ME 328: Medical Robotics
Winter 2019

Lecture 6: Medical imaging and image-guided interventions

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Updates

Assignment 3

Due this Thursday, Jan. 31

Note that this assignment is purposely somewhat open-ended. This and the remaining assignments will continue be like "mini projects".

Tours: Save the dates

Auris Health: Friday, February 22
Intuitive Surgical: Friday, March 1

We will send polls for attendance and drivers. 40 people max. for each.

first, a brief introduction to image-guided procedures

reference: Image-Guided Interventions, edited by Terry Peters and Kevin Cleary

idealized time-line description of image-guided procedures

Phase I: Pre-operative planning

Phase II: Intraoperative plan execution

Phase III: Postoperative assessment

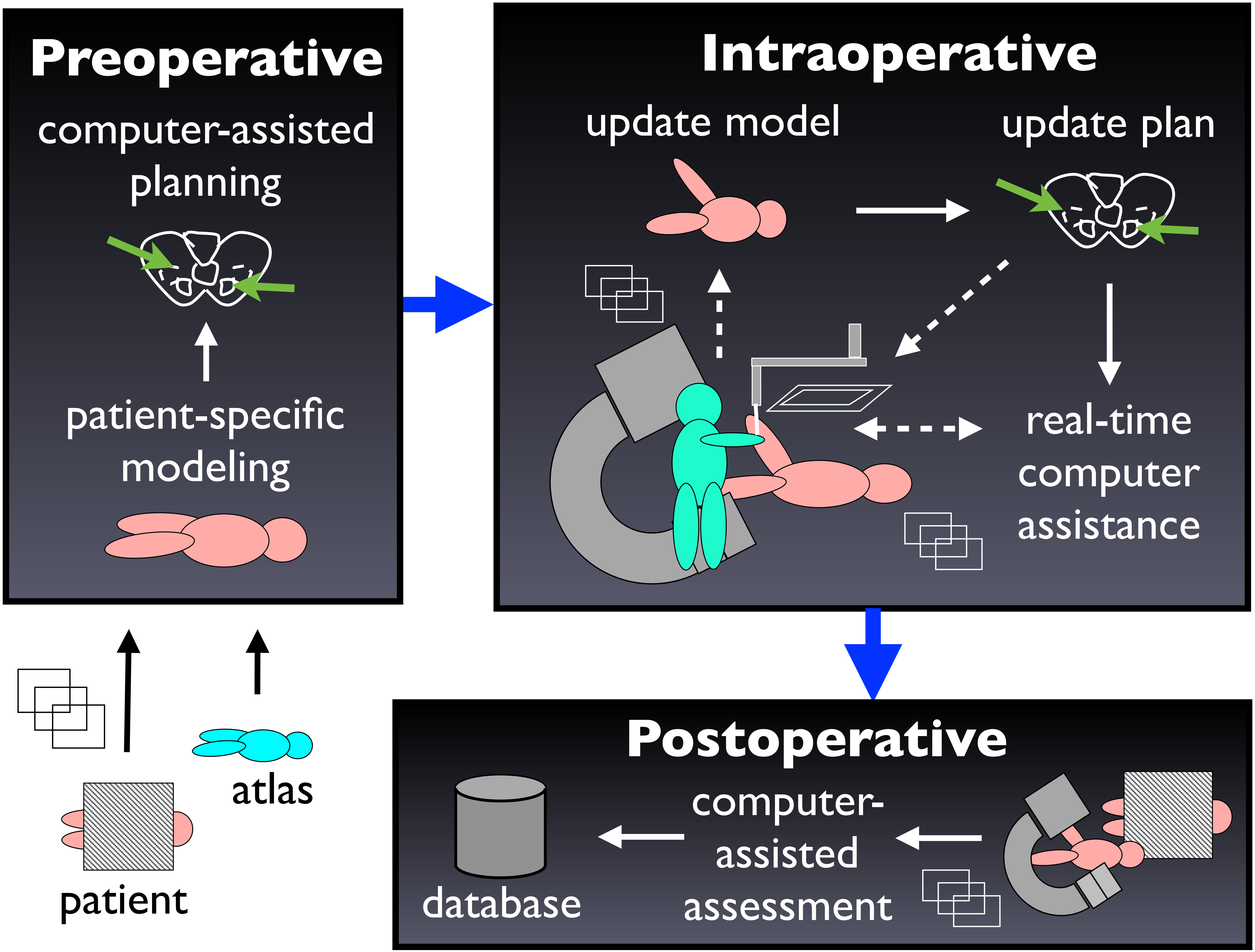

Preoperative
computer-assisted planning
patient-specific modeling
Intraoperative
update model
update plan
real-time computer assistance
Postoperative
database
computer-assisted assessment
patient
atlas

image guidance enables minimally invasive procedures

previously:

surgery

now:

