Visualisierung Medizinischer Daten 2
2. Vorlesung
Medical Imaging

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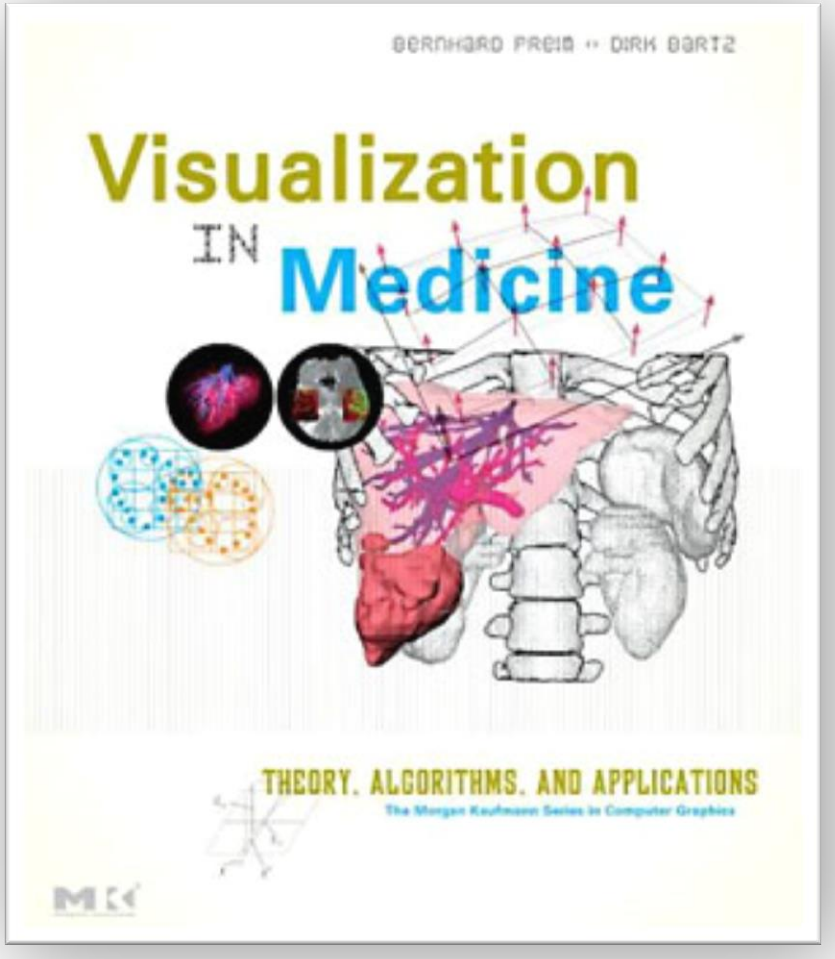
Literature

- Visualization in Medicine
- www.medvis-book.de



Imaging Modalities

- Started by discovery of X-rays in 1895 by Wilhelm C. Röntgen
- Depicts anatomical information by using physical characteristics

X-ray of W. C. Röntgens wife‘s hand, 1896

Parameters of Imaging Modalities

- Radiation exposure
- Cost & duration
- Application constraints

- Characteristics
  - Spatial resolution (pixel dimension)
  - Temporal resolution (scanning time)
  - Image matrix (number of pixels)
  - Measurements (cross-section, projection, volume)

Outline

- X-Rays
- Angiography
- DSA
- CT / CTA
- MRI / MRA
- PET
- US

X-Rays

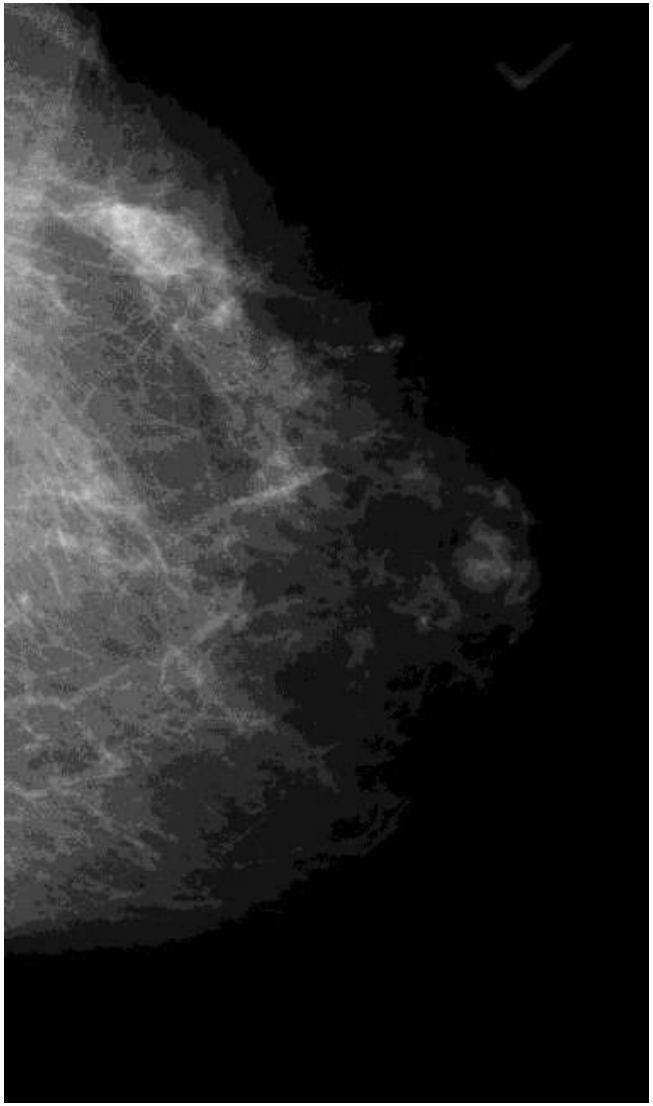
- Discovered by Wilhelm Conrad Röntgen in 1895
- Imaging based on the attenuation of X-rays through different types of tissues
- Depending on the density of radiated tissue
  - Highly dense materials absore more (e.g., bone)
  - Soft tissue absorbs less

X-Rays

- Hard beam X-rays
  - > 100 kV
  - Absorbed in very dense materials
  - Illustration of bones

X-Rays

- Soft beam X-rays
  - Illustration of soft tissue
  - Considered more harmful since almost completely absorbed



X-ray of the female breast, mammography

Angiography

- Displays the lumen (= inner open space) of blood filled structures
- Uses X-ray images
- Invasive since catheter is inserted into the arterial system of the patient to inject contrast agent
- Vessel opacification or enhancement

Digital Subtraction Angiography (DSA)

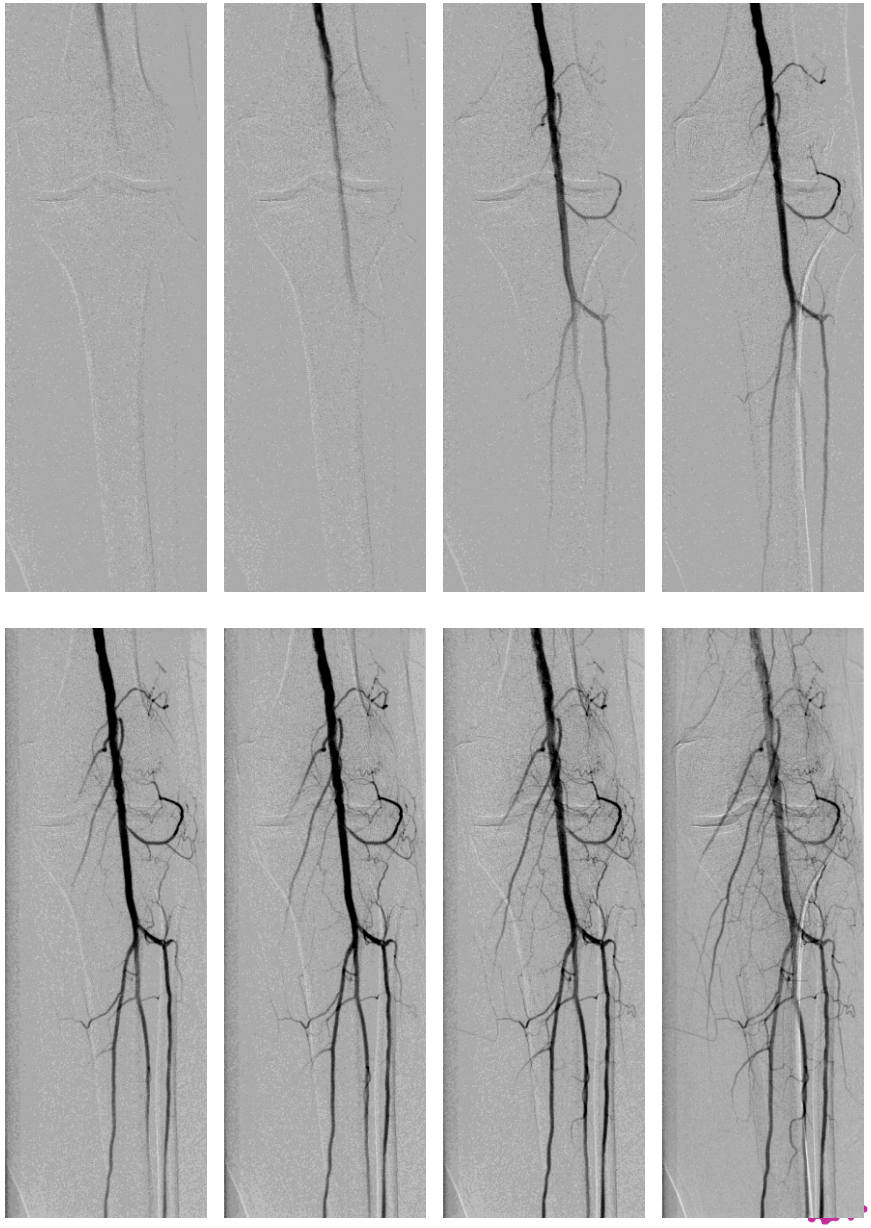
- Illustrate vessels by
  - Using X-rays
  - Using a contrast agent for opacification
- Idea
  - One image without contrast agent (**mask image**)
  - One image with contrast agent (**live image**)
  - Subtract both images to obtain obstruction free view of vessels

