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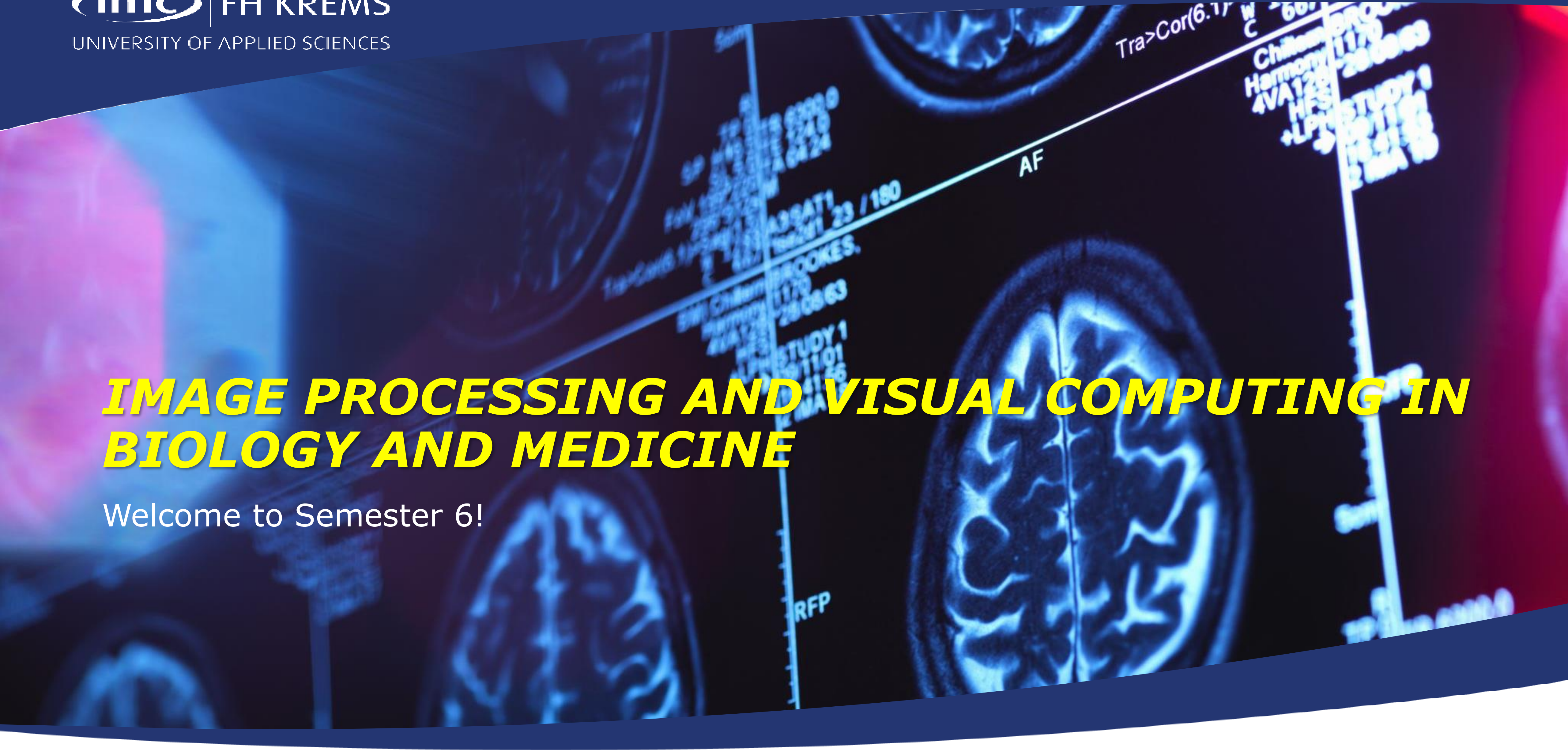
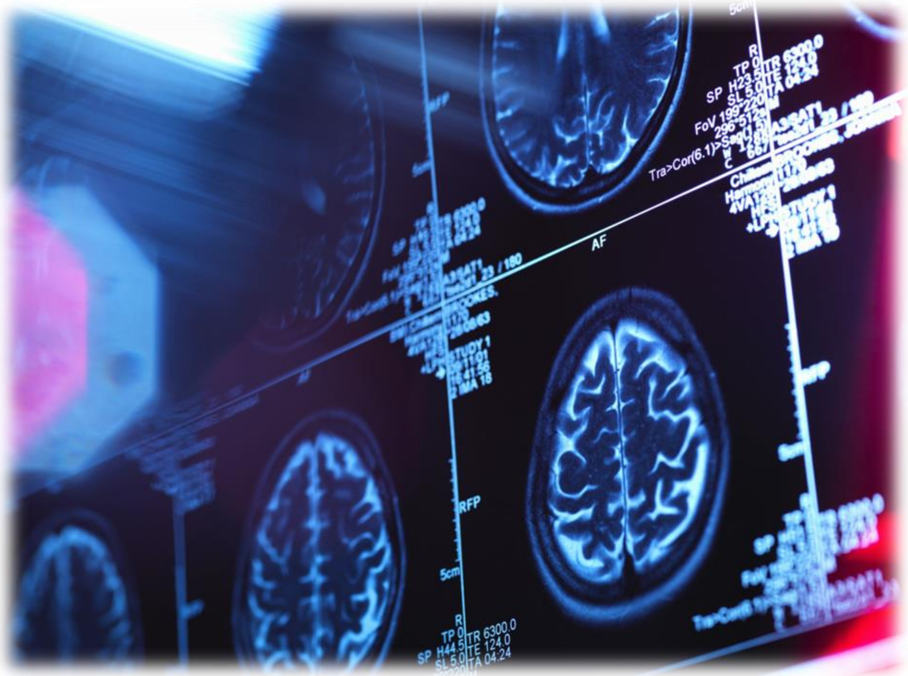


IMAGE PROCESSING AND VISUAL COMPUTING IN BIOLOGY AND MEDICINE

Welcome to Semester 6!

Today’s Agenda

- Logistics
- Medical imaging and the role of ML
  - Medical imaging modalities
  - Image representation
  - ML Applications
- Image Segmentation
  - Histograms



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Logistics

First things first

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Course Overview

Content

- Focus: imaging modalities
- Image Processing 101:
  - Filtering, Smoothing, Segmentation, Registration, Normalization
- Feature Extraction (Quantitative and Semantic)
- Visualization: showing a 3D/4D on a 2D Screen
- Machine (& Deep) Learning for Images
- Decision Support and Interpretation

Course Overview

Exercises

10

20%

3

Course Overview

Exercises

- Homework Exercises
  - Due 10 days after class
  - Late submission – 20% penalty, per day
  - 3 Days – overall - for emergency usage

- Competition – Image Processing Task
  - Bonus points

Course Overview

Assessment

- Final Presentation
  - Read and **present** a recent academic paper
  - **Explain** the basic idea and its novelty
  - Be able to **answer** questions

- Grade composition
  - 40% - Exercises
  - 40% - Final Presentation
  - 20% - Class Participation

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Medical Imaging Modalities

And the role of Machine Learning

Medical Imaging Modalities

- An approach to obtain a diagnosis of the patient
- Provides a personalized approach for the diagnosis
- Non-invasive technique (no need of a surgery)

Test yourself:

1. How many different modalities can you list?
2. What can they test?
3. How do they work?

You got 2 Minute

How many did you find?

And can you explain:

1. What can these modality test?

   What are they good for?

2. How do they operate?

   How do they generate an image?

Biomedical Imaging

- **Structural**
  - Ultrasound
  - MRI
  - X-Ray / CT
  - Projectional X-Ray
    - Computed Radiography (CR)
    - Digital Subtraction Angiography (DSA)
    - Mammography
  - Microscopy
  - Photoacoustic Imaging
  - Medical Optical Imaging
- **Functional**
  - fMRI
  - Emission CT
    - PET
    - SPECT
  - Medical Optical Imaging

Large variability in imaging modalities:
Each gives a **different view** of the body structure and functionality

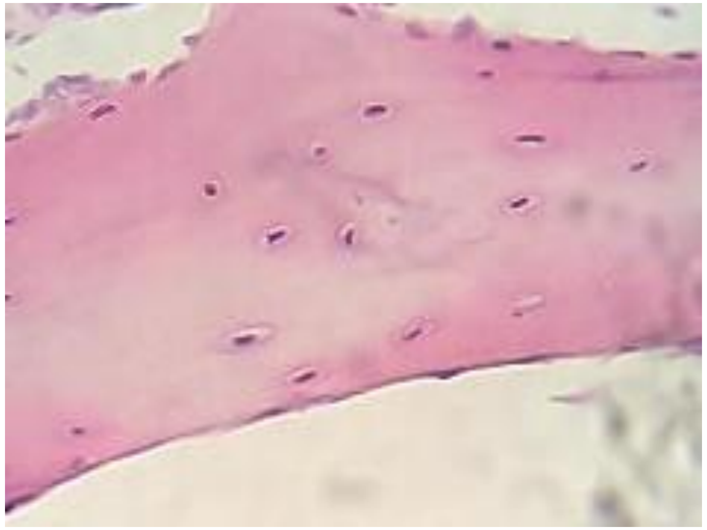
Microscopy

Histopathology: examining tissues and/or cells under a microscope

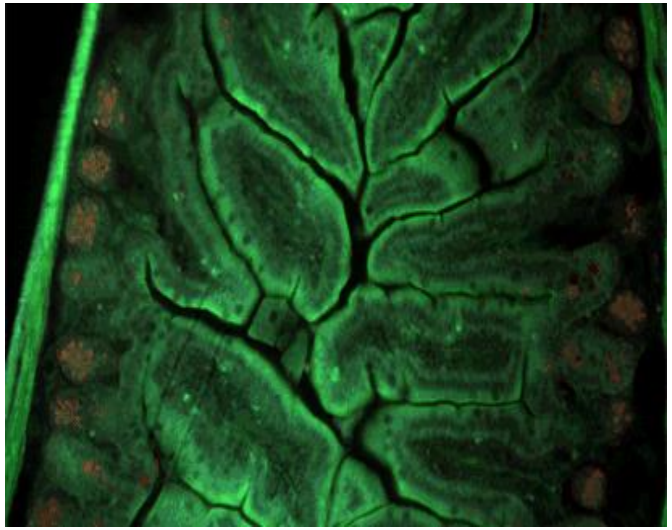
Biopsy: Histopathology & Staining

- **Histopathology** – the diagnosis and study of diseases of the tissues.
- **Staining** - enhance contrast in microscopic samples

Hematoxylin and eosin (H&E) stain



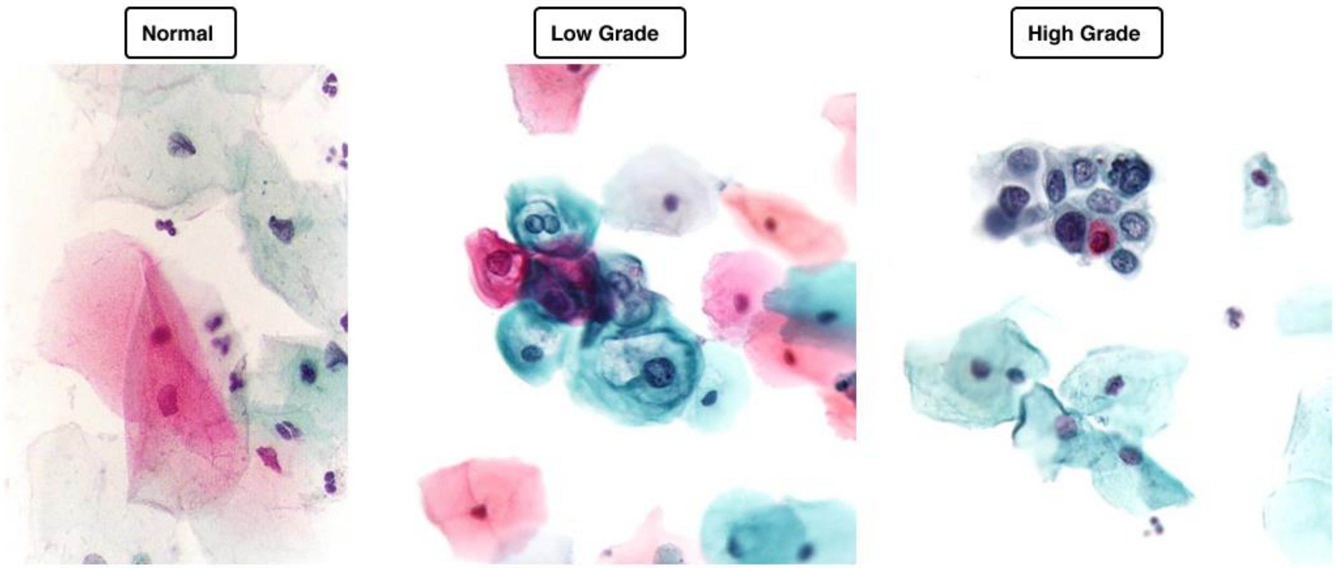
Autofluorescence

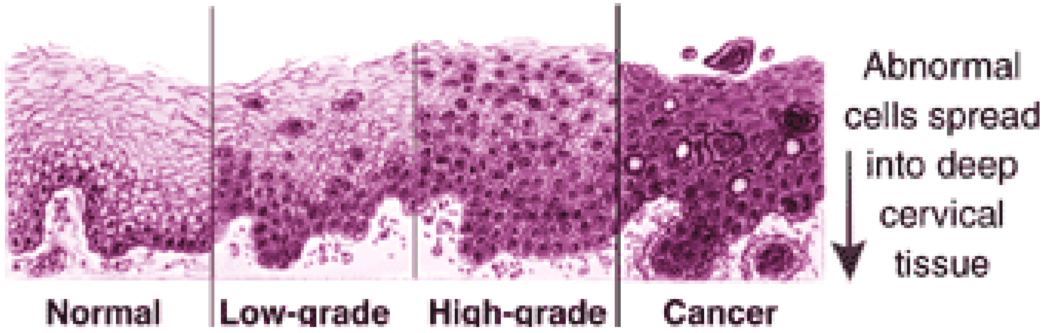


Histology

Abnormal cells detection using pap-test:

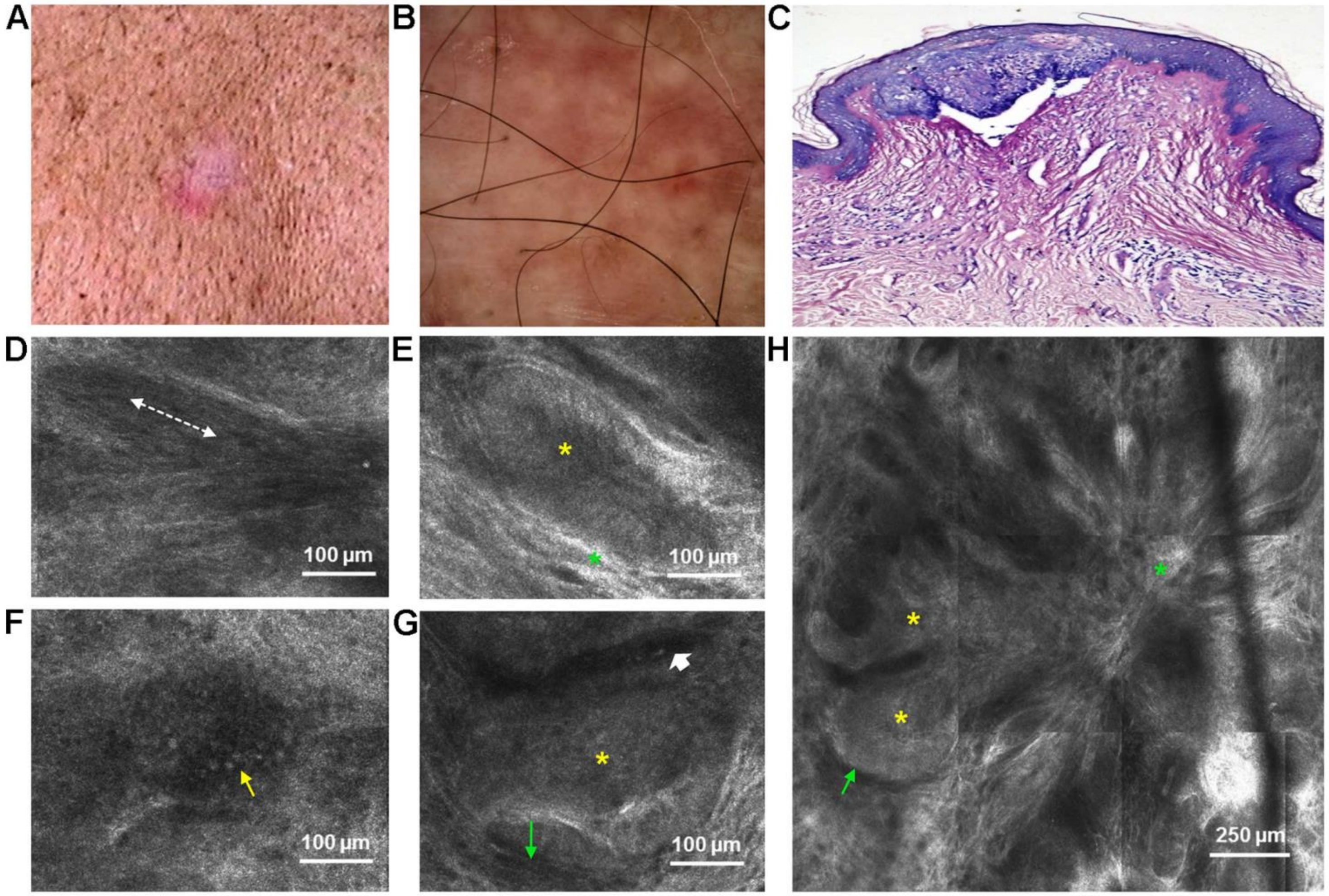
- Viral Infections (e.g., HPV – low grade)
- Benign / Malign Cells (e.g., carcinoma - high grade)





Reflectance Confocal Microscopy

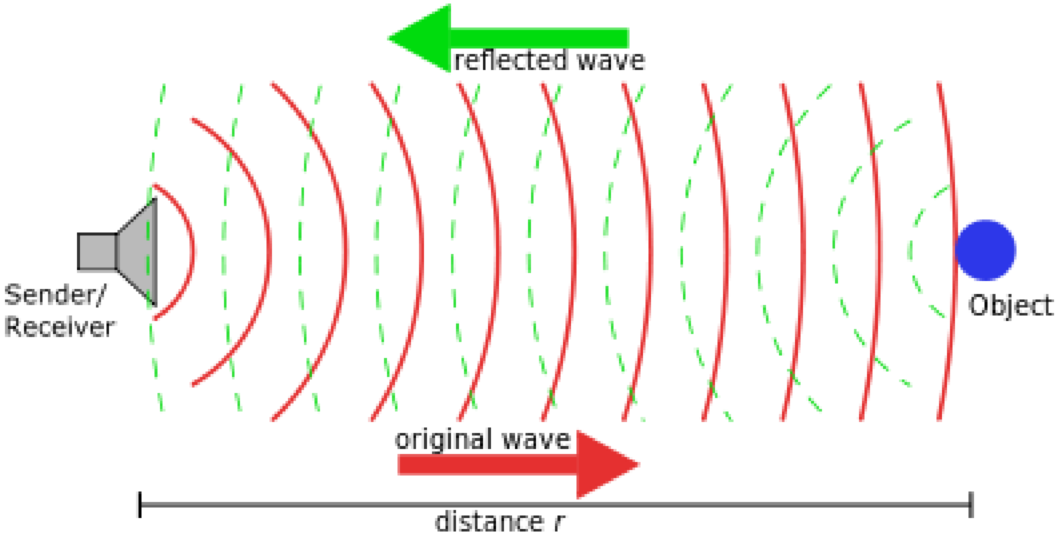
- RCM for short
- Non-invasive
- Very high-res
- For dermatology
  - Skin cancer
- B&W Images
  - Harder to interpret



Medical Sonography (Ultrasound)

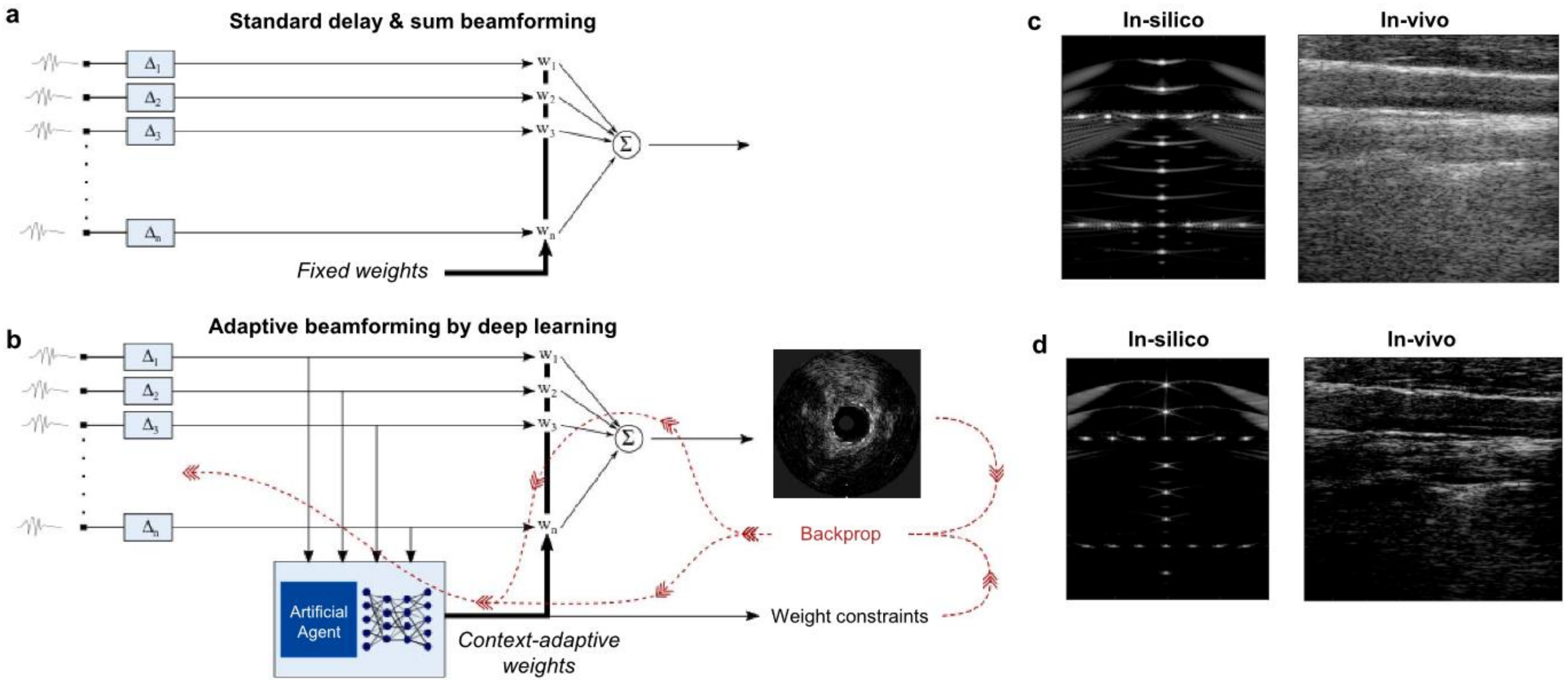
- Shows parts in motion: heart beating, blood flow.
- Pregnancy, heart, bones, and more.

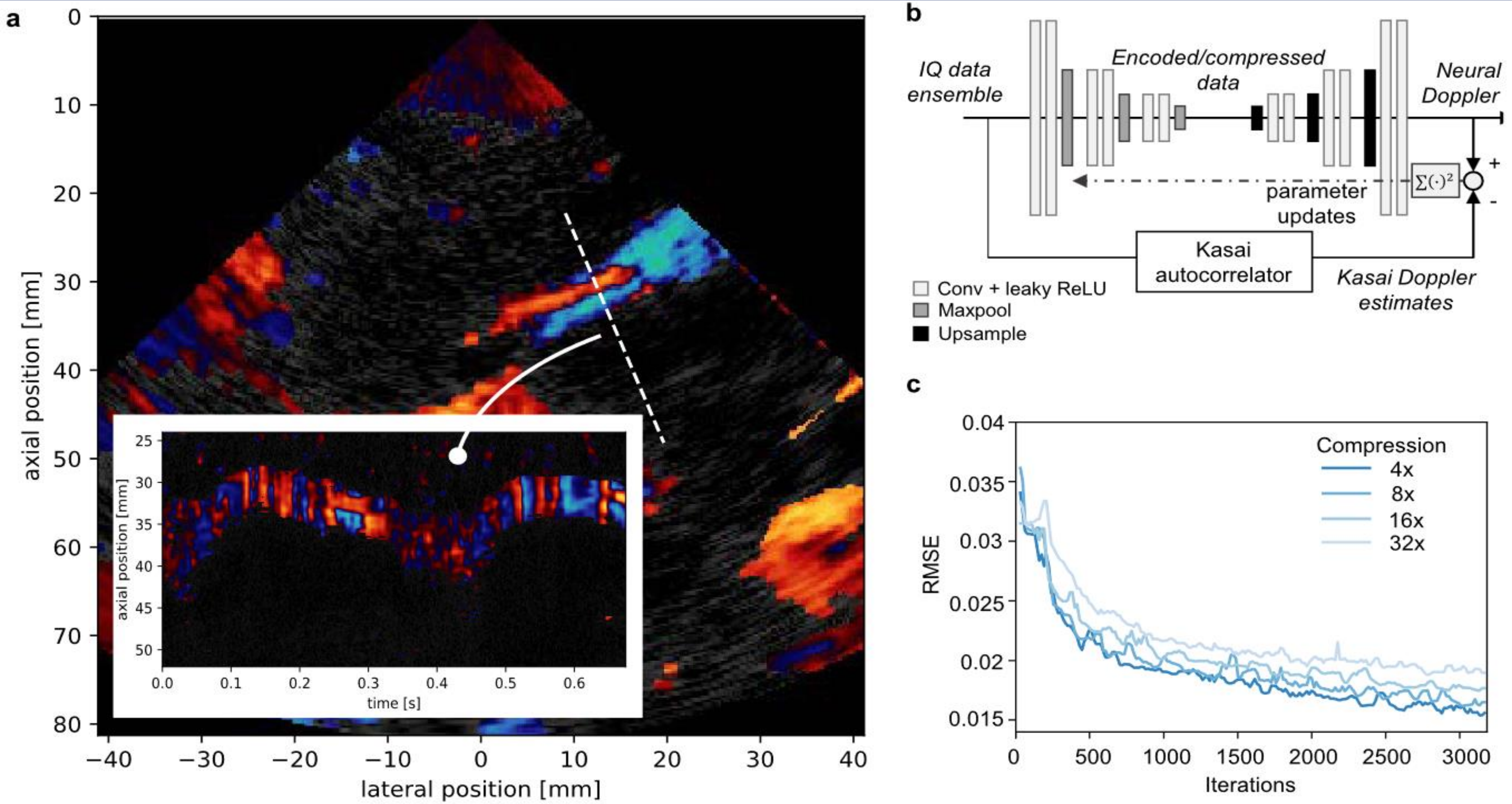
The transducer sends sound waves and collects the reflected signal.



Medical Sonography (Ultrasound)

Raw Signal Acquisition (Adaptive Beam Forming)

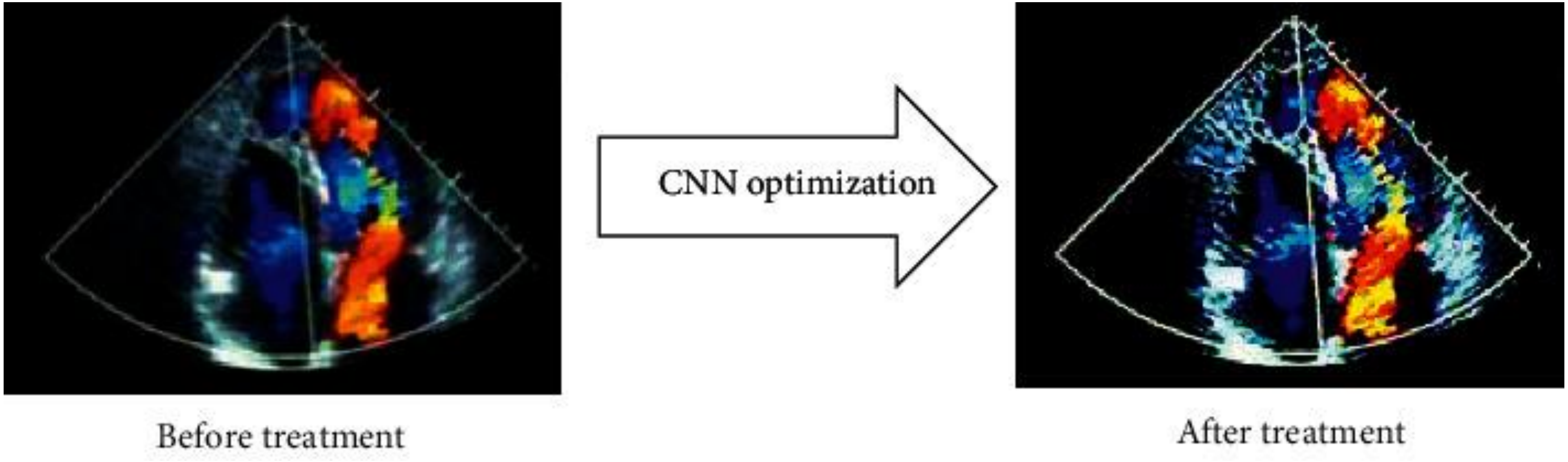




[Deep Learning in Ultrasound Imaging (weizmann.ac.il)](https://www.weizmann.ac.il)