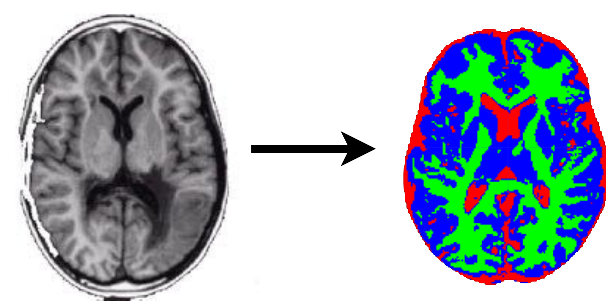
a wide variety of specialties exist for medical interventions, and they are not all considered “surgery” (consider cardiology, radiology)

key technologies associated with image-guided procedures

medical imaging and image processing

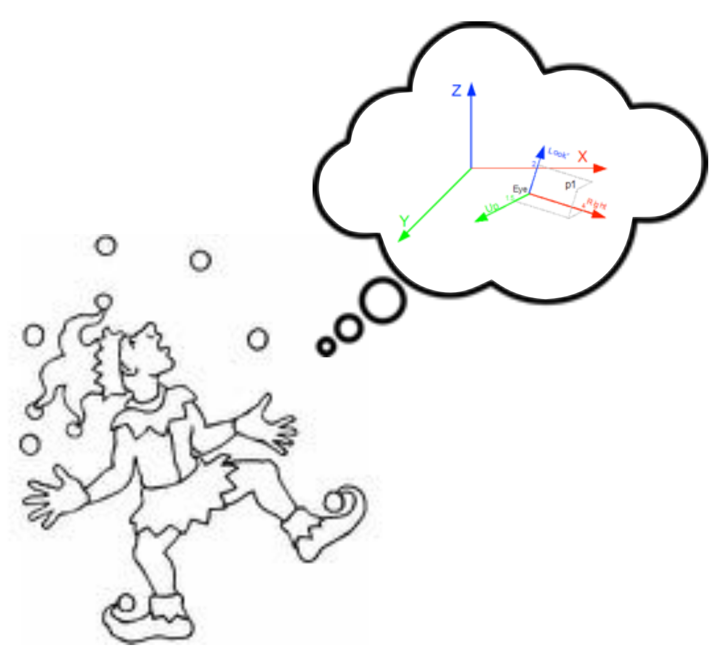
replaces vision

data visualization and image segmentation



replaces visual reasoning

registration, tracking systems, and human-computer interaction



replaces hand-eye coordination

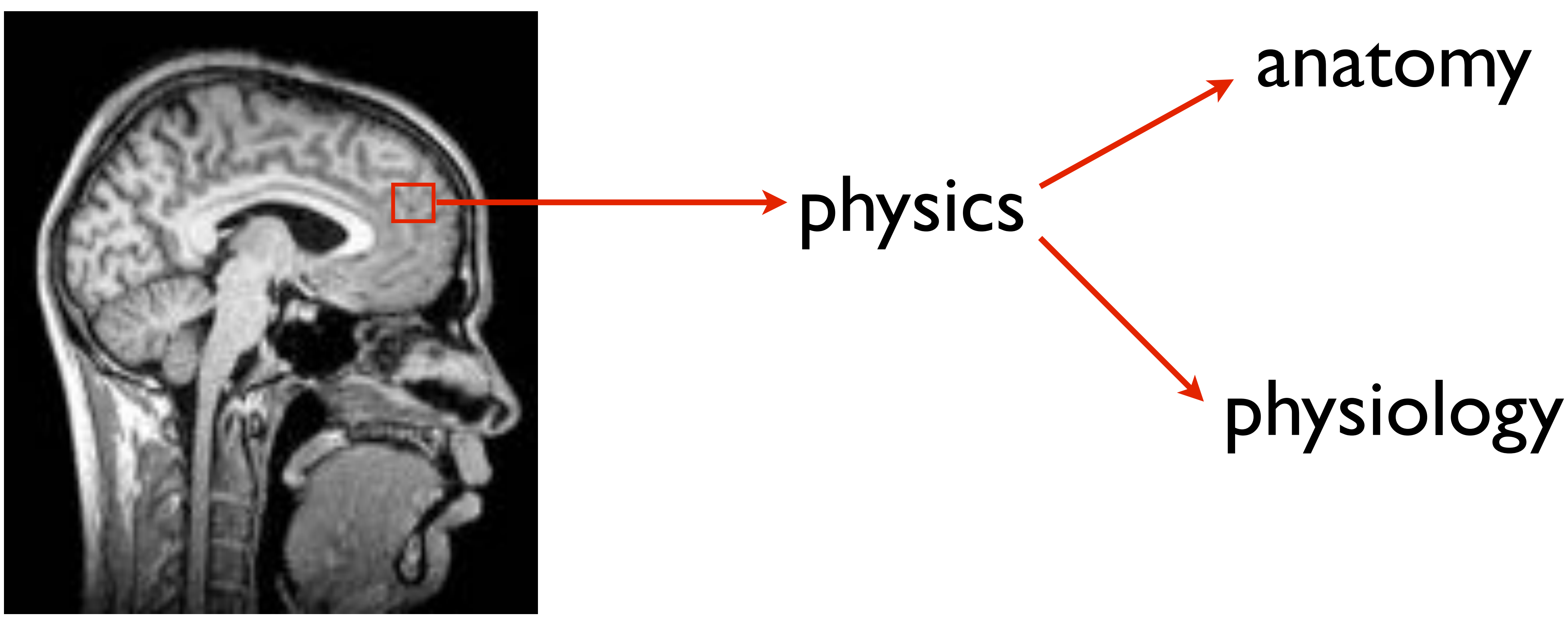
Physicians mentally integrate their knowledge of anatomical structures with patient-specific medical images to produce a plan and execute it.