Digital Subtraction Angiography (DSA)

- Illustration of vessel pathologies
  - Stenoses
  - Thromboses
  - Aneurysms
  - „Short circuits“

Digital Subtraction Angiography (DSA)

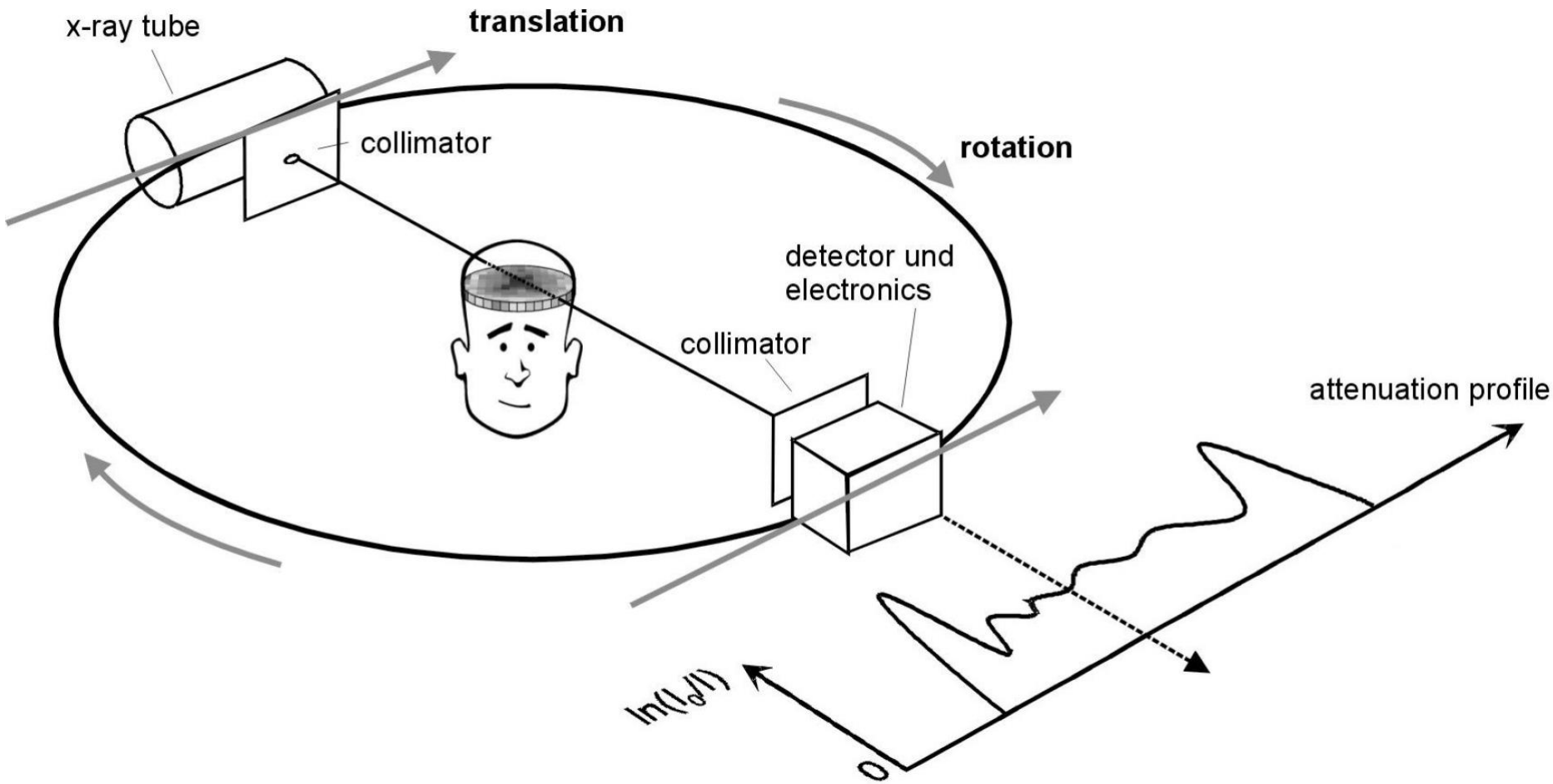
- Diffusion of the contrast agent in the vessels
- High local and temporal resolution
- Luminograms: Cannot provide information about the components of plaque and the surrounding tissue of vessels



Computed Tomography (CT)

- Established by Godfrey Hounsfield
- 1972 first prototype
- <u>Goal:</u> Non-overlapping illustration of body regions in cross-sections
- Basis: X-rays
- Rotating emittor/detector measures the absorbed radiation of the human body
- Cross-sectional data is computed
- Equidistant parallel cutting planes

Computed Tomography (CT)



[Kalender, 2000]

Computed Tomography (CT)

- Attenuation coefficients normalized according to the attenuation of water
- Standardization to Hounsfield Units (HU)

$$\mu_{rel} = (\mu_T - \mu_{water})/\mu_{water} * 1000$$

Tissue Type	HU
Air	–1000
Lung tissue	–900. . . –170
Fat tissue	–220. . . –30
Water	0
Pancreas	10. . . 40
Liver	20. . . 60
Heart	20. . . 50
Kidney	30. . . 50
Blood	40. . . 100
Enhanced blood	150. . . 500
Soft plaque	0. . . 200
Calcified plaque	500. . . 1000
Bones	45. . . 3000
Metal	>3000

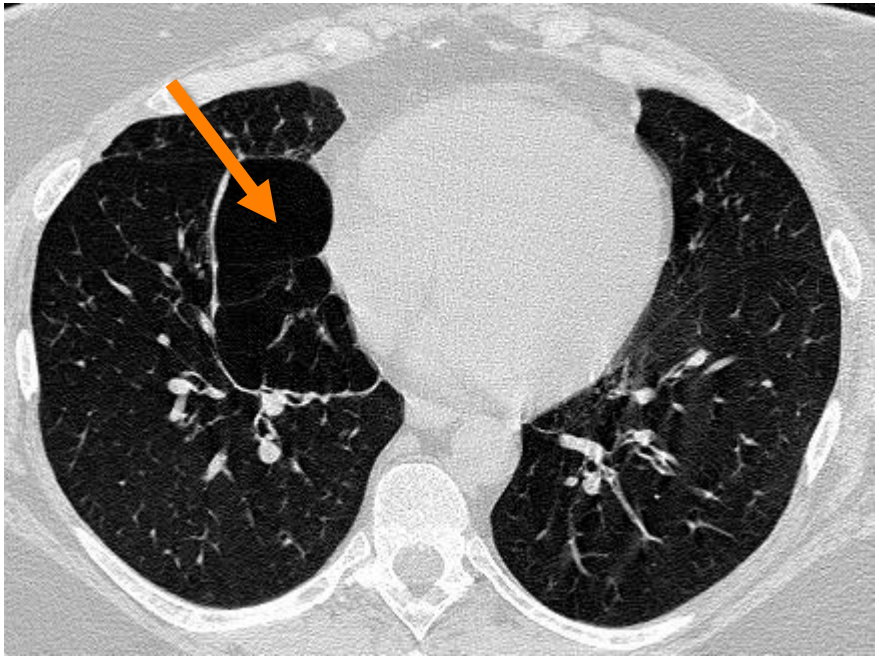
Computed Tomography (CT)

- Pros
  - High resolution (small slice distance)
  - Illustration of fractures and bleedings
  - Illustration of large vessels

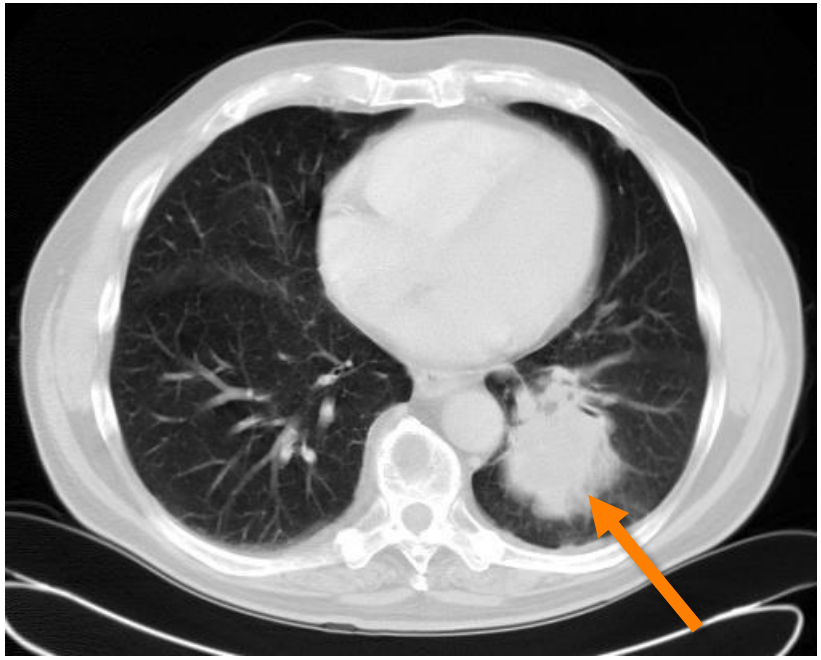
- Cons
  - Low soft tissue contrast
  - Ionizing radiation
  - Difficult to separate different types of tissue with a single threshold

Computed Tomography (CT)

[Preim and Bartz, 2007]



