Medical Robotics
Lecture 18
Medical Imaging
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Outline

- Introduction of Image Guided Procedures
- Medical Imaging
  - Specifications
  - Modalities
  - Image guided robotic procedures

Resources:

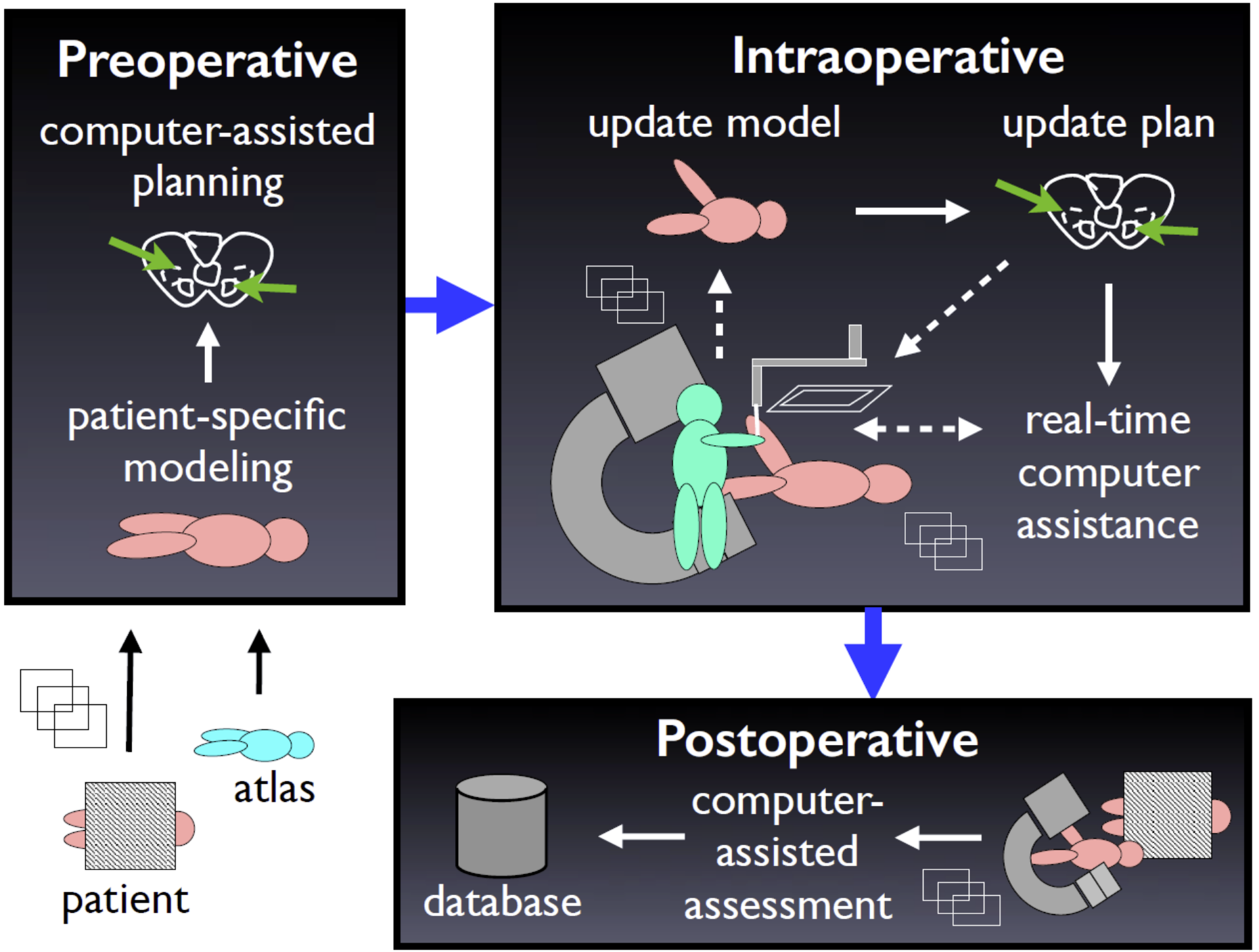
- Professor Allison Okamura, Stanford
- Image-Guided Interventions, edited by Terry Peters and Kevin Cleary
- Image-Guided Procedures: A Review, by Ziv Yaniv and Kevin Cleary (2006)

Image Guided Procedures

- **Goal:** Image guidance enables minimally invasive procedures
- Previously: surgery
- Now: a wide variety of specialties exist for medical interventions, and they are not all considered "surgery".