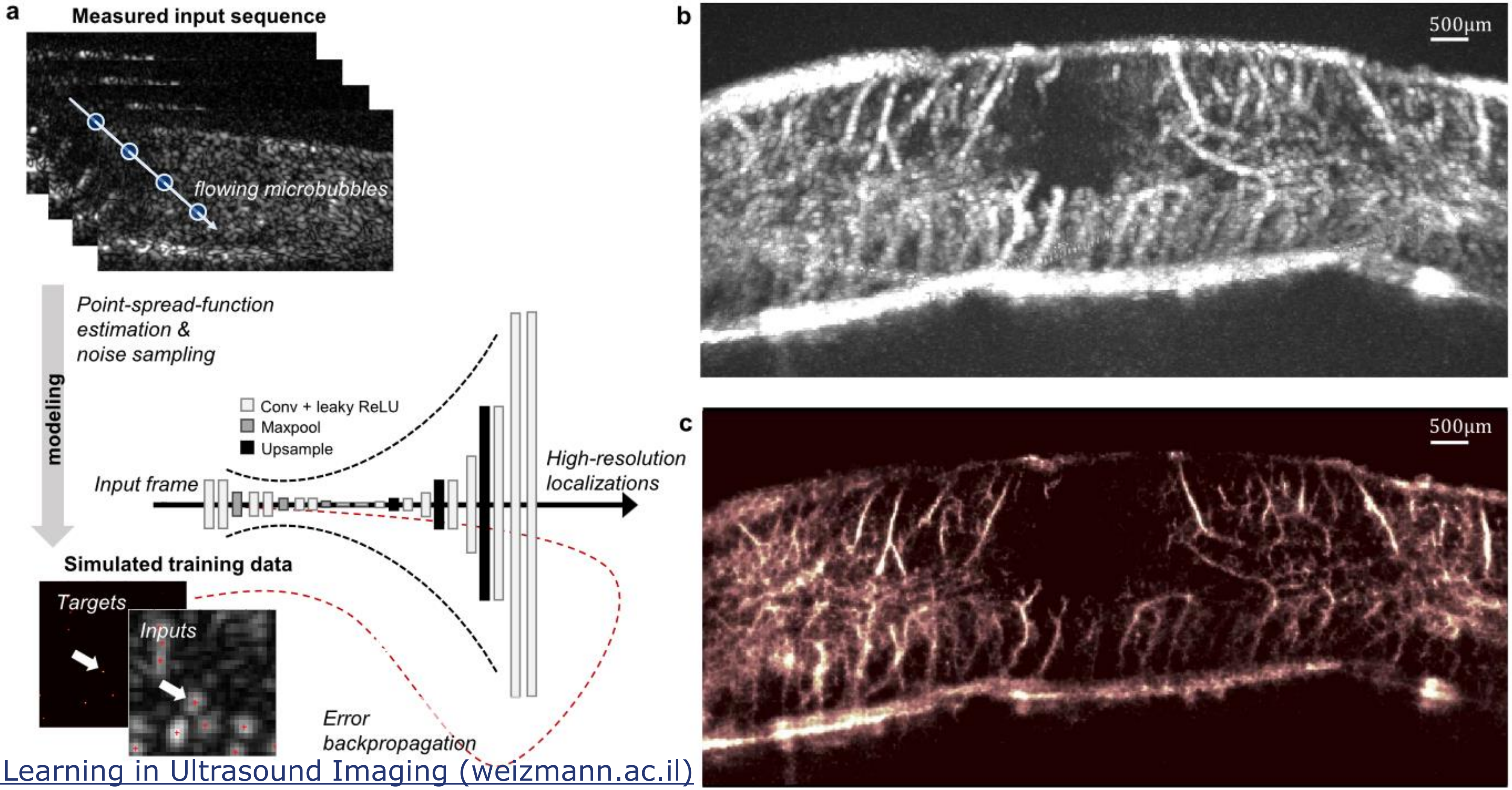
Ultrasound

Medical Sonography with Machine Learning – coloring and image enhancement



[Deep-Learning-Based Color Doppler Ultrasound Image Feature in the Diagnosis of Elderly Patients with Chronic Heart Failure Complicated with Sarcopenia - PubMed (nih.gov)]

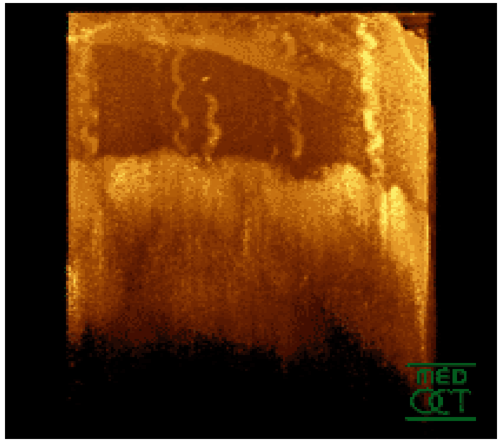
Ultrasound Localization Microscopy (ULM)

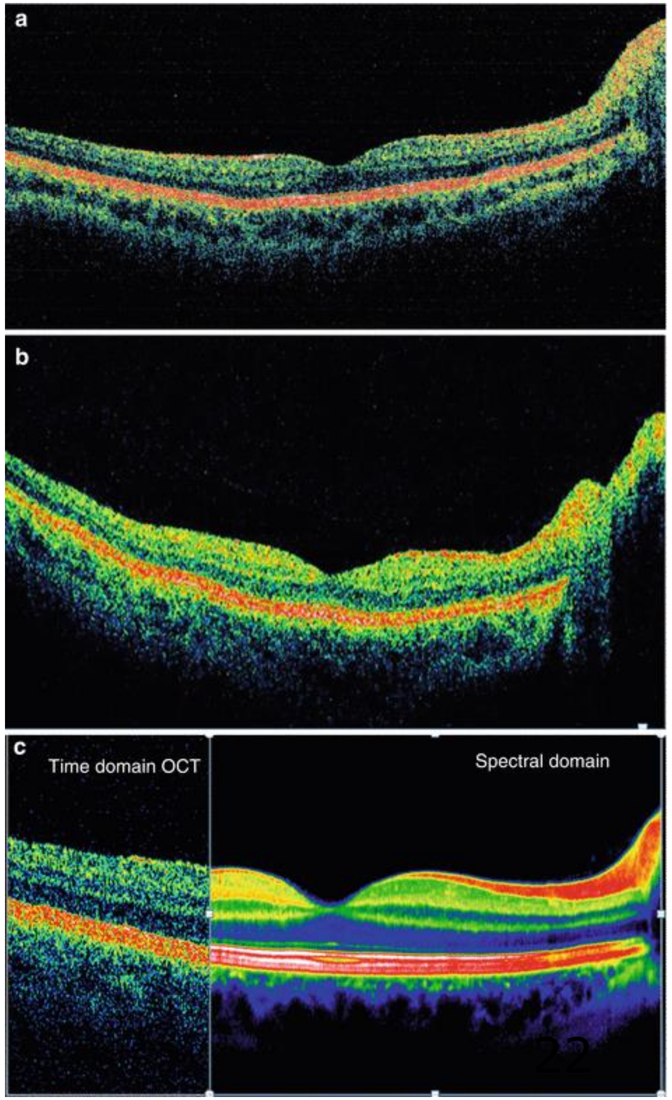


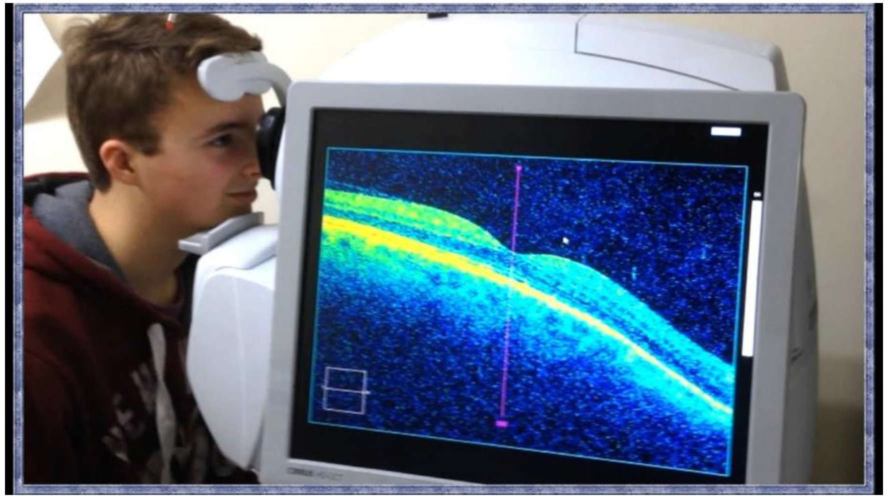
Deep Learning in Ultrasound Imaging (weizmann.ac.il)

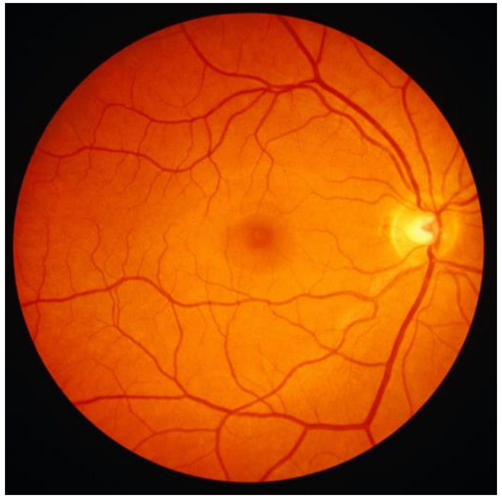
Optical Coherence Tomography (OCT)

- Same as UltraSound – but using light waves
- Common for Eye-imaging
- Ophthalmology (Surgeries)
- Diagnosis:
  Glaucoma, Diabetes, and more.



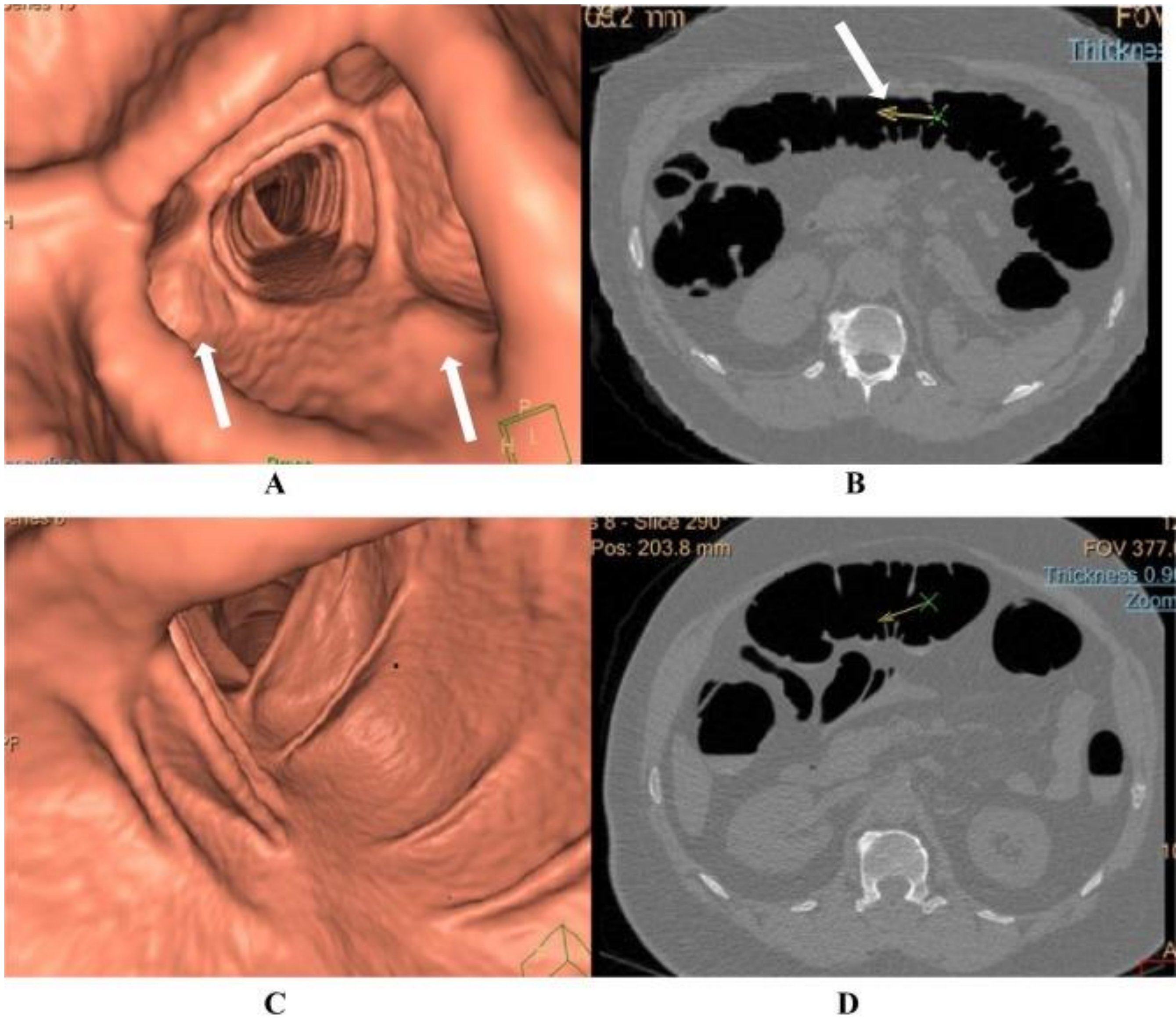






Colonoscopy

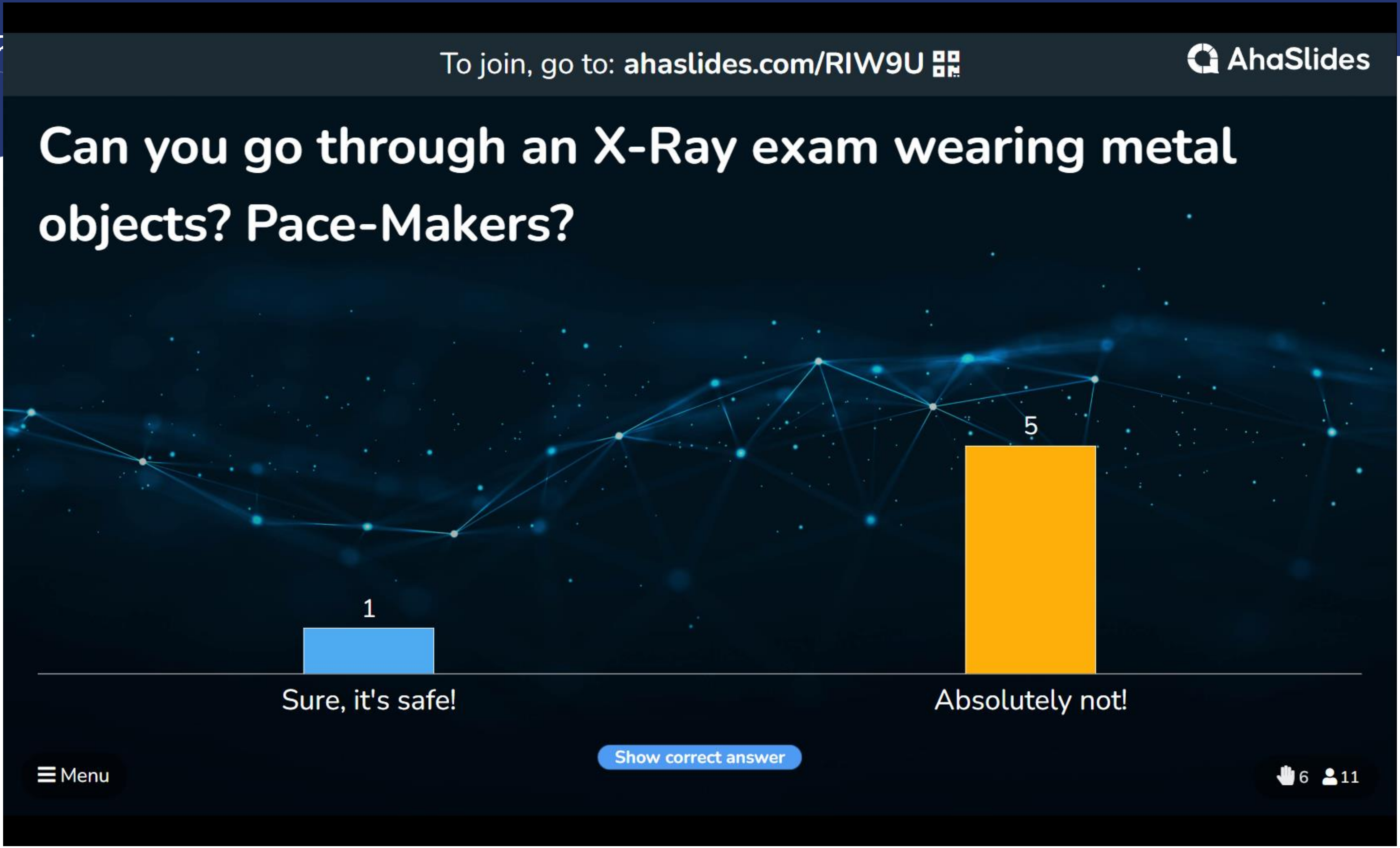
- Long-cable camera
- Polyp detection
- Standard procedure



Pop-Quiz!