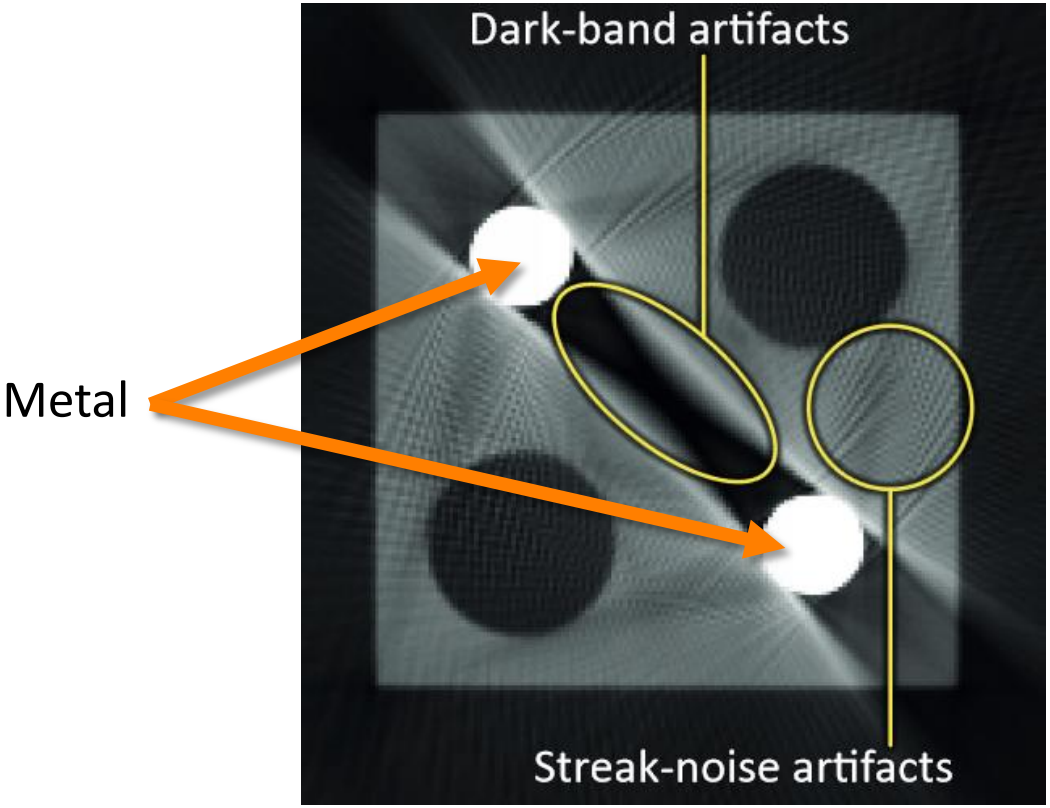
pulmonary emphysema



lung tumor

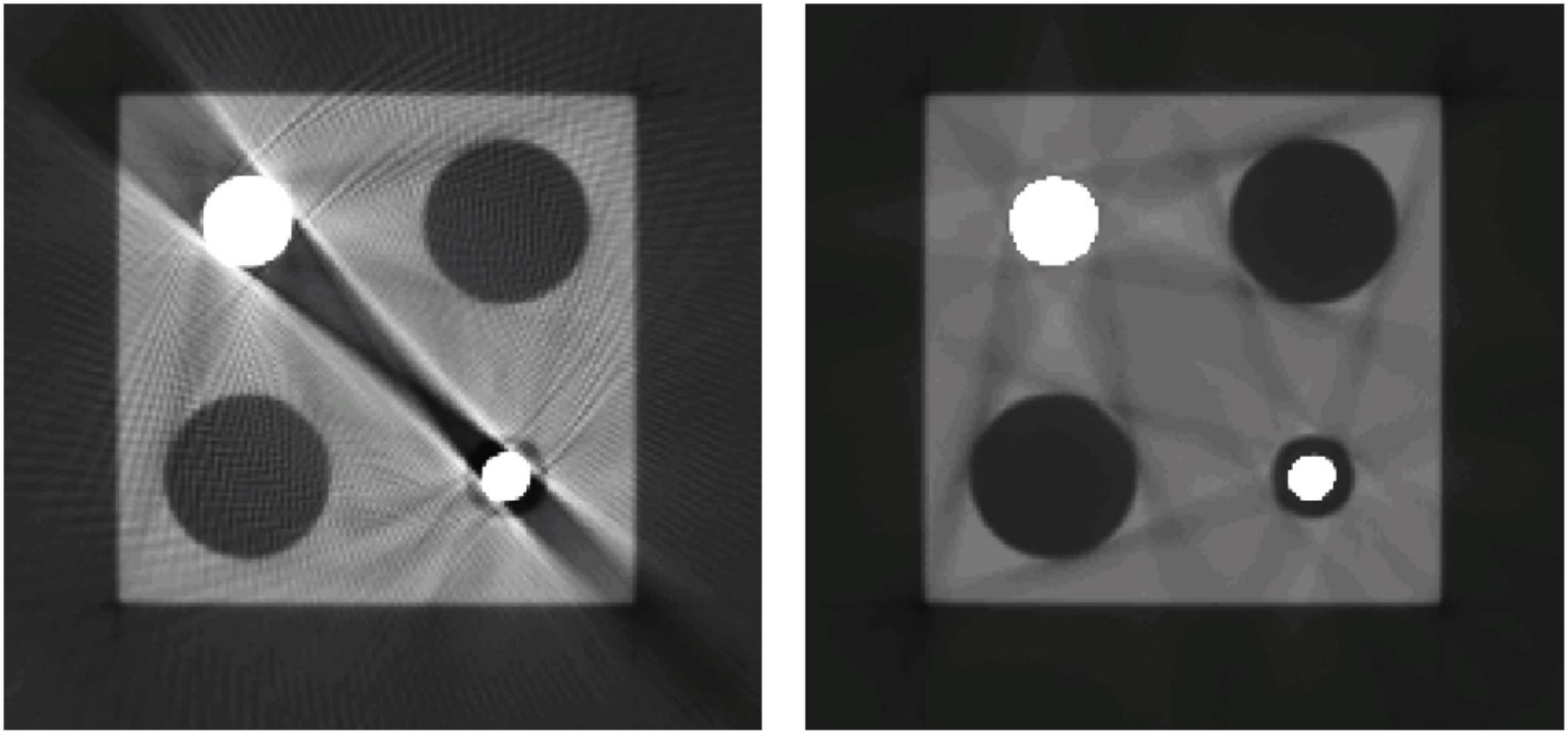
CT – Artifacts

- Artifacts caused by metal implants
  - Dark-band artifacts
  - Streak-noise artifacts



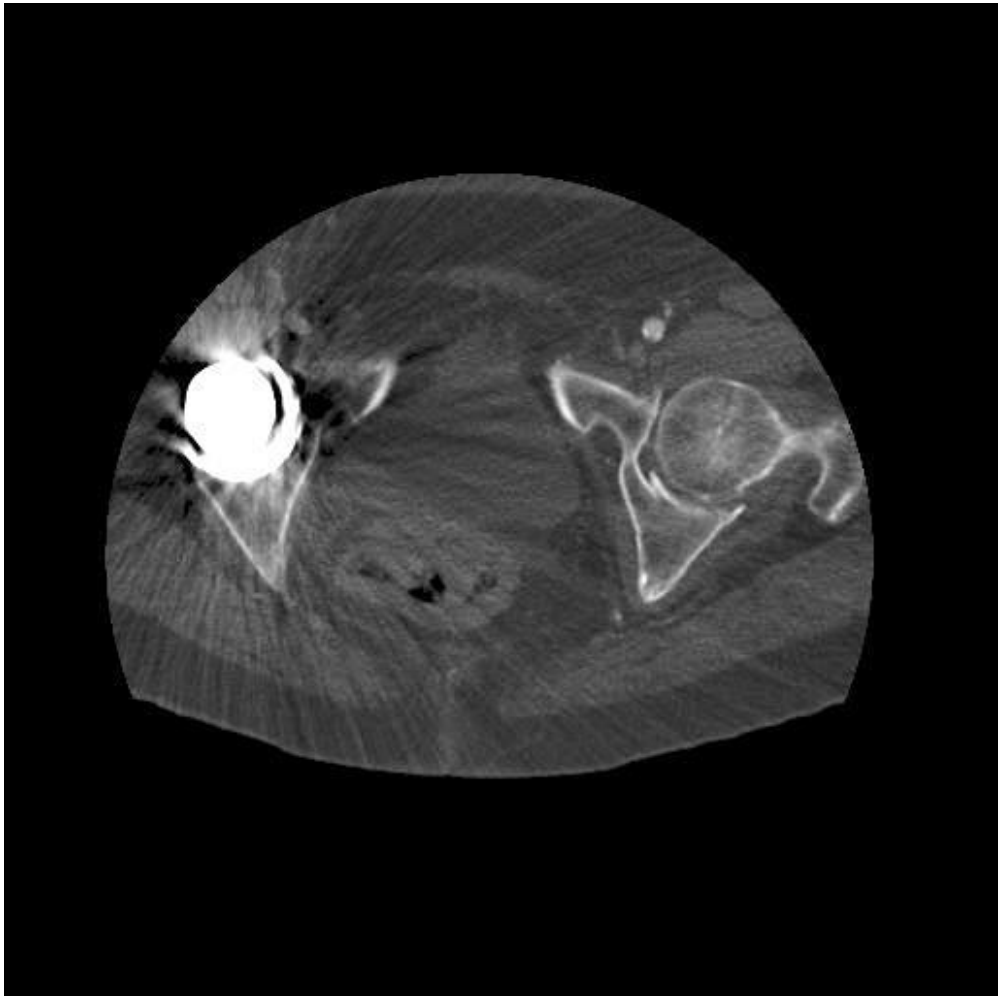
[Amirkhanov et al. 2011]

CT – Metal Artifact Reduction



[Amirkhanov et al. 2011]

CT – Artifacts



Higher Resolution CT

- Usually 512 x 512 pixels per slice
- Recently 1024 x 1024 image matrix
- 4x more data
- Same scanning procedure, different reconstruction algorithm
- Better resolution in the lower legs

Dual-Energy Computed Tomography (DECT)

