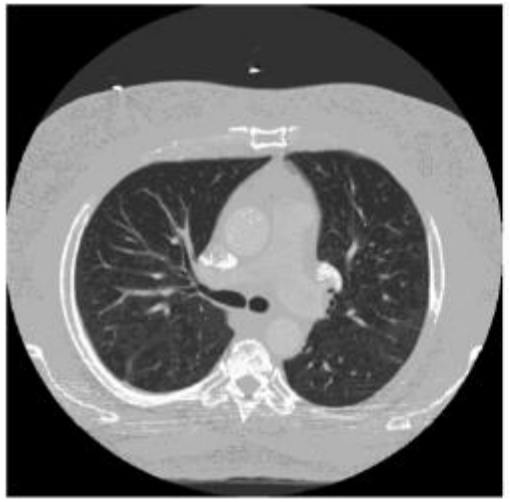


Adaptive Histogram Equalization

Limits contrast expansion in flat regions of the image





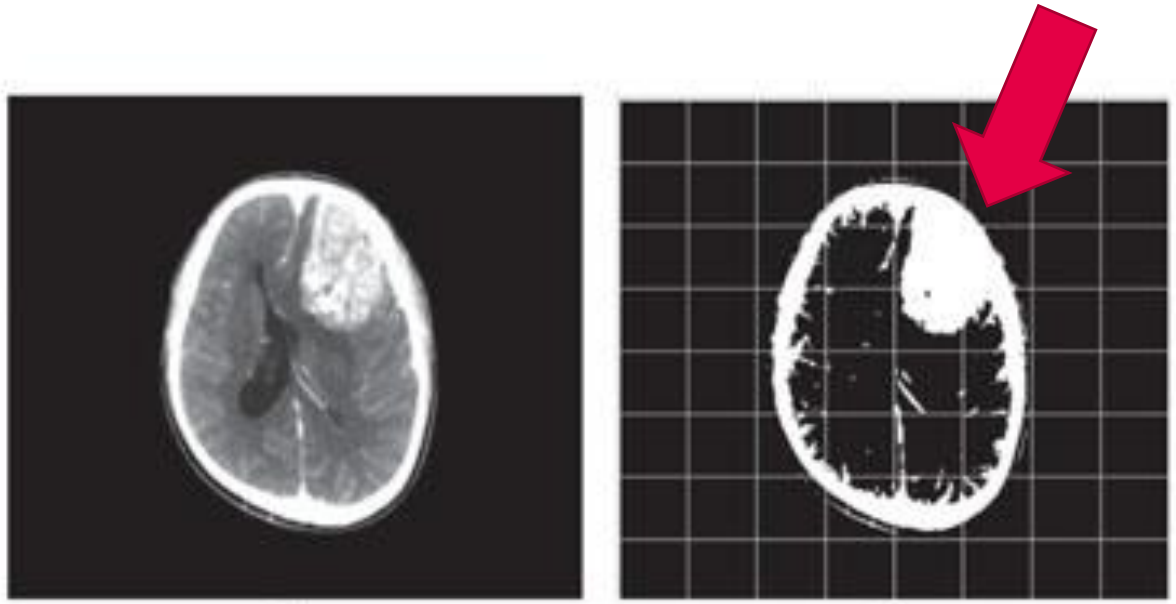


Quantization

Mapping different gray scales into a single shade.

Bits Compression.

Enables segmentation.



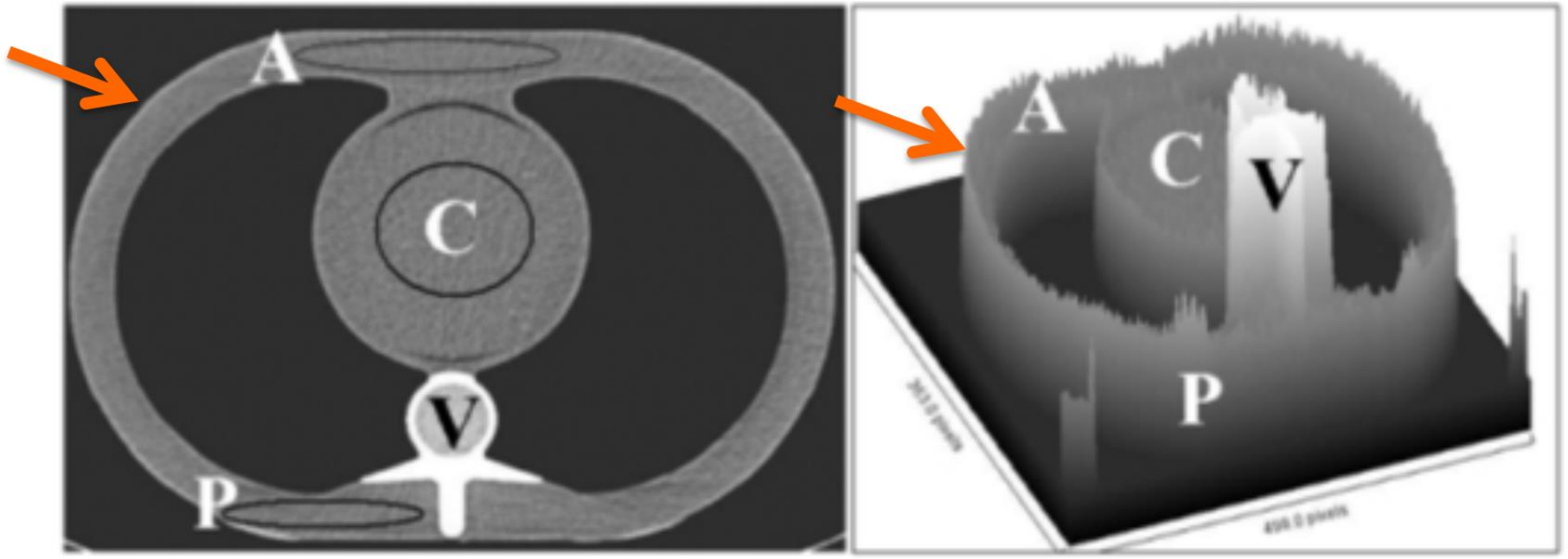
(a) (b)

FIGURE 10: Binary image reconstruction.

Color Value as a 3D Surface

Each pixel value is interpreted as the height

We can perform segmentation using **thresholding** or with a model: **K-Means**



Color Value as a 3D Surface