Image-guided systems use a similar approach, where all information sources are integrated and used to provide guidance to the physician.

Image-Guided Procedures: A Review, by Ziv Yaniv and Kevin Cleary (2006) medical imaging

why use medical images?

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



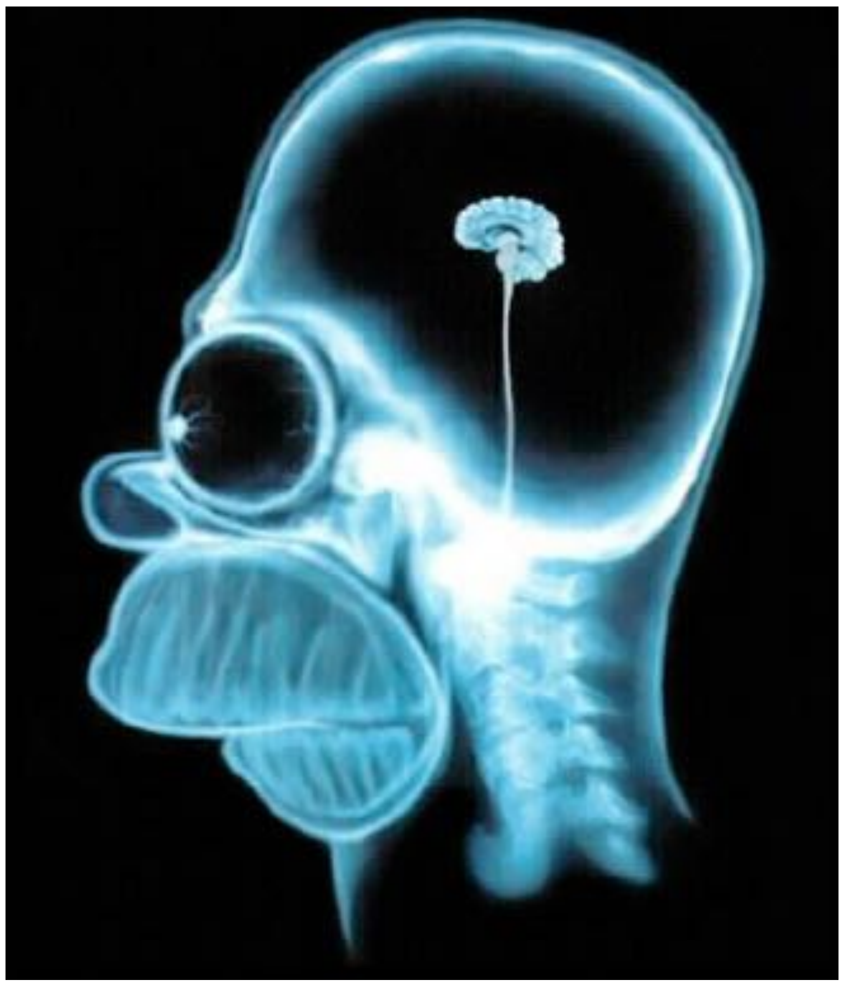
what should you consider when selecting an imaging modality?

technical specifications:

- spatial resolution
- temporal resolution
- field of view
- types of biological and physiologic information

possible interaction between the imaging modality and intervention (e.g., does a metal robot cause image artifacts? does the magnet of the MRI machine cause the robot to malfunction?)

traditional imaging vs. functional imaging



physiologic information
is interpreted

physiologic information
is computed

projection imaging:

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

vs.

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)