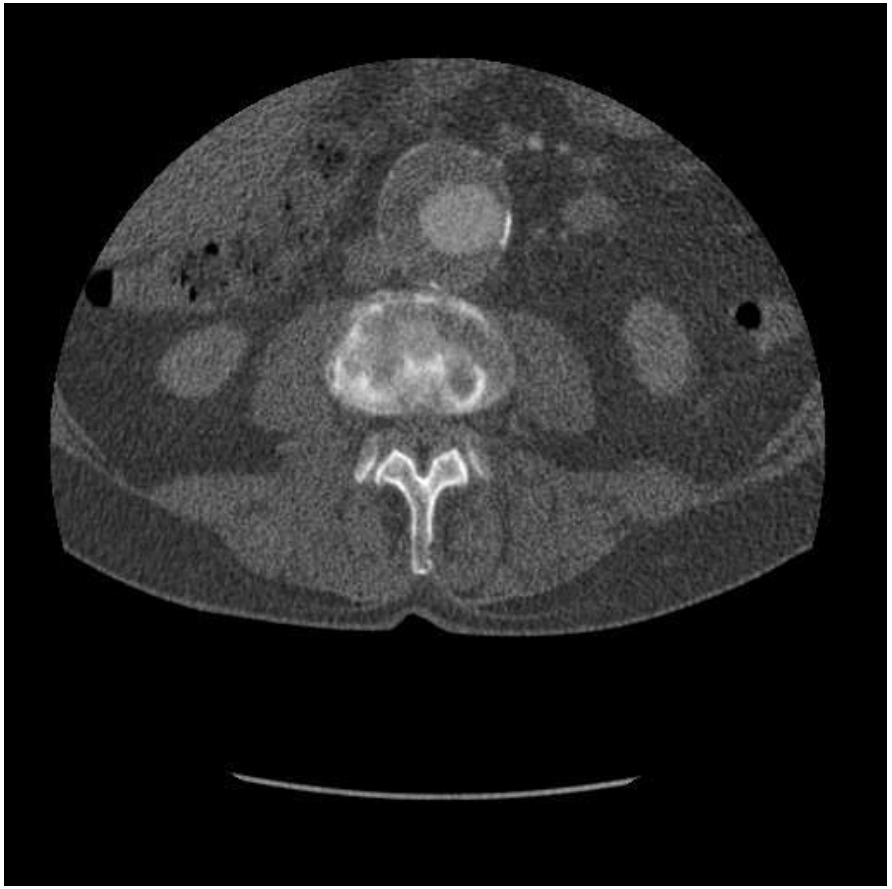
- Different energy levels for both radiation sources

- Low energy data set
  - Higher contrast between tissues
  - Noisier

- High energy data set
  - Less contrast
  - Less noise and sharper edges

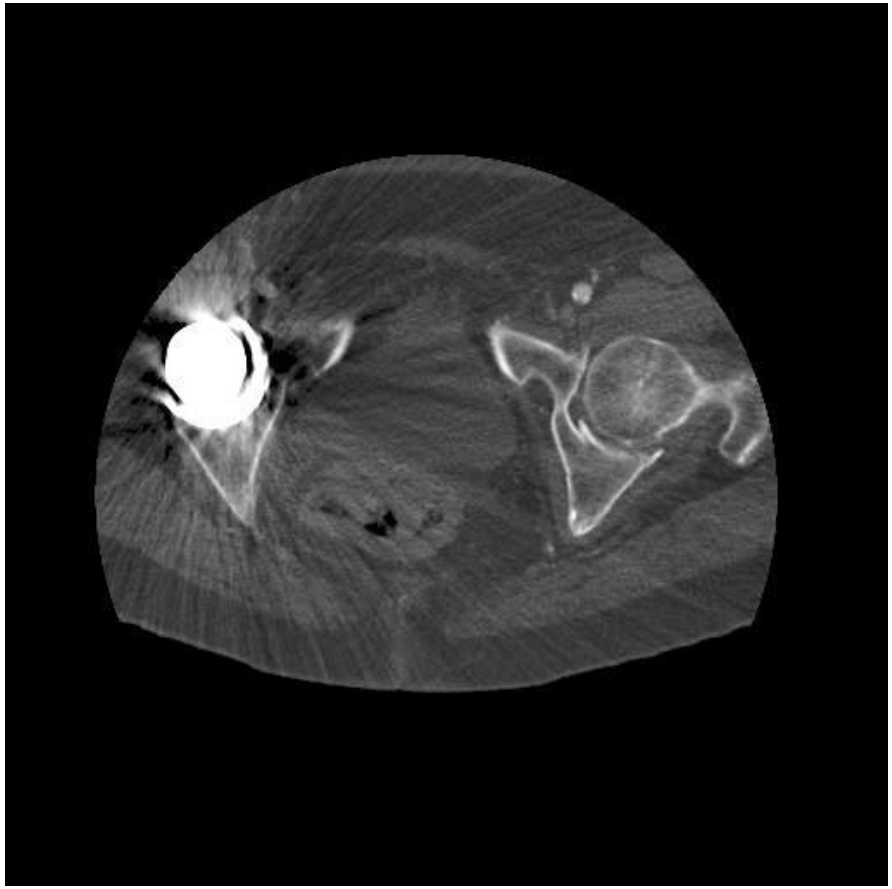
Dual-Energy Computed Tomography (DECT)

80 kV

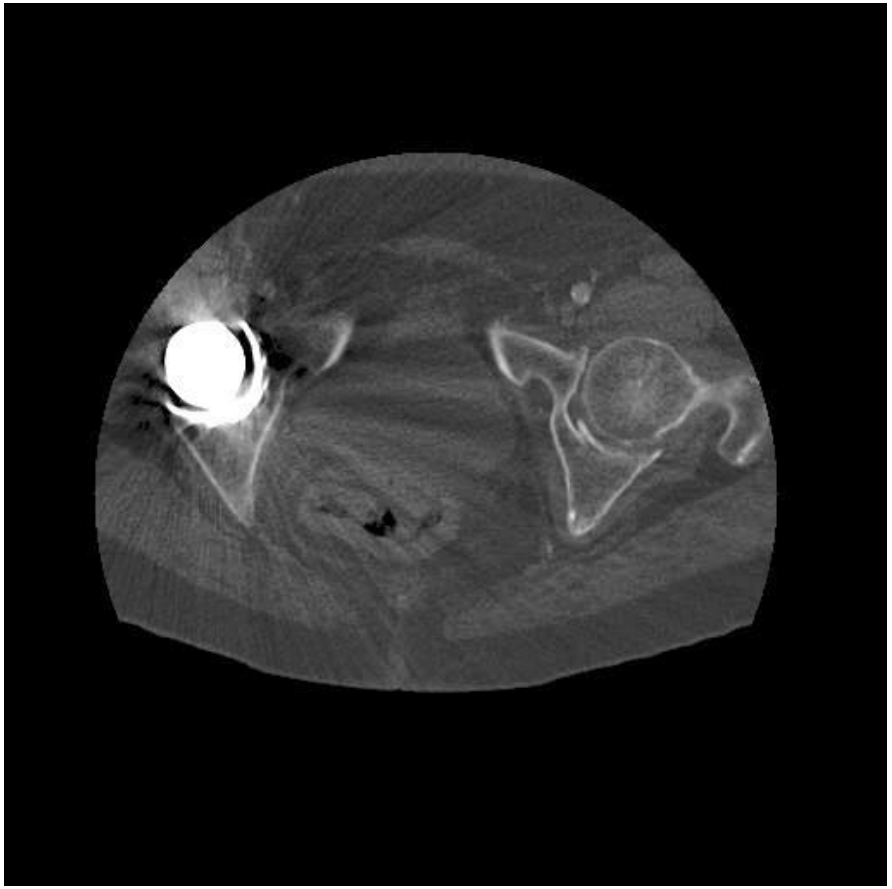


140 kV

Dual-Energy Computed Tomography (DECT)