Time Line of Image Guided Procedures

- Phase I: Pre-operative planning
- Phase II: Intraoperative procedure
- Phase III: Postoperative assessment

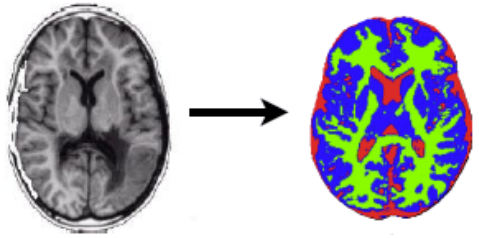

Preoperative
computer-assisted planning
patient-specific modeling
Intraoperative
update model
update plan
real-time computer assistance
Postoperative
computer-assisted assessment
database
atlas
patient

Key Technologies of Image Guided Procedures

medical imaging and image processing

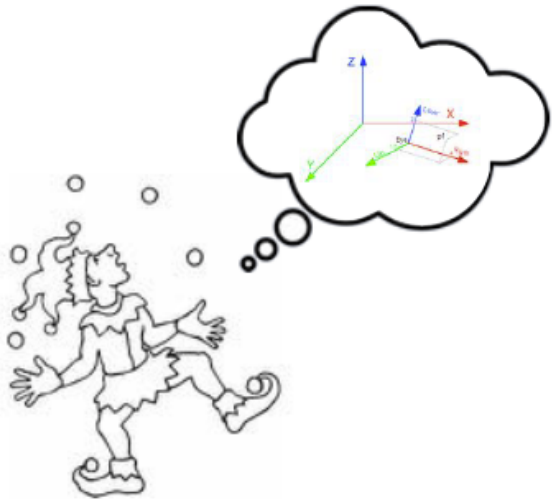
replaces vision

data visualization and image segmentation



replaces visual reasoning

registration, tracking systems, and human-computer interaction

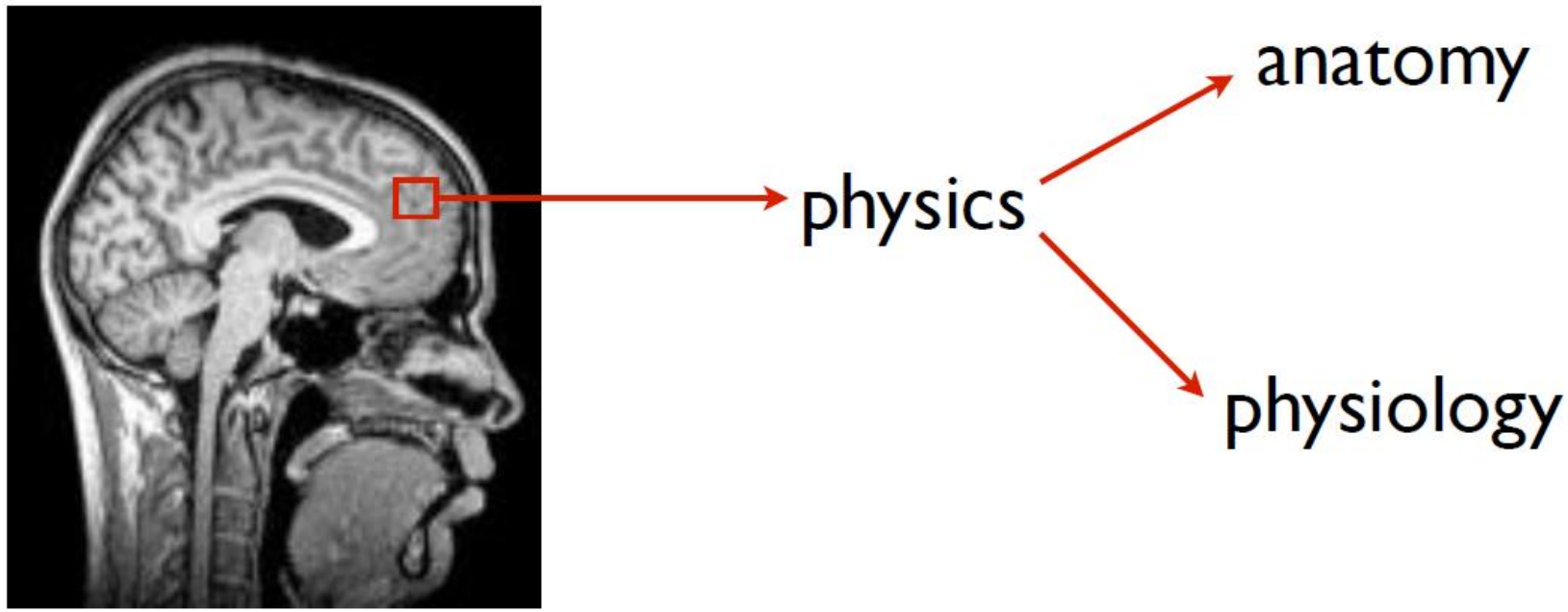


replaces hand-eye coordination

Medical Imaging

Why?

- intensity values are related to physical tissue characteristics which in turn relate to
  - (1) anatomical information and/or
  - (2) a physiological phenomenon



Selecting an Imaging Modality – Key Specifications?

