Politechnika Łódzka
Instytut Elektroniki

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Institute of Electronics

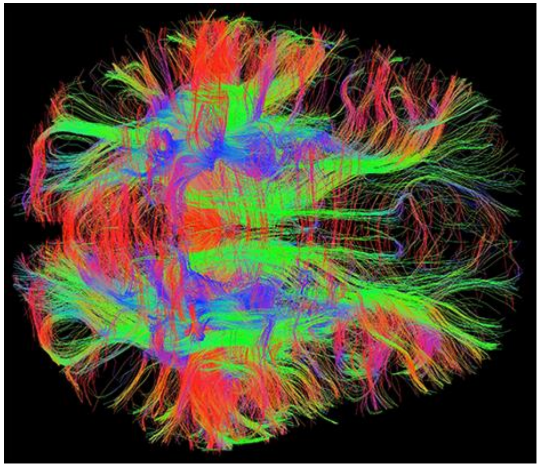
Medical Imaging

Introduction to Medical Imaging

Biomedical Engineering, 2023

Medical Imaging

- Introduction
- Image quality
- Imaging technology:
  - Radiography
  - Computed Tomography
  - Magnetic Resonance Imaging
  - Nuclear Medicine
  - Endoscopy
  - Thermography – prof. Marcin Janicki, DMCS
  - Ultrasonography
- Processing & analysis of medical images



Learning outcomes

- Written test

By the end of this subject student should be able to:

1. explain the basic principles of the major medical imaging techniques;
2. explain the mode of operation and medical applications of the major medical imaging techniques;
3. understand the advantages and disadvantages of the major imaging techniques, including potential hazards for patients;
4. define clinical applications of medical imaging modalities

5. make use of sample software (or implement simple algorithms) to display and process/analyse biomedical images.

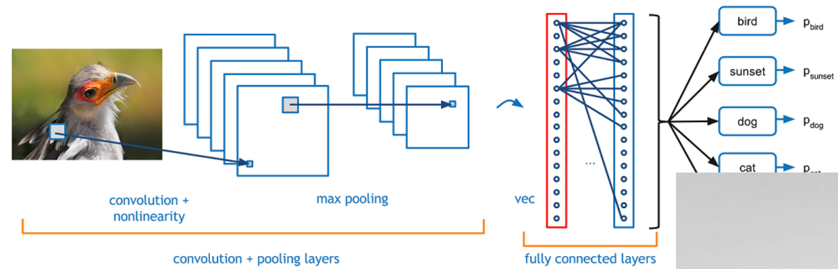
- Lab report

References

- Lecture notes (.pdf files)
- W. R. Hendee, E.R. Ritenour, Medical Imaging Physics, Wiley-Liss, 2002
- C. Guy, D. ffytche, An Introduction to The Principles of Medical Imaging, Imperial College Press, 2008
- R. Tadeusiewicz, J. Smietański, Pozyskiwanie obrazów medycznych oraz ich przetwarzanie, analiza, automatyczne rozpoznawanie i diagnostyczna interpretacja, Wydawnictwo Studenckiego Towarzystwa Naukowego, Kraków 2011 (PL)

Rewolution in medical diagnosis

- Advances in microelectronics and computer science (“imaging informatics”)
- Development of tissue imaging technology
- Qualitative diagnosis -> quantitative diagnosis
- “Evidence-based medicine”



Medical Diagnosis
- determination of the identity of a possible disease or disorder

medical diagnosis

consultation
(information obtained from the patient)

physical examination
(inspection, auscultation, measurements,…)

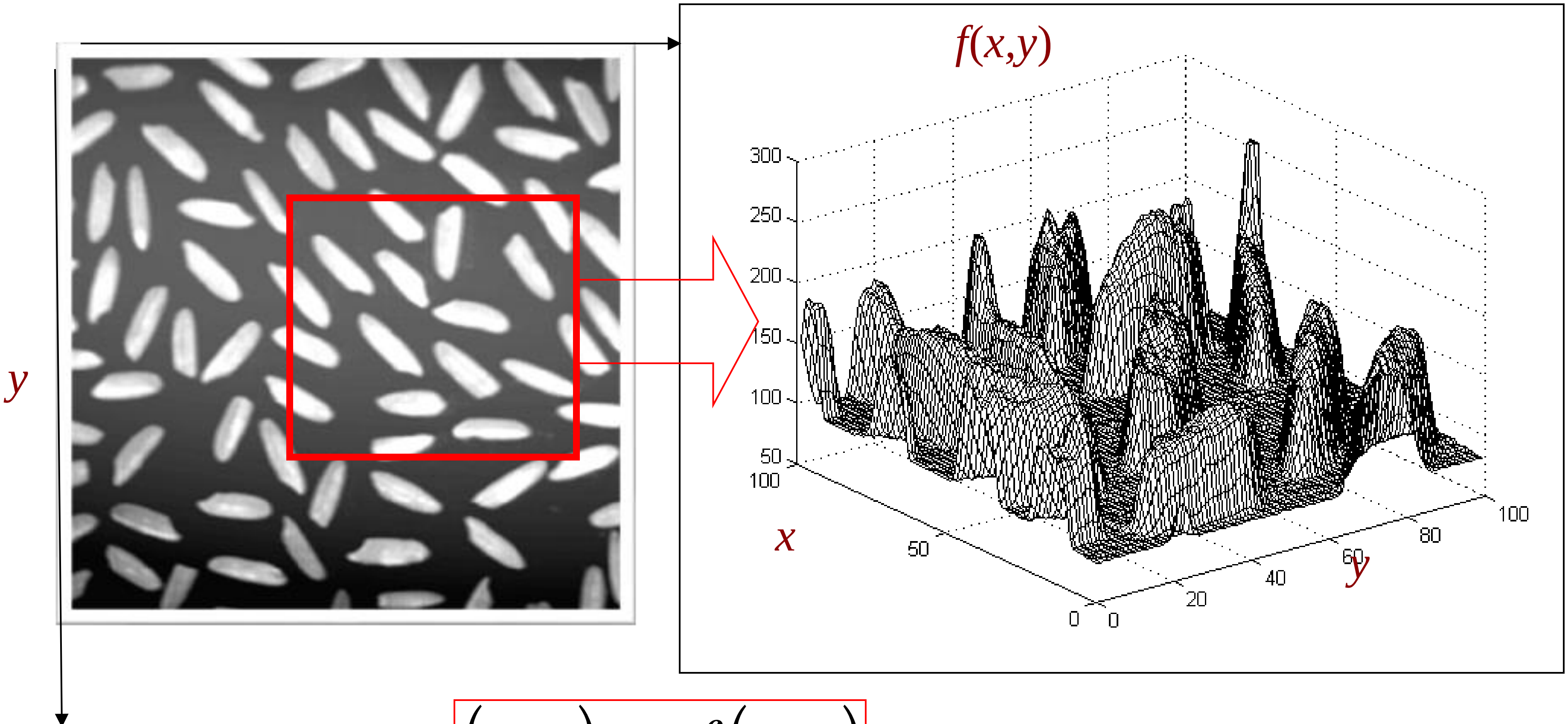
medical tests

laboratory analysis

biosignal analysis
(ECG, EEG, …)

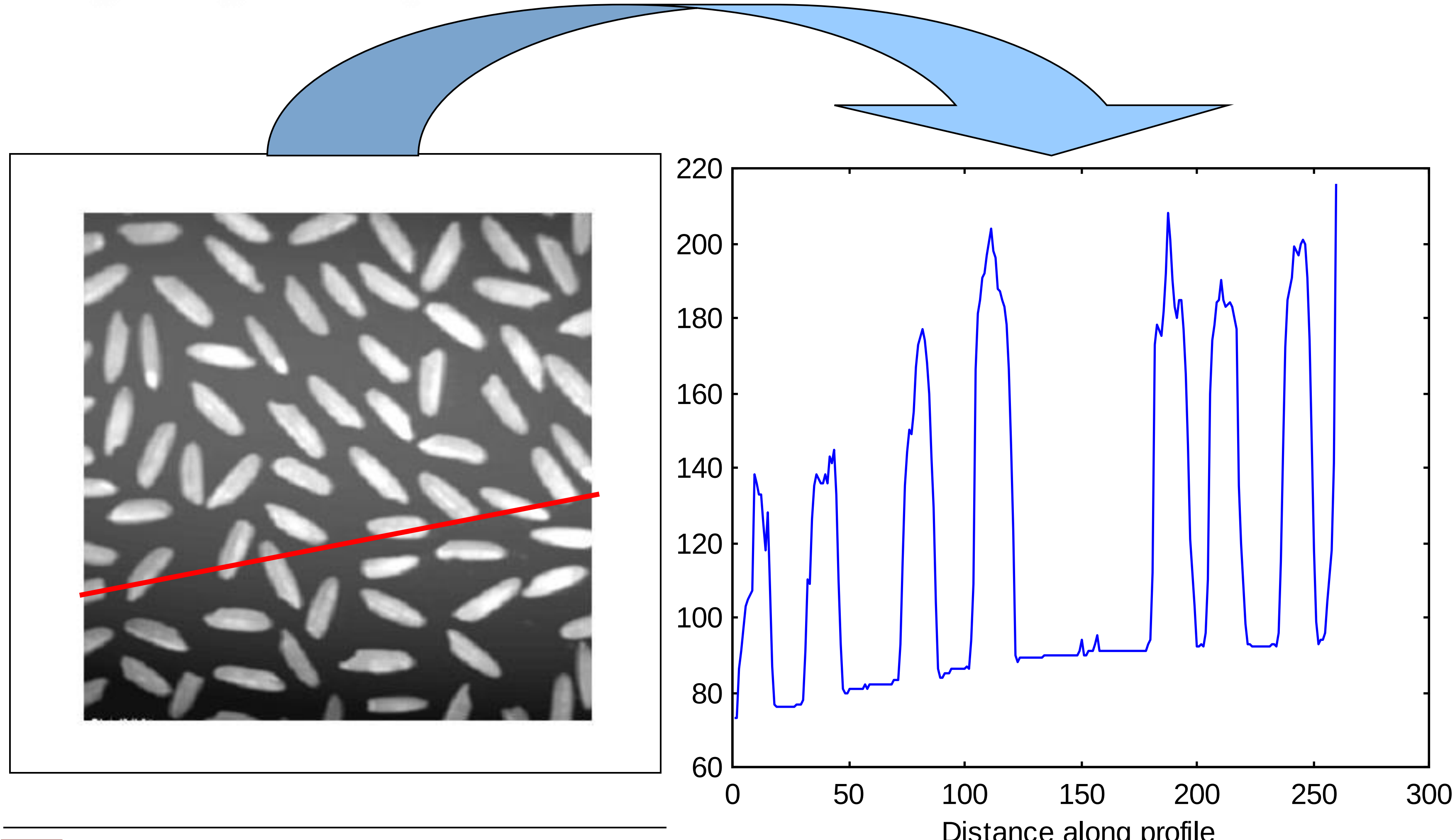
Image analysis

Monochrome image as a 2D function



$$\boxed{(x,y) \rightarrow f(x,y)}$$

Image brightness profile



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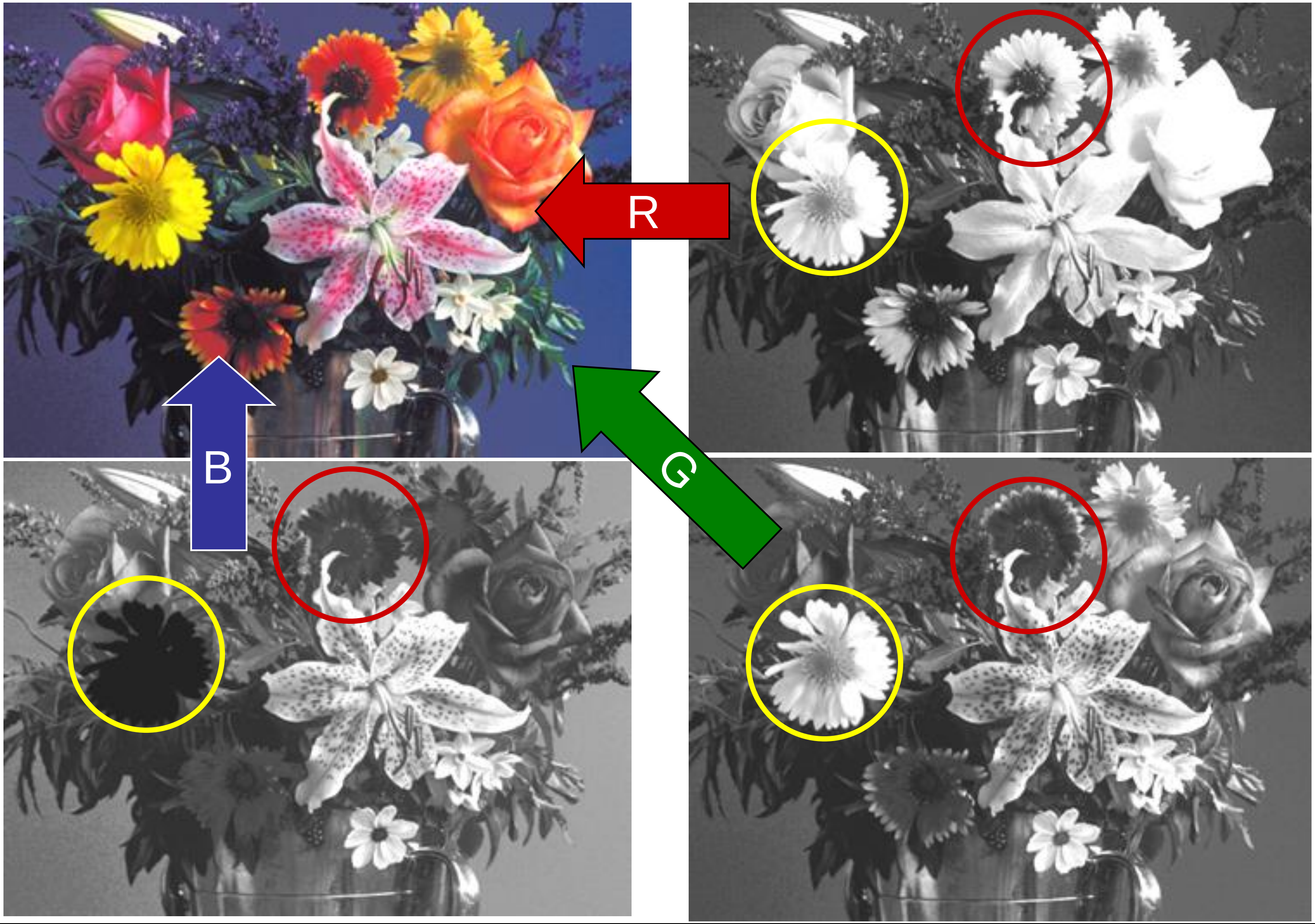
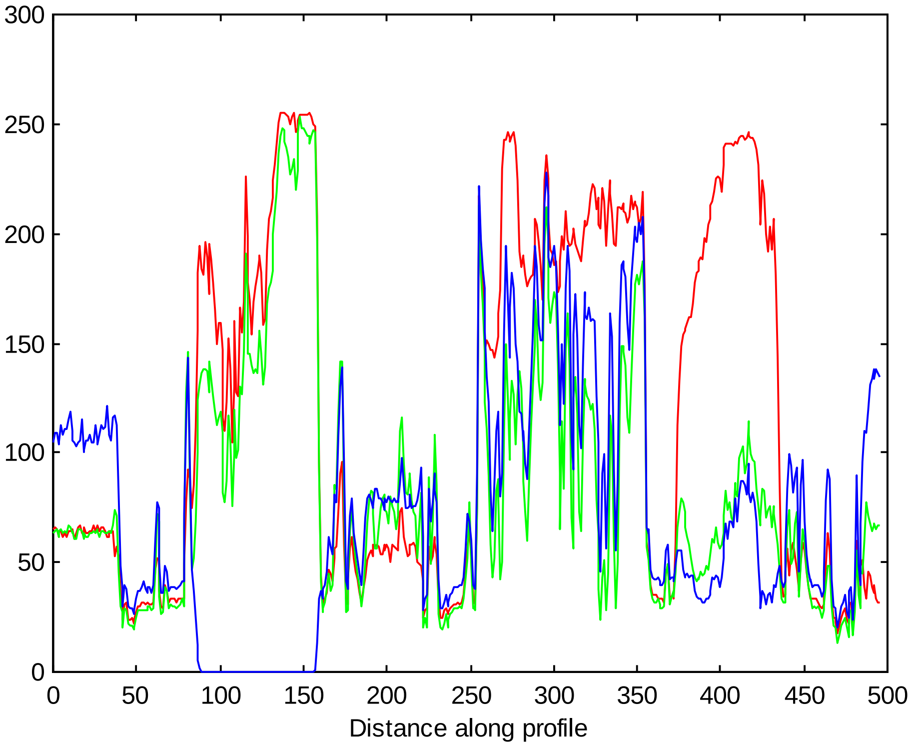
RGB color image