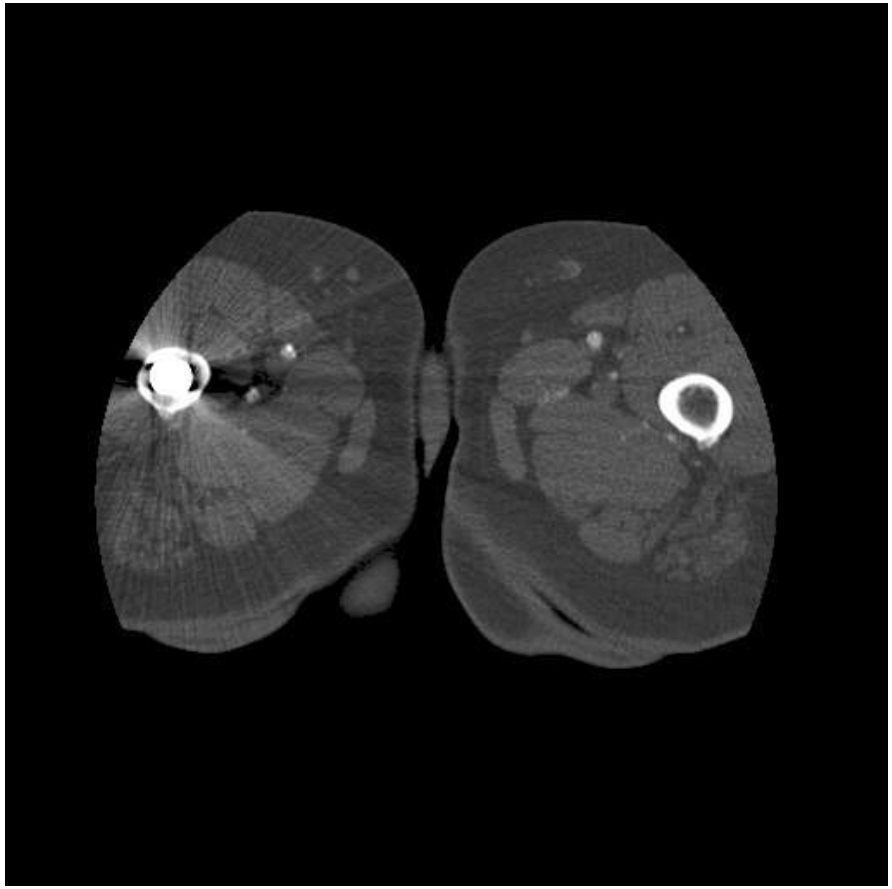


80 kV

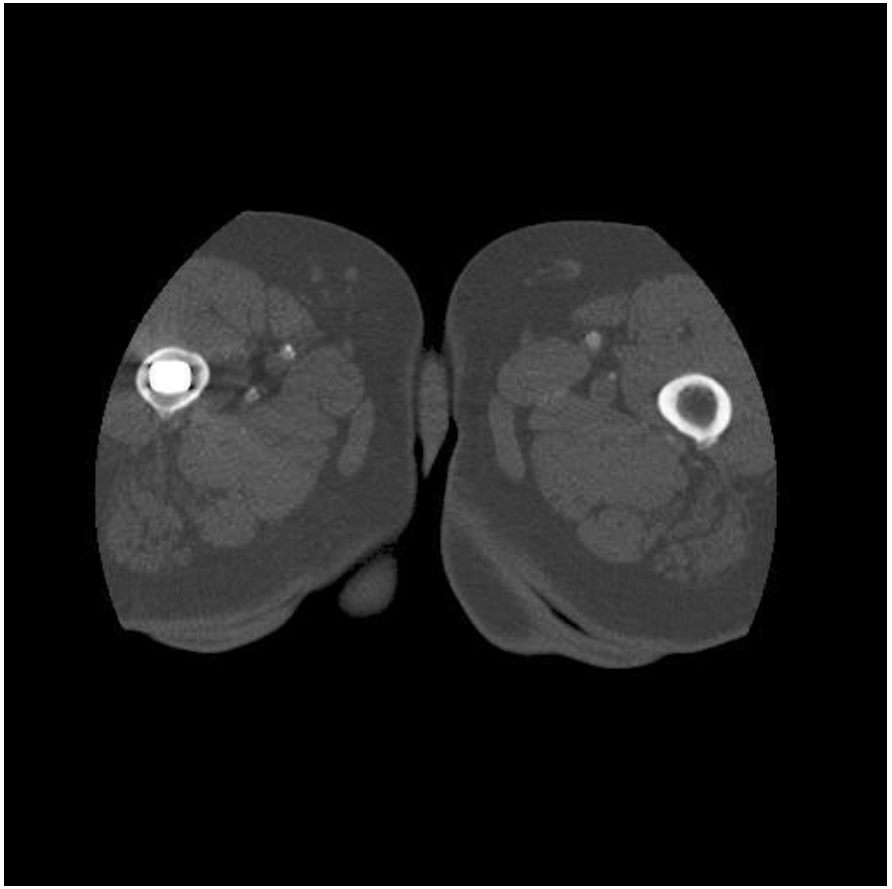


140 kV

Dual-Energy Computed Tomography (DECT)



80 kV



140 kV

Dual-Energy Computed Tomography (DECT)

- Goal: Utilize properties of both energy levels
- Nonlinear dependency of tissues between both energy levels

- Application areas
  - Automatic segmentation of bones
    → provide an obstruction free vasculature

Computed Tomography Angiography (CTA)

- Contrast agents injected into the veneous system of the patient
- Vessels are opacified / enhanced
- Less invasive than DSA, where the agent is inserted into the arterial system

- Blood flows at different speeds through various organs
- → Multiple opacification due to recirculation of blood through the heart

Computed Tomography Angiography (CTA)

- Non-ionic contrast agents (e.g. Iodine)

- Uniphasic injection of contrast agent might lead to a non-uniform enhancement of vessels
- Biphasic injection protocols inject first a constant amount of medium and then successively decrease the amount
- → Almost uniform vessel enhancement

Magnetic Resonance Imaging (MRI)

- Starting in the 1970s
- Since 1980s routine procedure (recording time several minutes instead of 1h)
- Patient is exposed to a strong magnetic field
- Interaction of atom nuclei with an external magnetic field (resonance)
- Considered non-invasive
- High resolution images with high soft tissue contrast from any region of the body

Magnetic Resonance Imaging (MRI)

- Application areas:
  - Tumor diagnostics
  - Functional diagnostics
  - Localization of brain functions

- Focus
  - Brain, spinal cord, soft tissue, cartilage, ligaments
  - Parenchymatous organs (liver, kidneys, spleen, …)

- Usually gadolinium-based contrast agents

Magnetic Resonance Imaging (MRI)

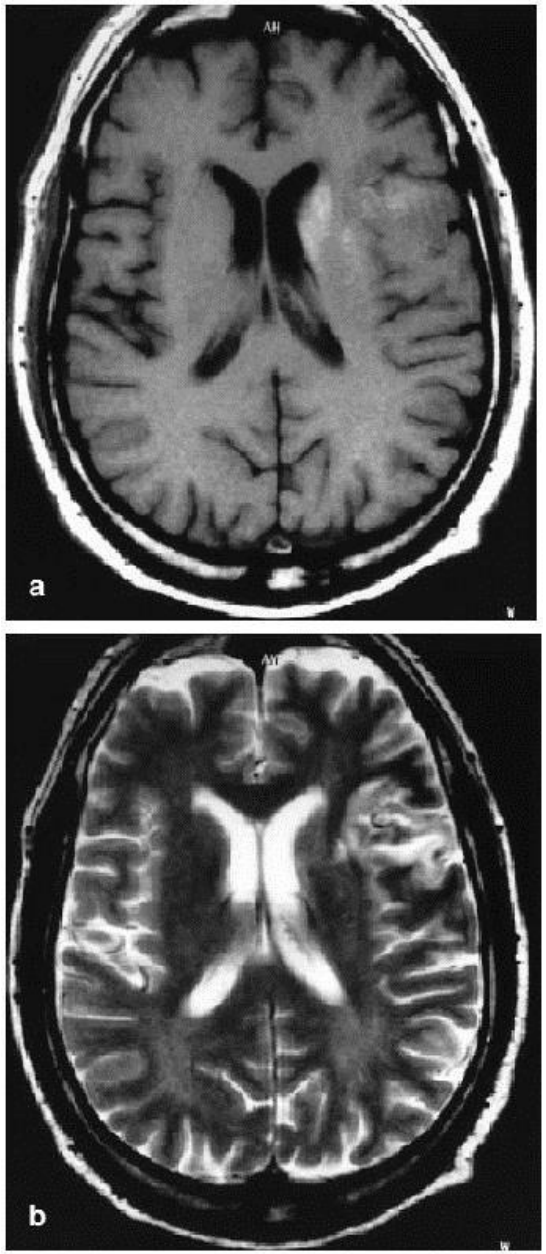
- Contraindications
  - Older, so-called *non-MRI compatible*, pacemakers
  - Metallic implants
  - Claustrophobia

- Excitation of the spin system with radio frequency (RF) impulses
- Relaxation: Returning back to equilibrium
- Relaxation times of different types of tissue differ by one magnitude

Magnetic Resonance Imaging (MRI)

- <u>Longitudinal relaxation (T1):</u> Interaction of the spins with the surrounding molecules (grids) → loss of longitudinal magnetization

- <u>Transversal relaxation (T2):</u> Mutual influence of the magnetic moments among the spins → loss of phase coherency



[Preim and Bartz, 2007]

MRI vs. CT

- No ionizing radiation
- Highly flexibe
- Noise through coils
- In principle unlimited resolution through geometry
- Good soft tissue contrast
- Several imaging parameters
  - T1 and T2 times
  - Proton density

- Ionizing radiation
- Imaging through weakening of X-rays
- Result: one image series
- Quite simple for the physician
- Bleeding good visible
- Worse contrast

MRI vs. CT

- High device-related costs (approx. 150 € per scan)
- Contraindications
  - metallic implants
  - Claustrophobia
- Optimal usage requires experience and intensive testing
- Creation of a wide range of images
  → time-consuming task

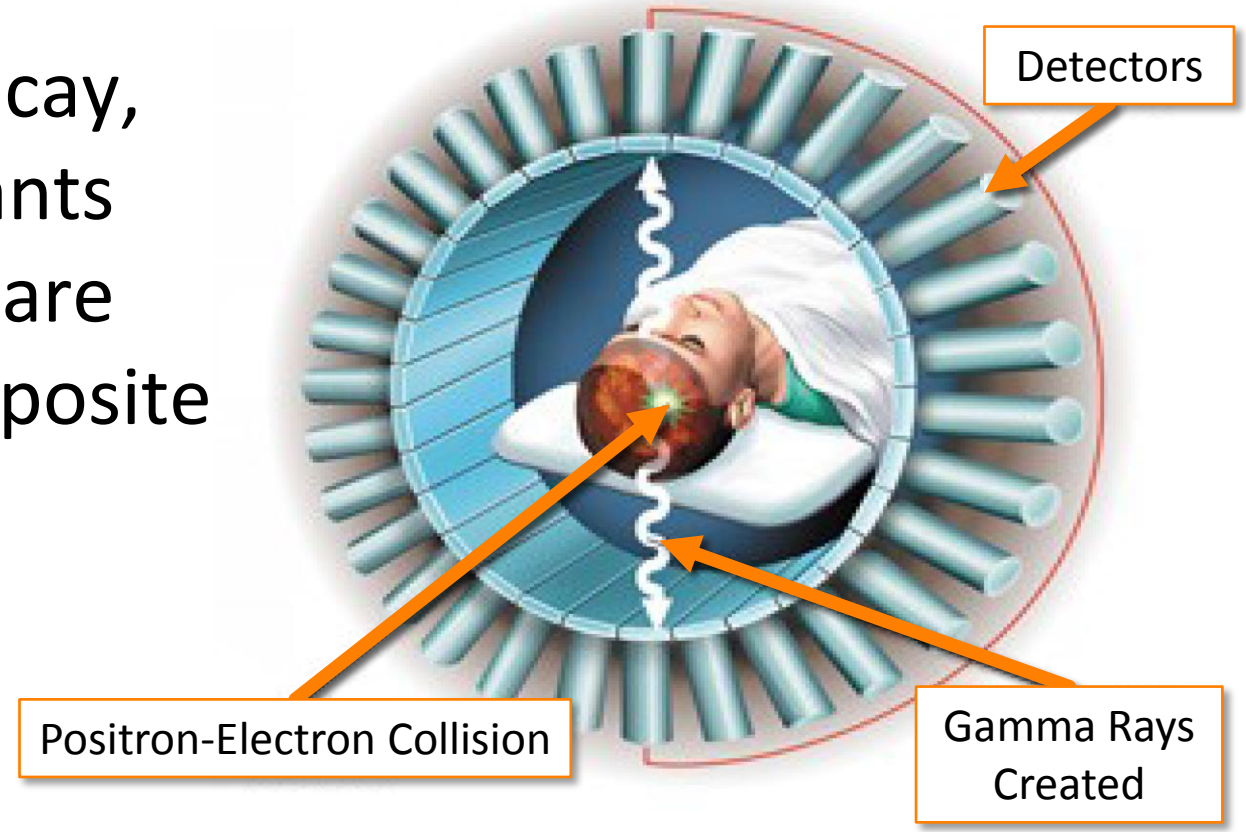
- Inexpensive
- Fast scanning times (approx. 40 sec for a full body scan)