Technical Specifications

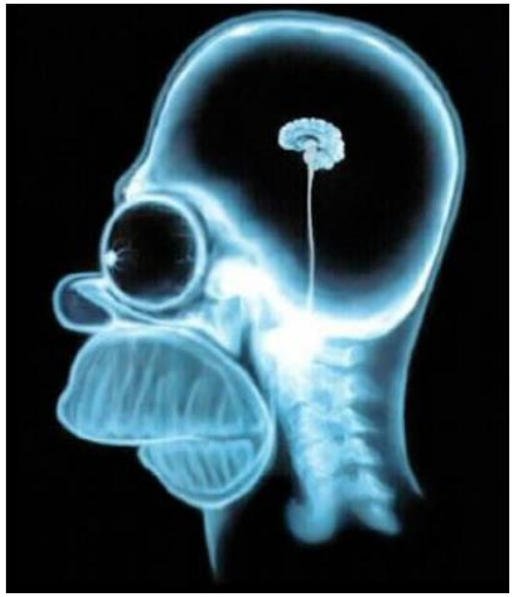
- spatial resolution
- temporal resolution
- imaging contrast
- field of view (including tissue penetration)
- types of biological and physiologic information
- metric accuracy
- interactions between imaging/procedure

Types of Medical Imaging – Anatomical vs Functional

traditional imaging

vs.

functional imaging



physiologic information is interpreted

physiologic information is computed

Types of Medical Imaging – 2D vs 3D

Projection imaging:

- **2D** cross images are generated by capturing a "view" from a single direction

Tomographic images:

- **3D** images are generated by stacking a set of 2D cross sectional image slices
- derived from the Greek tomos (slice) and graphein (to write)

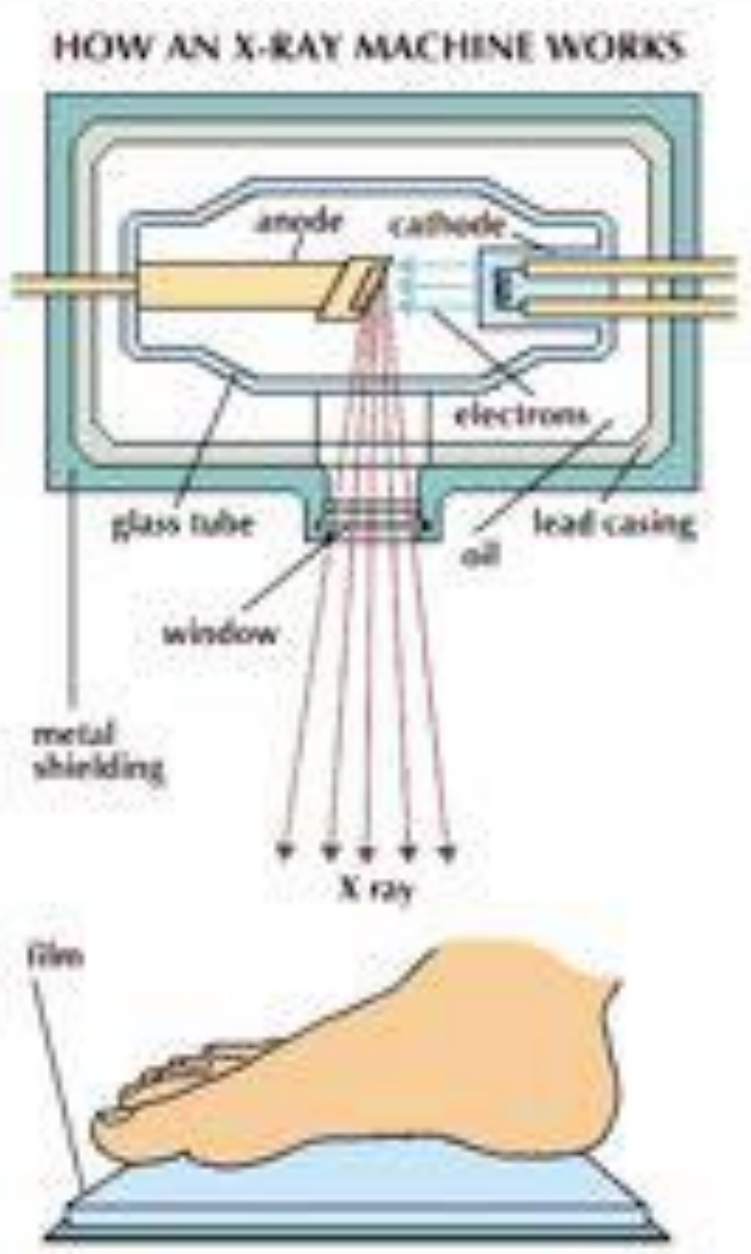
Types of Medical Imaging – Modalities

- **X-rays**: film, digital, fluoroscopy, Digital Subtraction Angiography (DSA)
- **CT**: Computed Tomography
- **Ultrasound**: 2D and 3D (stack of slices)
- **MRI**: Magnetic Resonance Imaging
- **Video**: laparoscopes and endoscopes (discussed later)
- **NM: Nuclear Medicine** (not covered)
  - PET -- Positron Emission Tomography
  - SPECT -- Single Photon Emission Tomography