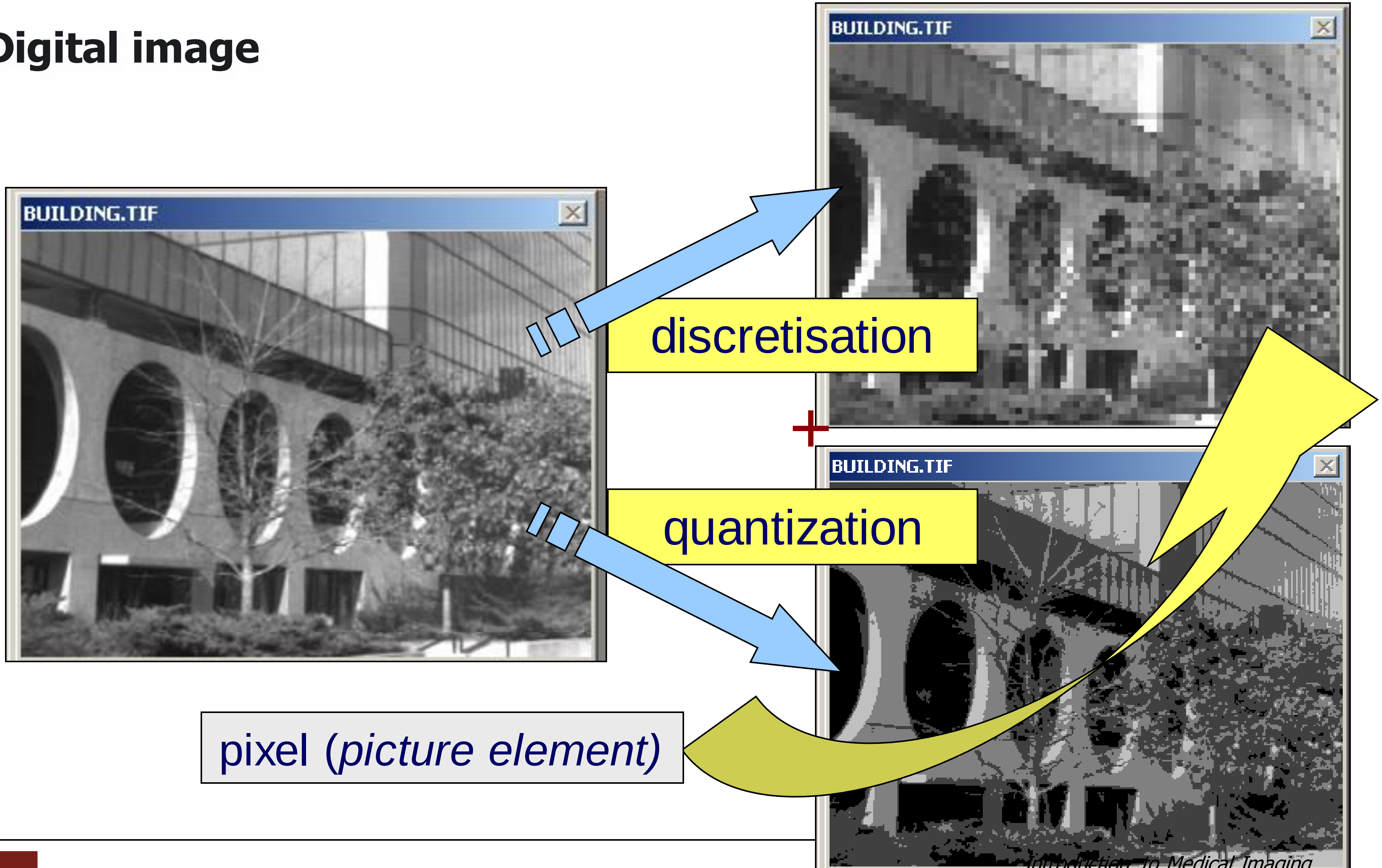


RGB color image color components profiles

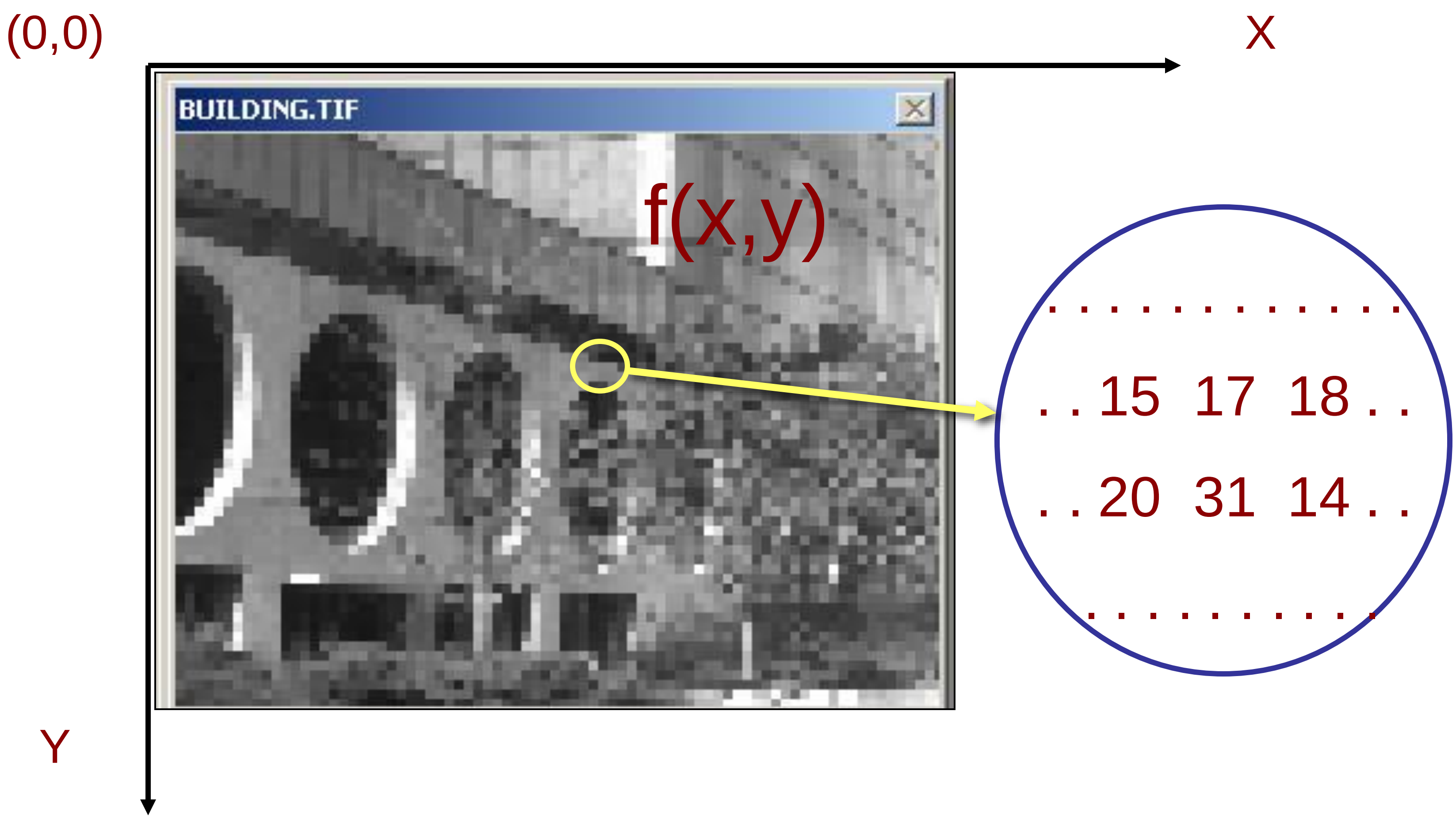


RGB image and colour components profiles

Digital image



Digital image as pixel array



Digital image as pixel array

Digital image $f(x,y)$:

2D array (M,N),
ie. of M rows and N columns,
of nonnegative elements assuming
a limited number of levels

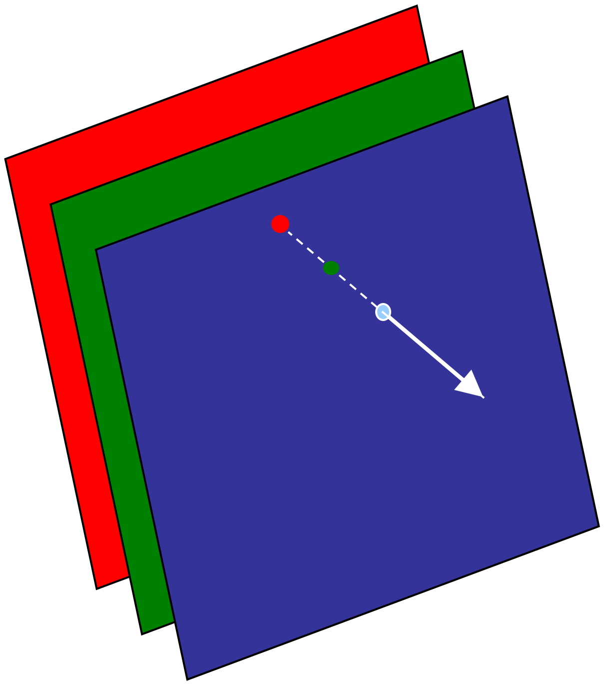
$$f(x,y) = 0,1,\ldots,L-1$$

(e.g. $L=256$)

$$x = 0,1,\ldots,N-1$$
$$y = 0,1,\ldots,M-1$$

Color digital image?

Color digital RGB image



If each of the color component is 8 bit coded then 2^{24} different colors can be obtained

$$\boldsymbol{f}(x,y)=(f_R, f_G, f_B)$$

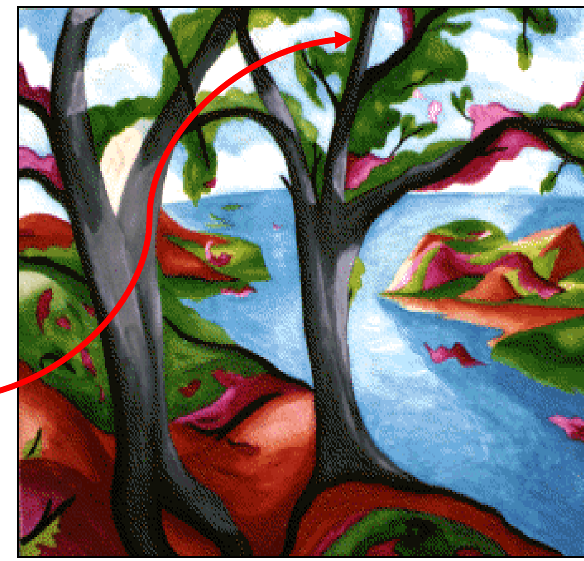
Color indexed image

f=25

Monochrome image

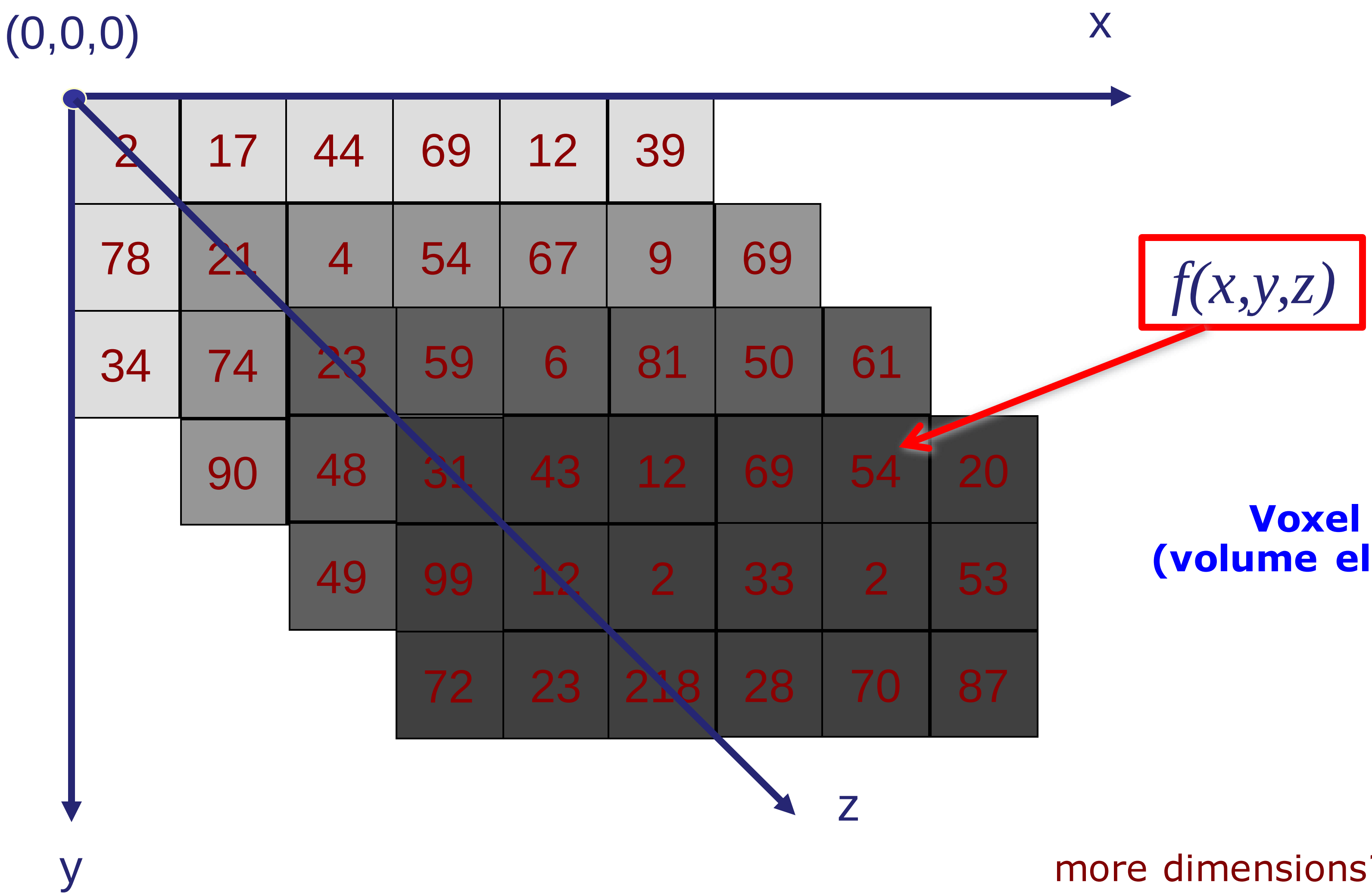
	R	G	B
0			
1			
2			
.			
.			
.			
	.	.	.
25	21	30	99
255			

Color palette
(look-up table)



Color image

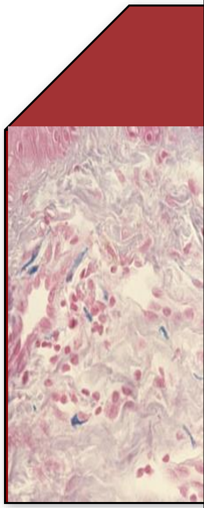
3D images

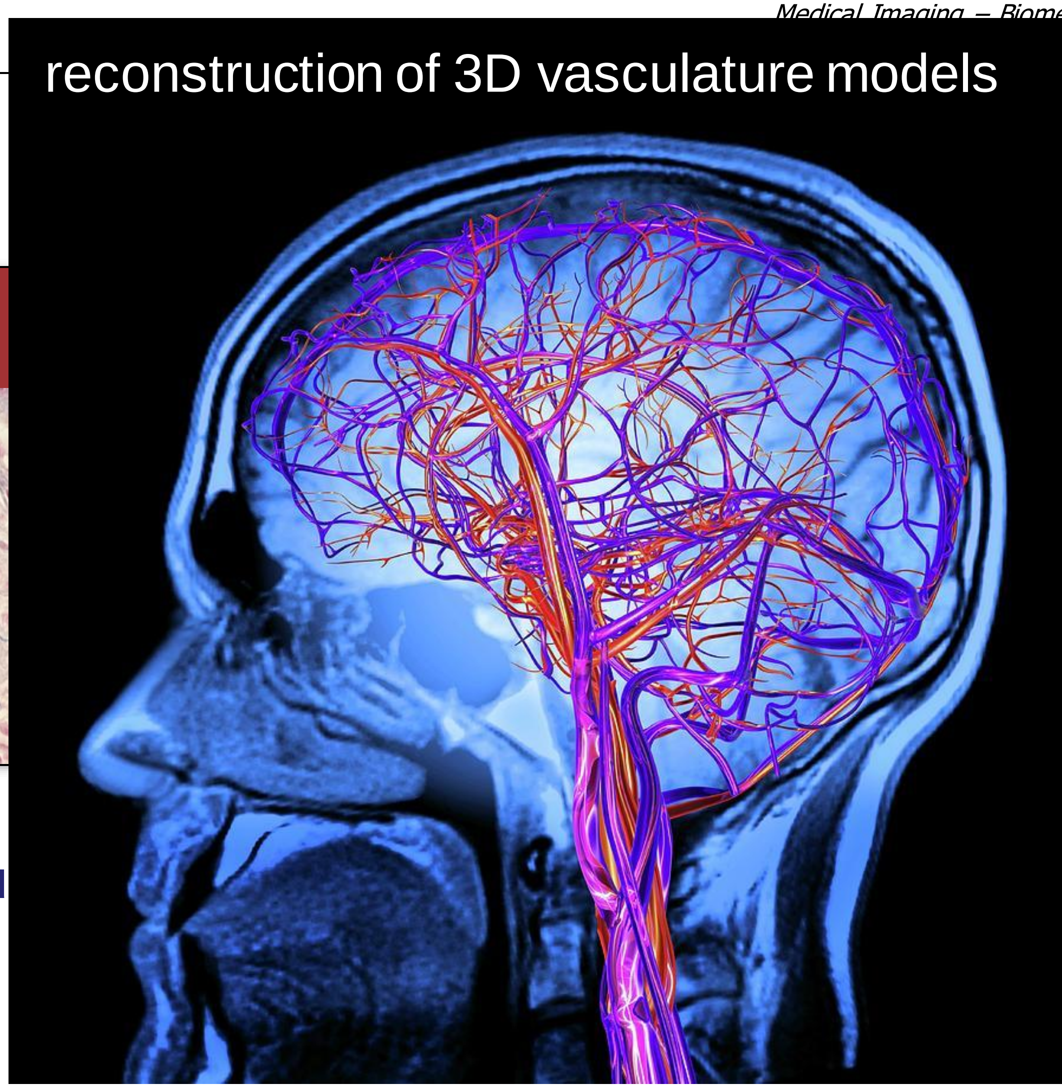


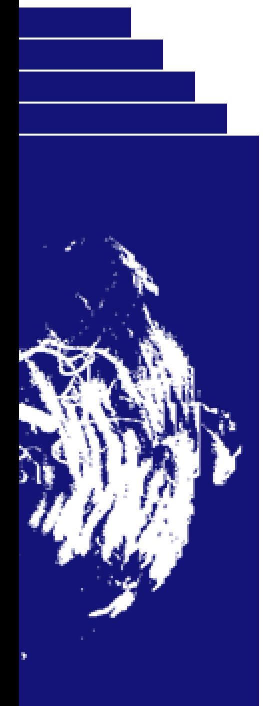
Voxel (volume element)

more dimensions?