Positron Emission Tomography (PET)

- Nuclear medicine procedure
- Radioactively marked substances (e.g. ^{11}C, ^{13}N)
- Displays physiological processes
  - Metabolism
  - Blood circulation
  - …
- Used isotopes (radionuclides)
  - Half-life of only a few minutes (requires local production)
  - Injected or inhaled

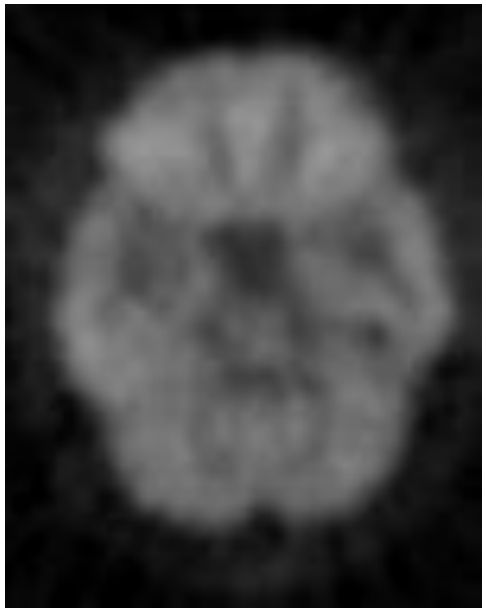
Positron Emission Tomography (PET)

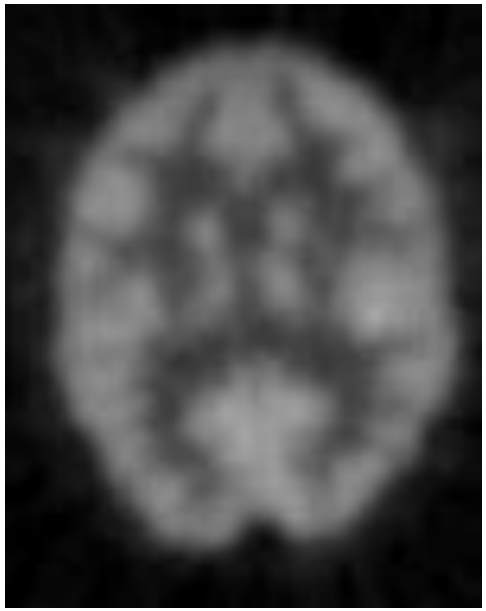
- Most sensitive nuclear medicine procedure
- Displays positrons emitted during decay of an atomic nucleus
- During the decay, 2 gamma-quants with 511 keV are emitted in opposite direction



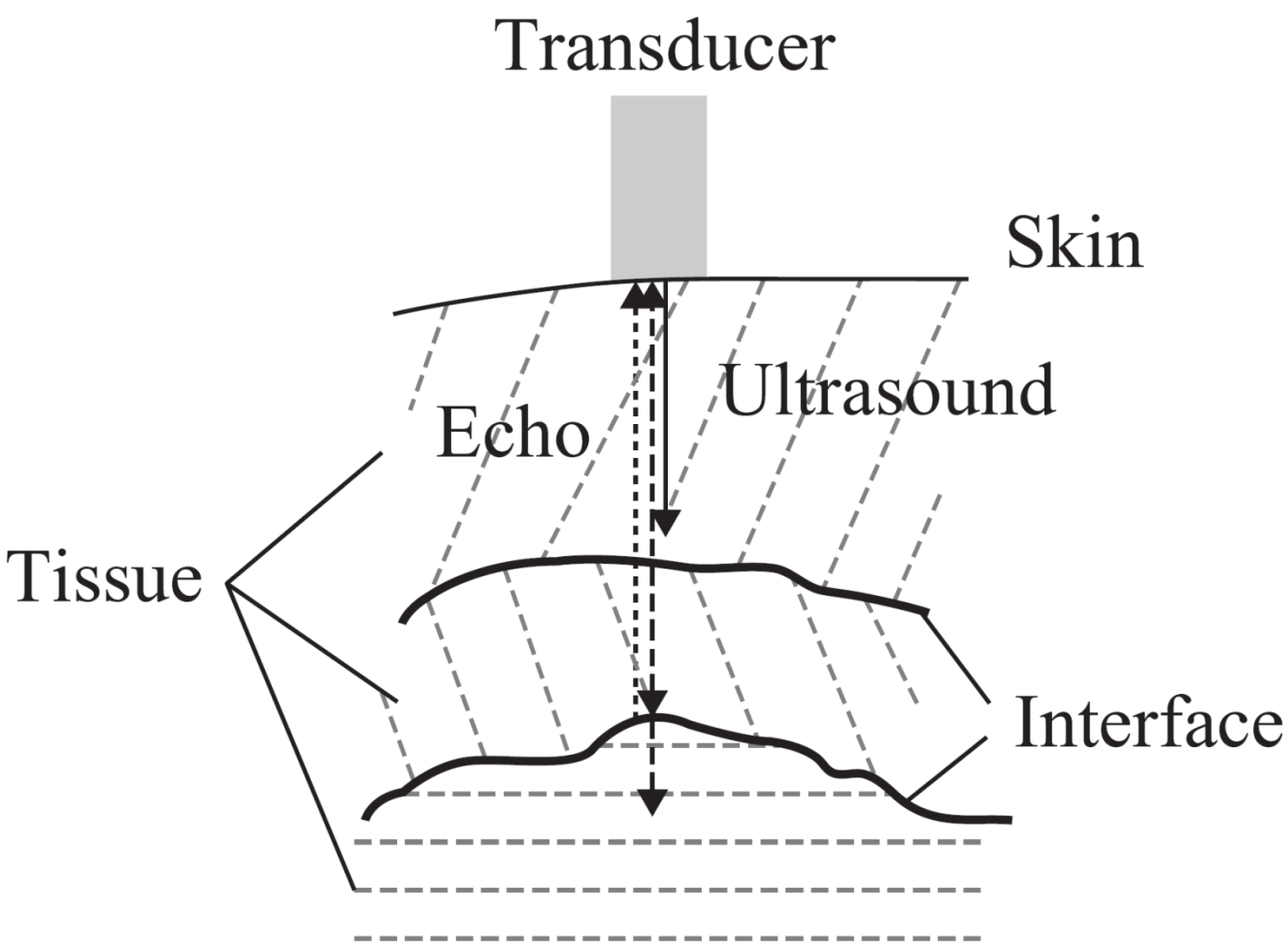
Positron Emission Tomography (PET)

- Resolution: 1-2 mm (head), otherwise 2-3 mm, image matrices: 64x64 and 128x128
- Application areas:
  - Examination of growth and metabolism of (brain) tumors
  - Epilepsy
  - Cardiology (infarct studies)





Ultrasound (US)



[Sakas et al. 1995]

Ultrasound (US)

- Pros
  - Not invasive
  - Relatively cheap procedure
- Cons
  - Noise and speckle
  - Less contrast than tomographic methods
  - Unsharp boundaries with varying gray values due to surface orientation
  - Interpretation requires considerable experience
  - No standardized data export such as DICOM

Ultrasound (US)

- Application areas:
  - Diagnosis and intraoperative navigation
  - Abdominal tumor diagnosis
  - Artery plaque measurements
  - Fetal examinations

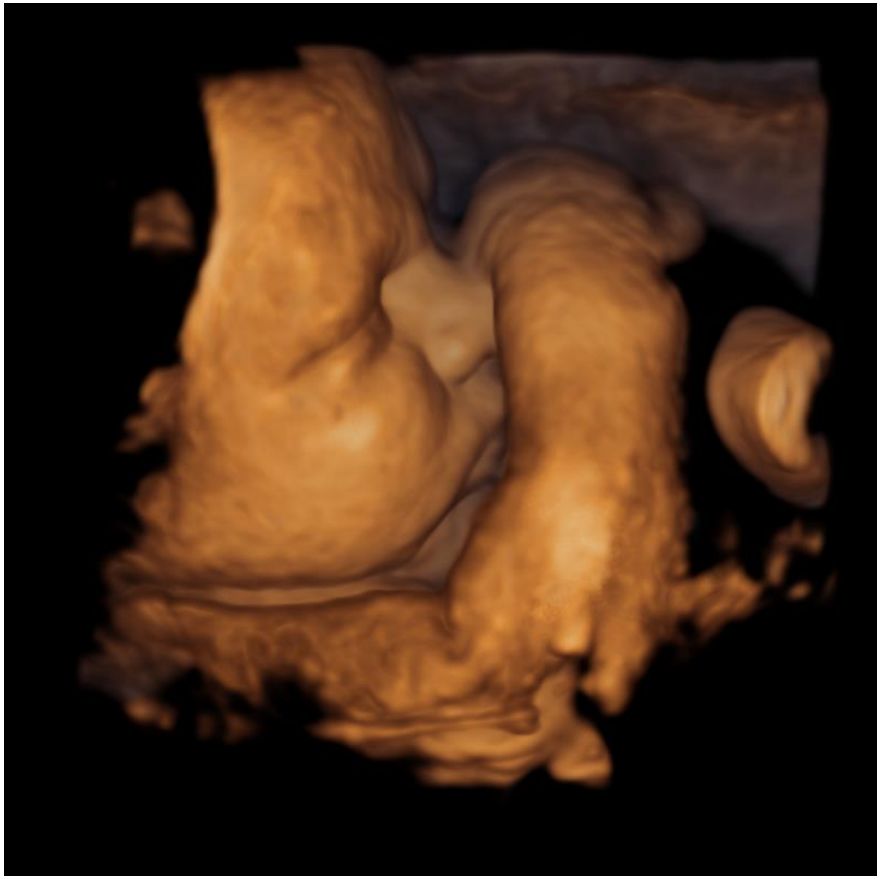
Ultrasound (US)

- Application: Fetascopic rendering

(© GE Healthcare)

Ultrasound (US)