X-Ray

- Oldest Medical imaging Modality (1895)
- Physics: density of x-ray absorption
- Invented by German scientist Wilhelm Röntgen
- Marie Curie developed first mobile x-ray in WWI
- Grey value on film is proportional to radiation energy

first “medical” x-ray, 1895



http://www.britannica.com/

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X-Ray – From Film to Digital

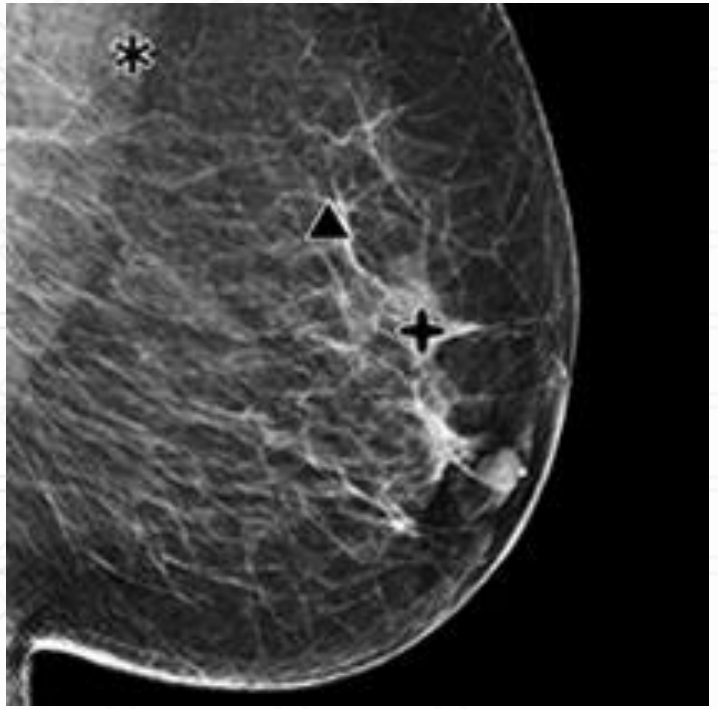
- traditional X-ray film is replaced by solid-state detectors that convert X-rays into electrical signals (CCD camera)

Advantages:

1. there is no film to process, so the images are available immediately
2. digital images can be shared or enhanced electronically
3. digital images can be used for computer-assisted detection (helps doctors confirm or draw more attention to suspicious areas on a digital image)
4. essential for real-time decision making in robot-assisted interventions