- Can one go through an X-Ray exam wearing metal objects?
- What about magnets?
- Or a pace-maker?

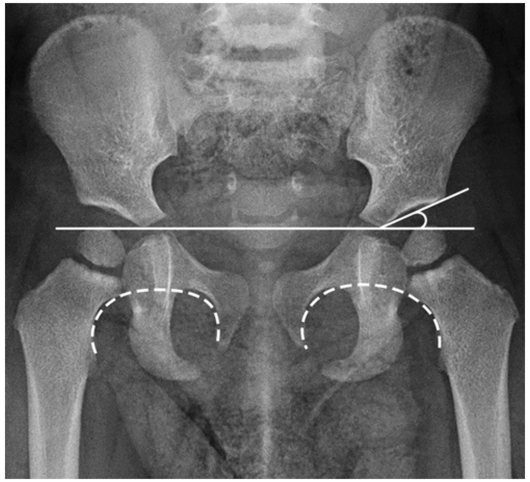
https://ahaslides.com/RIW9U

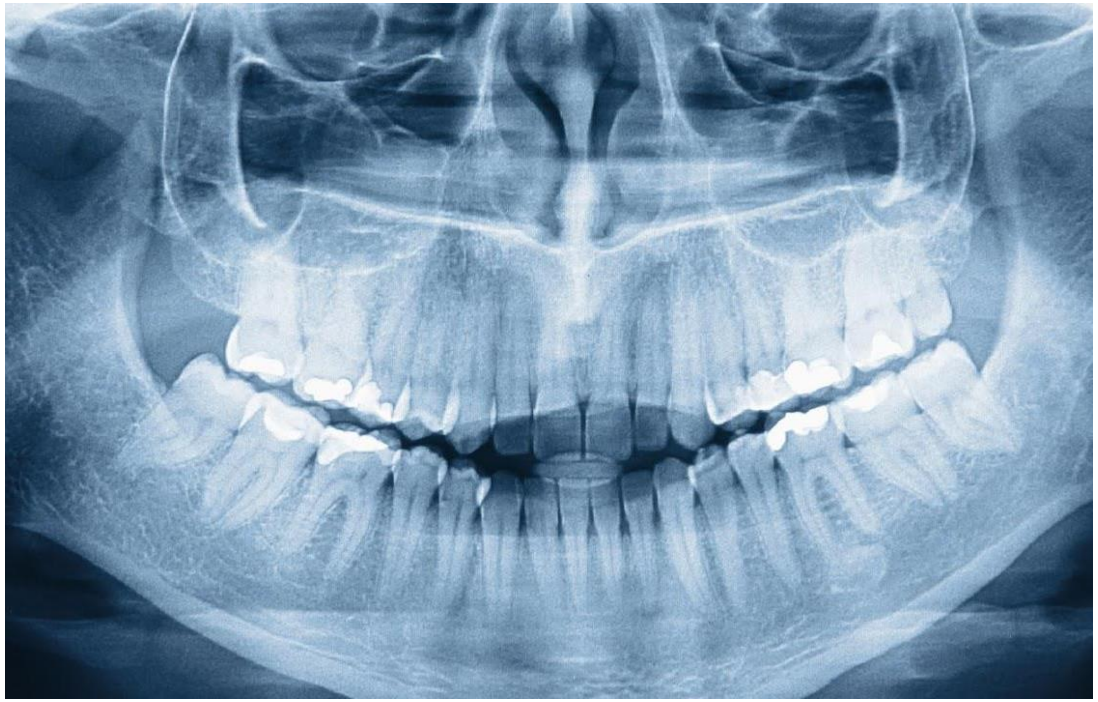

To join, go to: ahaslides.com/RIW9U
AhaSlides
Can you go through an X-Ray exam wearing metal objects? Pace-Makers?
1
5
Sure, it's safe!
Absolutely not!
Show correct answer
Menu
6
11

X-Ray

- Electromagnetic Radiation
- Photons absorption depends on the tissues (Dense tissues absorb less)
- A Projection technique ("Shadow" image)

X-Ray





- Cheap and widely used:
  - Bone fractures - knee, heap, legs
  - Chest: Lungs, scars, cancer, smoking issues
  - Teeth – visualizes roots, inflammations
- Analyzed by Radiologists in a dark room.
  - They annotate *everything* they see.
  - (Or by dentists, live, near the patient)

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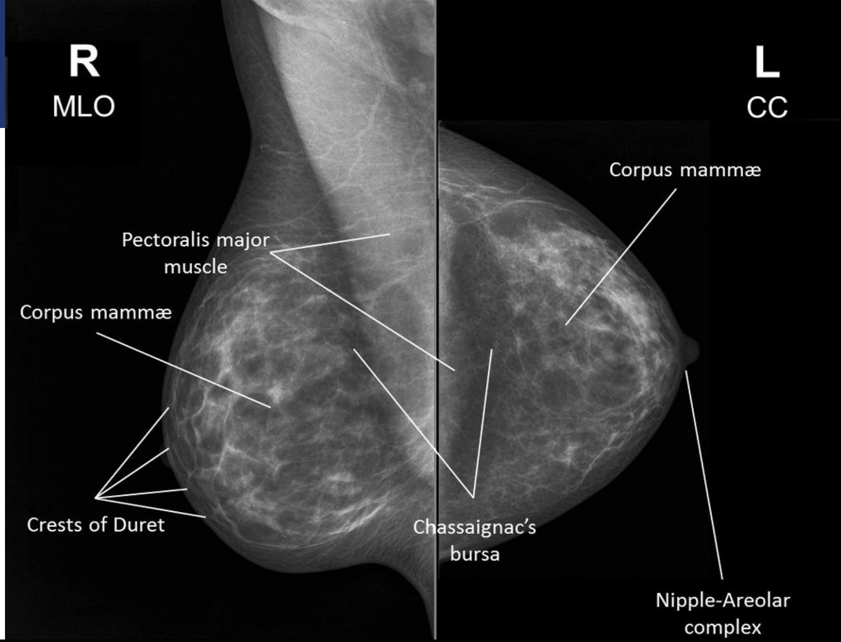
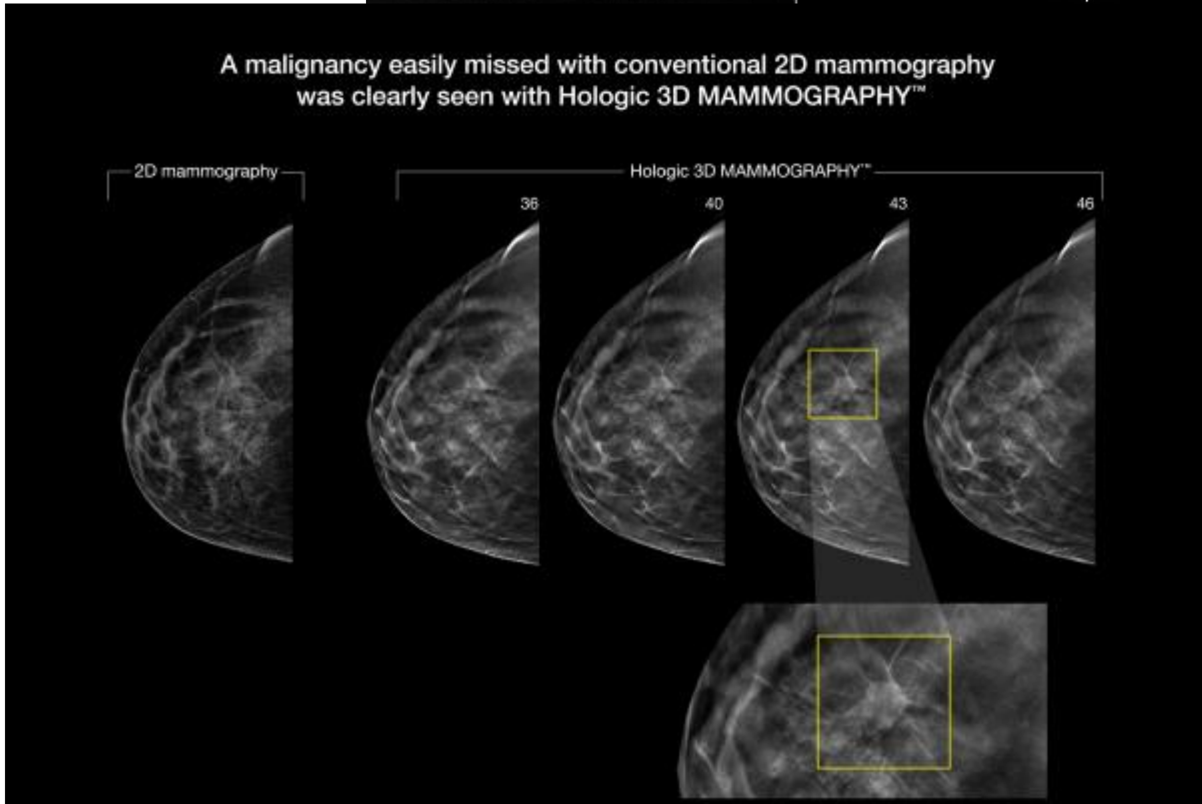
X-Ray

Mammography

- Low dose X-Ray
- For (early) detection of breath cancer





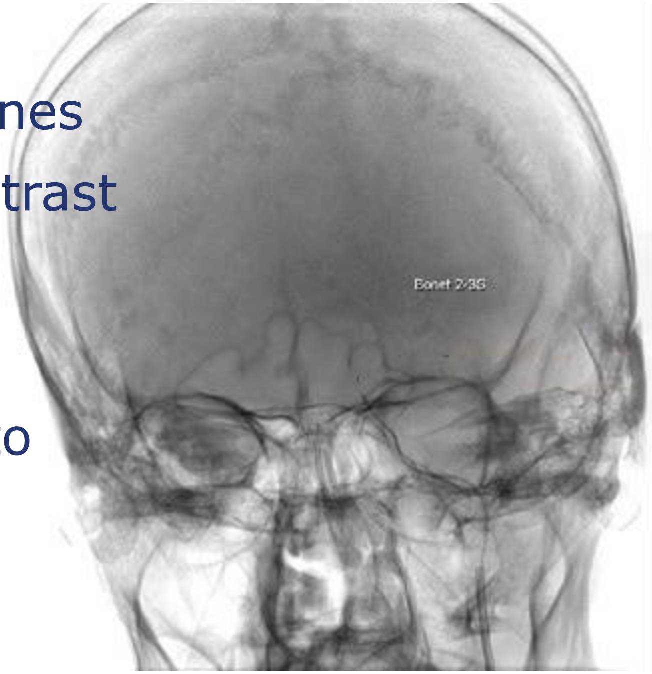
Digital Subtraction Angiography

X-Ray with a twist: A Fluoroscopy Technique

- Angio = Blood Vessel

- Visualizes blood vessels behind bones
- Requires injection of iodinated contrast

- Subtraction of the bones
- Can be combined with a catheter to prognose stroke

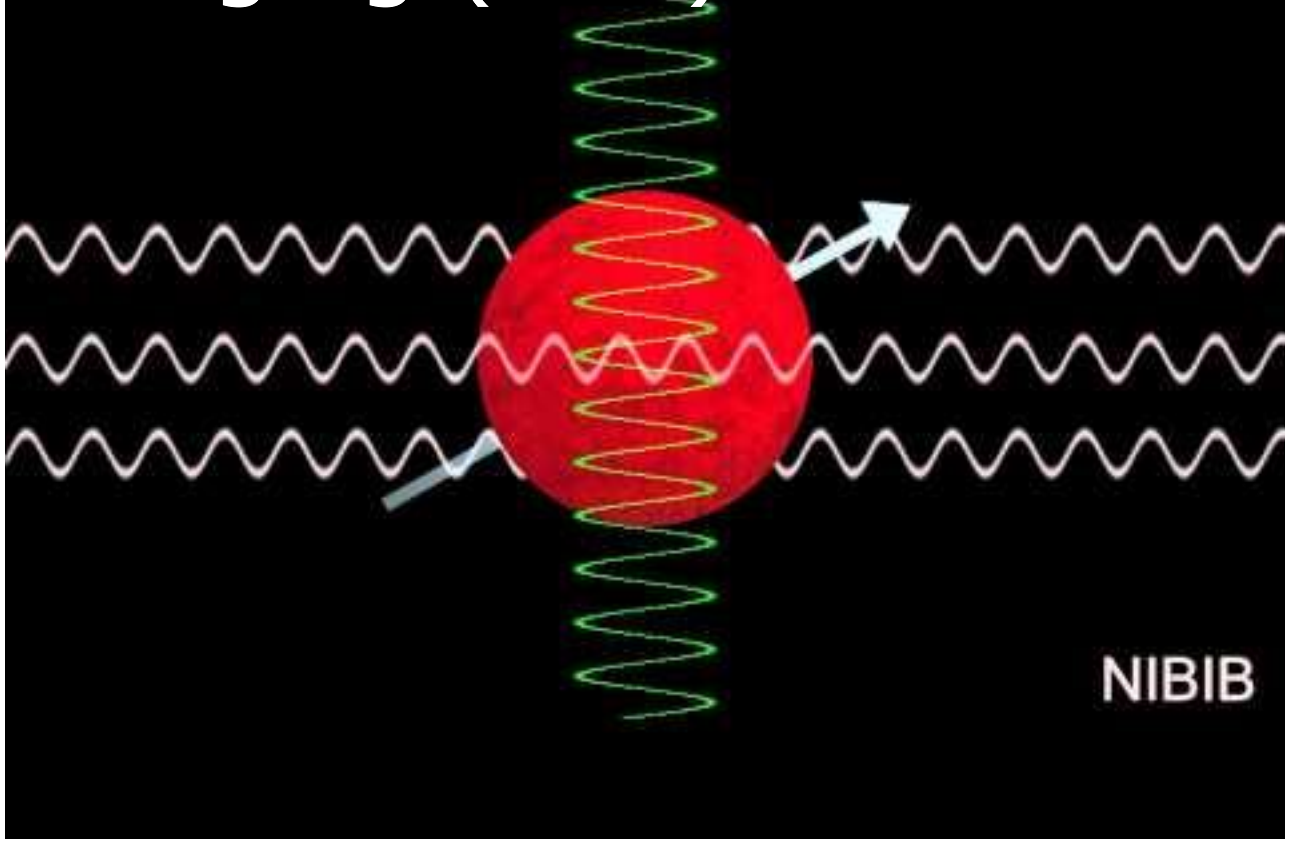


Computed Tomography (CT)

- Series of narrow X-Ray beams from different angles, combined programmatically.
- Is used to build a 3D image of soft tissues or bones.
- Produces a series of images.

Magnetic Resonance Imaging (MRI)

- Hydrogen atoms in our bodies are ***magnetic*** and behave like a ***needle in a compass***.
- Strong magnets in MRI affect those atoms.
- The returned energy is collected; The MRI constructs an image based on the *energy levels* and timing.