3D images





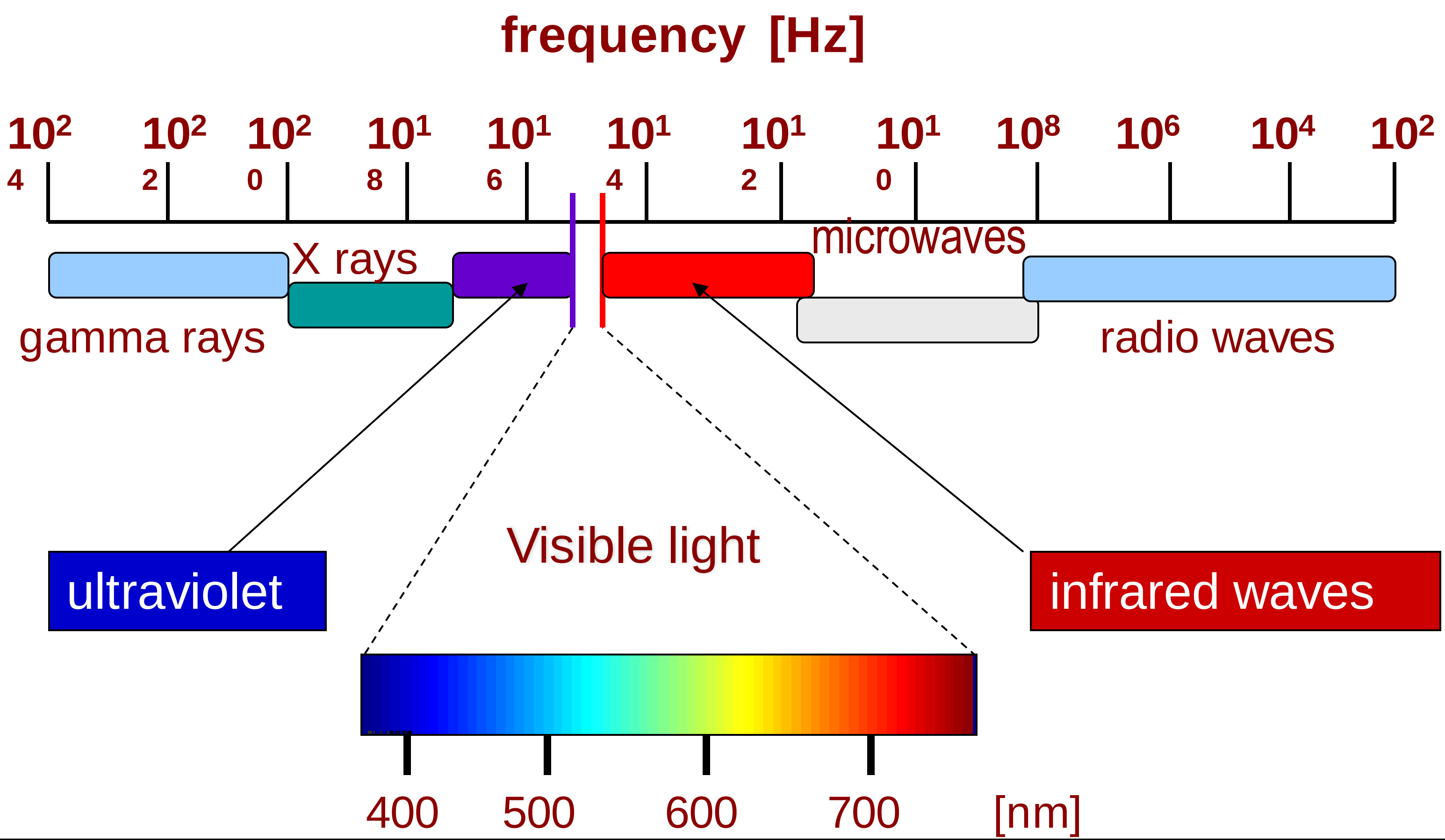


volu

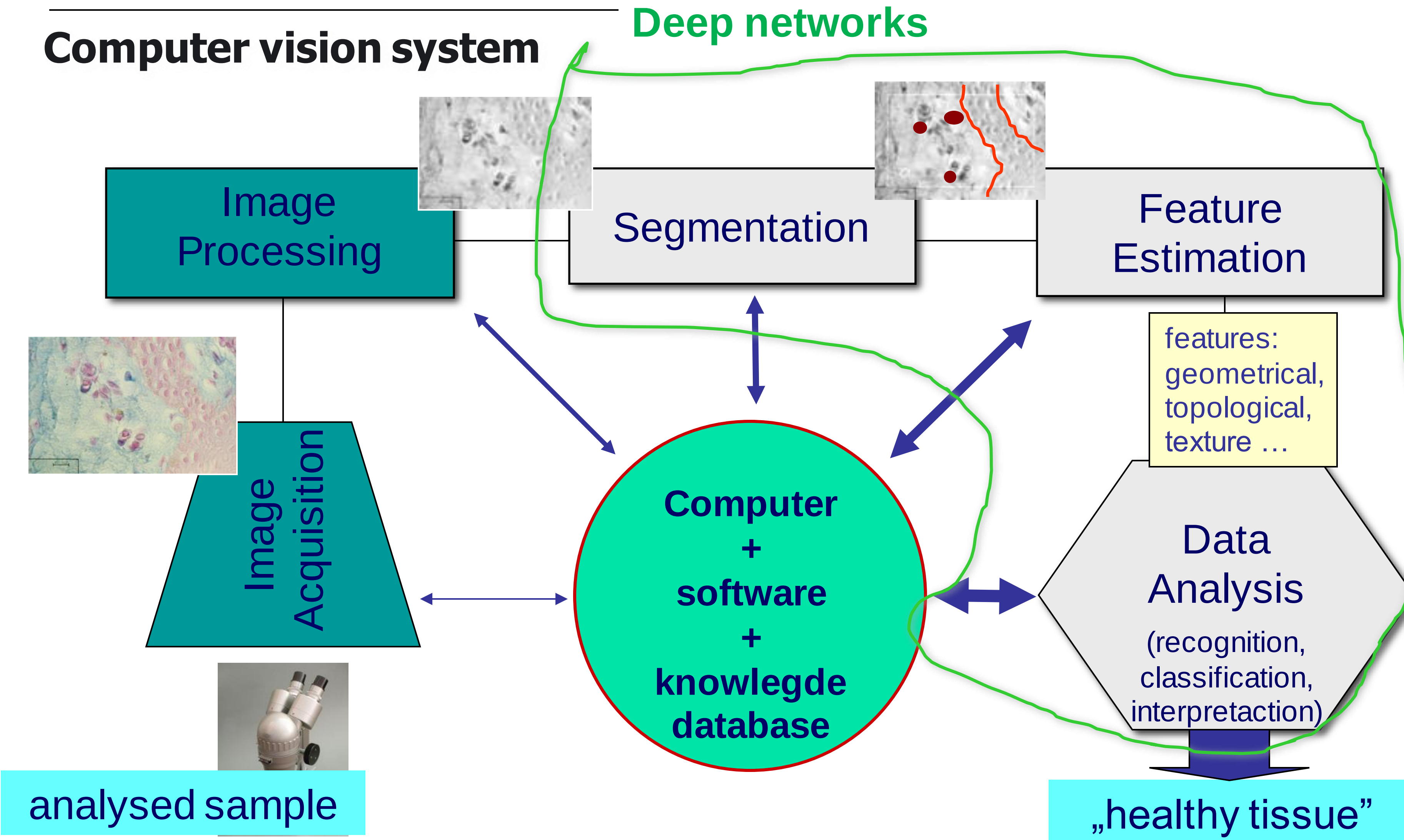
mages

nedical scanners)

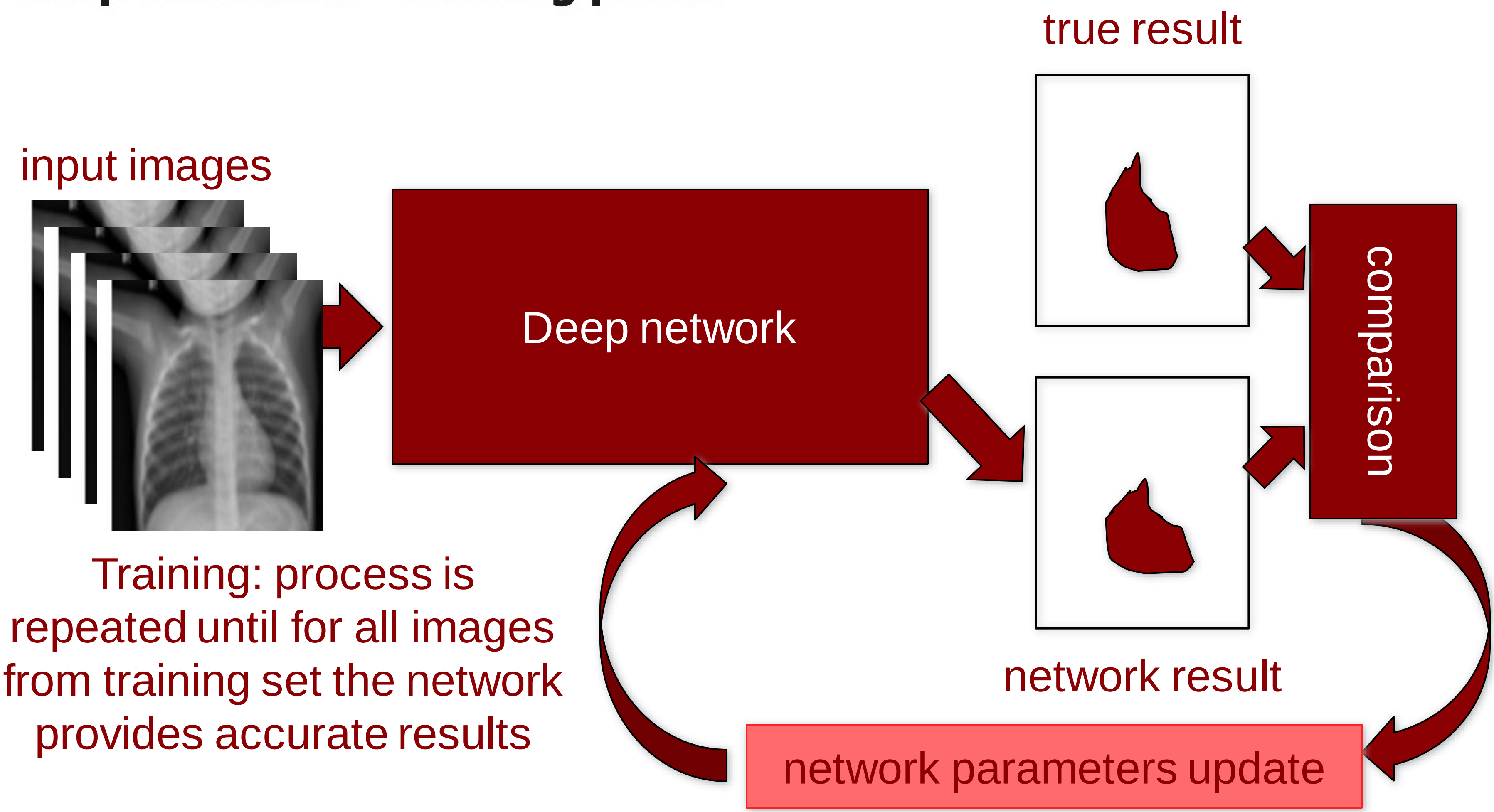
Electromagnetic spectrum



Computer vision system



Deep networks – training phase



Training: process is repeated until for all images from training set the network provides accurate results

Deep networks – testing phase

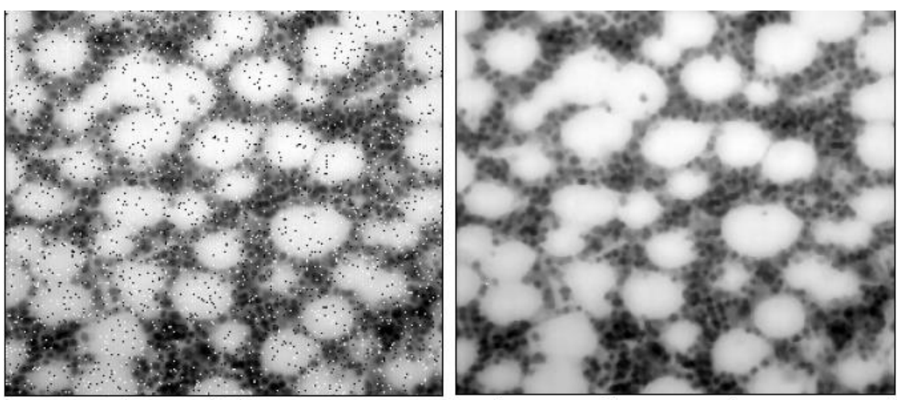
input image

testing: network analyses images not present in training set (generalization)

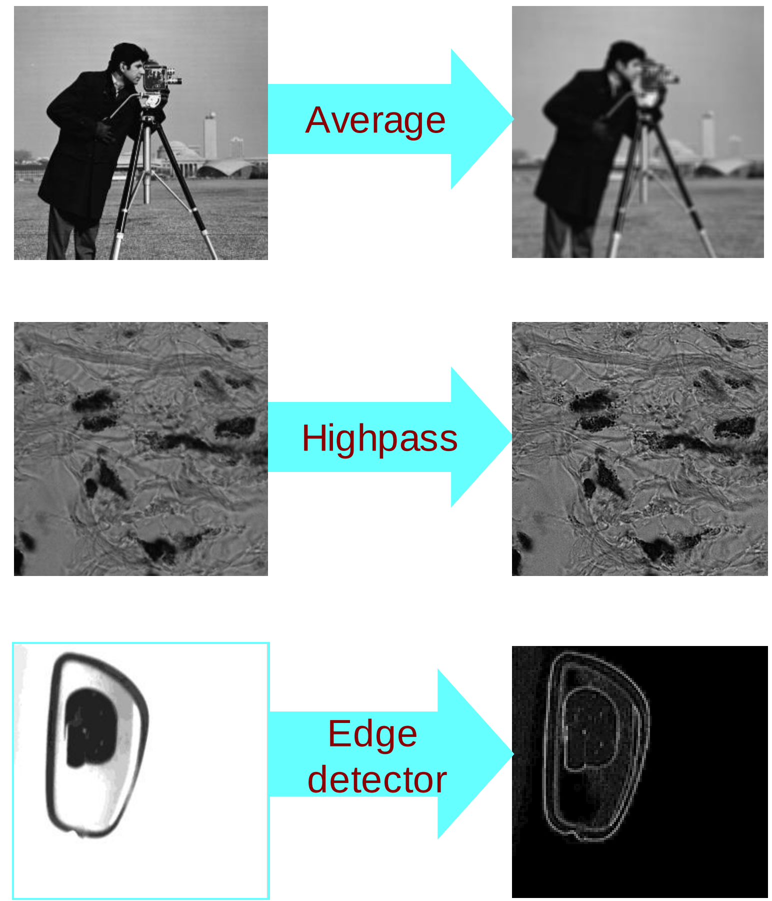
network result: segmented organ, detected disease or pathology, degree of changes

Image filtering in intensity domain

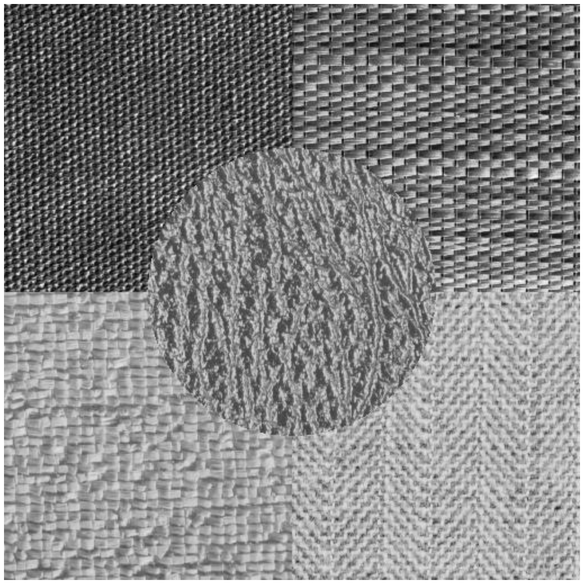
- Linear filters
  - „smoothing” (noise reduction)
  - „sharpening” (details enhancement)
  - Edge detectors
- Nonlinear filters
  - -- rank filtering (median)