X-Ray – Mammography Example

- uses low-energy X-rays for detection of early cancer

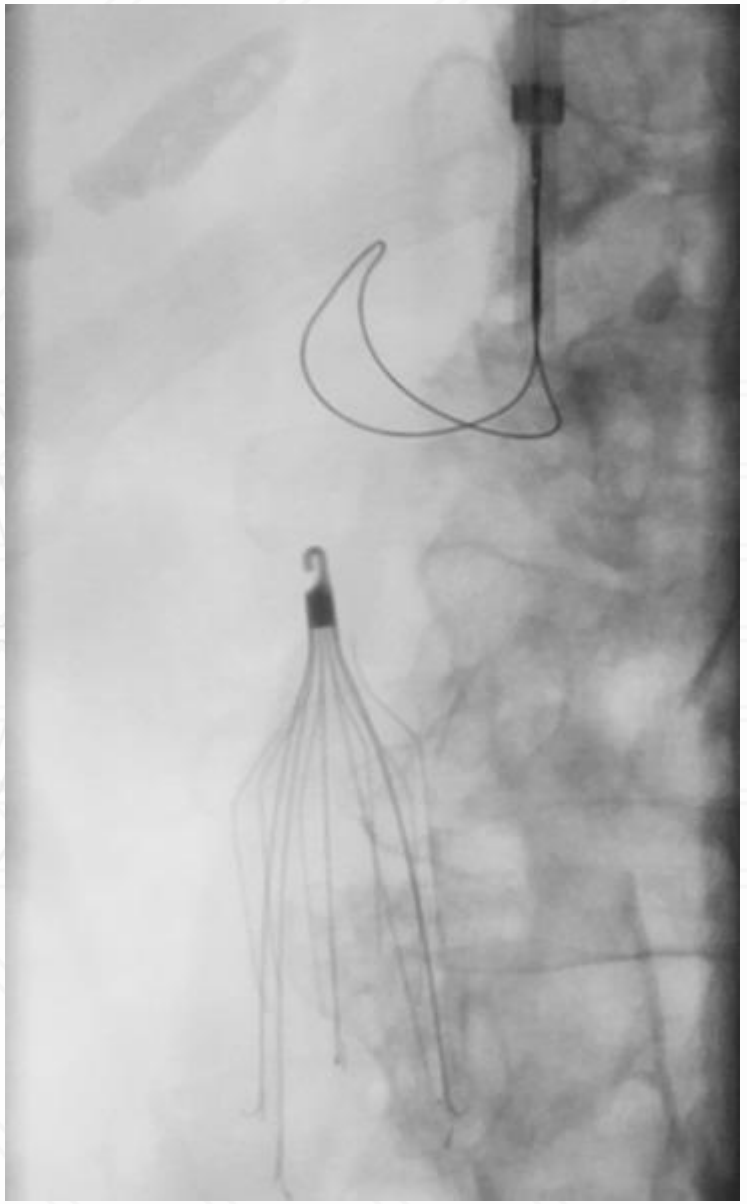


Hologic.com

X-Ray – Fluoroscopy

- X-ray movies: Used to guide interventions

Philips Healthcare



Example: Blood clot filter removal

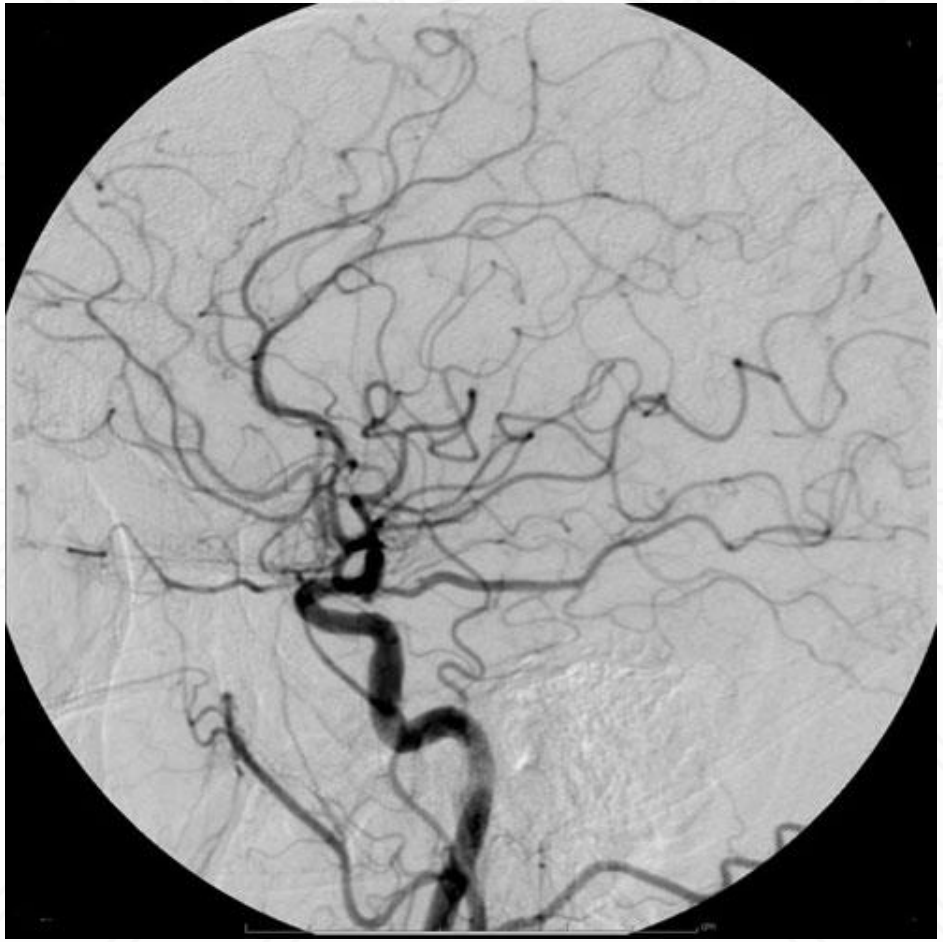
X-Ray – Robotic C-Arm

- Imaging from Different Angles

Siemens Zeego (CT-like imaging, more on CT later)

X-Ray – digital subtraction angiography (DSA)

- create a pre-contrast image, then subtract it from later images after a contrast medium has been introduced



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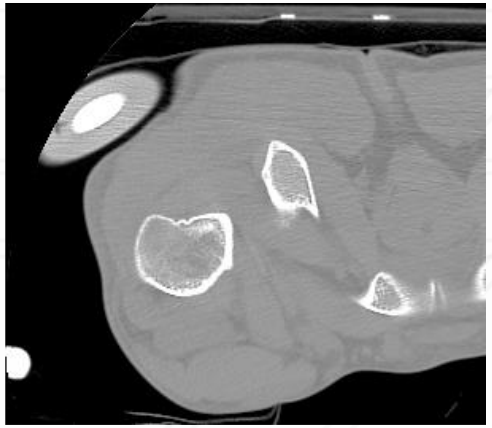
Iodine and barium are common contrast mediums