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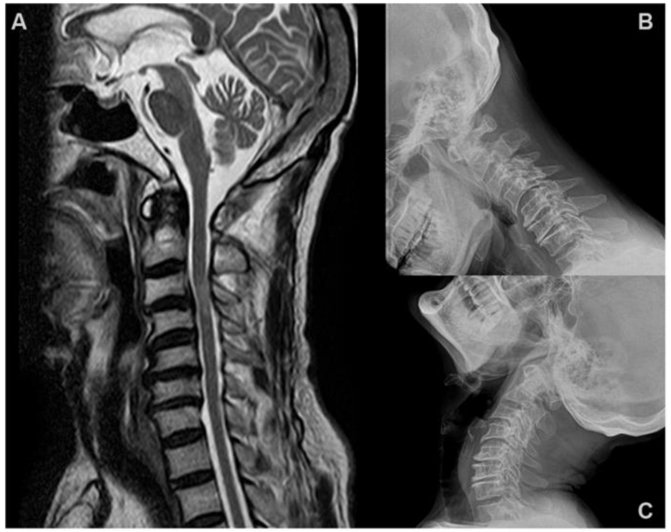
Magnetic Resonance Imaging (MRI)

- No X-Ray is involved (unlike CT)
- Used to examine **Soft Tissues** (not bones)
  - Cancer research
- **functional** Magnetic Resonance Imaging (fMRI)
  - Can show blood flows
  - Brain disease (e.g., Parkinson, Alzheimer)
  - Heart disease
  - Brain structure
  - Cognitive Tasks



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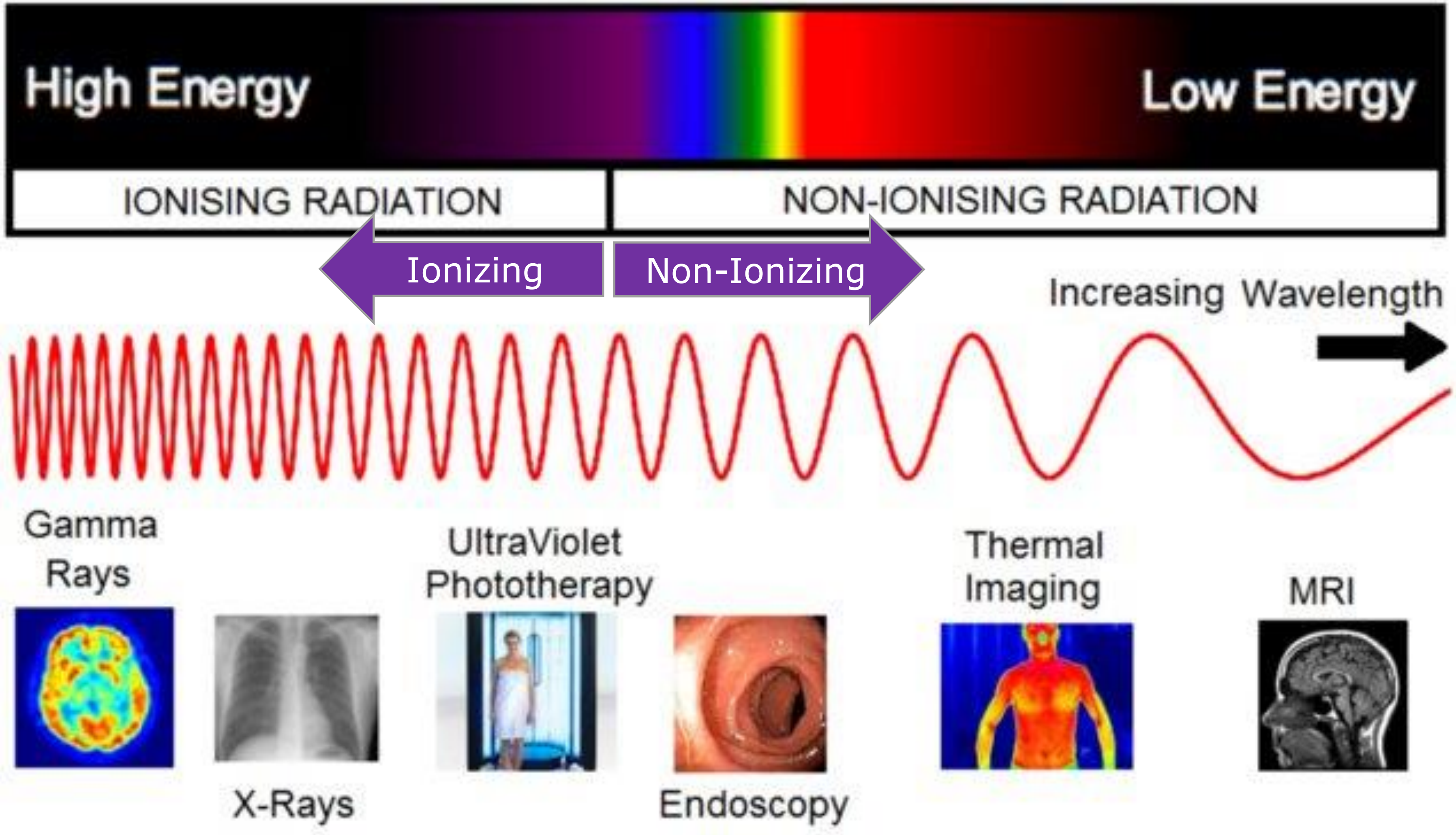
Imaging Spectrum

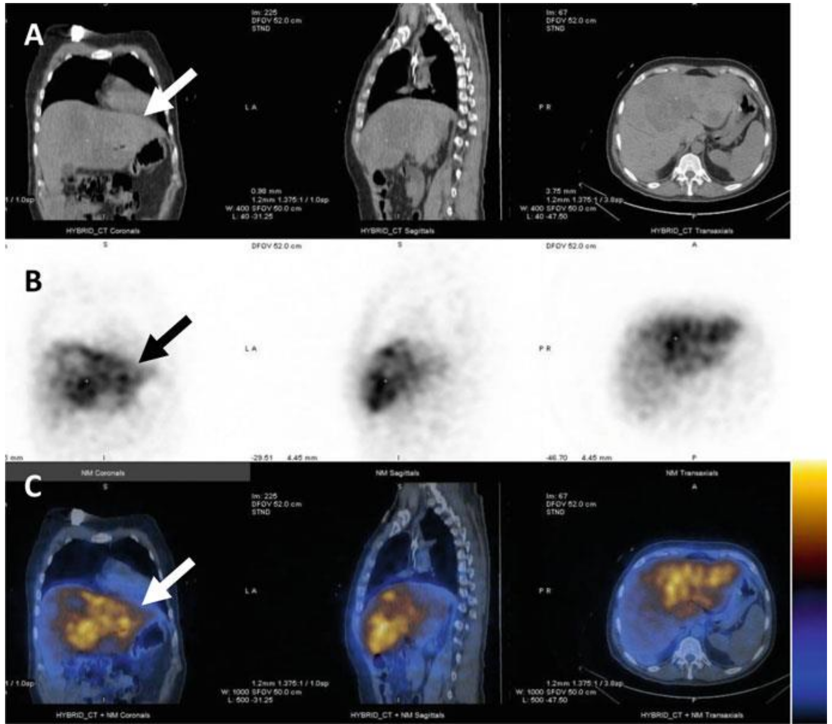


[(10) (PDF) Review Research of Medical Image Analysis Using Deep Learning (researchgate.net)]()

Emission Tomography - Radioactive Tracers Molecules:

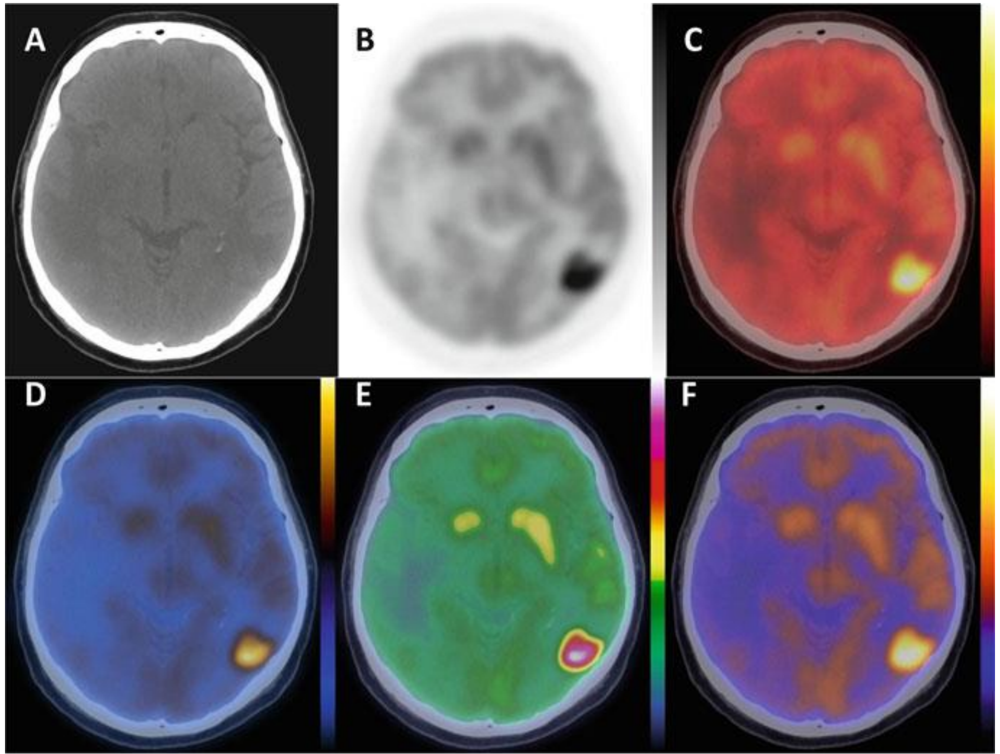
Single **P**hoton **E**mission **C**omputed **T**omography (**SPECT**):

- Bone fractions, Heart, liver tumors
- Cheaper - but low quality
- Often combined with MRI or CT



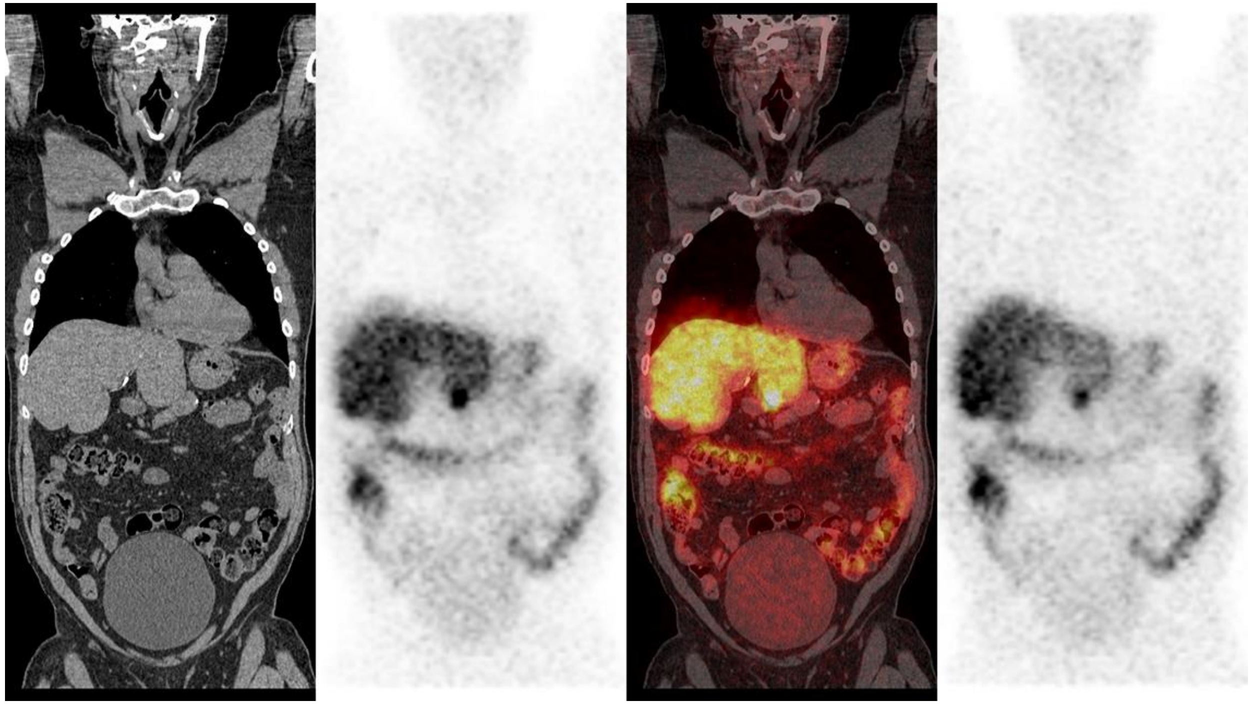
Positron **E**mission **T**omography (**PET**):