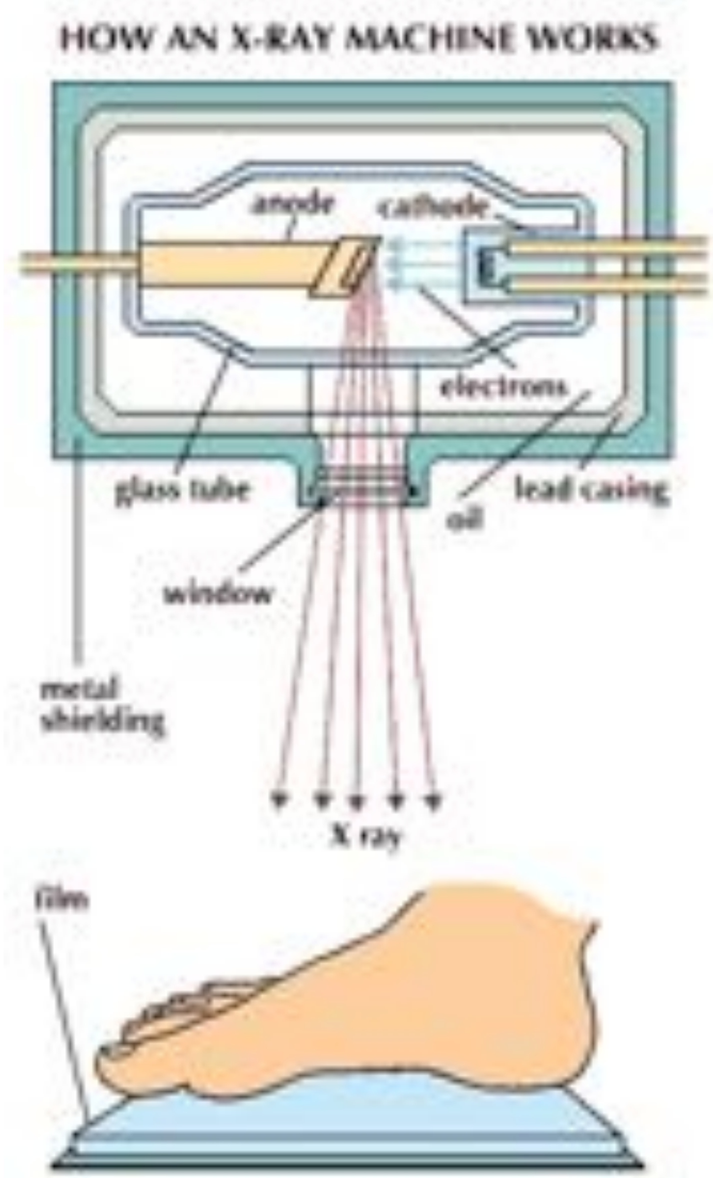
most common types of imaging modalities

- **X-rays**: film, digital, fluoroscopy, Digital Subtraction Angiography (DSA)
- **CT**: Computed Tomography
- **Ultrasound**: 2D and 2.5D (stack of slices)
- **MRI**: Magnetic Resonance Imaging (discussed later)
- **Video**: laparoscopes and endoscopes (discussed later)
- **NM: Nuclear Medicine** (not covered)
  - PET -- Positron Emission Tomography
  - SPECT -- Single Photon Emission Tomography

in the beginning, there was x-ray

physics: density of x-ray absorption (x-rays are a form of ionizing radiation)

first "medical" x-ray, 1895



http://www.britannica.com/

gray value on film is proportional to radiation energy

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

mammogram machine

uses low-energy X-rays for detection of early cancer (microcalcifications)

common screening method, lately somewhat controversial

traditional configurations of x-ray and fluoroscopy machines

early fluoroscope
(Britannica Film)

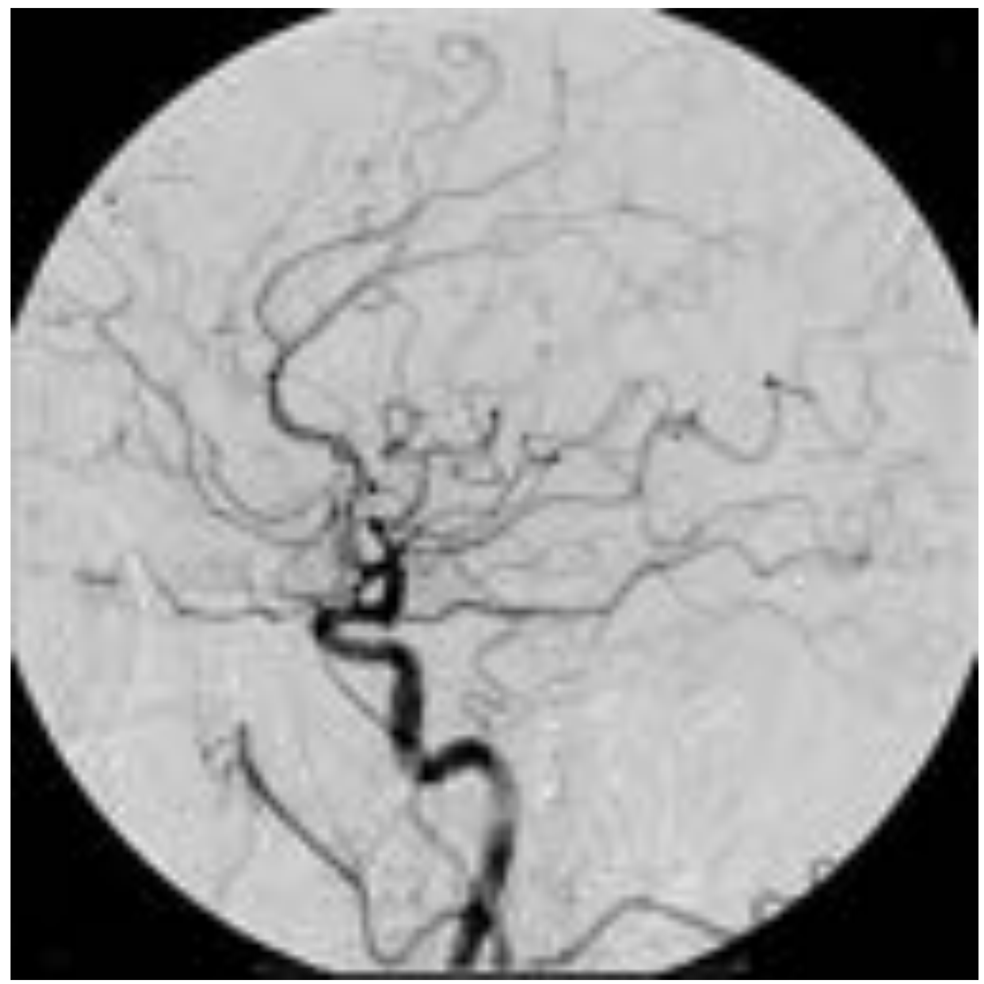
Philips digital multi-
functional X-ray system

c-arm fluoroscopy

Philips XperCT (CT-like imaging, more on CT later)

digital subtraction angiography (DSA)