X-Ray – Discussion

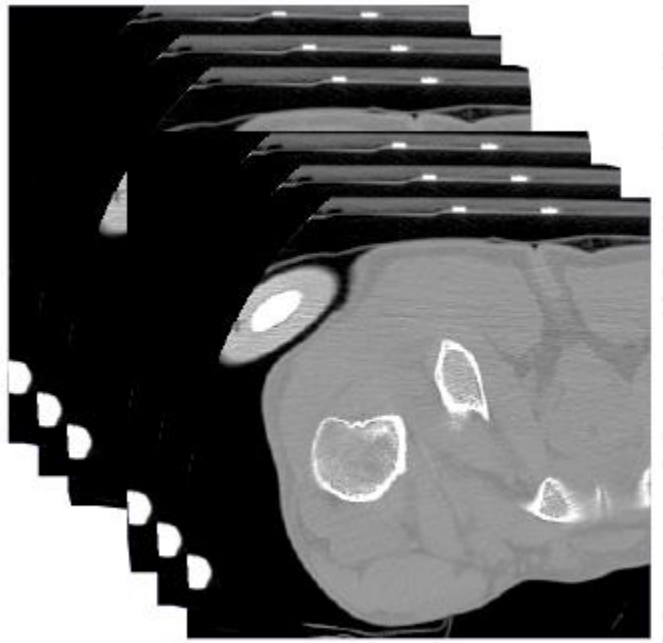
- how can robots improve x-ray/fluoroscopy procedures?
- how can x-ray/fluoroscopy be used in robotic interventions?

CT – Computed Tomography

- 3D images are generated from a large series of 2D X-ray images taken around a single axis of rotation
- Physics: Same as X-Ray