- Combined with MRI/CT for oncology imaging
- Better quality - more expensive

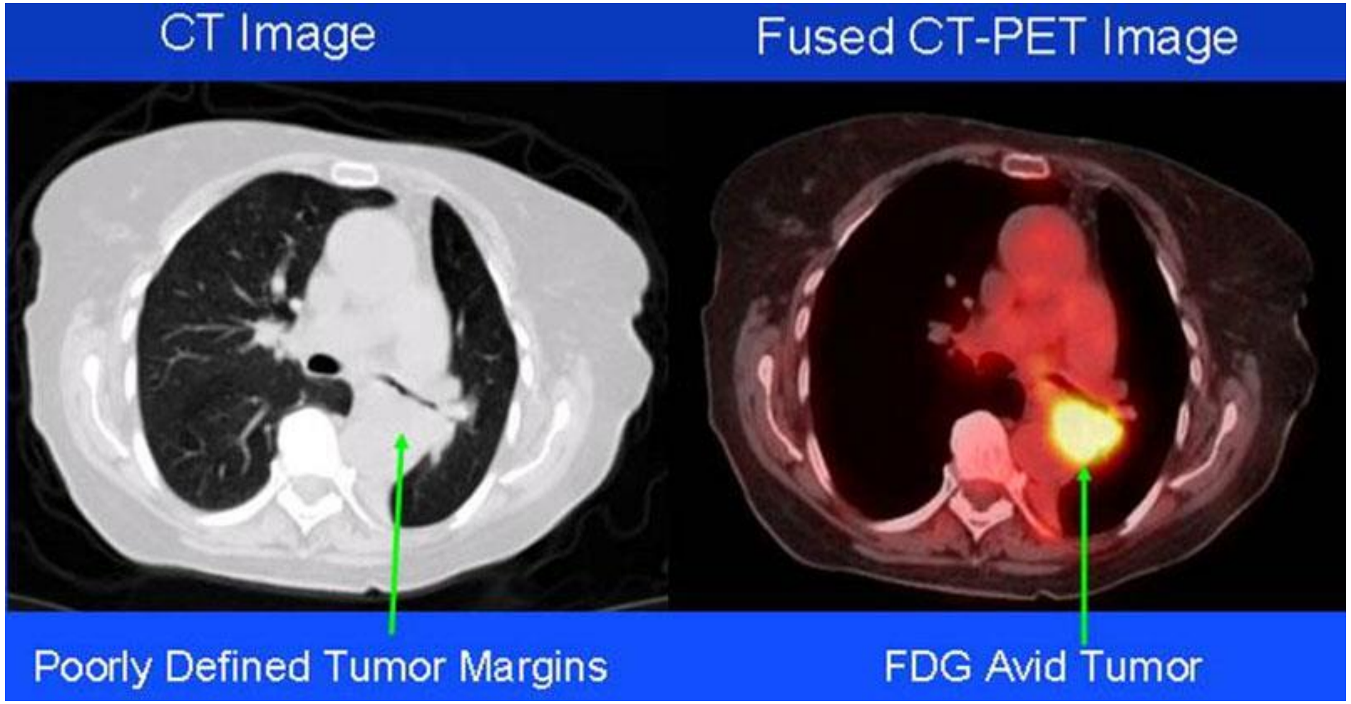


Multimodality: SPECT-CT

A fusion of both scans

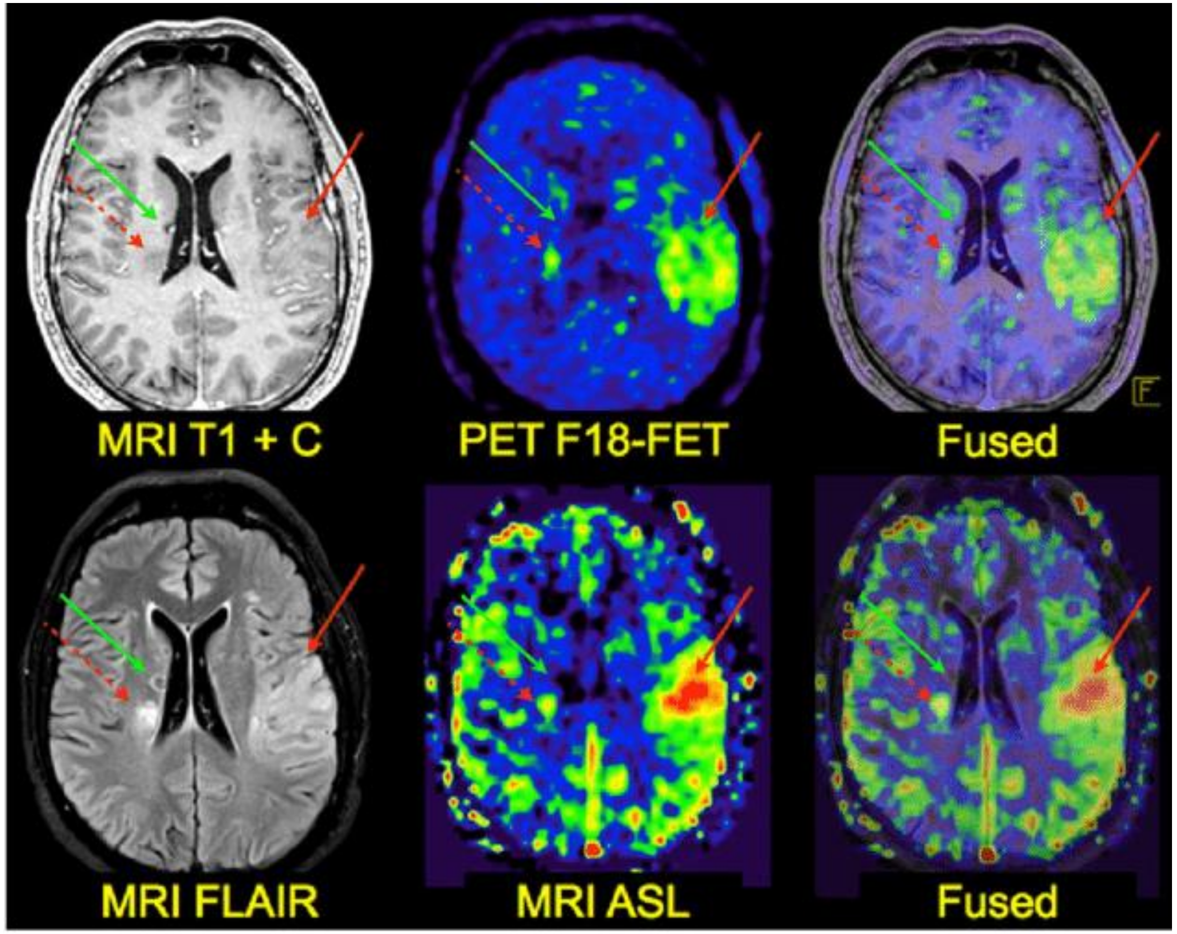


Multimodality: CT-PET



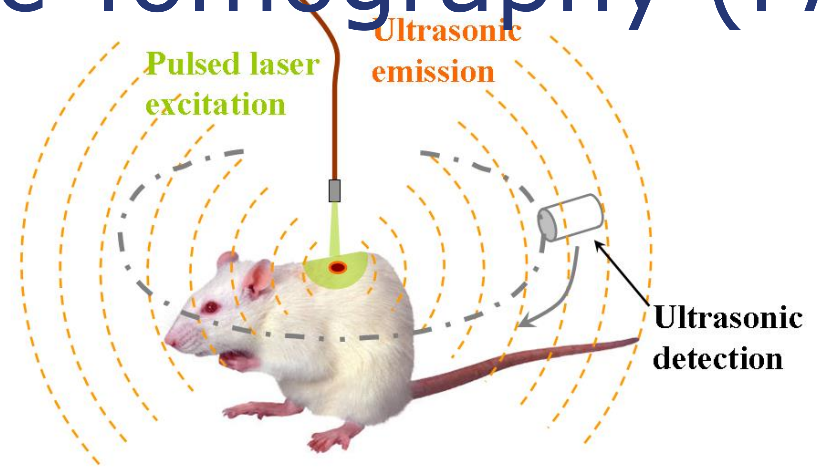
Multimodality: MR-PET

MRI + PET combined

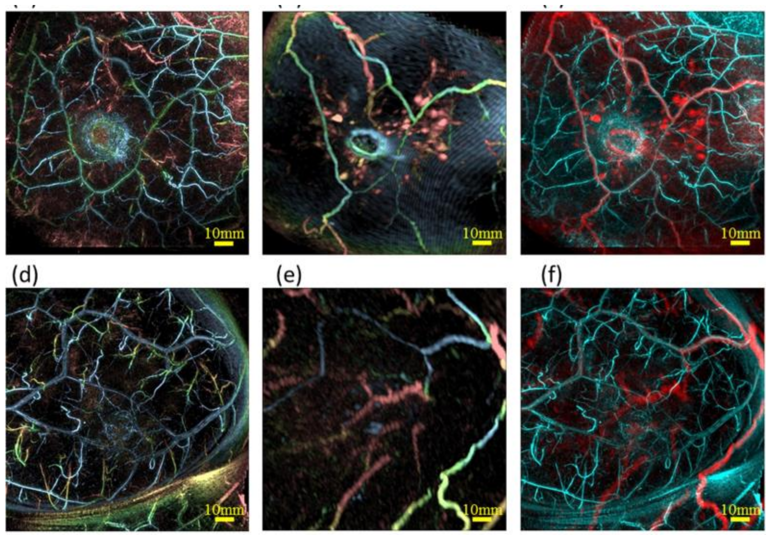


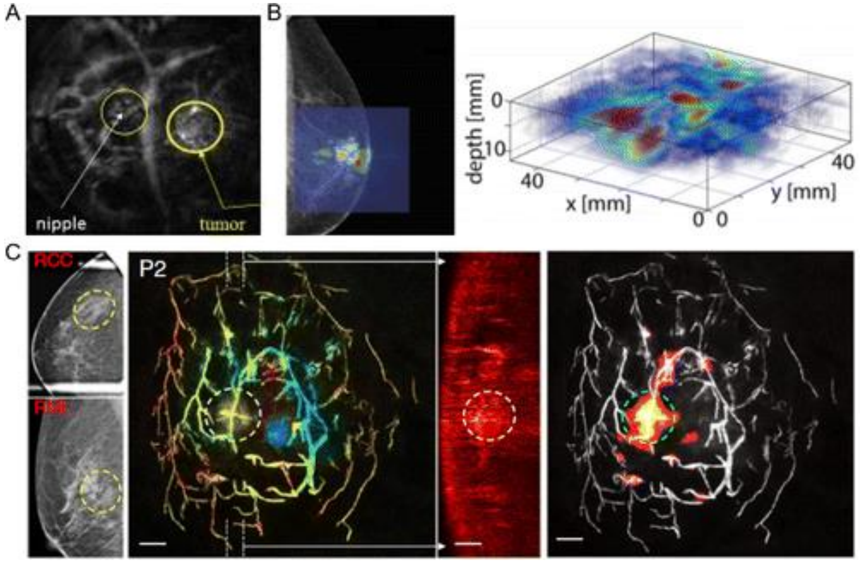
Photoacustic Tomography (PAT)

Very new technology



Laser/ RF pulse → Absorption → Thermal expansion → Acoustic waves → Ultrasonic detection → Image formation



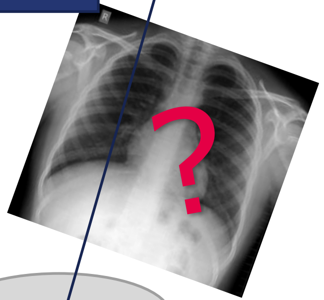


- Method:
  - Light (laser) heats the sample
  - The thermal expansion creates acoustic waves
  - 3D absorption map is created.
- Useful for vasculature imaging, breast cancer.

Medical Imaging

Current state

Picture Archiving & Communication System



ER

Clinic

PACS

Delay

limited time to review an ever-increasing number of images

Take-Aways

Image Modalities

- Many different modalities exist:
  - X-Ray, CT, MRI, SPECT, PET, Microscopy, OCT, etc.

- They can be combined too:
  - SPECT-CT
  - PET-MRI
  - (Requires ML for Registration)

Radiologists Tasks

- Detection
- Measurement
- Diagnosis
- Reporting

Busy work – 80% of the time is spent on **these**

Critical Tasks – time should be spent on that

The need for AI

- 25 Seconds CT scans produce up to 2000 images
- PET/CT requires a review of up to 6000 images
- Breast Ultra-Sound can create 5000 images
- 5 Billion studies per year worldwide (and growing...)

- Human error in diagnostics plays a role in up to 10% of patient deaths
- ~20M radiology reports per year contain clinically significant errors
- ⅔ of the world population lacks access to radiology specialists (~5 Billion people)

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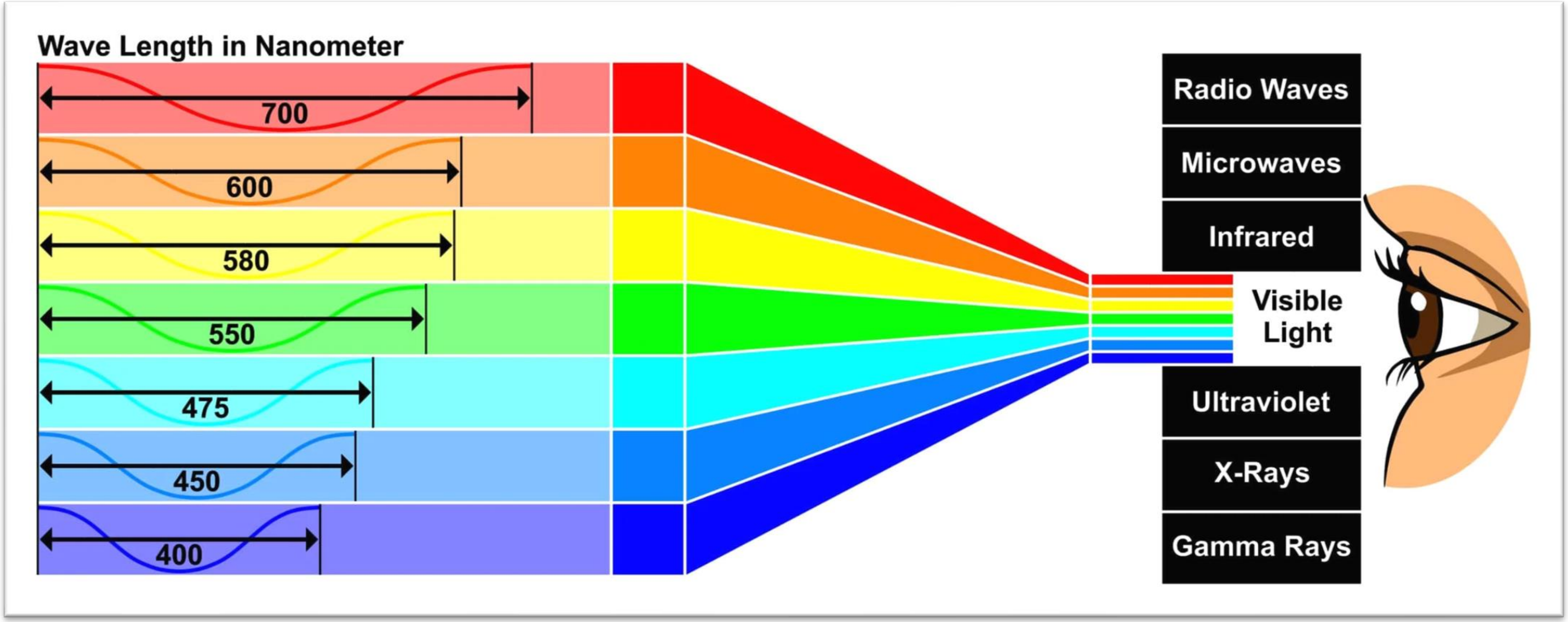
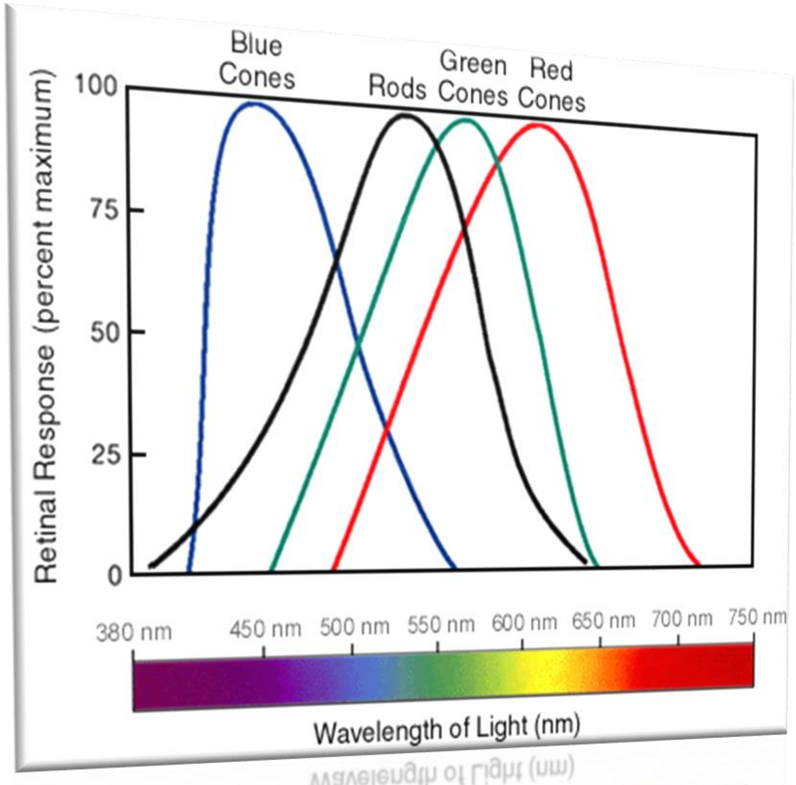
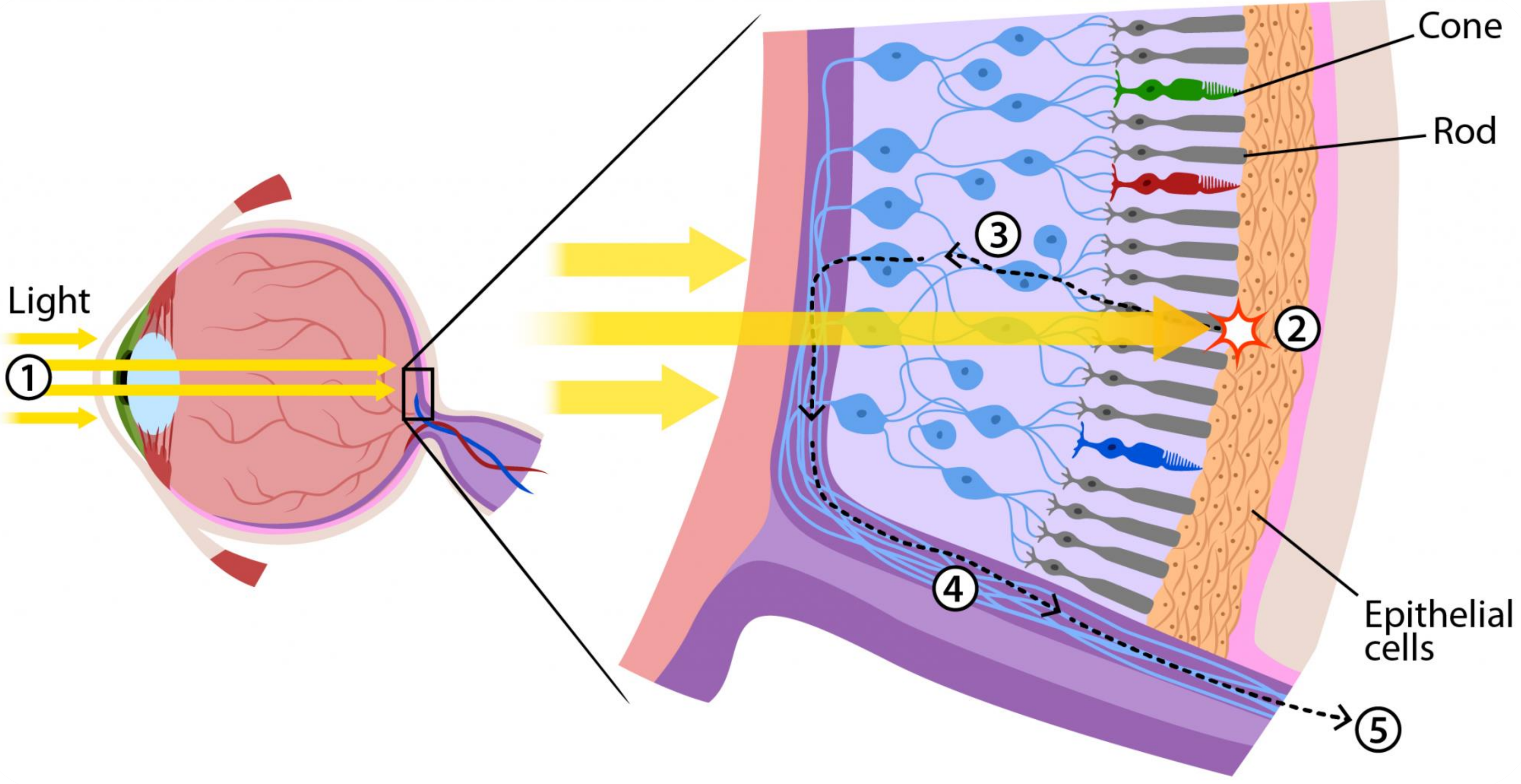
Human Vision