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



iodine and barium are common types of contrast mediums for x-ray, since they attenuate x-rays (vessels become dark)

discussion

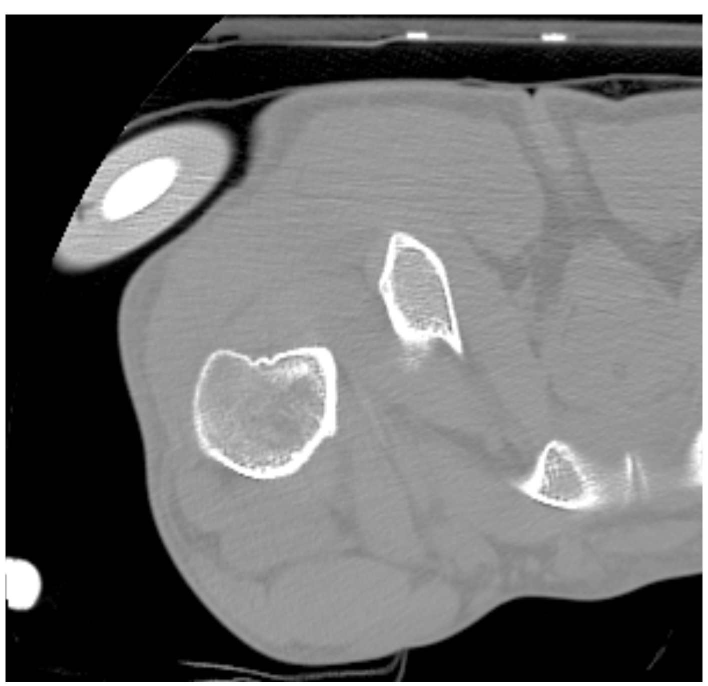
how can robots improve x-ray/
fluoroscopy procedures?

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

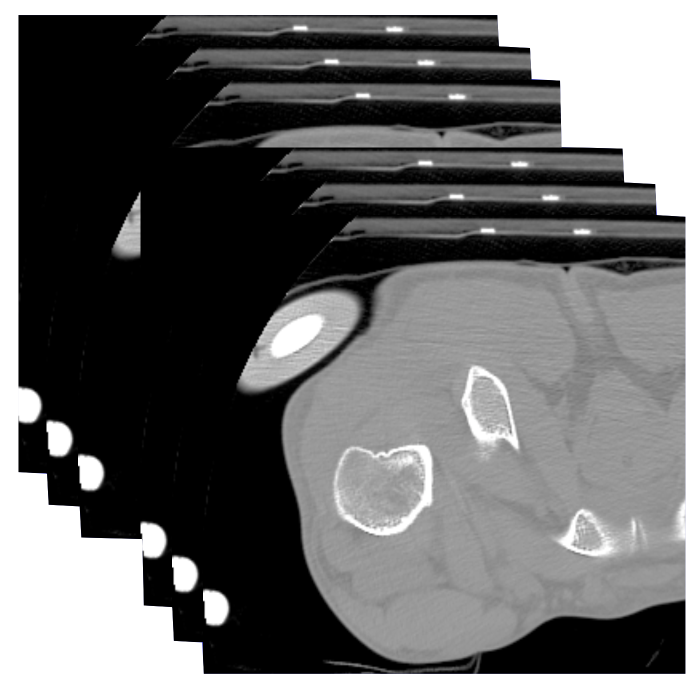
computed tomography (CT scan)

3D images are generated from a large series of 2D X-ray images taken around a single axis of rotation (produces a volume of data for analysis)