Single slice



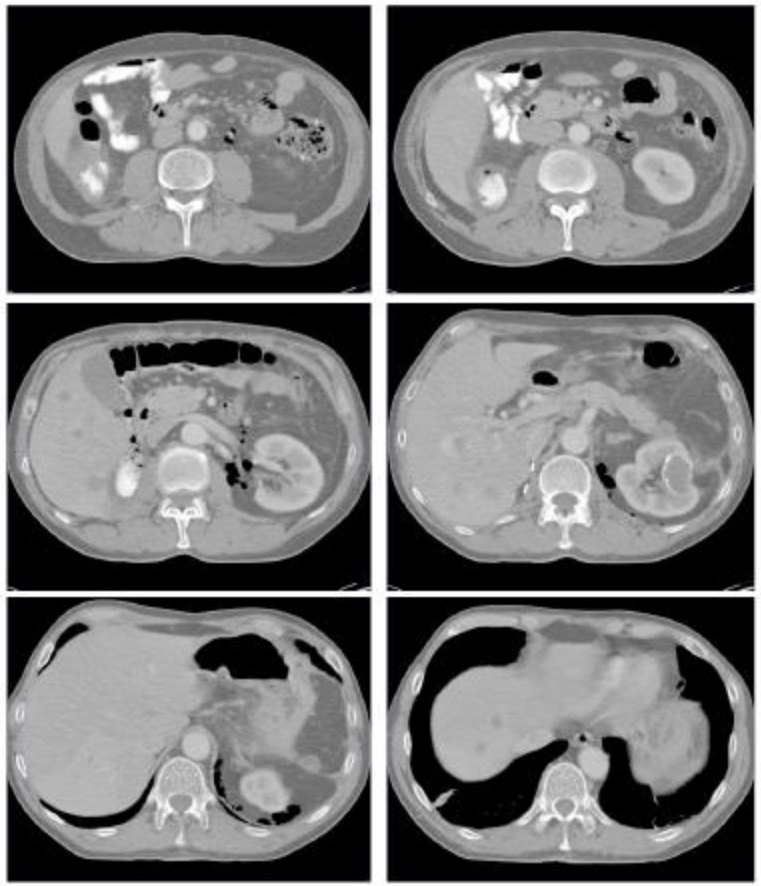
Series of parallel slices 2mm apart

Source: L. Joskowicz

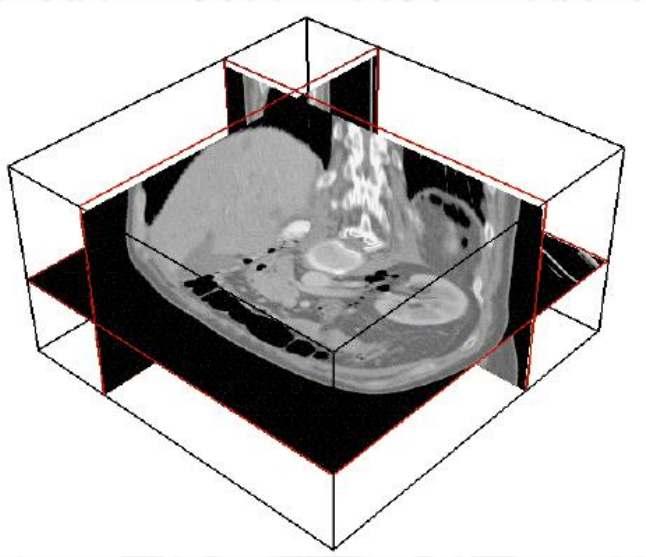
CT – Computed Tomography

- Emitter/Receiver configuration
- https://www.youtube.com/watch?v=M-4o0DxBgZk

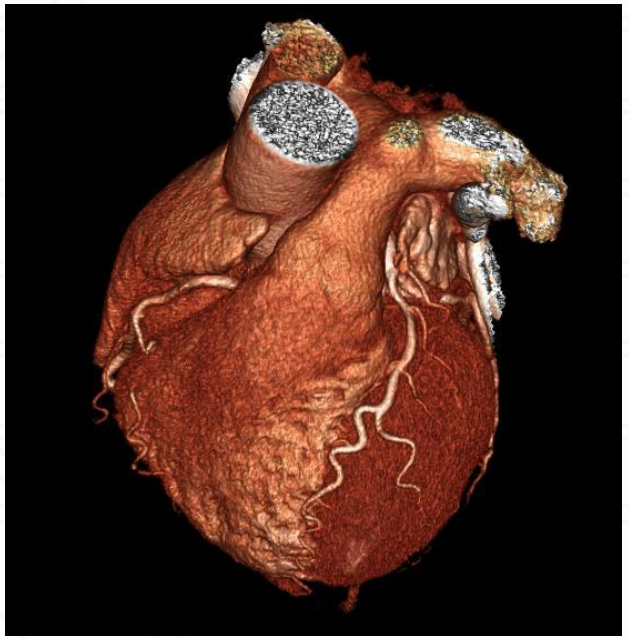
CT – Computed Tomography



Series of 2D Slices



3D Volume Imaging



3D Rendering after filtering and segmentation

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CT Scanners

- Slice count of a CT scanner refers to the number of simultaneous slices a CT scanner can produce from one rotation.

128 slice CT Scanner – Philips Healthcare

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CT Scanners - Discussion

- what challenges might exist in performing CT-guided robotic interventions?

Ultrasound

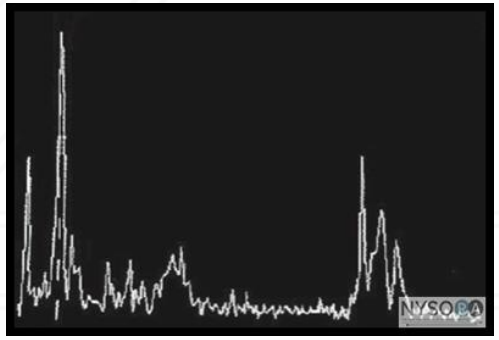
- Physics: variations of acoustic impedance

1. probe sends high-frequency sound waves (1-5 MHz) into the body
2. sound waves travel into tissue and get reflected by boundaries
3. reflected waves are recorded by the probe
4. time of flight gives spatial information about the boundaries

the desired frequency of signal is chosen based on a trade-off of resolution and attenuation

Ultrasound

- **A-mode** (amplitude mode): a single transducer scans a line through the body with the echoes plotted on screen as a function of depth.
- **Therapeutic ultrasound** aimed at a specific tumor is also A-mode, to allow for accurate focus of the destructive wave energy.
- **B-mode** (brightness mode) or 2D mode: a linear array of transducers simultaneously scans a plane through the body that can be viewed as a two dimensional image on screen



A Mode Image

B Mode Image of a Liver with hepatic Veins

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Ultrasound – Example Fetal Ultrasound

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Ultrasound – Characteristics

- No radiation
- Cheap and easy to use
- Fast temporal resolution
- Limited spatial resolution (~1mm)
- Non-uniform, distortion, noisy
- Low penetration properties
- One 2D slice or several slices (2.5D)
- Preoperative and intraoperative use