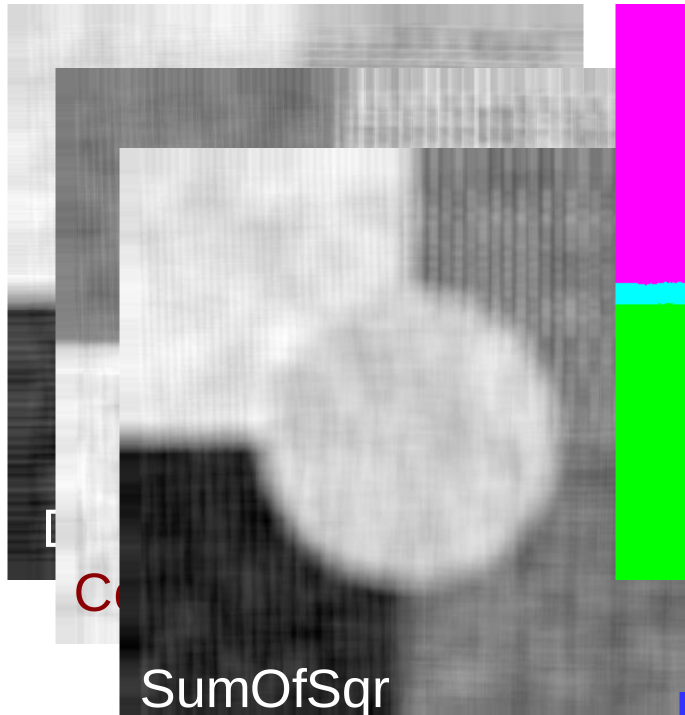
distorted image after median filtration



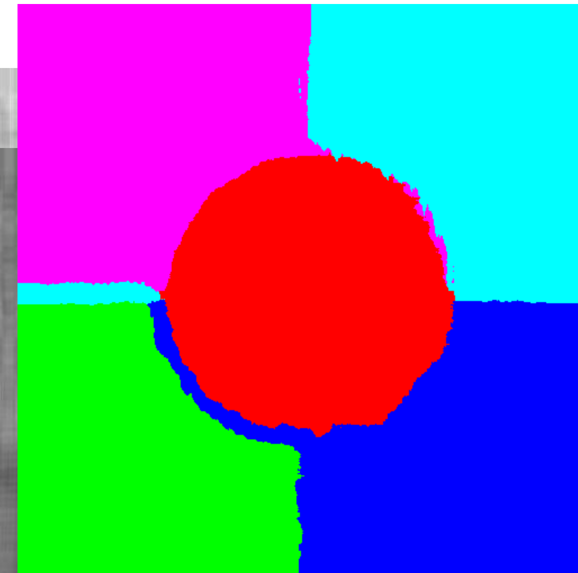
Segmentation of Brodatz textures



statistical features

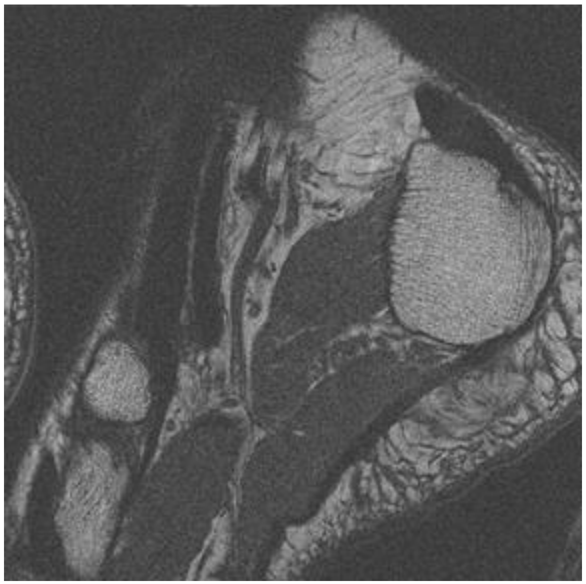


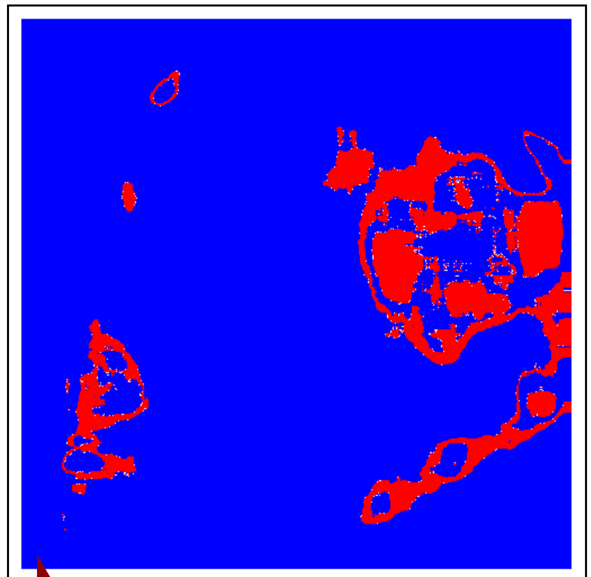
feature maps

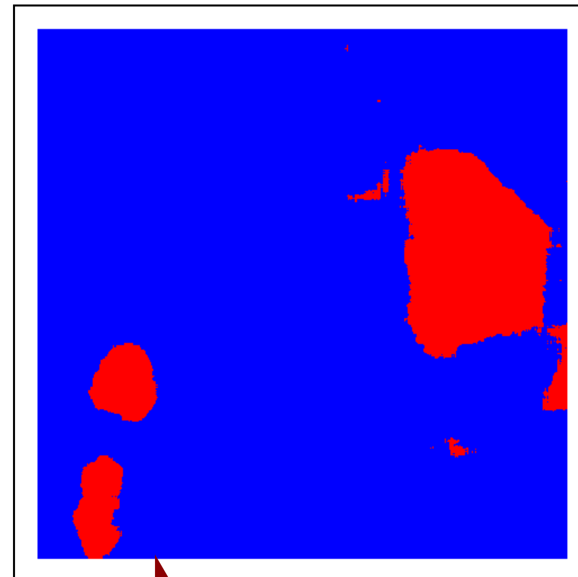


k-means segmentation results

Segmentation of MR foot image





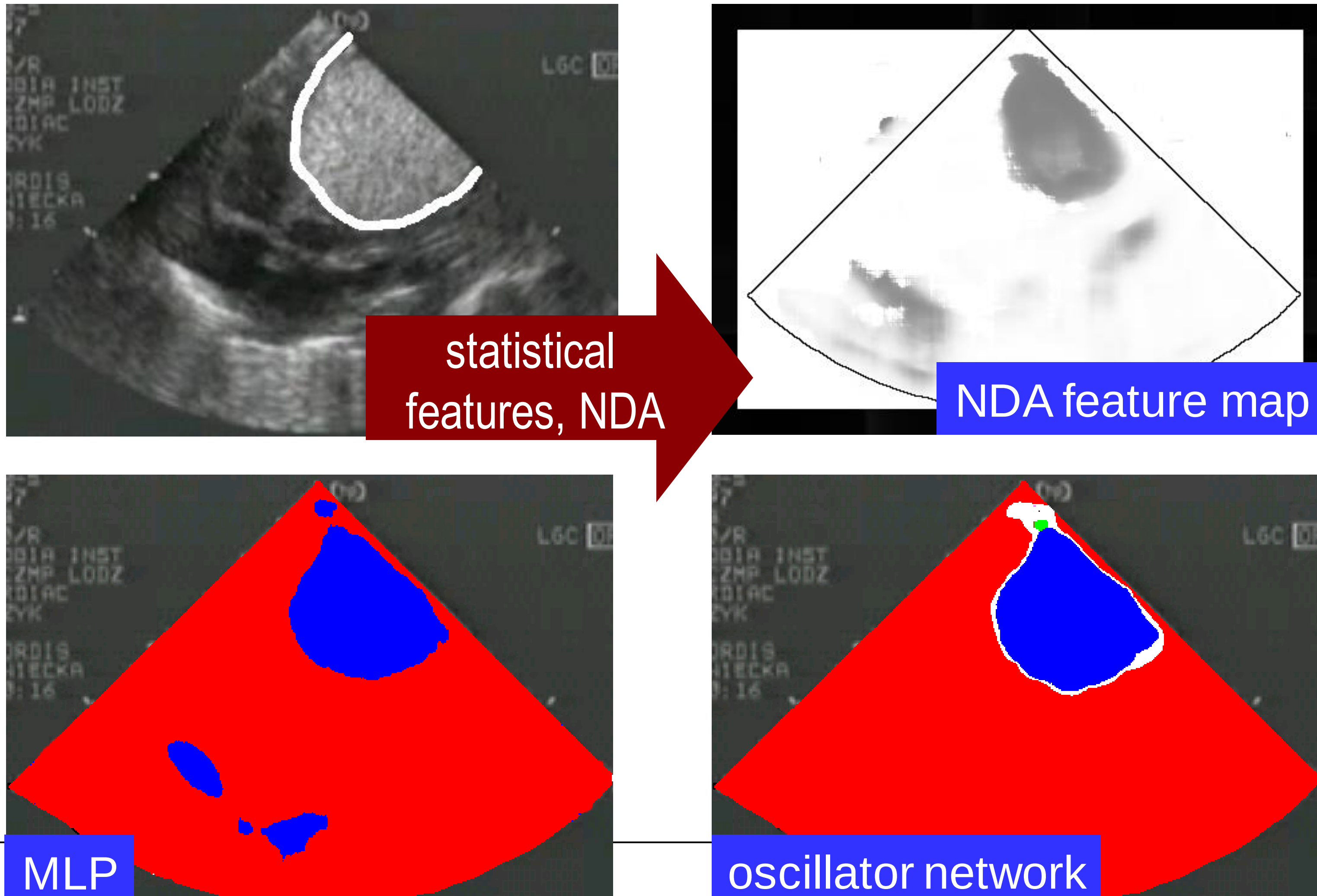


statistical features

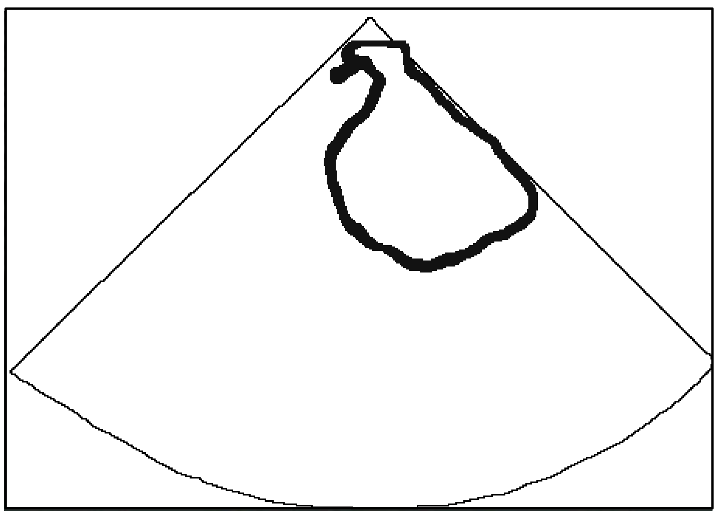
GMRF model parameters

multilayer perceptron (MLP)

Segmentation of heart mass echocardiogram

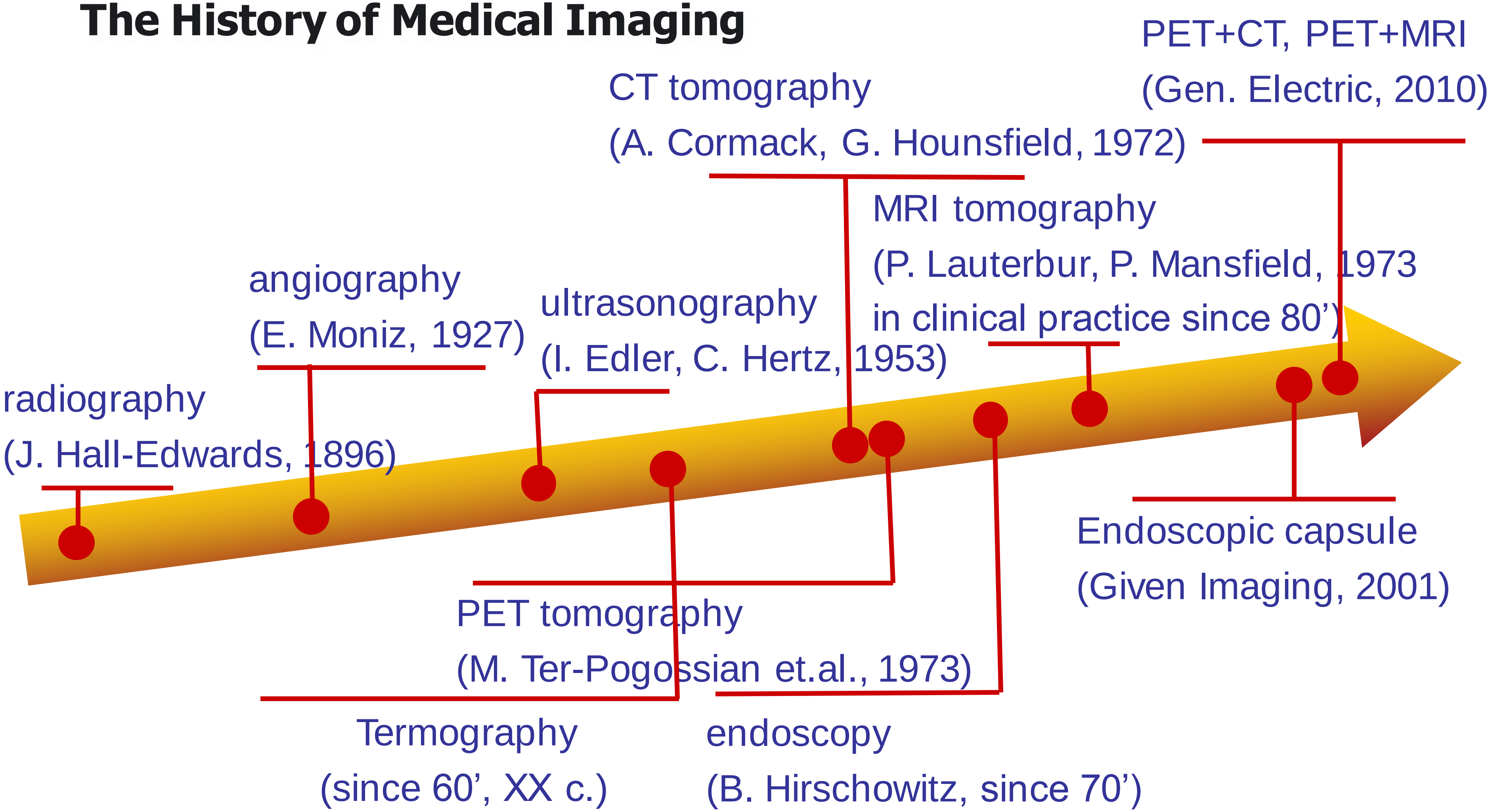


Segmentation based on edge detection

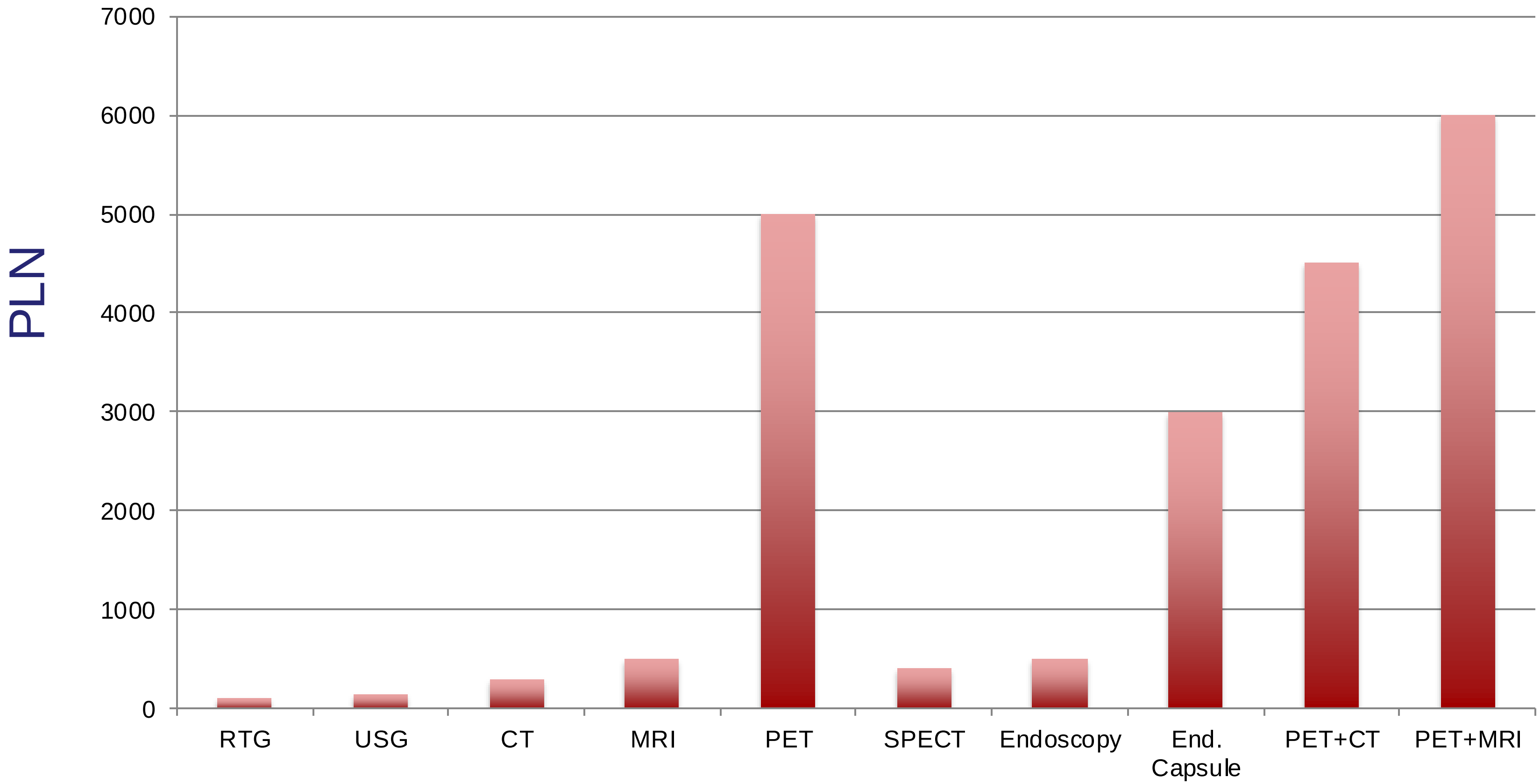


oscillator network

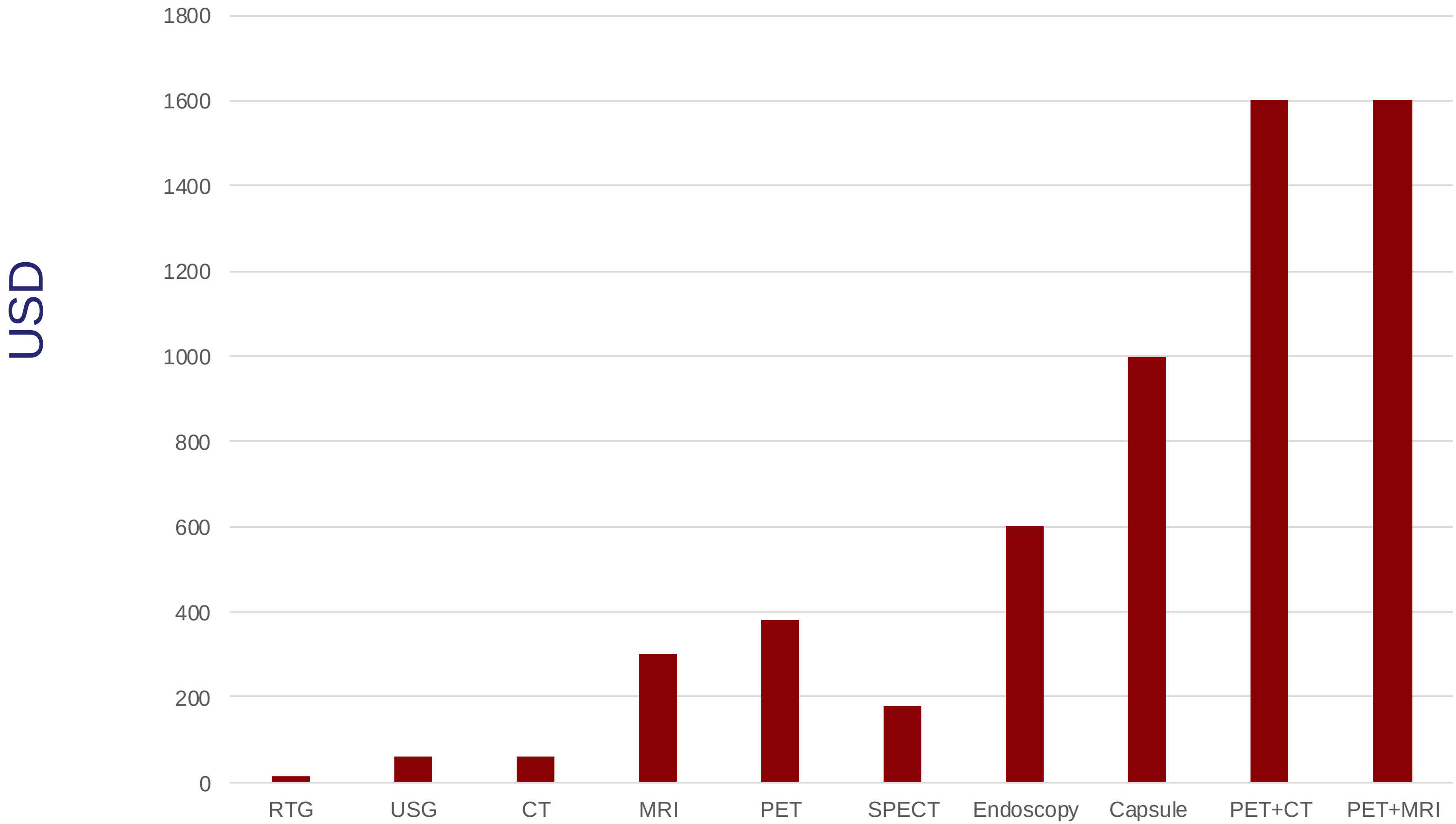
The History of Medical Imaging



Examination costs (Poland)

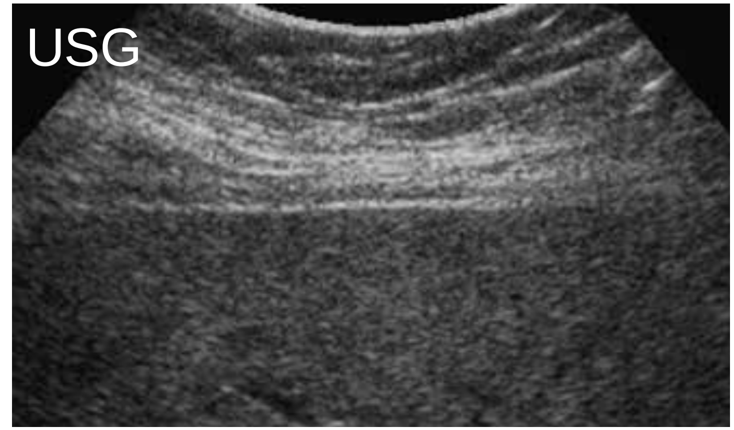


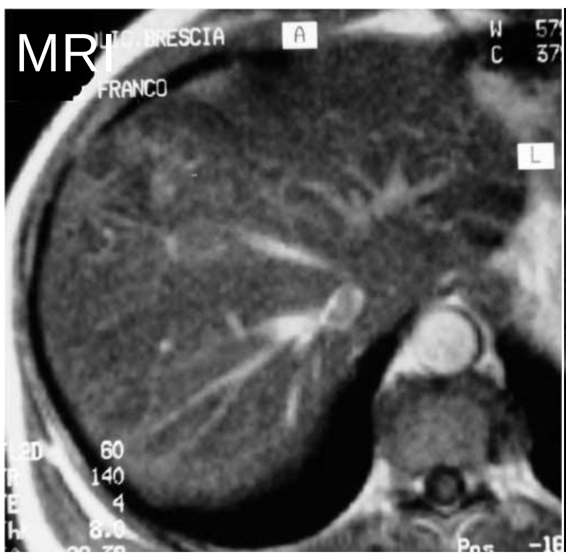
Examination costs (US)

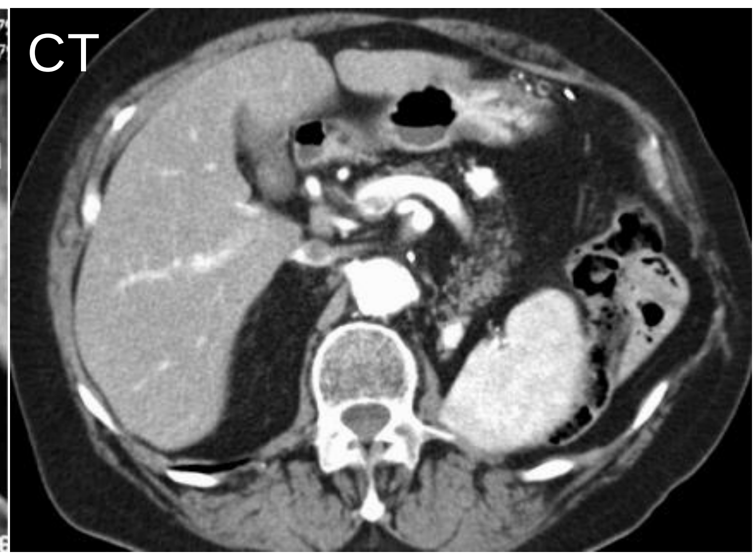


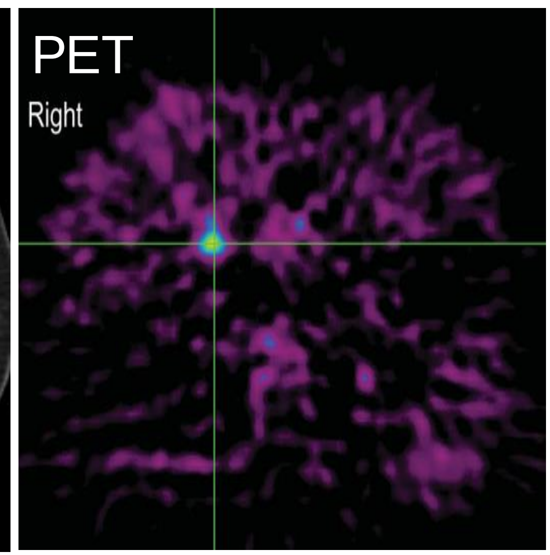
Why so many imaging modalities?