- Application: Fetascopic rendering



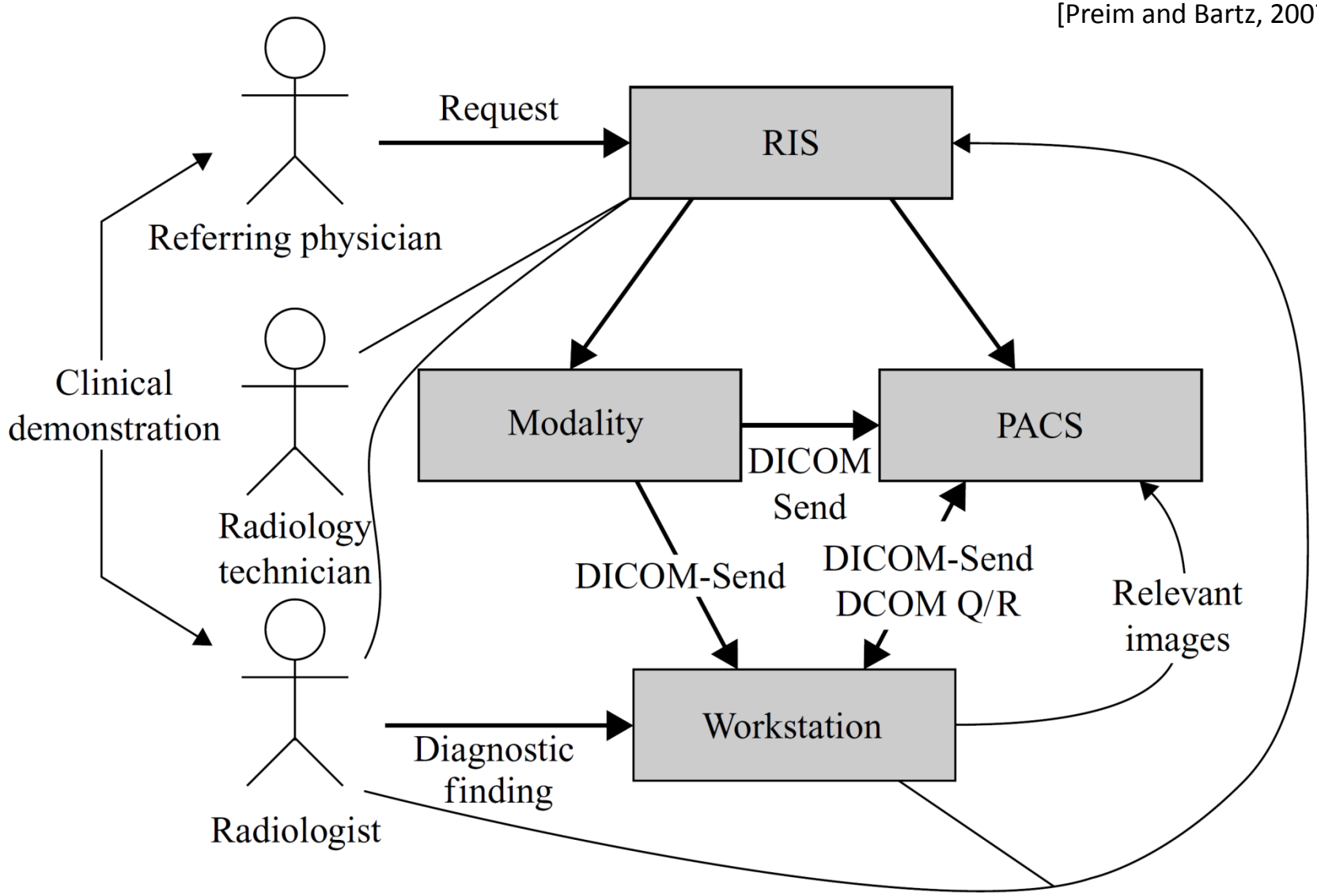
(© GE Healthcare)

Medical Imaging Workflow

- Large variety of imaging modalities
- Large variety of output devices (printer, monitors with different spatial and gray value resolution)
- Huge amount of data archived
- Imaging devices, output devices, workstations are interconnected
- Performance problems due to the large amounts of data are frequent and annoying
  → Spatial resolution is often reduced to avoid performance problems

Medical Imaging Workflow

[Preim and Bartz, 2007]



Medical Imaging Workflow – Requirements

- Interoperability of devices from different manufacturers
- Standardized image data format
- Data protection, security and reliable identification of patient
- „Correct“ or optimal display on different output devices

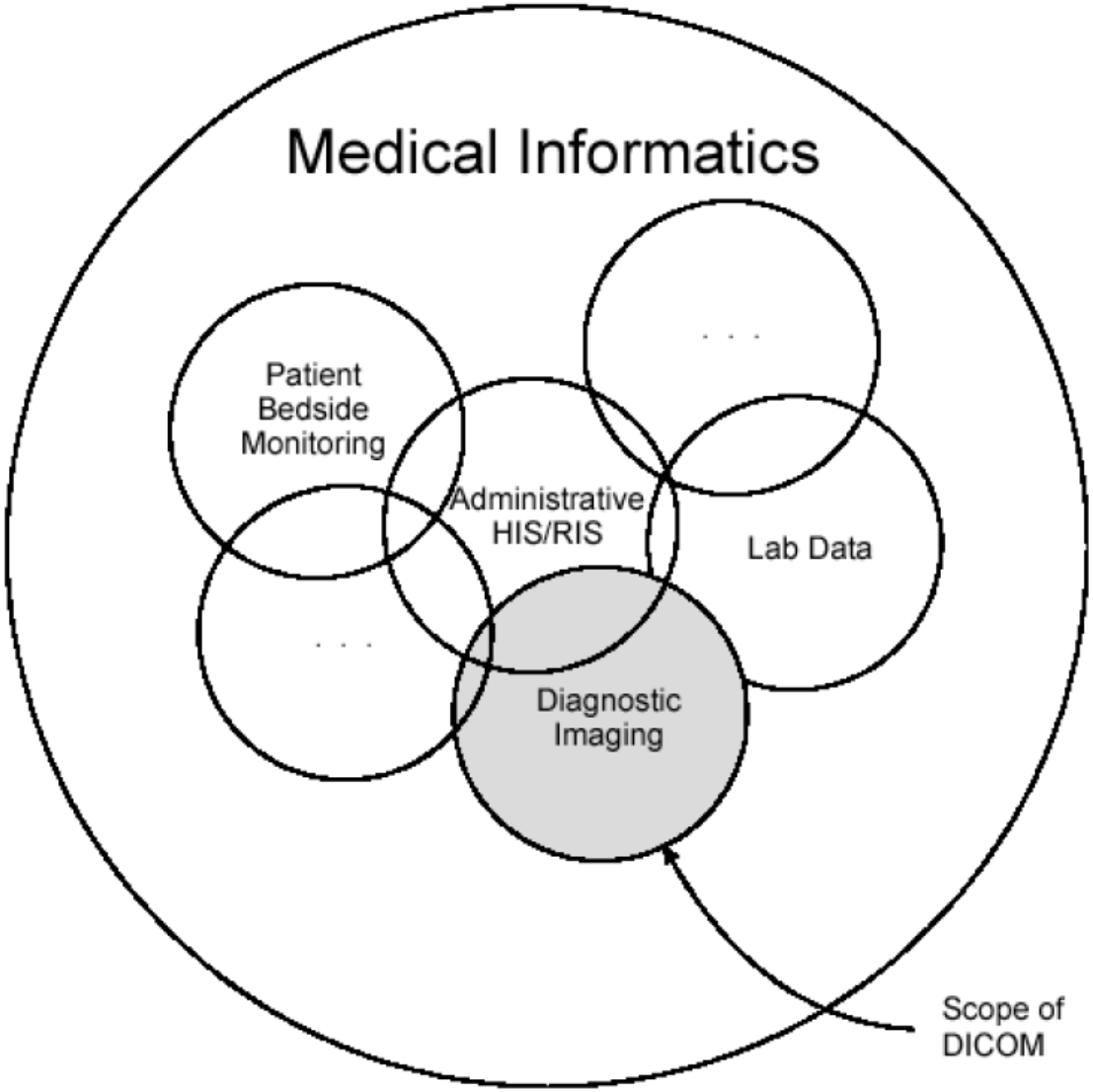
Medical Imaging Workflow

- Soft copy reading
  - Images are not printed
  - Stored in a database, **P**icture **A**rchiving or **C**ommunication **S**ystem (PACS)
- Task
  - Windowing
  - Browsing slices
- Analysis tools
  - Length measurements
  - Intensity distribution in a region