Ultrasound Machines

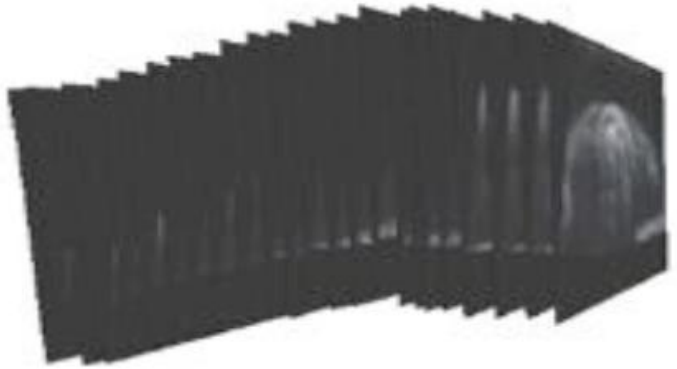
Ultrasonix

ultrasound transducers/probes

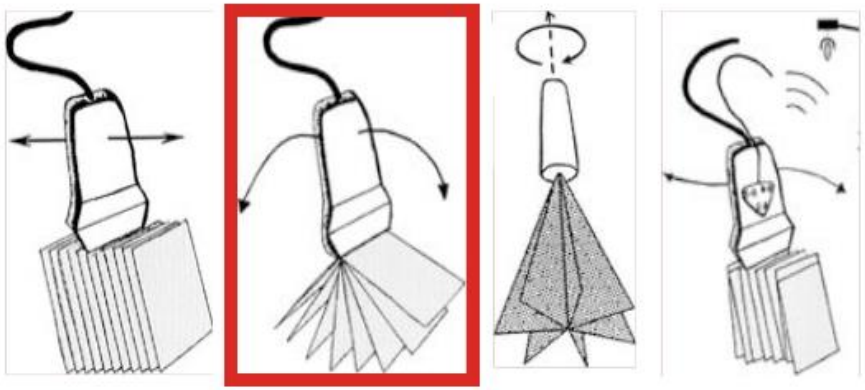
http://used-medicalequipmentblog.blogspot.com/

3D Ultrasound

reconstruct 3D data from 2D slices



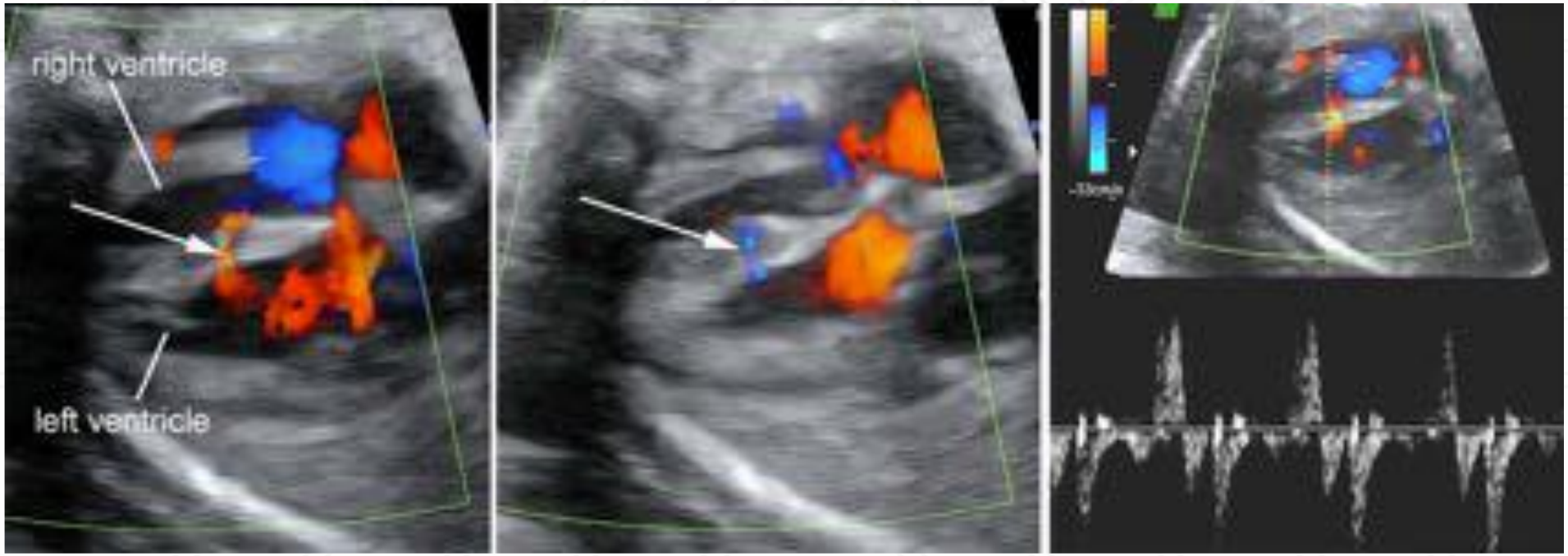
acquisition methods: linear, rotation, fan-like, hand



L. Joskowicz © 2011

Doppler Ultrasound

- employs the Doppler effect to determine whether structures (typically blood) are moving towards or away from the probe, and their relative velocity



Example: color and pulsed Doppler of blood shunting across a muscular ventricular septal defect (in the heart)

Ultrasound- Discussion

- what challenges might exist in performing ultrasound-guided robotic interventions?