- Sonography (53%-77% lesions)
- CT (l. vasculature gold standard)
- MRI (91% benign – malignant discrimination)
- PET (highest sensitivity in tumor detection)



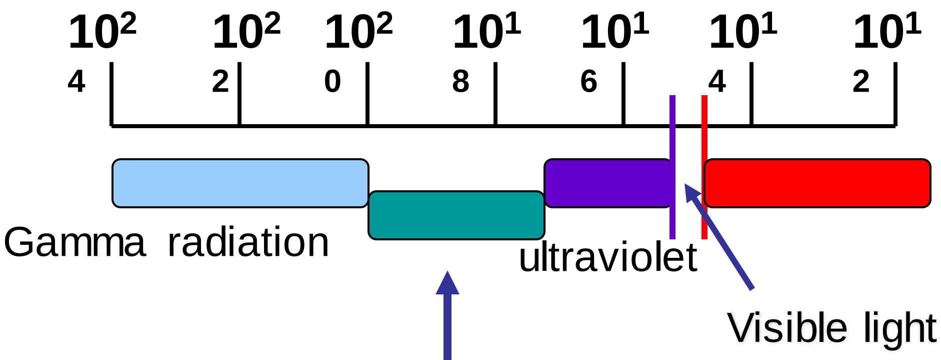






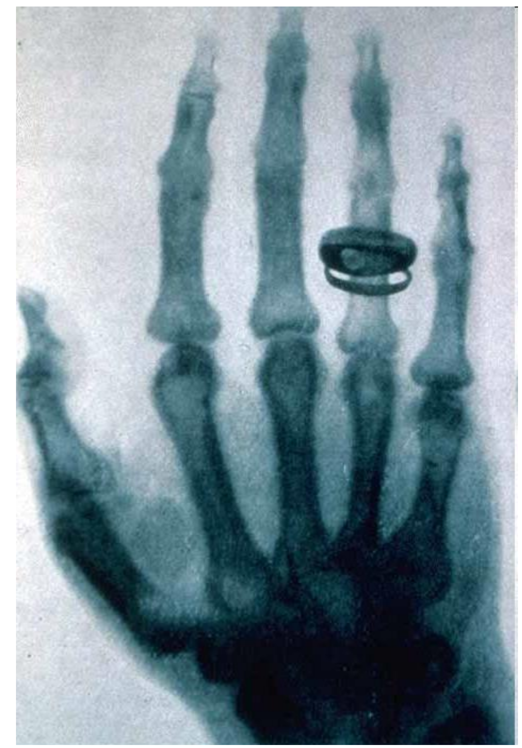
Radiography

Roentgen radiation (X-ray radiation), discovered and described by Wilhelm Röntgen in 1895, Nobel prize in physics in 1901.



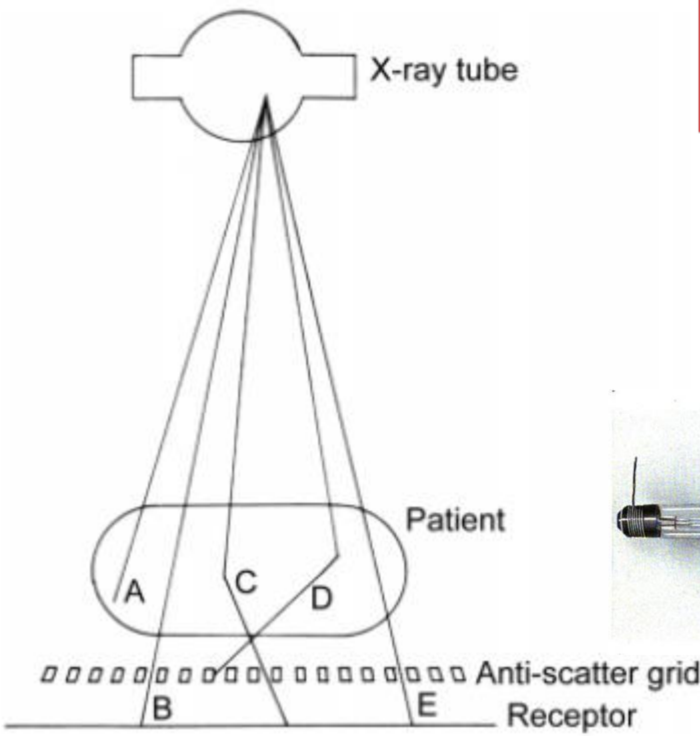
X-rays

5pm-100pm (hard)
100pm-10nm (soft)

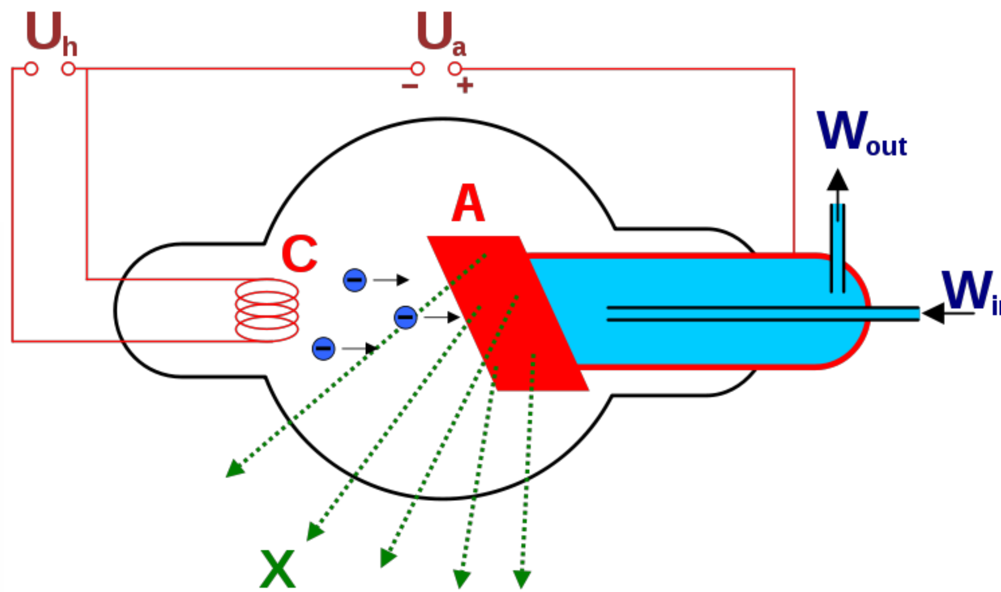


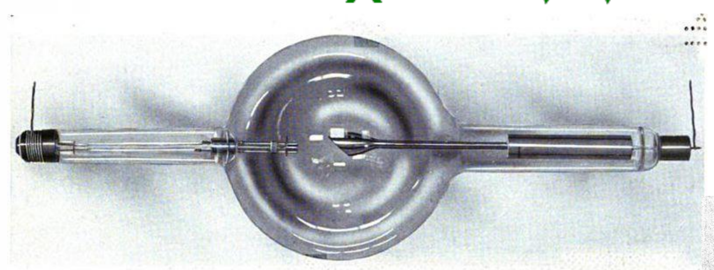
Ms. Röntgen hand x-ray

X-ray devices

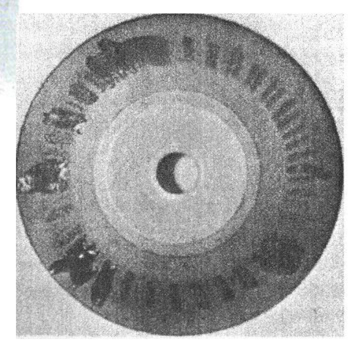


resulting image is a projection





tungsten anode



Radiography

- film images,
- digital images,
- invasive examination,
- limited quality,
- low equipment price, mobility

Radiography

Applications:

orthopedics

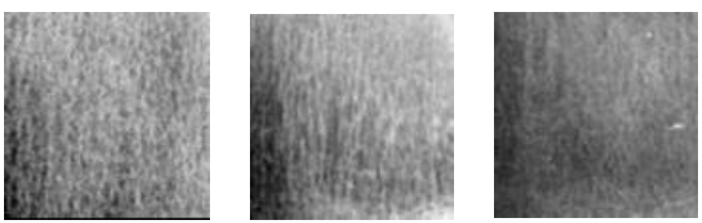
pulmunology

dentistry

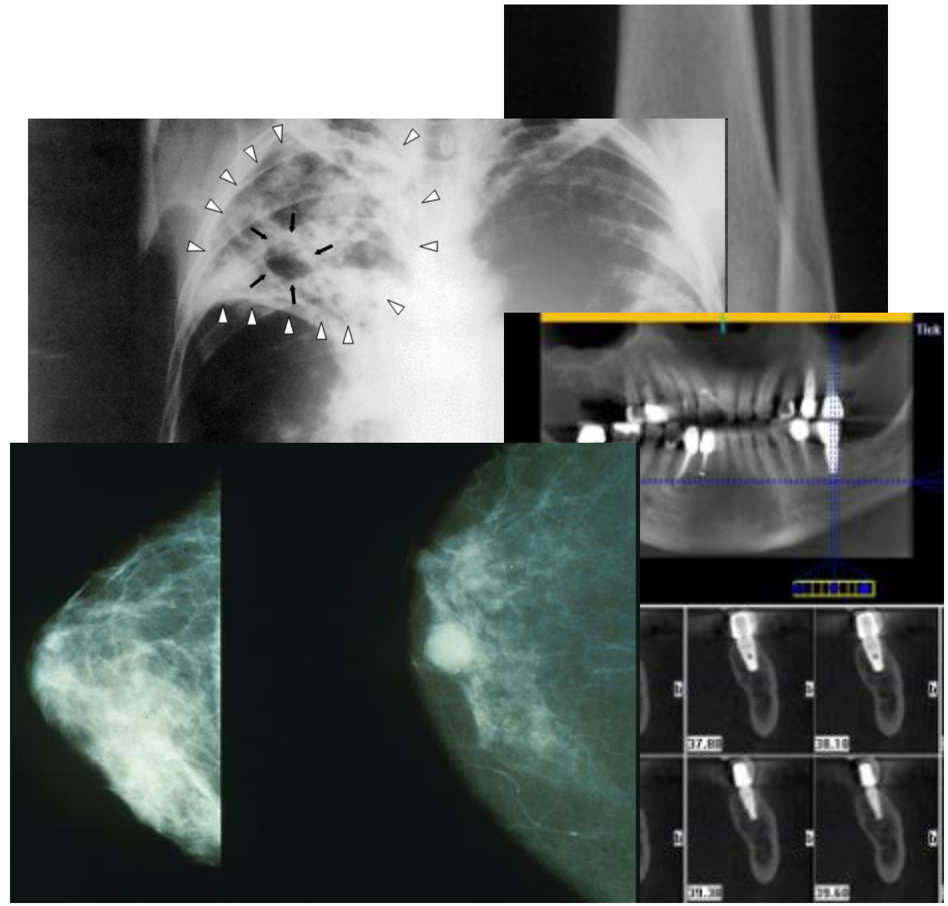
Diagnosis:

breast cancer (mammography)

osteoporosis

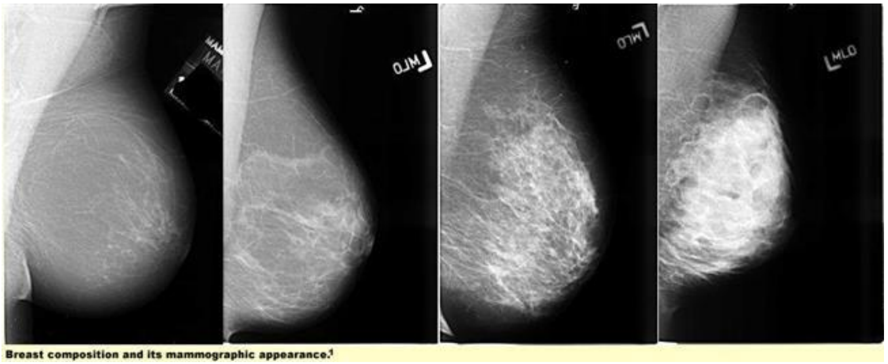


dr Piotr Cichy



www.kavo.pl, Gendex

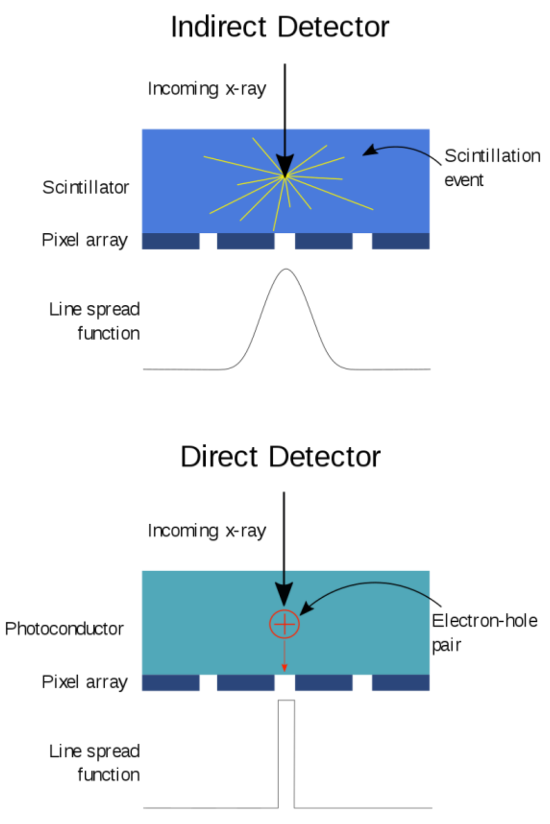
Digital Breast Tomosynthesis



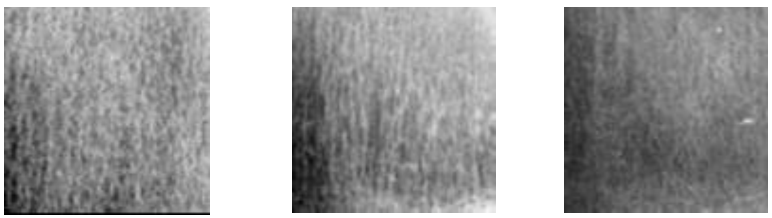
mammography

DBT

Fluoroscopy – ra sequence of X-ray images



Analysis of wrist radiograms

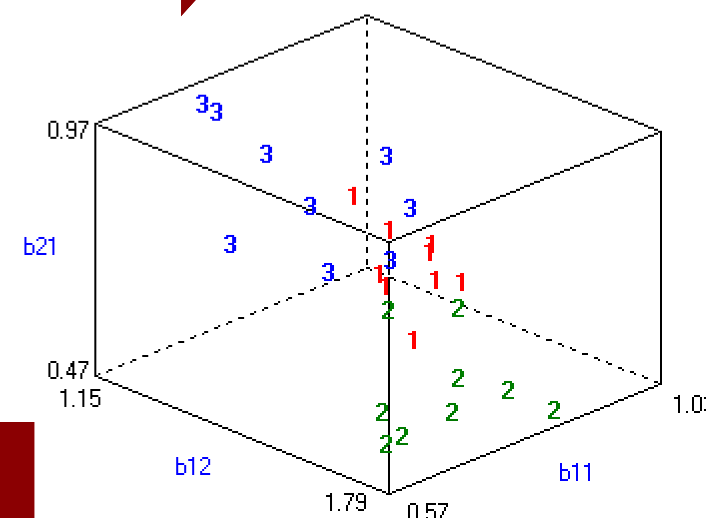


Control (1)

Osteopenia (2)

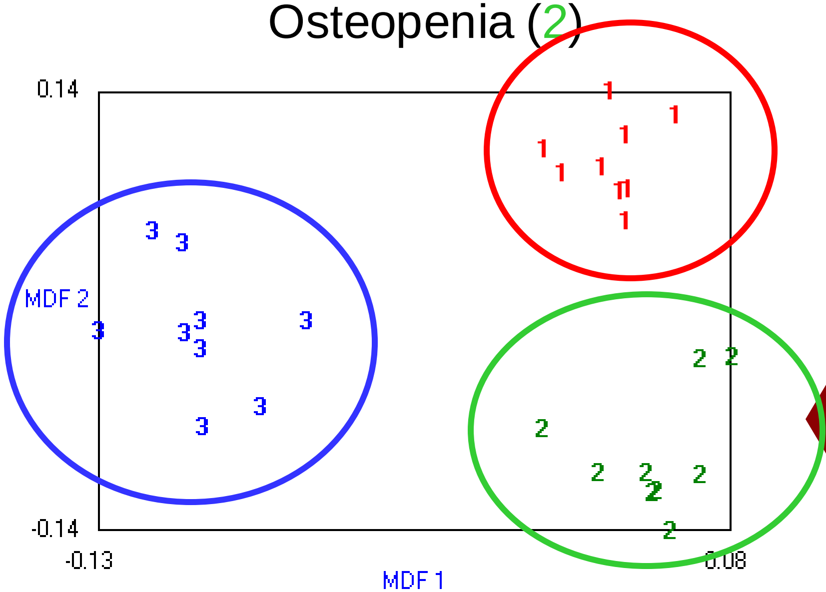
Osteoporosis (3)

Markov Random Field model



Classsifcation error: 9%

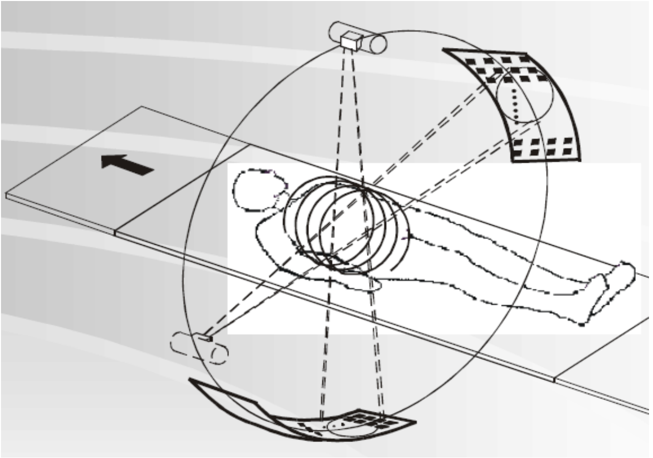
Liniear Discriminant Analysis



Classification error: 0%

Computed Tomography (CT)

- cross-section images (not a projections)
- not applicable for soft tissues,
- very good image quality,
- invasive examination,
- high equipment price



biomech.pwr.wroc.pl/
konferencja/Cierniak.pdf

Hounsfielda units

The Hounsfield units scale is a linear transformation of the measurement of the linear X-ray attenuation coefficient in which the radiological density of distilled water at standard temperature and pressure (0°C, 1000 hPa) is defined as zero Hounsfield units (HU), while air density under standard conditions is defined as - 1000 HU. [https://pl.wikipedia.org/wiki/Skala_Hounsfielda]

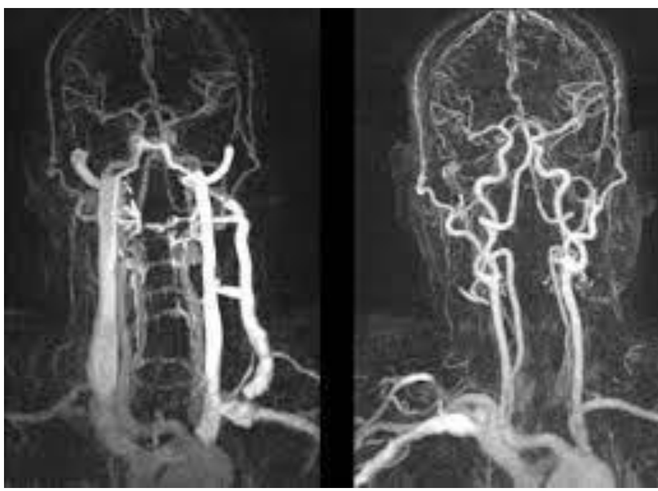
$$HU = \frac{\mu_X - \mu_{H_2O}}{\mu_{H_2O} - \mu_{air}} 1000$$

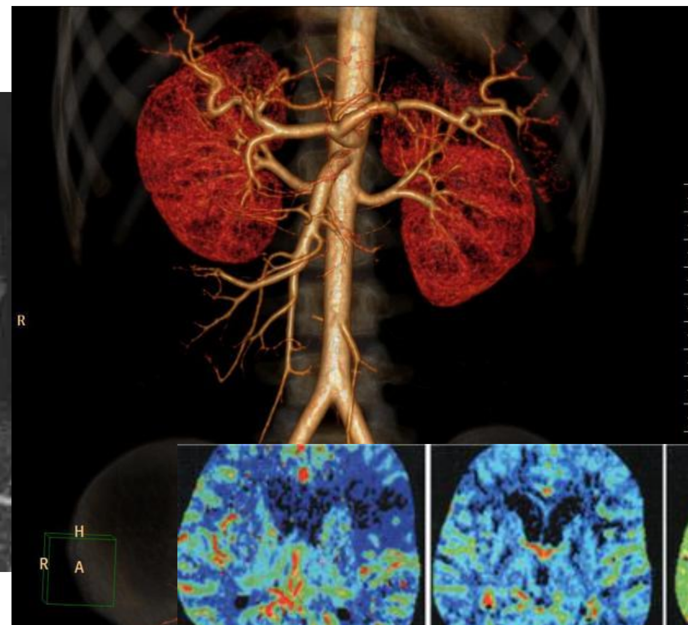
Rodzaj tkanki	Współczynnik pochłaniania (jH.)
Kości	od 300 do 1000
Tarczyca	70 ± 10
Wątroba	65 ± 5,0
Śledziona	50 ± 5,0
Nerka	30 ± 10
Trzustka	40 ± 10
Tkanka tłuszczowa	–65 ± 10
Płuca	od –600 do –800
Płyny ustrojowe:	
• Krew wynaczyniona (do 6–8 dnia po krwotoku)	80 ± 10
• Krew żylna	55 ± 5,0
• Wysięk	>18 ± 2,0
• Przesięk	<18 ± 2,0