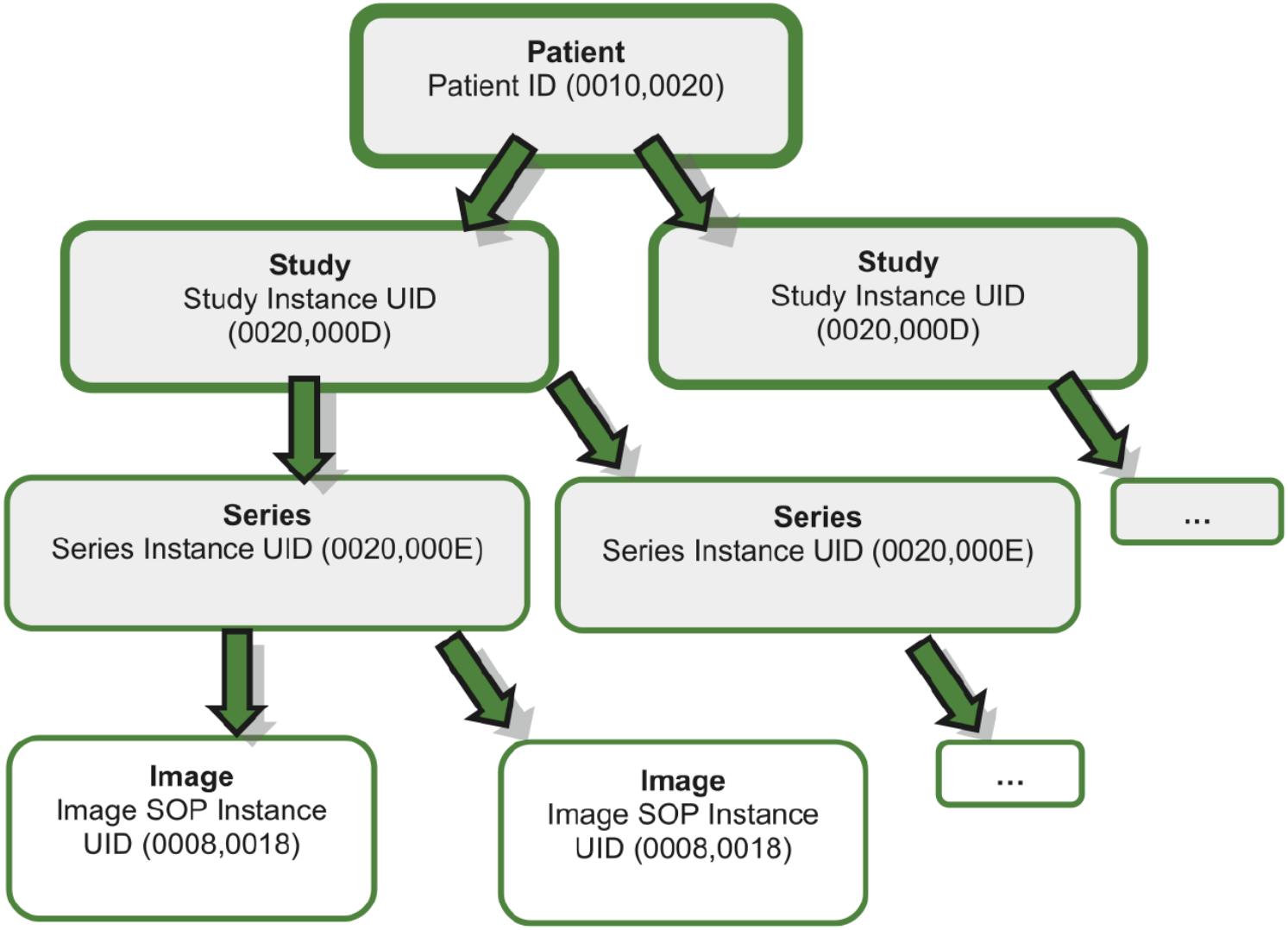
DICOM

- **D**igital **I**maging and **Co**mmunications in **M**edicine (DICOM)
- Defines a set of protocols to be followed by devices claiming DICOM conformance
- The syntax and semantics of commands and associated information which can be exchanged using these protocols
- Information that must be supplied with an implementation for which the DICOM conformance is claimed

Scope of DICOM



Scope of DICOM



[Oleg S. Pianykh, 2012]

DICOM

- Links and documentation
  - http://medical.nema.org/
  - http://dicom.offis.de/dcmintro.php.de

- DICOM viewers
  - Osirix (Mac): http://www.osirix-viewer.com/
  - RadiAnt: http://www.radiantviewer.com/
  - DicomWorks: http://www.dicomworks.com/

DICOM

- DICOM File Meta Information
- DICOM DataSet/Message
  - Sequence of Data Elements
  - Order by Group and data element numbers
- DICOM Data Element
  - Tag
    - Group Number (8 bit)
    - Data Element Number (32 bit)
  - Data length (32 bit)
  - Data (length in bytes)

DICOM Groups

- Even numbers:
  - 0008 Identifying information
  - 0010 Patient
  - 0018 Acquisition
  - 0020 Relationship
  - 0028 Image Presentation
  - 4000 Text
  - 6000-601E Overlay
  - 7FE0 Pixel Data
- Odd numbers vendor specific

DICOM Groups

- Identifying information
  - (0008,0020) DA Study Date # yyyy.mm.dd
  - (0008,0030) TM Study Time # hh.mm.ss.frac
  - (0008,0060) CS Modality

- Patient information
  - (0010,0010) PN Patient Name
  - (0010,0030) DA Patient birth date # yyyy.mm.dd
  - (0010,0040) CS Patient Sex # M, F, O for other

DICOM Groups

- Identifying information
  - (0008,0020) DA Study Date # yyyy.mm.dd
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  - (0010,0040) CS Patient Sex # M, F, O for other

Tag	Value Represent-ation	Attribute Name

DICOM Groups

- Acquisition information
  - (0018,0010) LO Contrast/Bolus Agent # or NONE
  - (0018,0050) DS Slice Thickness # mm
  - (0018,0080) US Repetition Time # ms
  - (0018,0081) DS Echo Time # ms
  - (0018,1120) DS Gantry Tilt # degrees

- Relationship information
  - (0020,1040) LO Position Reference # eg. iliac crest
  - (0020,1041) DS Slice Location # in mm (signed)

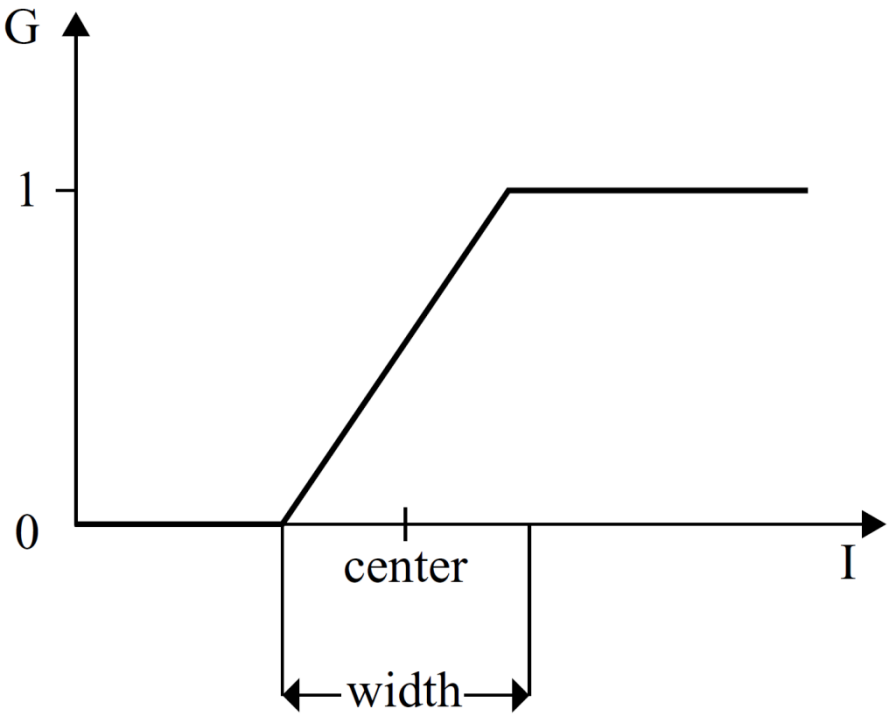
DICOM Groups

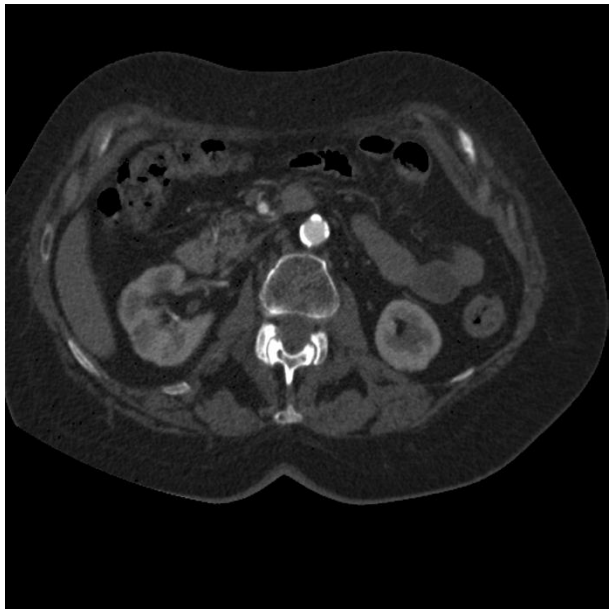
- Image representation
  - (0028,0010) US Rows
  - (0028,0011) US Columns
  - (0028,0030) DS Pixel Size # row\col in mm
  - (0028,0100) US Bits Allocated # eg. 12 bit for CT
  - (0028,0101) US Bits Stored # eg. 16 bit
  - (0028,0102) US High Bit # eg. 11
  - (0028,0103) US Pixel Representation

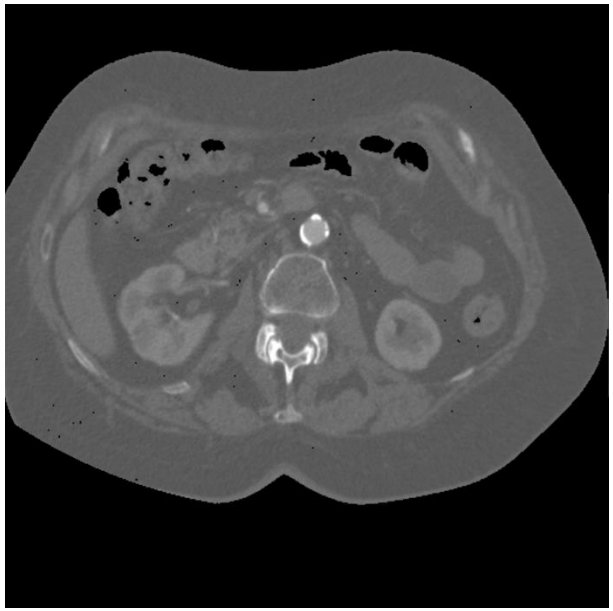
- Data can be anonymized!

Windowing Function

- Maps 12 bits to 8 bits
- Brightness / contrast







Questions?

- Webpage: http://cg.tuwien.ac.at/courses/MedVis2/VU.html
- Abgabesystem: https://lva.cg.tuwien.ac.at/vismed2/

References

- A. Amirkhanov, C. Heinzl, N. Reiter, J. Kastner, M. E. Gröller: Projection-Based Metal-Artifact Reduction for Industrial 3D X-ray Computed Tomography, *IEEE Transactions on Visualization and Computer Graphics*, 17(12):2193-2202, 2011
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- Alexey Karimov
- Artem Amirkhanov