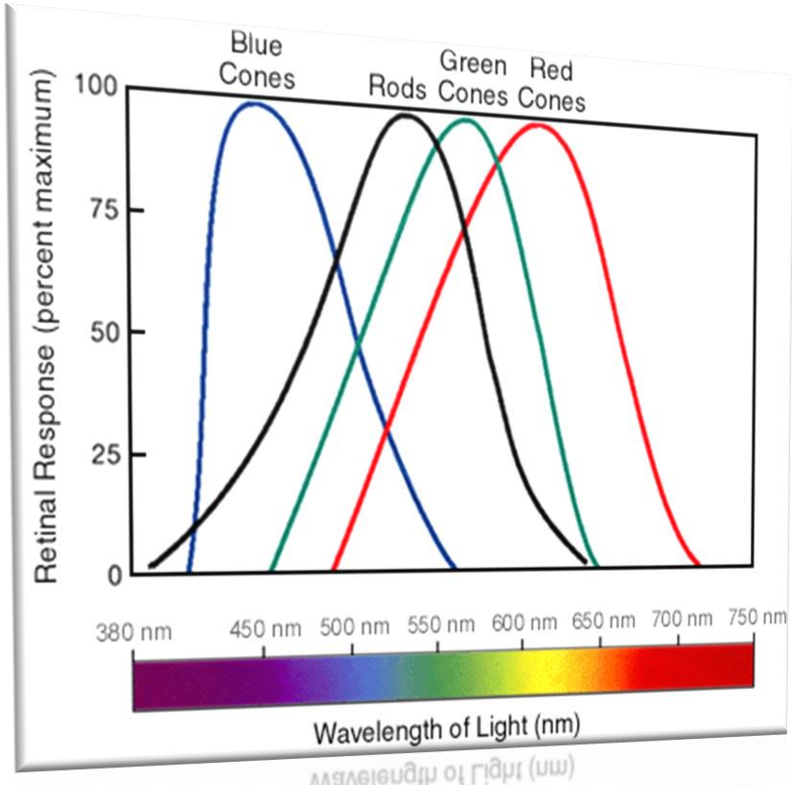
How Do We See Light? | Ask A Biologist (asu.edu)

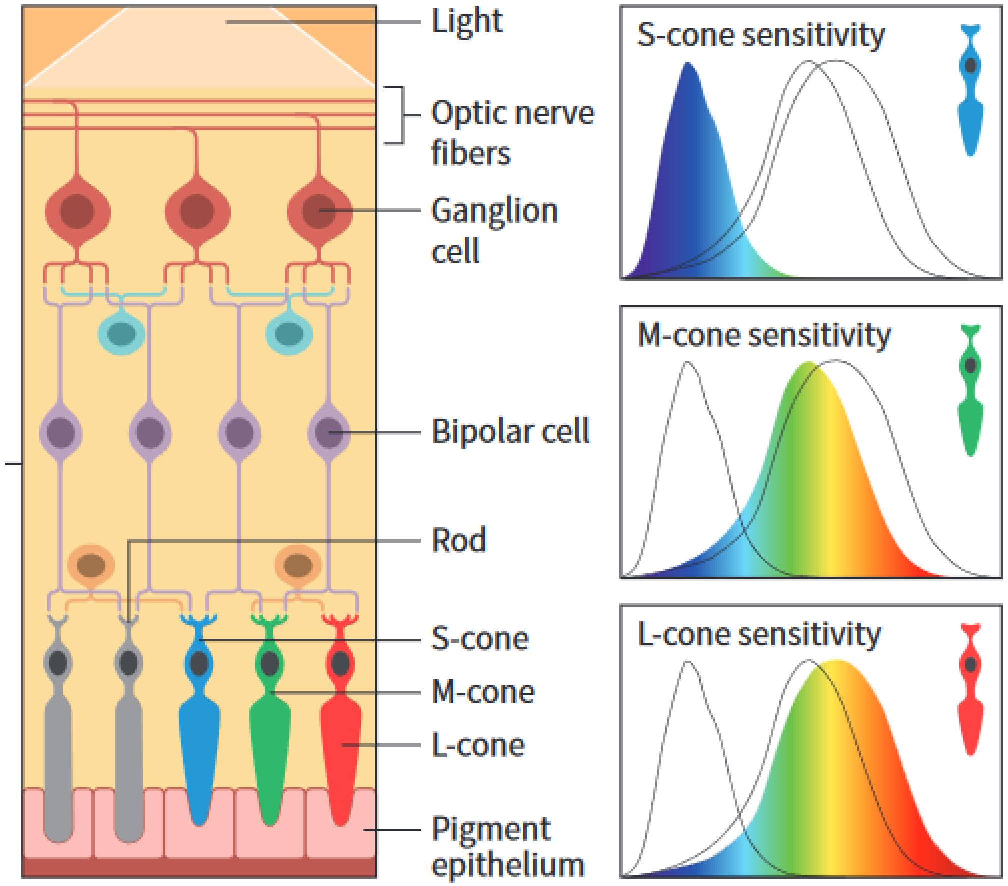
Human Vision



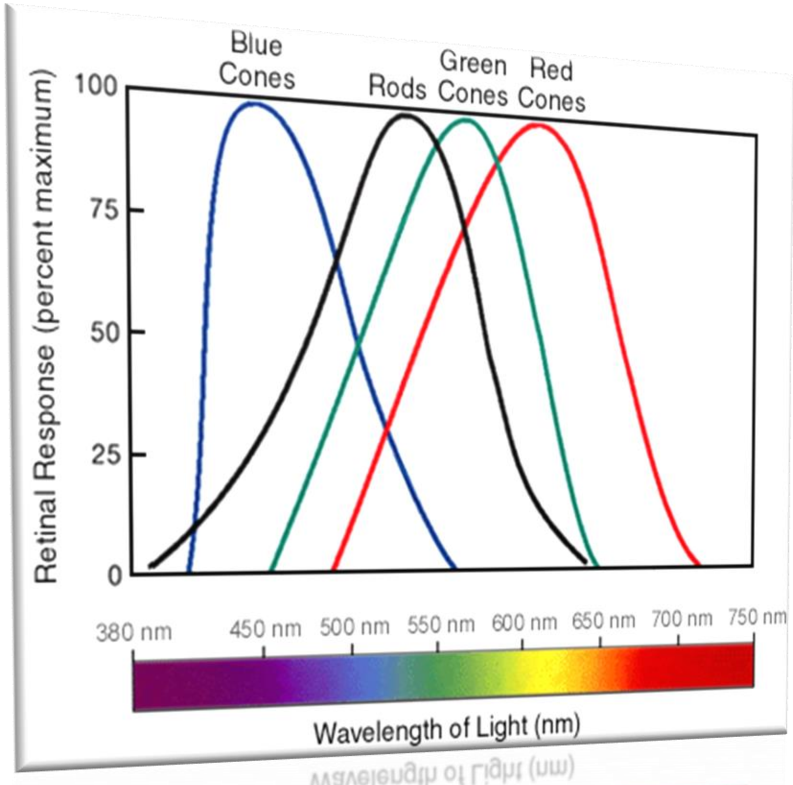


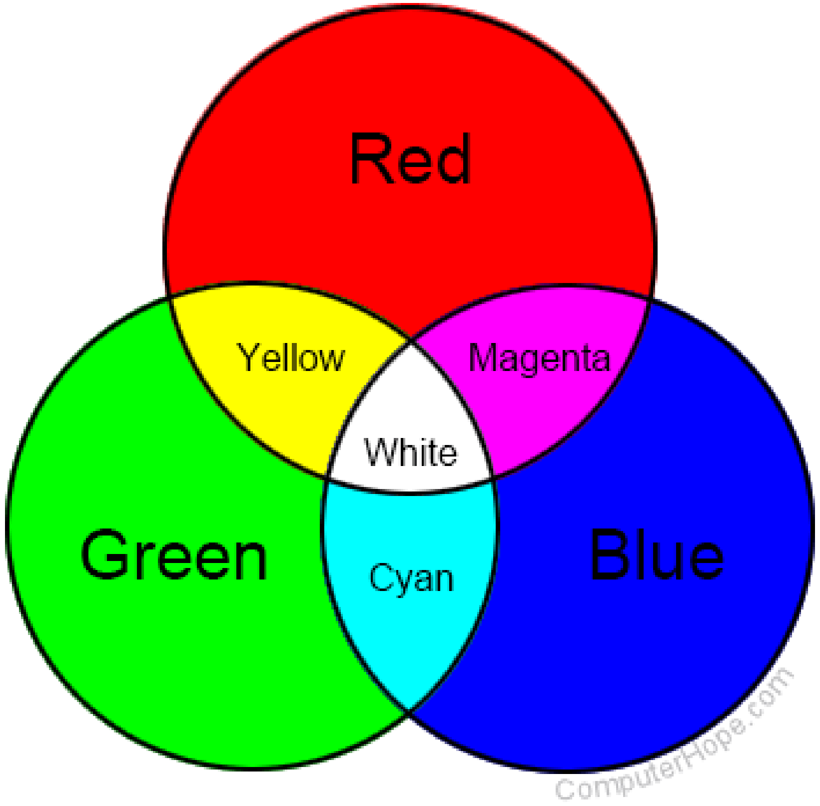
Human Vision - Color



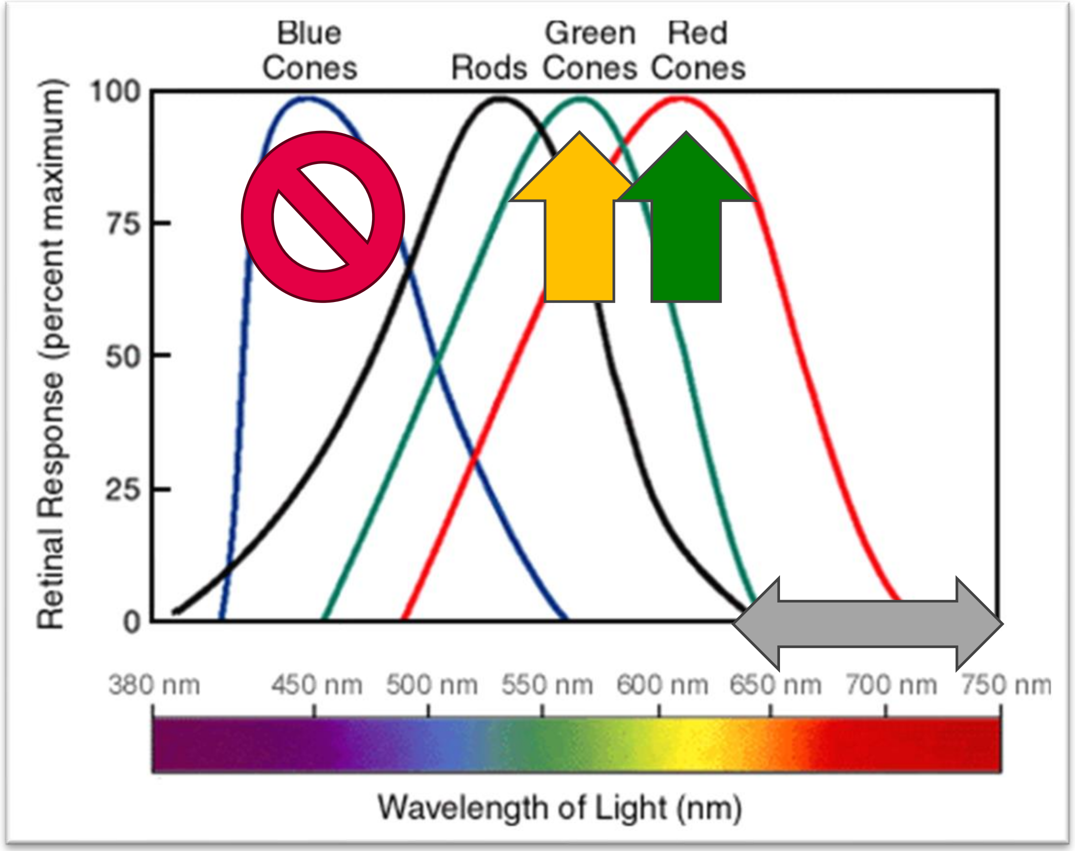


Human Vision - RGB





Which Cones are Activated?