physics: same as x-ray



single slice

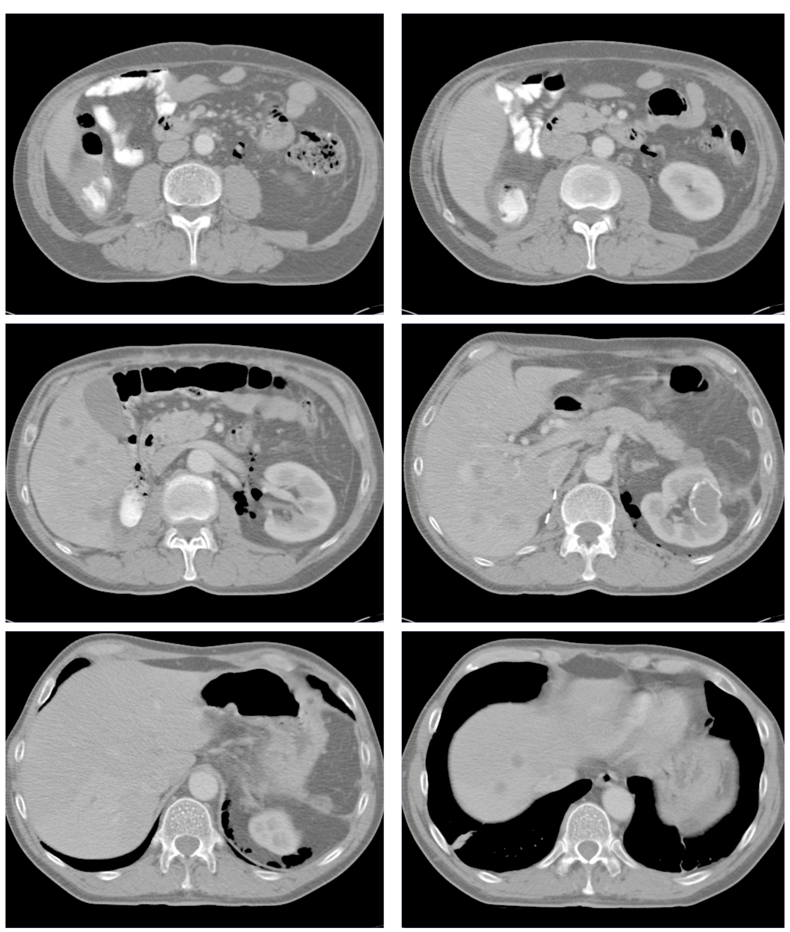


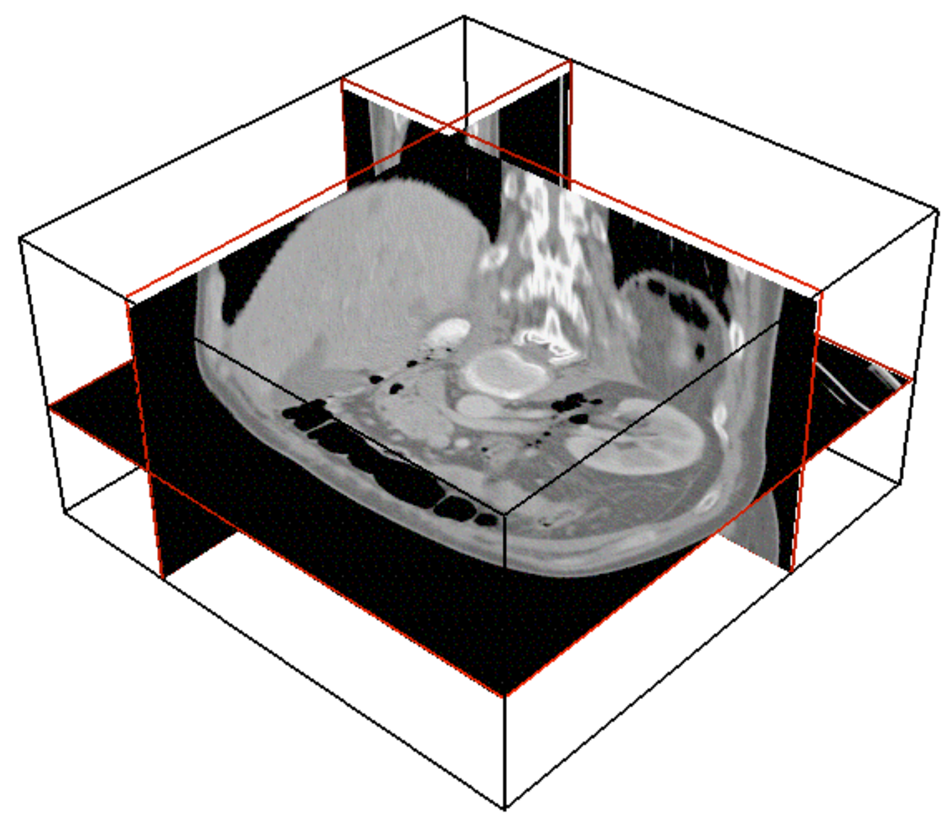
series of parallel slices 2mm apart

computed tomography (CT scan)

3D images are generated from a large series of 2D X-ray images taken around a single axis of rotation (produces a volume of data for analysis)

physics: same as x-ray





emitter/receiver configuration

http://www.youtube.com/watch?v=M-4o0DxBgZk

CT machines

two examples from Philips (Brilliance 6 and 40)

differ in number of images per second, number of detectors, etc.

discussion

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

ultrasound imaging (diagnostic)

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 or calculus is also A-mode, to allow for accurate focus of the destructive wave energy.