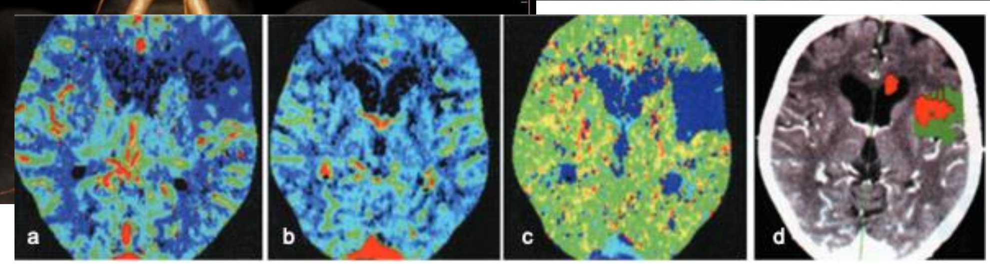
[B. Pruszyński, Tomografia komputerowa, PZWL]

CT angiography

contrast examination: detection of aneurysms, analysis of arteries in the lungs, kidneys, aortic dissection examination, assessment of the blood supply to the brain







Computed Tomography (CT)

Applications:

neurology

cardiology

pulmunology

gastroenterology

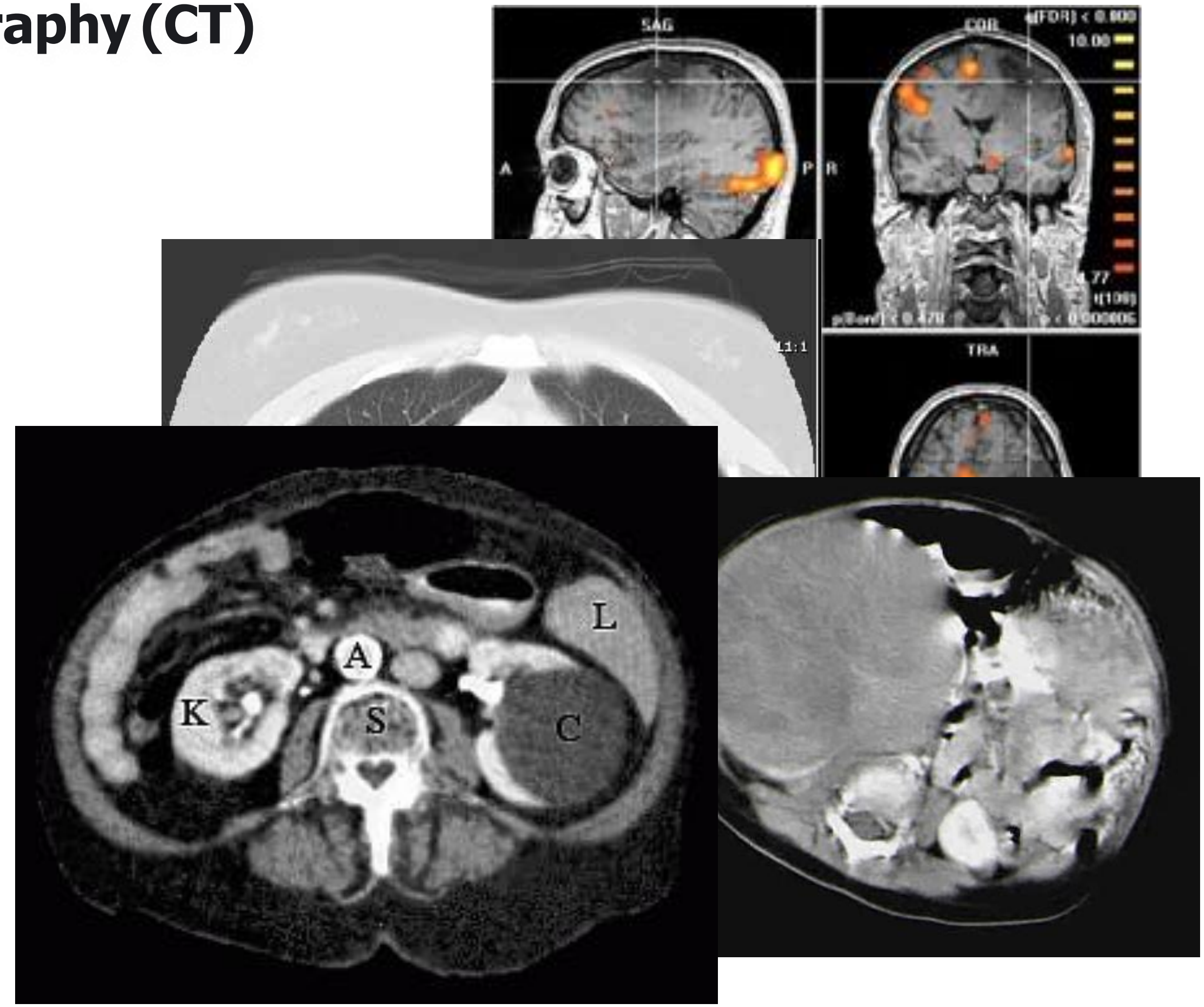
……

Diagnosis:

brain tumors

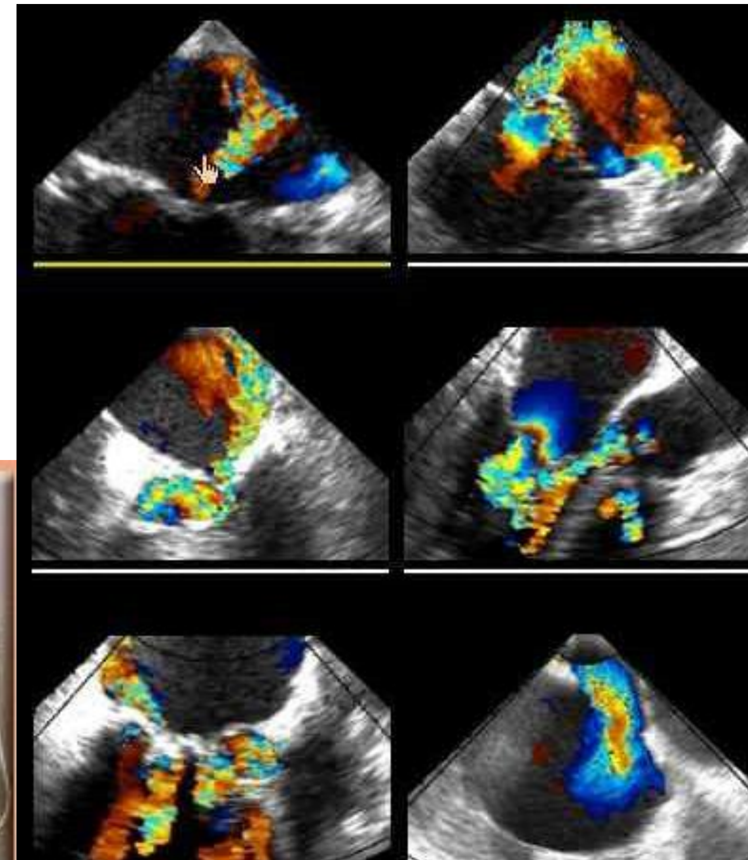
kidney, liver

lung diseases

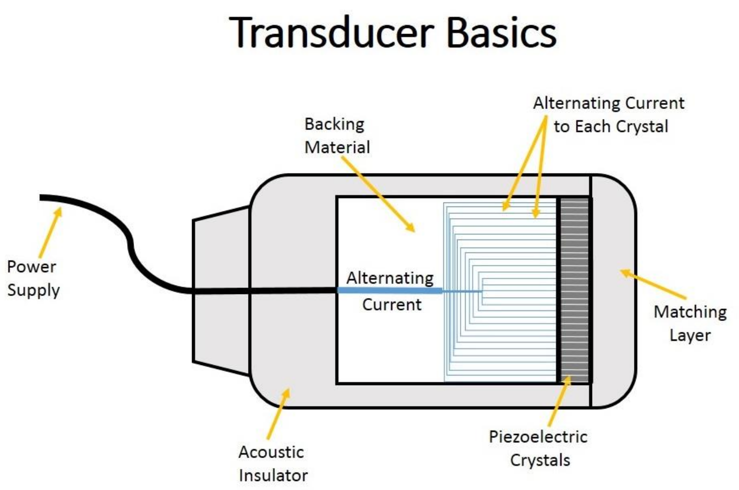


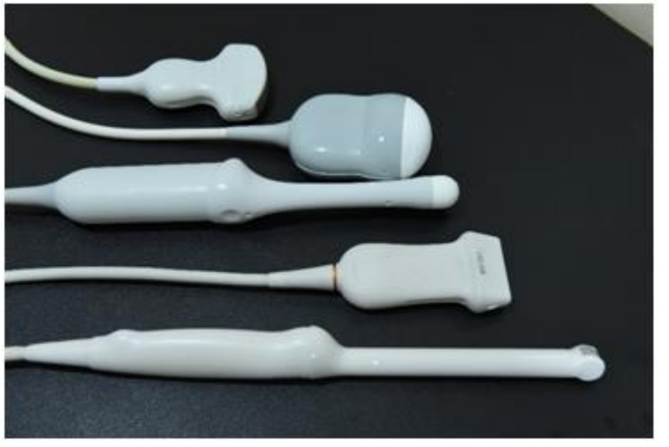
Ultrasonography

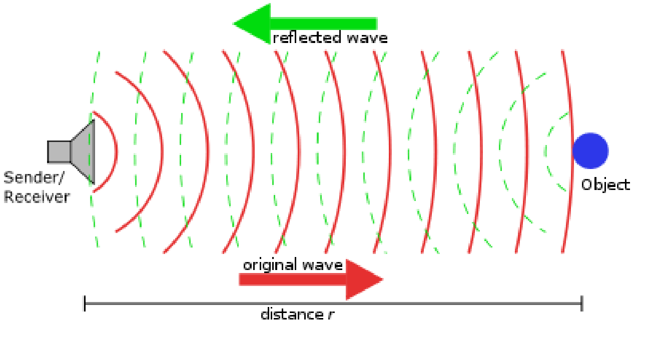
- low image quality,
- difficult for interpretation,
- Ultrasound elasticity (tissue stiffness measurement)
- blood flow examination (Doppler effect),
- non-invasive examination,
- low equipment price, mobility



Ultrasonography







Ultrasonography

Applications:

cardiology

ginecology&obstetrics

urology

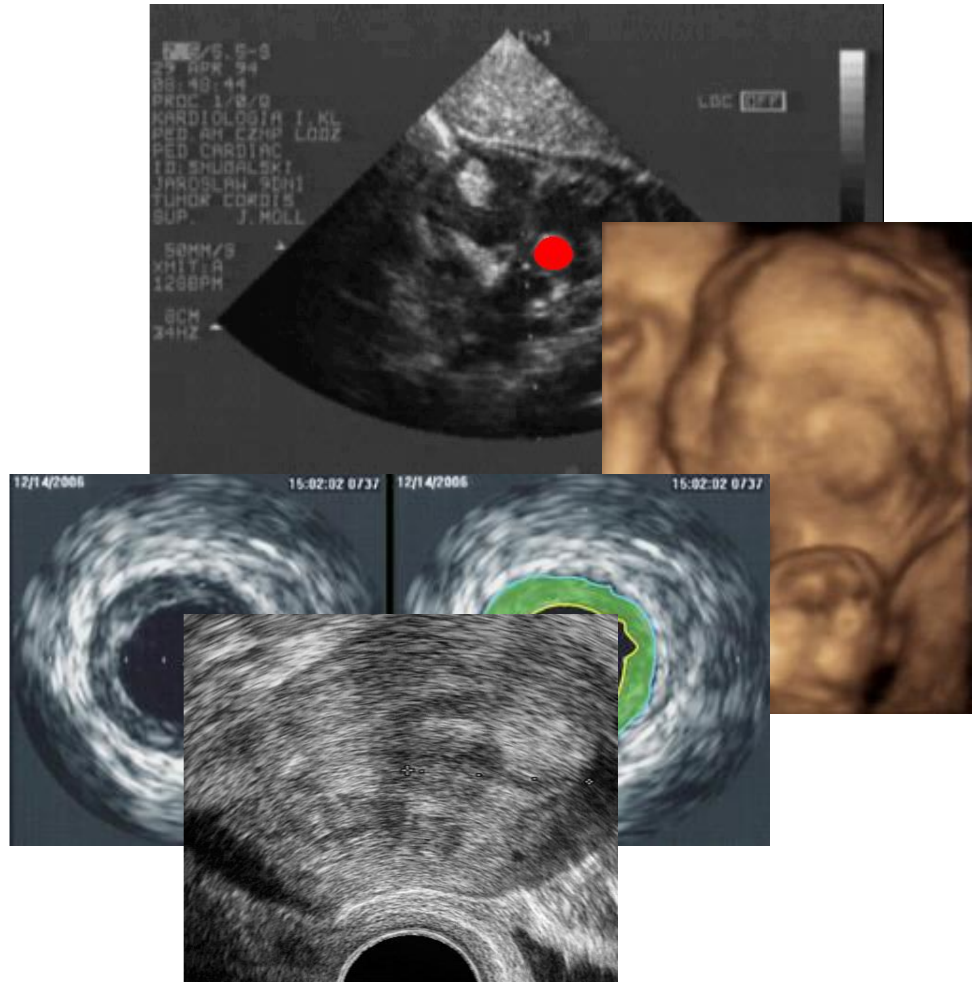
gastrology

……

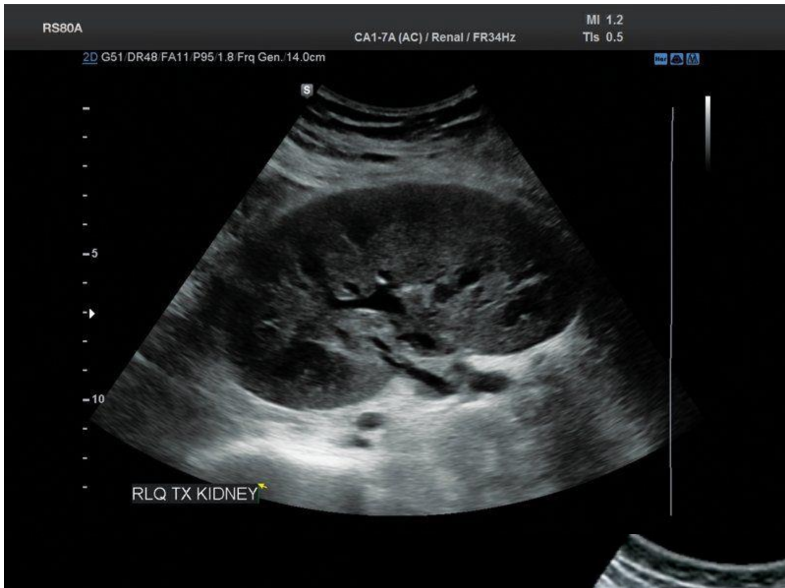
Diagnosis:

prostate, urinary bladder

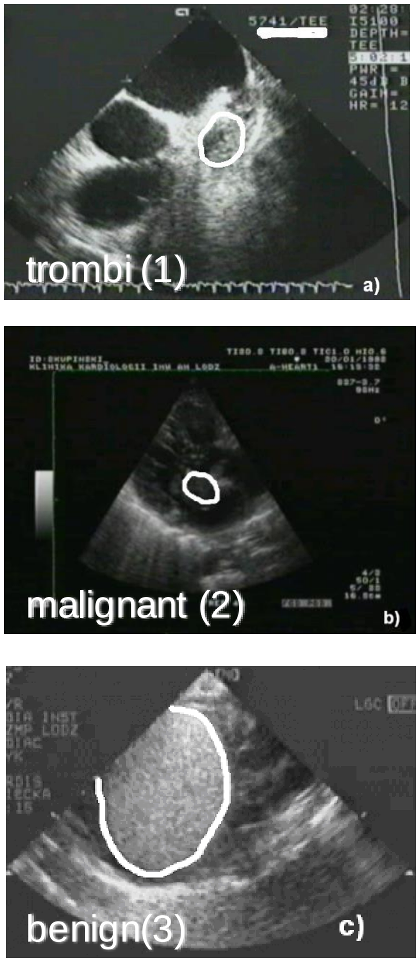
uterus

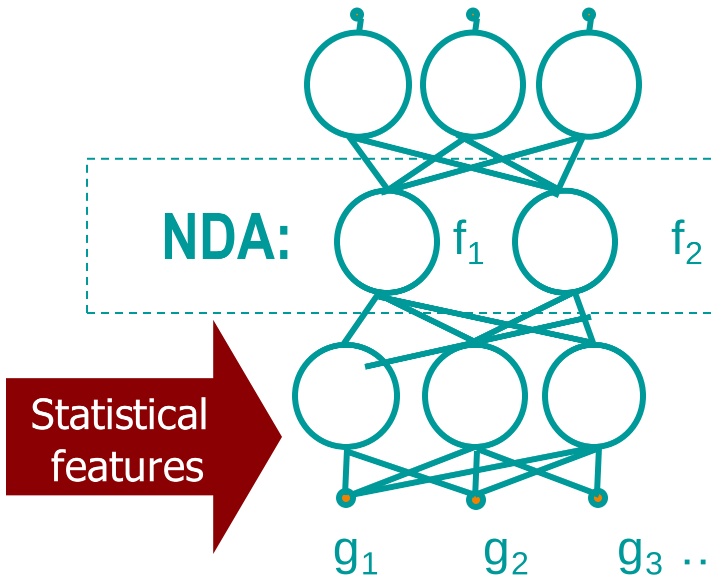


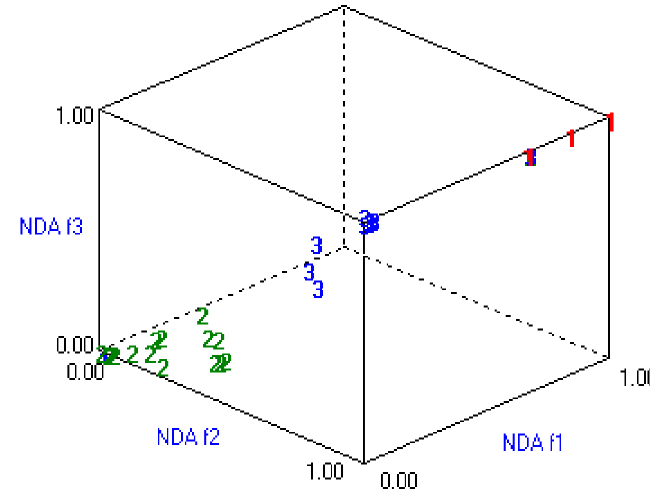
Ultrasonography



Analysis of heart echo images (classification)