Vision Problems

Reason: *Aging*, *genetics*, *injuries*

Examples: *Cataract*, *Glaucoma*

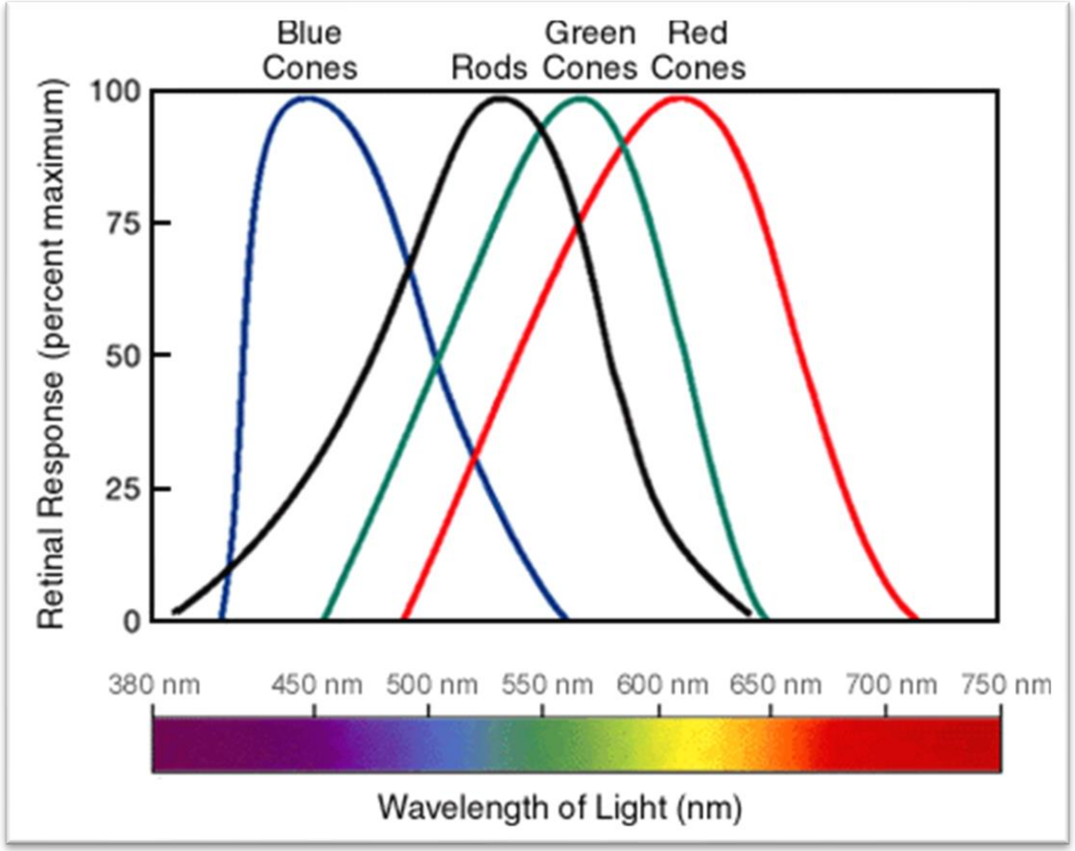
Cone-cells issues:

Protanomaly: L-Cones

Deuteranomaly: M-Cones

Tritan: S-Cones

Achromatopsia: grayscale vision



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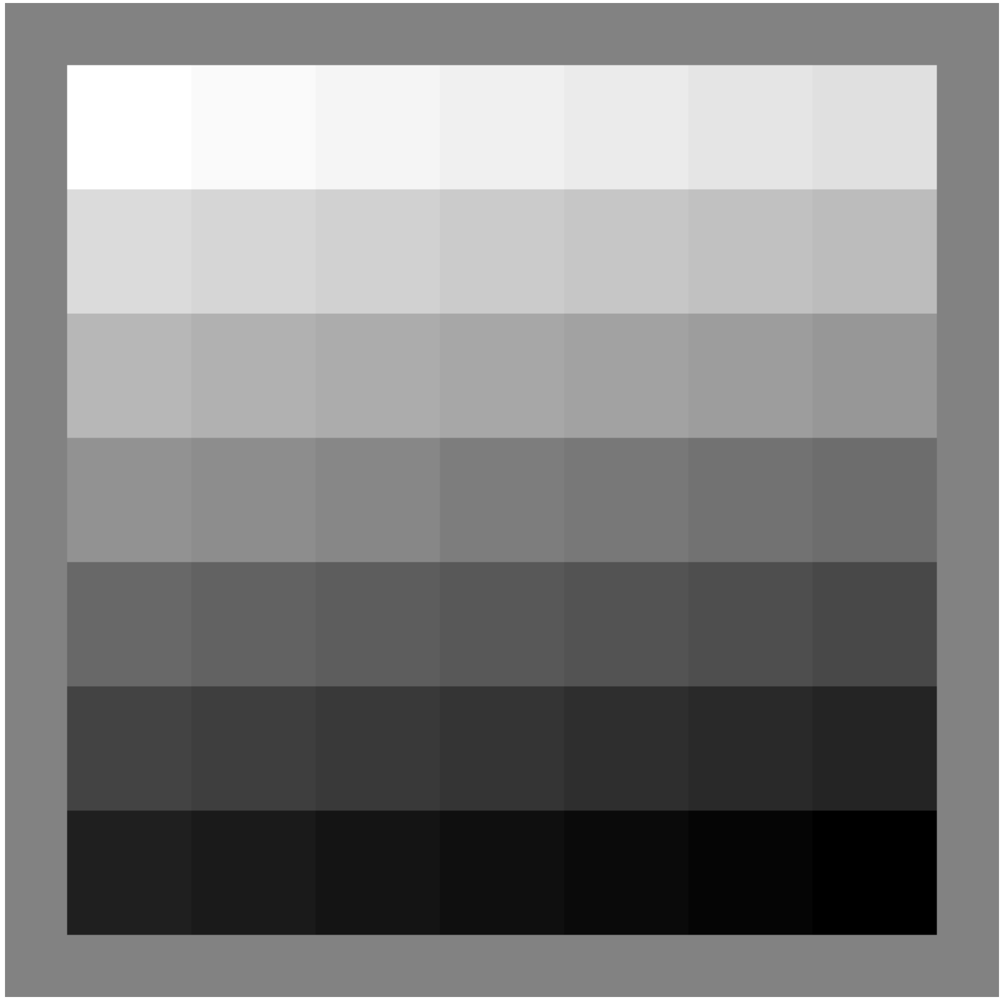
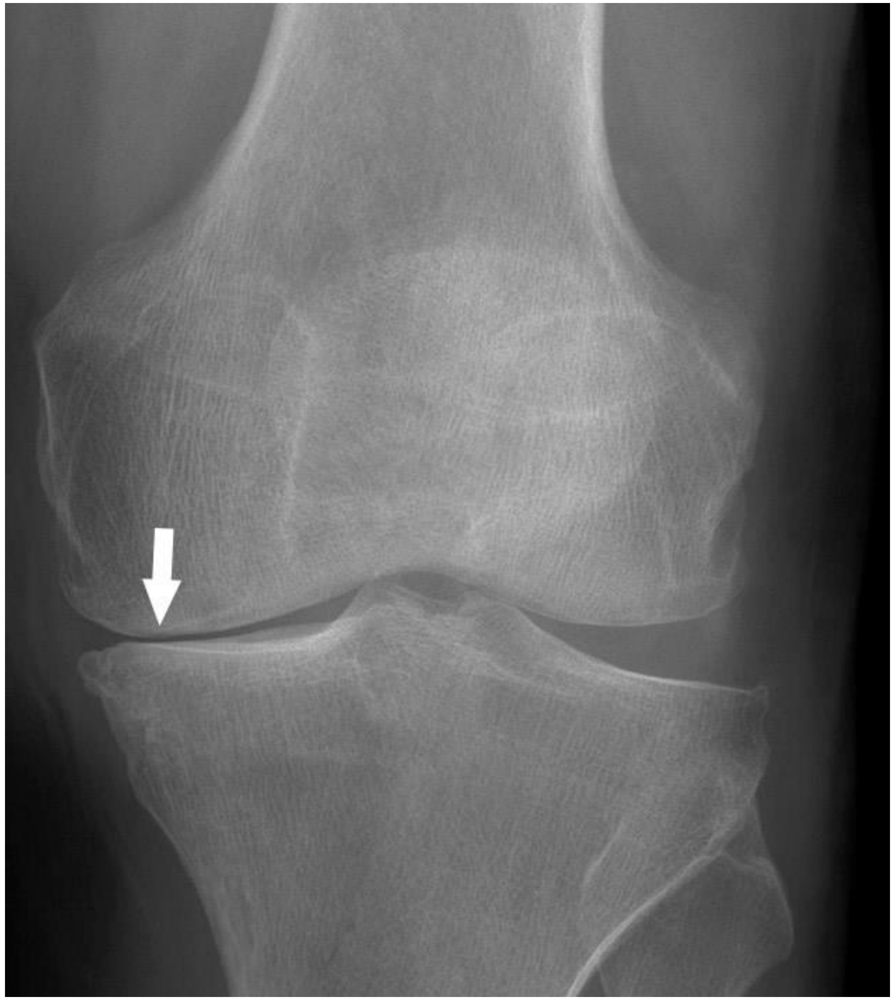
50 Shades of gray



Can you distinguish among all the pairs?

50 Shades of gray

Difficulty to distinguish among grayscale



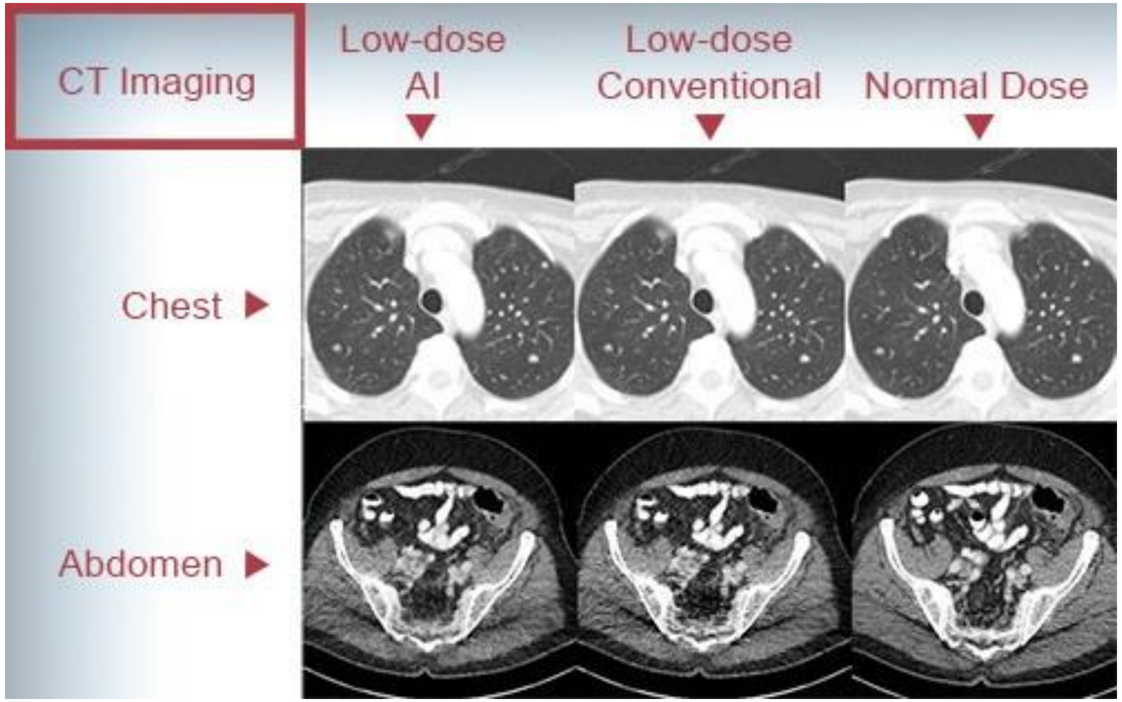
WHERE COULD AI HELP?

What would **YOU** solve with ML?

AI for Medical Imaging

Where can AI help?

- ✓ Early Diagnosis
  - Diseases detection on different modalities
  - Replace invasive tests
- ✓ Patient state monitoring
  - Treatment follow-up
- ✓ Enhancement
  - Convert low CT scans into high-dose ones
  - PET-Scan generation
  - Super-resolution (e.g., of ultrasound)
- ✓ Presurgical planning



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Medical Imaging is Challenging

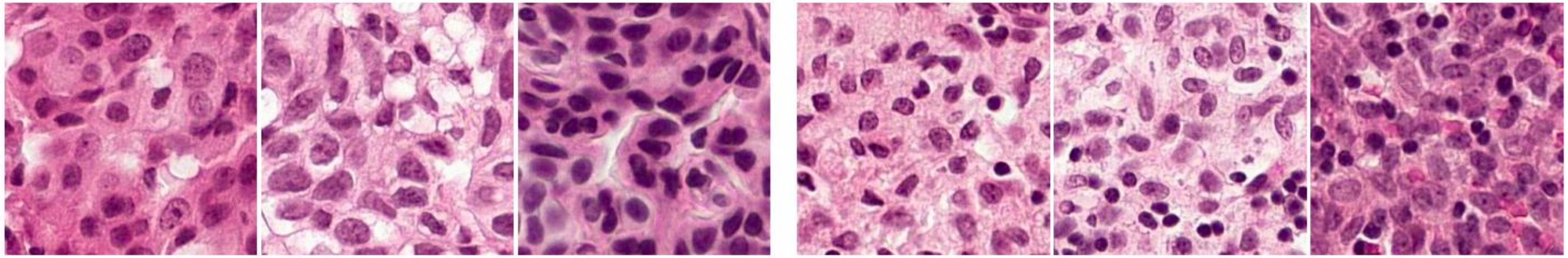
- **Collecting** medical images is difficult; done by experts
- **Labeling** of medical images is difficult; done by experts
  - ➔ Noisy labels
- Ownership and **privacy** issues
- Very limited national-level open datasets
- Limited Amount of Medical Data

Computer Vision		**Medical Imaging**	
	# images		# images
ImageNet	1.2M	Liver lesion detection (LiTS17)	130
SVHN	~600K	DRIVE	40
CIFAR10	60K	GlaS	165

Medical Imaging is Challenging

- Composed of unstructured data (Images and Text)
- Feature creation may require medical know-how
- Medical Images can be complicated to interpret

Could you tell which 3-group is **cancer** and which is **benign**?



AI for Medical Imaging

The Deep Learning Aspect

- Needs Big Data
  - Not enough available data for training

- Classical Methods
- Transfer learning
- Data Augmentation
  - Translation (skewing), rotation, flipping, scaling
  - Synthetic Augmentation: GAN (Generative Adversarial Network), Stable Diffusion

AI for Medical Imaging

CAD - Computer-Aided Detection

“CAD assistance reduced reading times by up to 44%”

ARTICLE IN PRESS

Original Investigation

Integration of Chest CT CAD into the Clinical Workflow and Impact on Radiologist Efficiency

Matthew Brown, PhD, Patrick Browning, MD, MA, MSL, M. Wasil Wahi-Anwar, BS, Mitchell Murphy, MS, BS, Jayson Delgado, BSc, Hayit Greenspan, PhD, Fereidoun Abtin, MD, MBBS, Shahnaz Ghahremani, MD, Nazanin Yaghmai, MD, BSs, Irene da Costa, MA, BA, Moshe Becker, BSc, MBA, Jonathan Goldin, MbChb, PhD, FRCR

Integration of Chest CT CAD into the Clinical Workflow and Impact on Radiologist Efficiency - PubMed (nih.gov)

AI for Medical Imaging

CAD - Computer-Aided Detection

More accurate earlier detection of cancer.

Example: Identifying high-risk breast cancer patients, 5 years in advance.

A Deep Learning Mammography-based Model for Improved Breast Cancer Risk Prediction | Radiology (rsna.org)

Toward robust mammography-based models for breast cancer risk | Science Translational Medicine

Take-aways

- Benefits:
    - Medical image processing can assist radiologists to analyze the image content quickly and more efficiently.
    - (VERY!) Early diagnosis
    - Help to save lives
- Challenges:
    - Different types of Imaging modalities (X-ray, CT, MRI, Microscopy, U.S.)
    - Same domain images have low variance
    - Lack of (good/correct) annotated data

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References

- Error and discrepancy in radiology: inevitable or avoidable?
- Medical Imaging Systems - A. Maier (Springer 2018) - Open Access
- Optical Coherence Tomography – Open Access