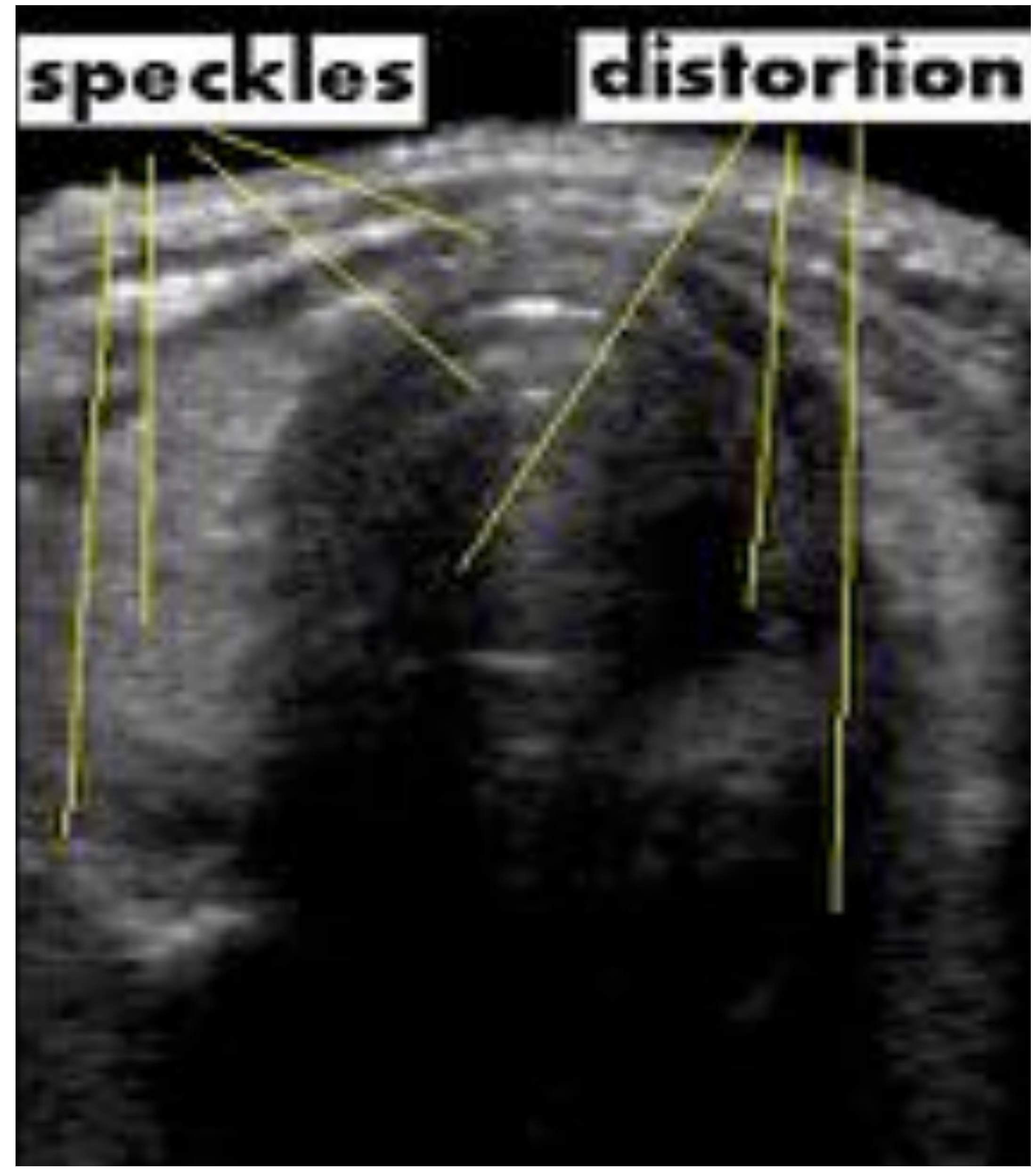
B-mode (brightness mode) or 2D mode: a linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on screen

common application: fetal ultrasound

images courtesy Nora M. Su

ultrasound characteristics

- No radiation
- Poor resolution (~1mm) non-uniform, distortion, noisy
- Low penetration properties
- One 2D slice or several slices (2.5D)
- Relatively cheap and easy to use
- Preoperative and intraoperative use