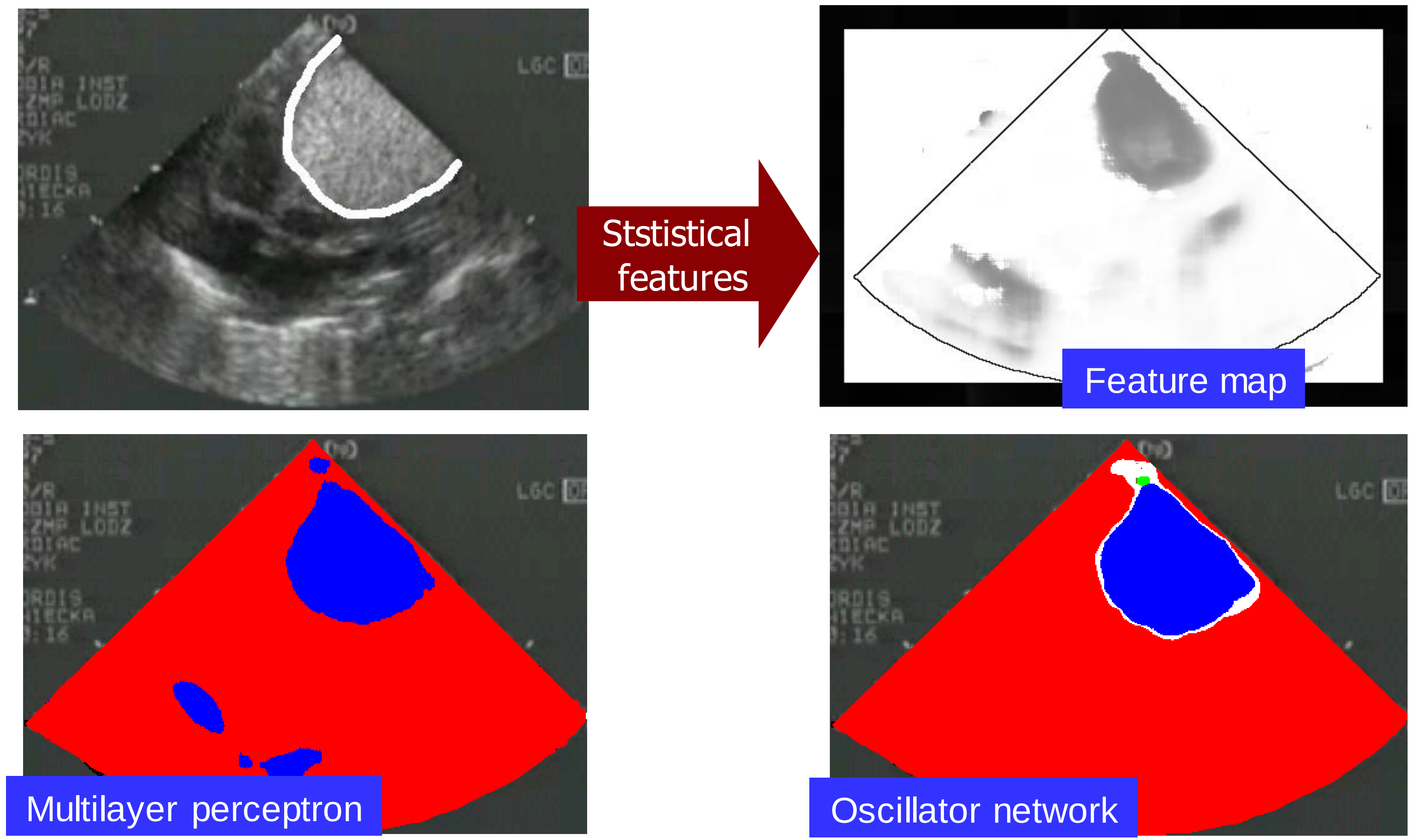




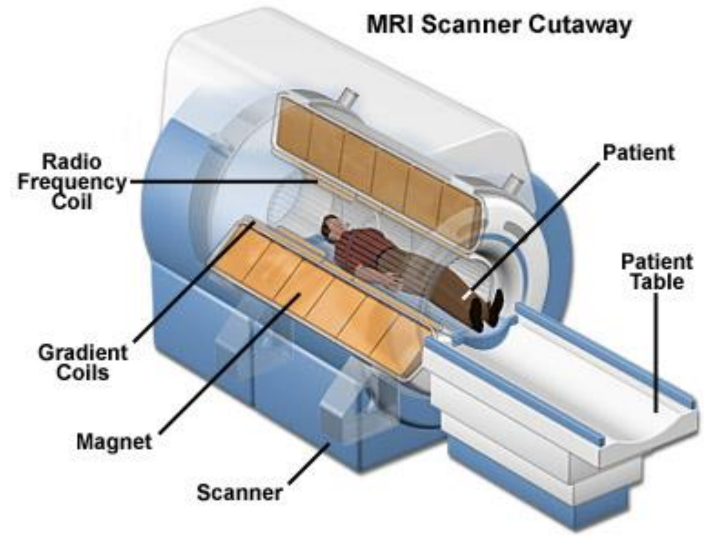


Classification error: 10% (55 images)

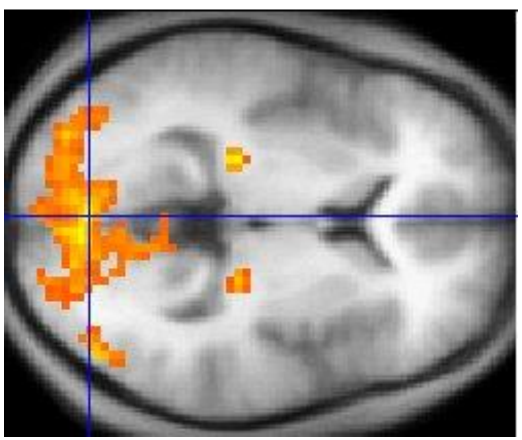
Analysis of heart echo images (segmentation)



Magnetic Resonance Imaging (MRI)



- effective for soft tissues,
- functional tomography (BOLD),
- MR angiography,
- very good image quality,
- non-invasive examination,
- high equipment price



Magnetic Resonance Imaging (MRI)

Applications:

neurology

angiography

gastroenterology

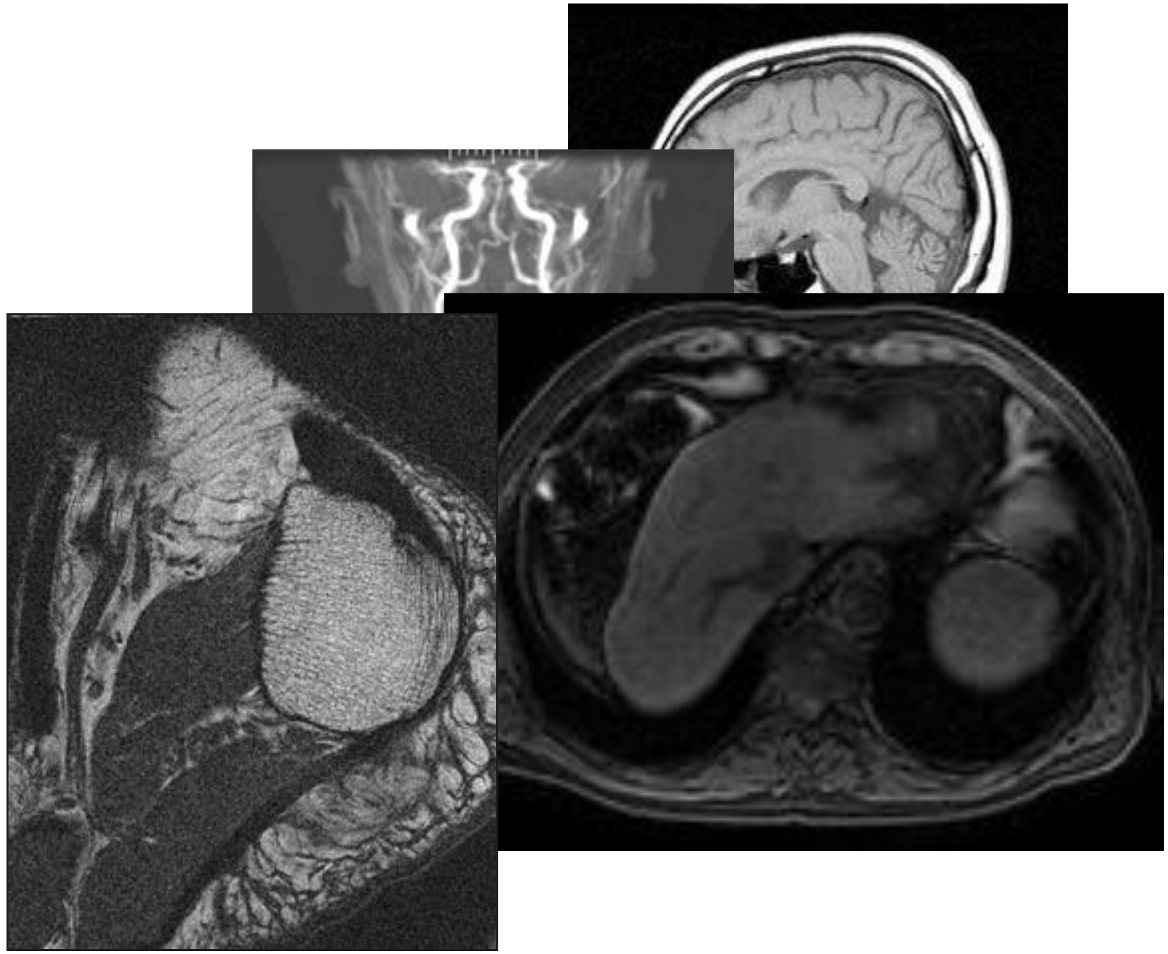
……

Diagnosis:

brain tumors

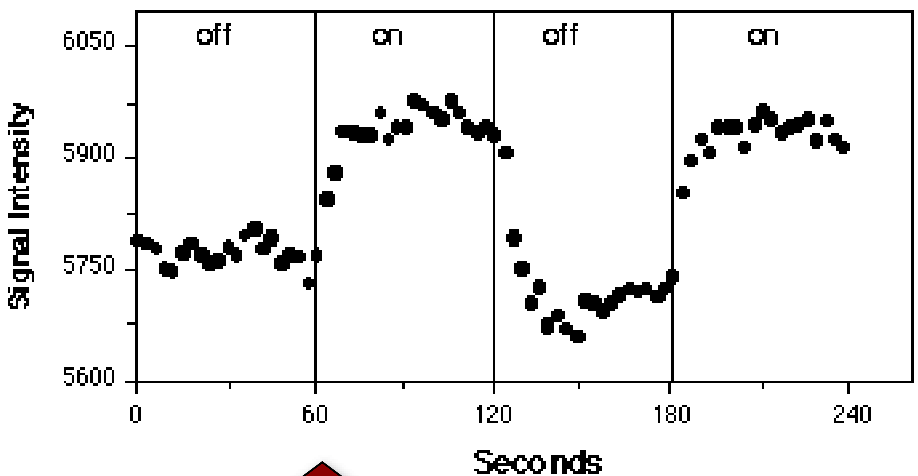
abdomen organs

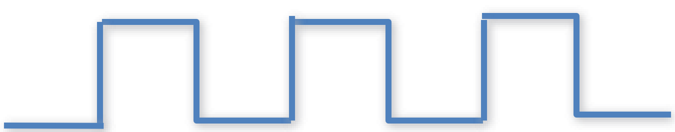
osteoporosis



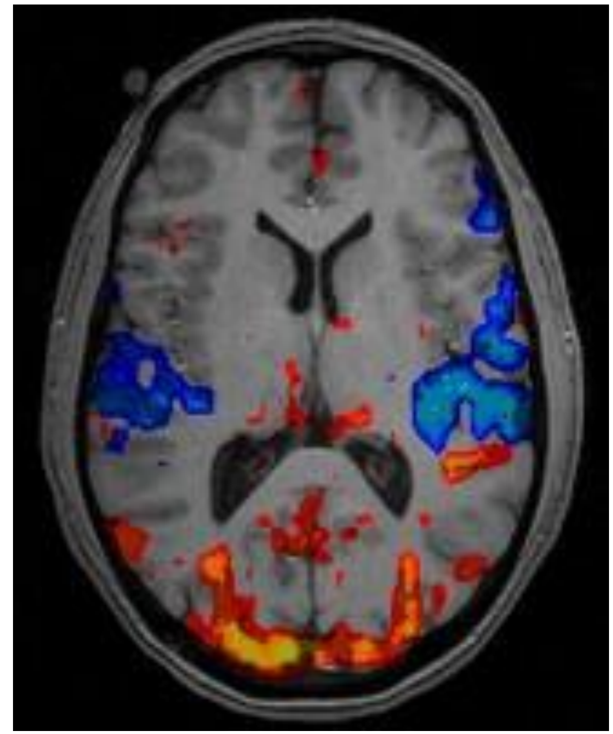
Functional Magnetic Resonance Imaging (fMRI)

Measured brain signal





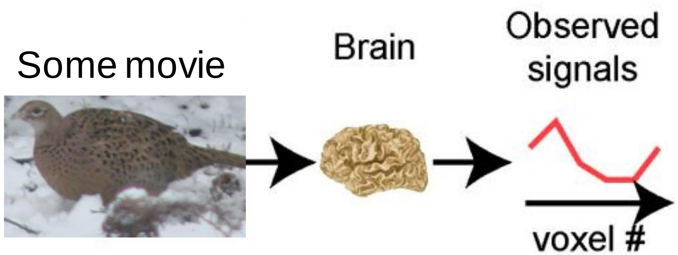
Visual stimulus



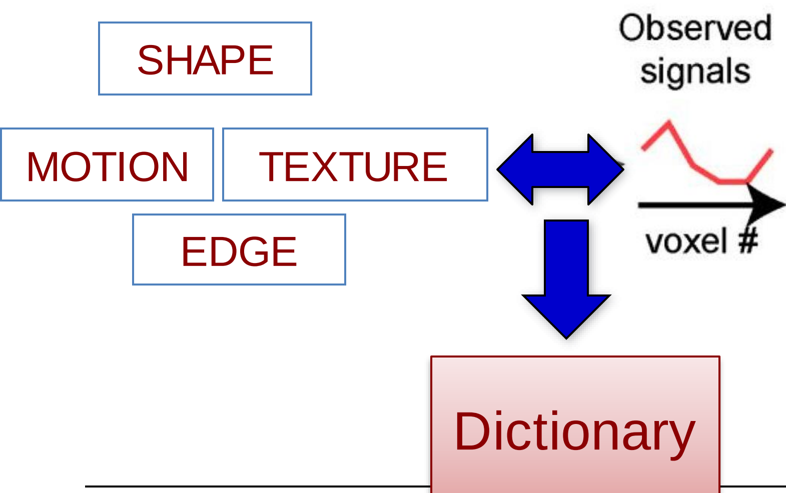
Brain activation map

Functional Magnetic Resonance Imaging (fMRI)

Reconstructing visual experiences from brain activity evoked by natural movies (The Gallant Lab, UC Berkeley)



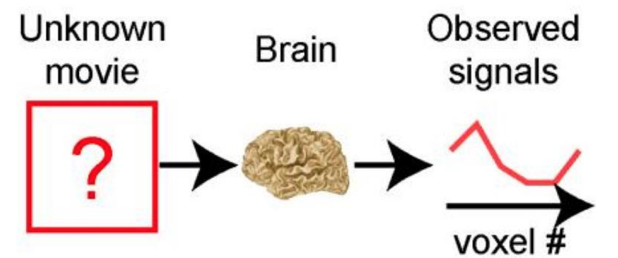
[1] Record brain activity while the subject watches several hours of movie trailers.



[2] Build dictionaries (i.e., regression models) that translate between the shapes, edges and motion in the movies and measured brain activity. A separate dictionary is constructed for each of several thousand points at which brain activity was measured.

Functional Magnetic Resonance Imaging (fMRI)

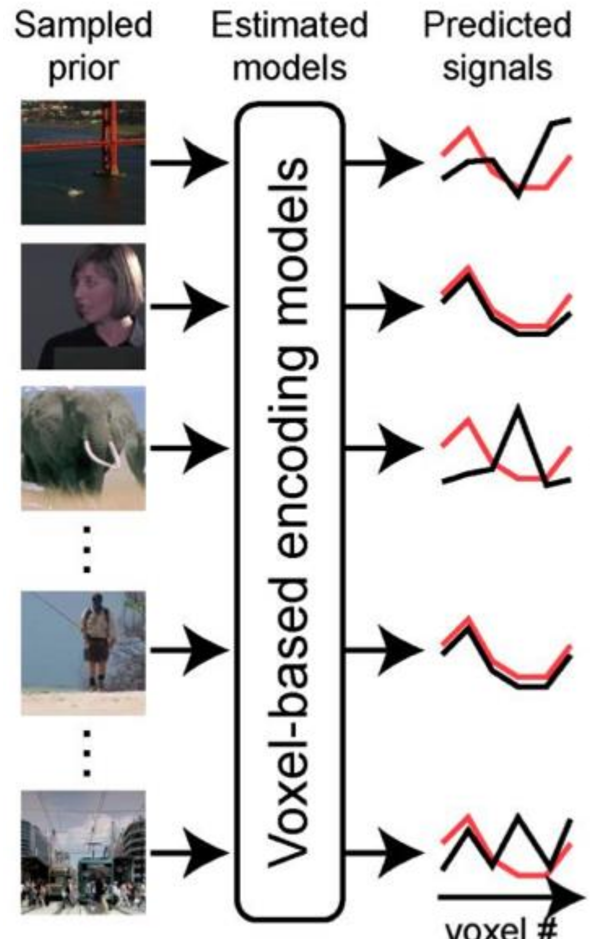
[3] Record brain activity to a new set of movie trailers that will be used to test the quality of the dictionaries and reconstructions.



https://www.youtube.com/watch?v=6FsH7RK1S2E

Functional Magnetic Resonance Imaging (fMRI)

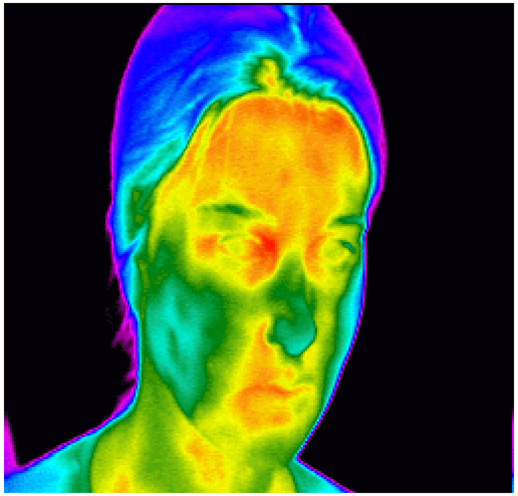
[4] Build a random library of ~18,000,000 seconds (5000 hours) of video downloaded at random from YouTube. (Note these videos have no overlap with the movies that subjects saw in the magnet). Put each of these clips through the dictionaries to generate predictions of brain activity. Select the 100 clips whose predicted activity is most similar to the observed brain activity. Average these clips together. This is the reconstruction.

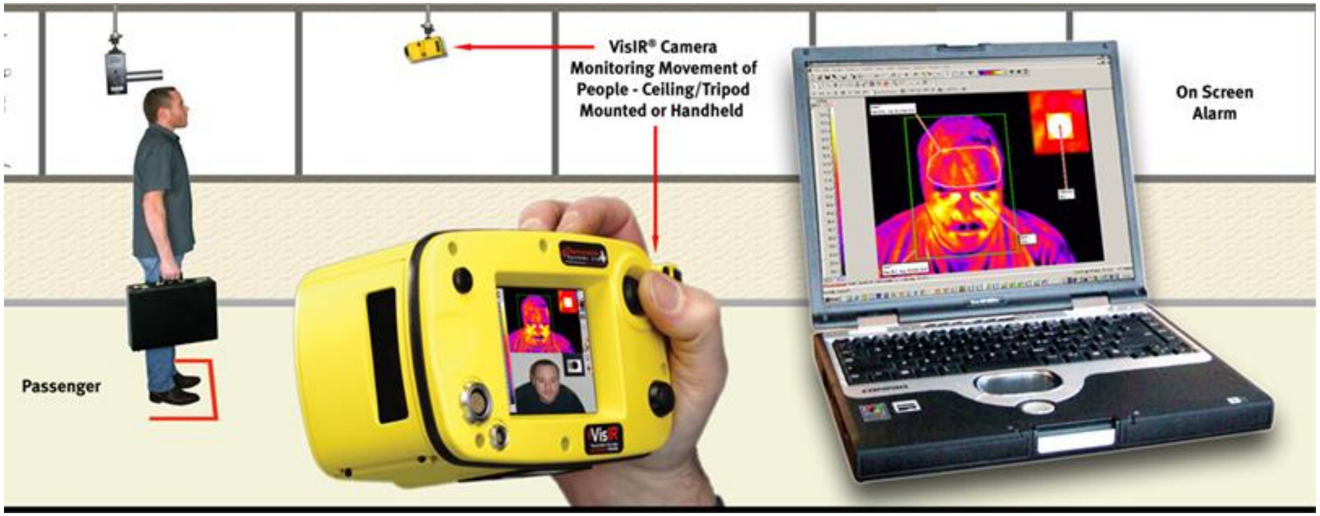


http://www.youtube.com/watch?v=nsjDnYxJ0bo

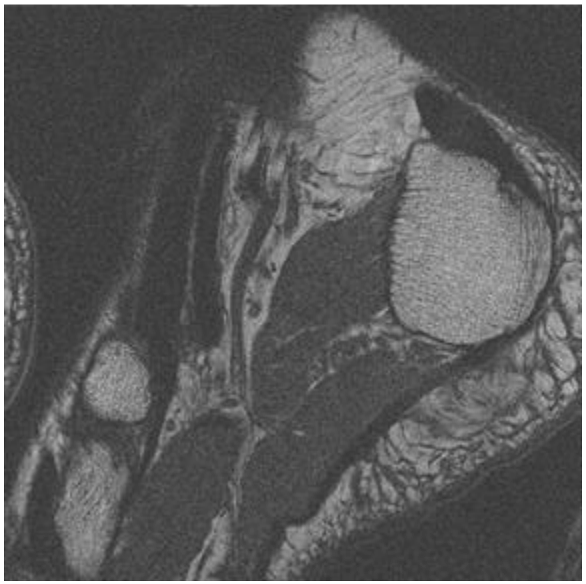
Medical Termography

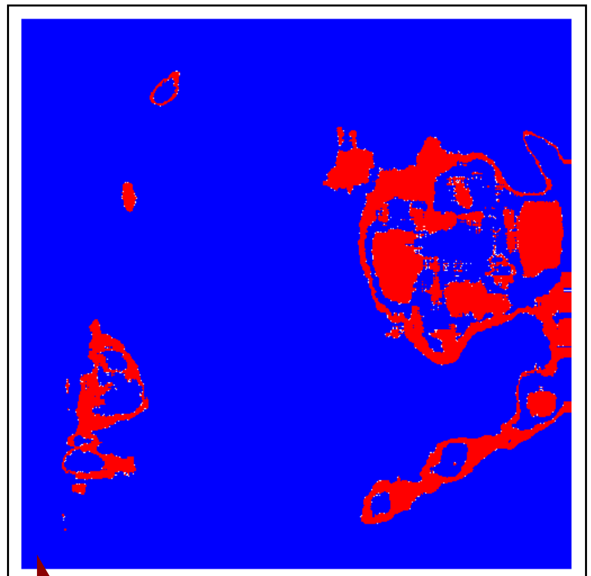
- low image quality
- complementary procedure to other diagnostic modalities
- non-invasive examination
- low equipment price, mobility

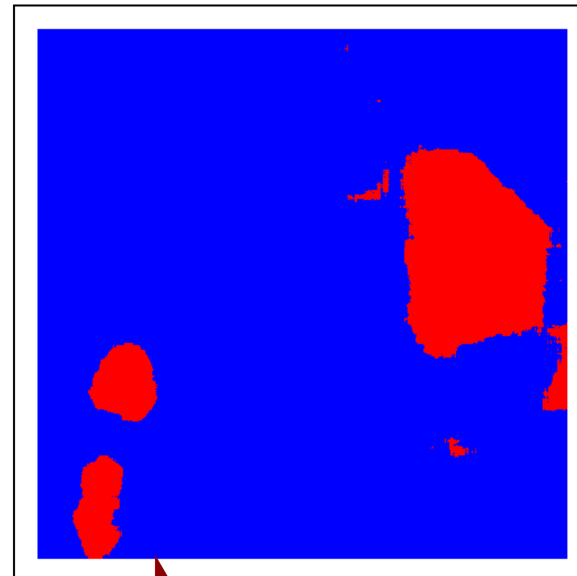




Segmentation of MR foot image





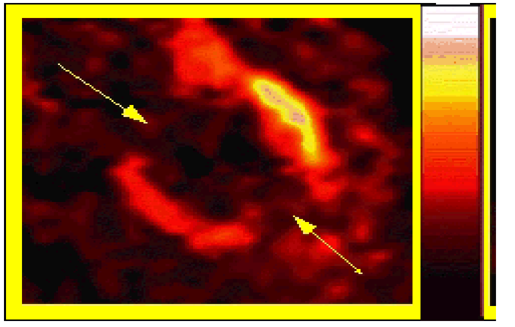


statistical features

GMRF model parameters

multilayer perceptron (MLP)

Nuclear Medicine



- different approaches (PET, SPECT, Scintigraphy)
- analysis of molecular changes,
- often together with CT,
- short examination time (limited by half-life disintegration of radioisotope),
- invasive examination,
- high equipment price

Nuclear Medicine

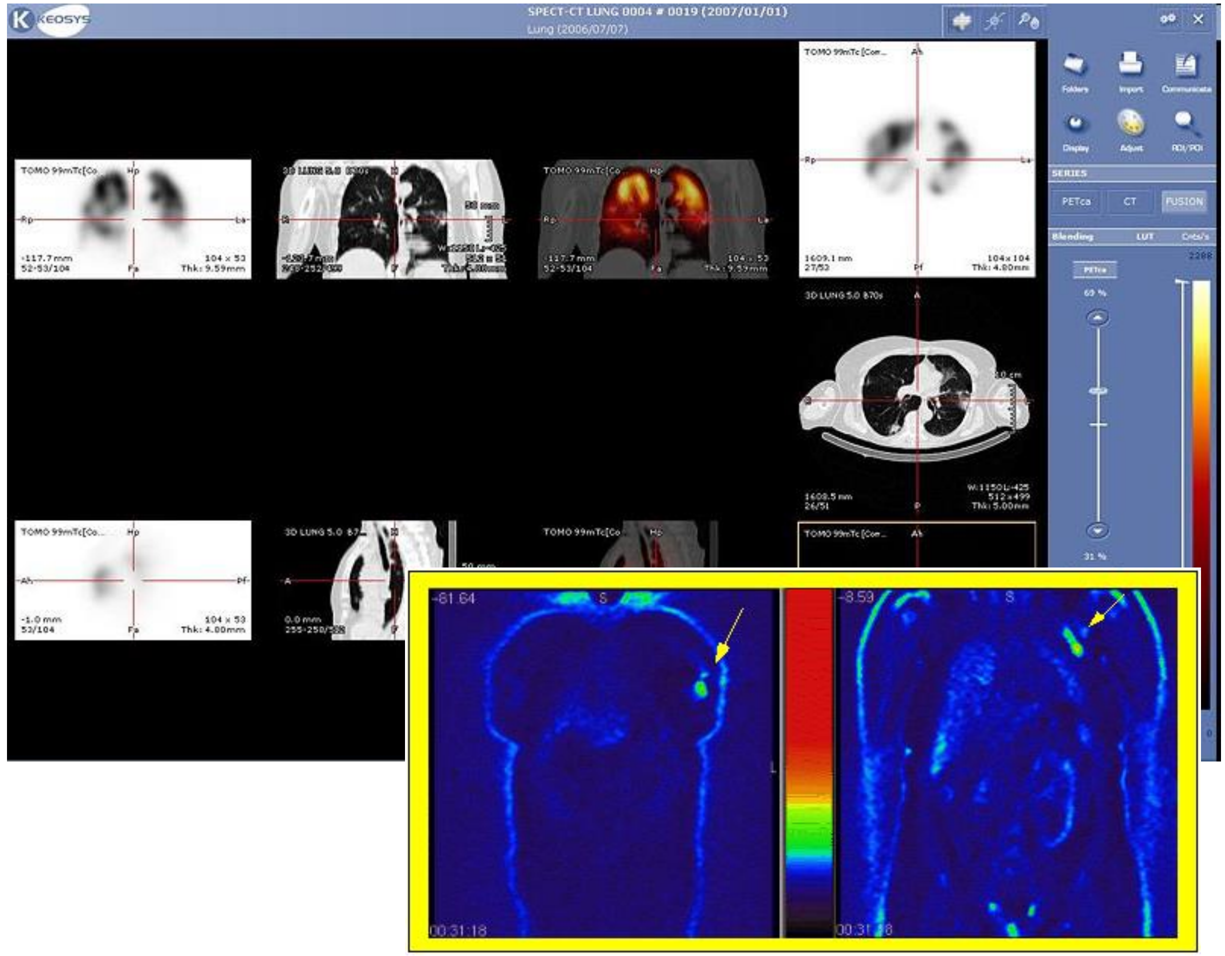
Applications:

almost all medical specialties

Diagnosis:

Huntington, Alzheimer, Parkinson diseases

early stage tumor detection



Endoscopy

- optical images of internal organs,
- additional surgical intervention (laparoscopy),
- endoscopic capsules,
- image processing is necessary,
- invasive examination,
- high equipment price

Endoscopy

Applications:

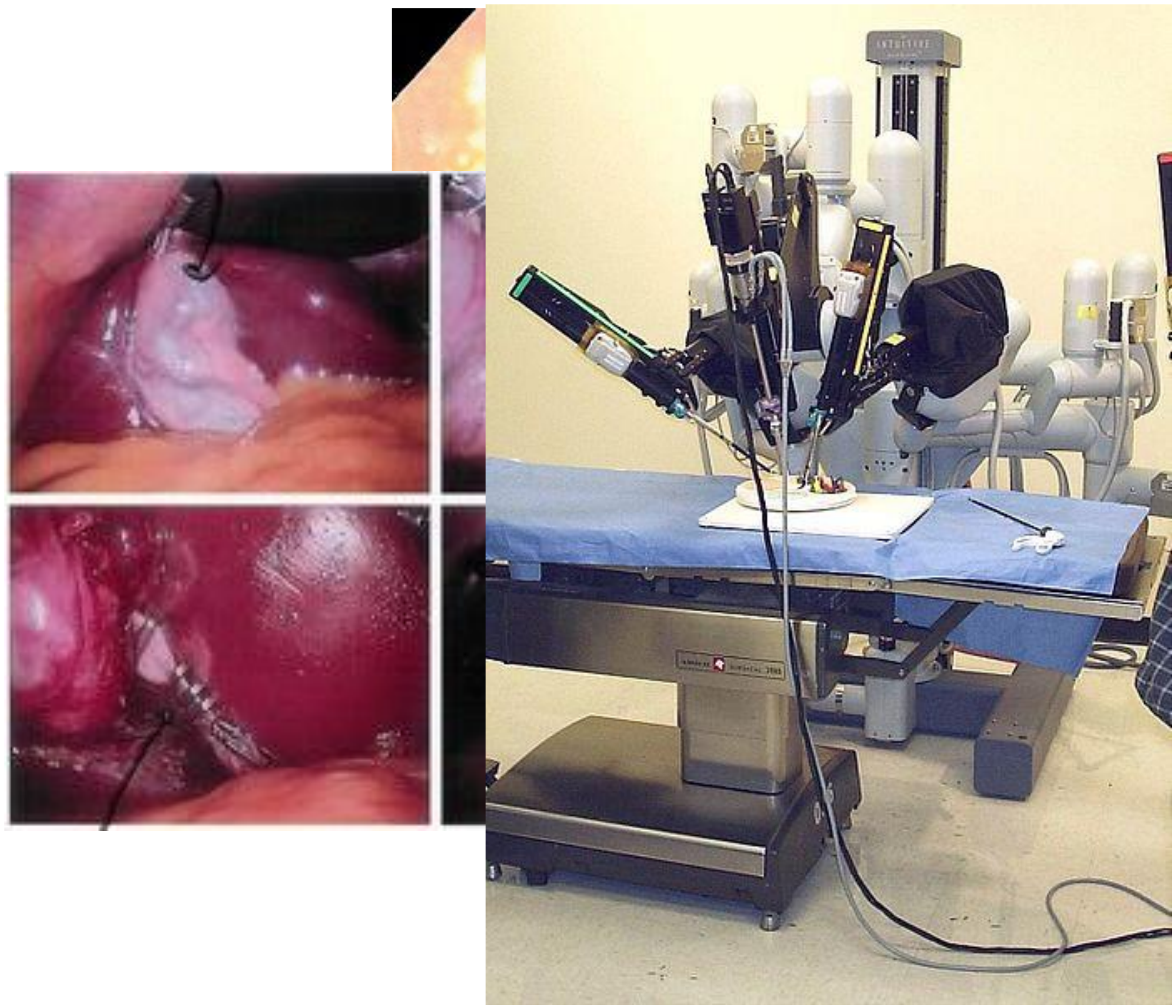
gastrointestinal tract (stomach, intestine, colon)

respiratory tract

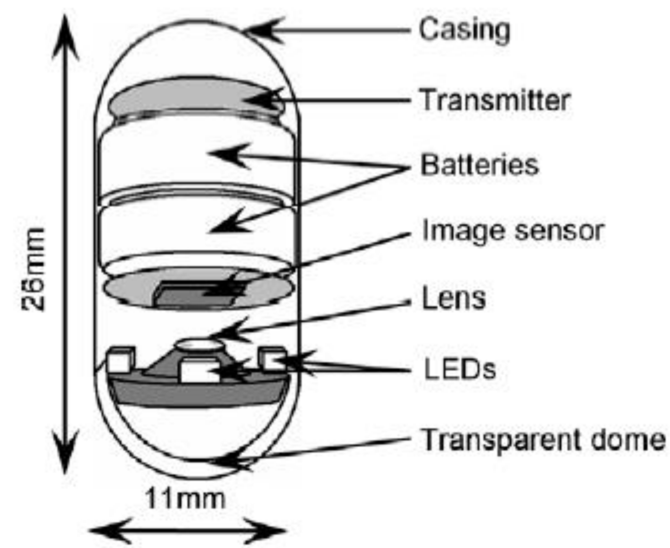
urinary tract

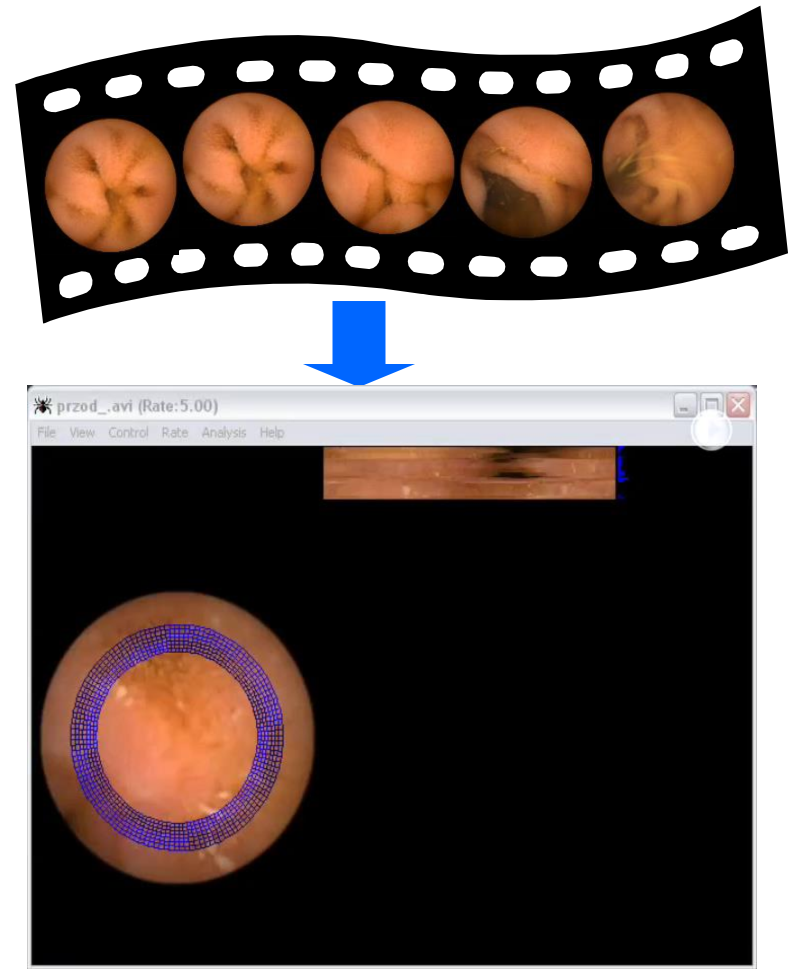
Laparoscopy:

removal of the gallbladder, polyp,…



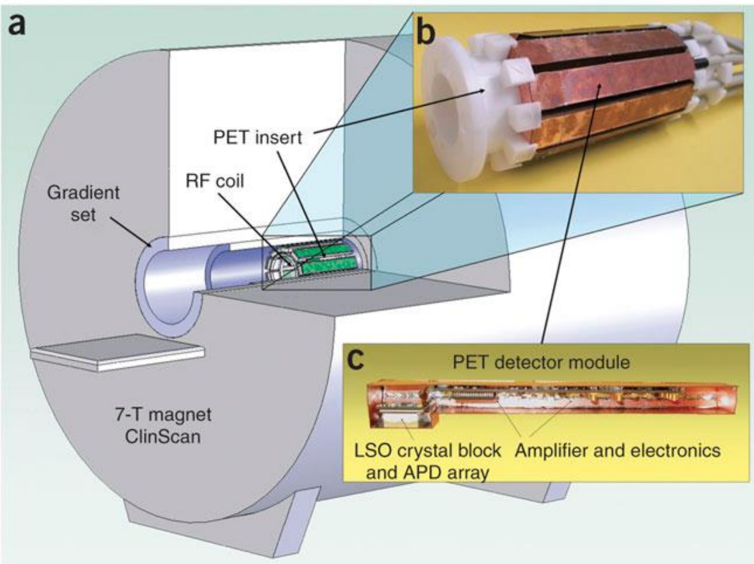
Endoscopic capsule

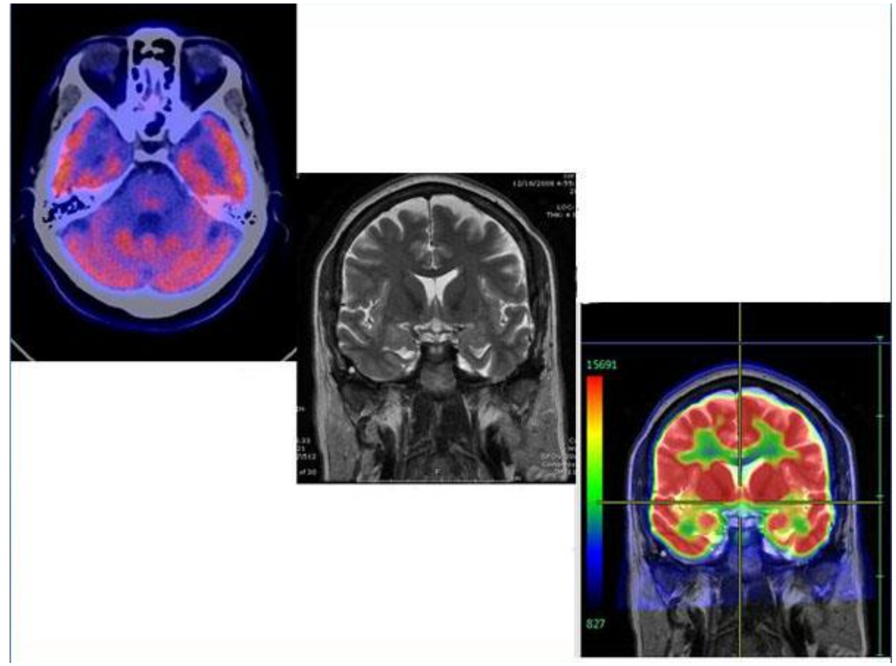




prof. Piotr Szczypiński, IE

Recent advances: PET + MRI





Imaging device that simultaneously performs positron-emission tomography (PET) and magnetic resonance imaging (MRI) scans, producing more detailed images than either technique alone and thus providing extended diagnostic information.

http://www.youtube.com/watch?feature=player_embedded&v=K2hAcri-ZlE

https://www.youtube.com/watch?v=r3TiTfMNLw8

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- http://en.wikipedia.org/wiki/Medical_imaging
- http://en.wikipedia.org/wiki/Computed_tomography