ultrasound machine

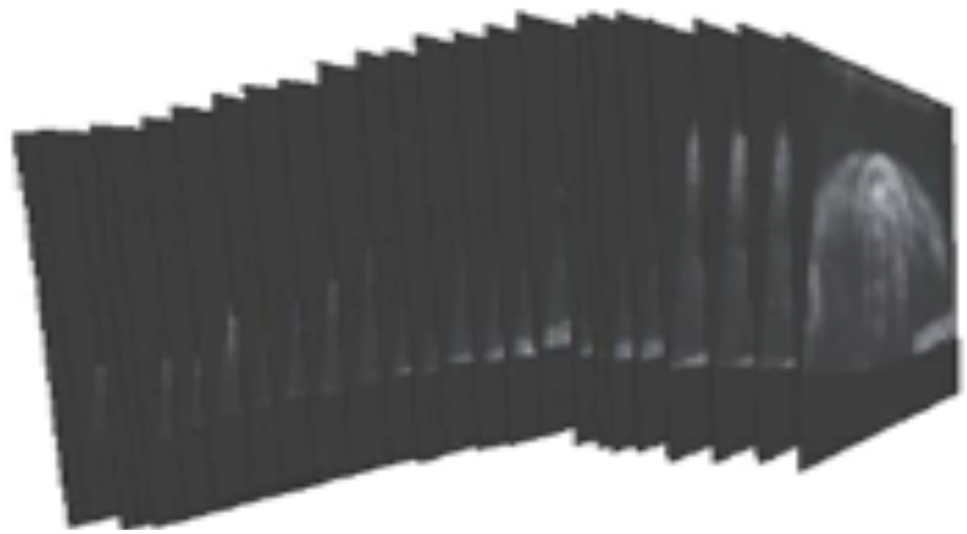
Ultrasonix

ultrasound transducers/probes

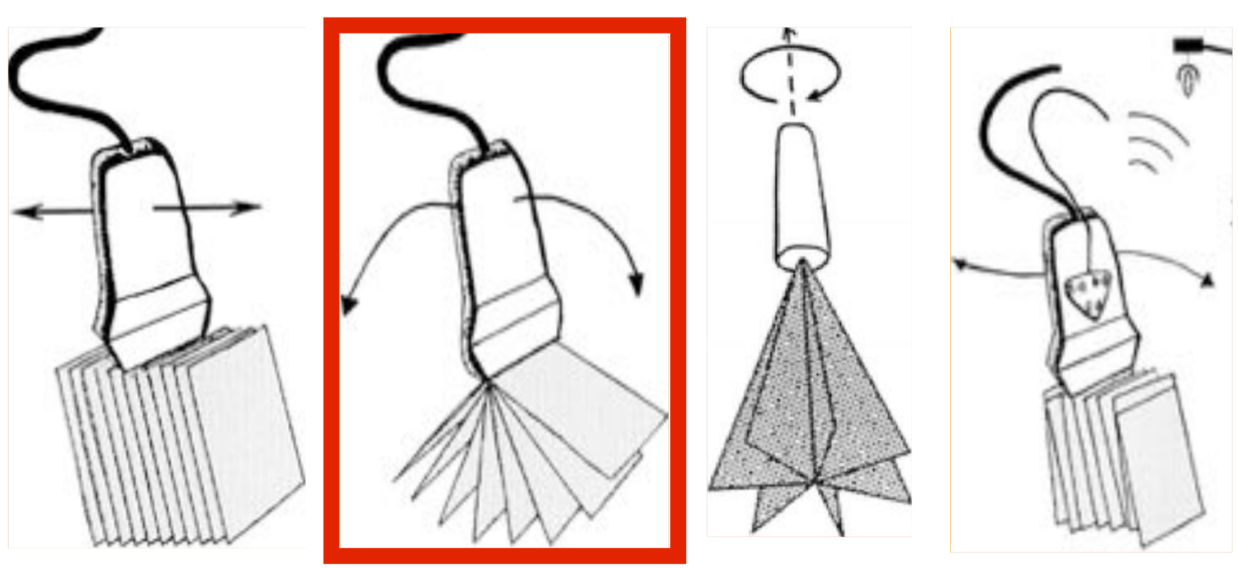
http://used-medicalequipmentblog.blogspot.com/

3D ultrasound

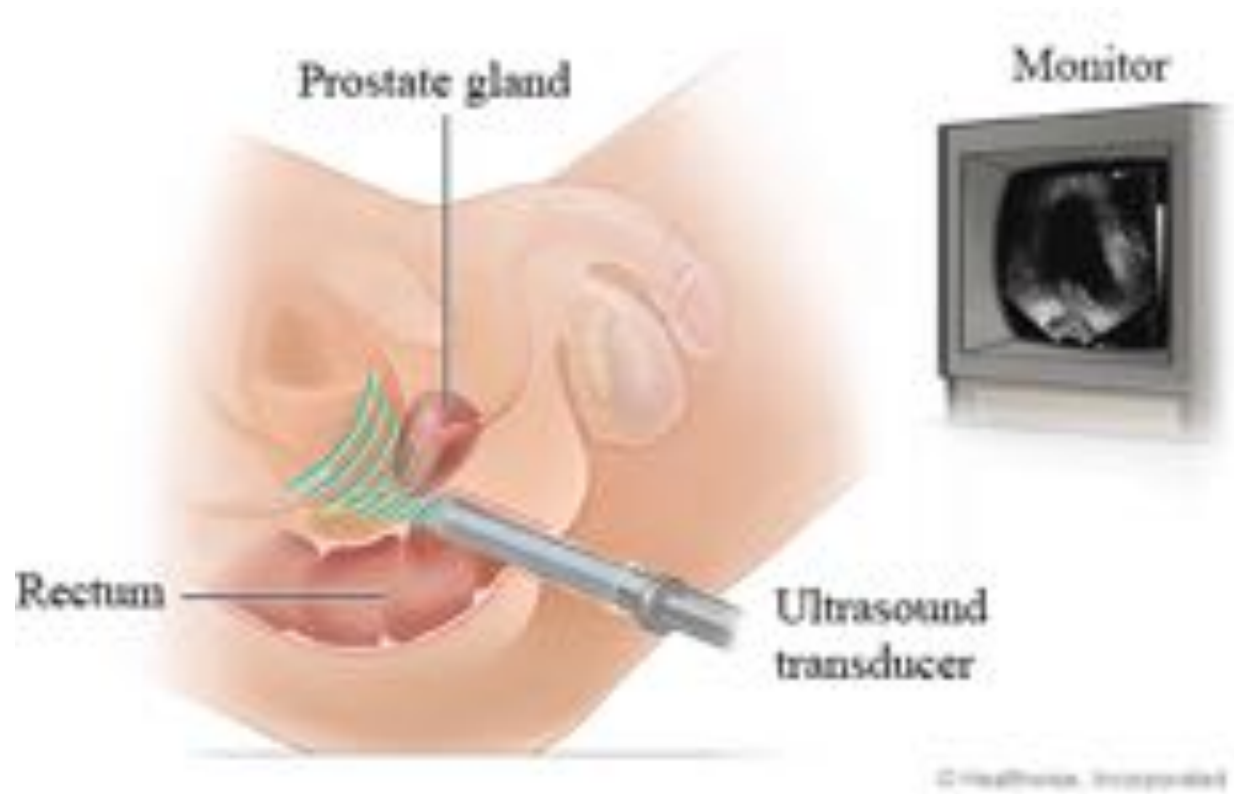
reconstruct 3D data from 2D slices

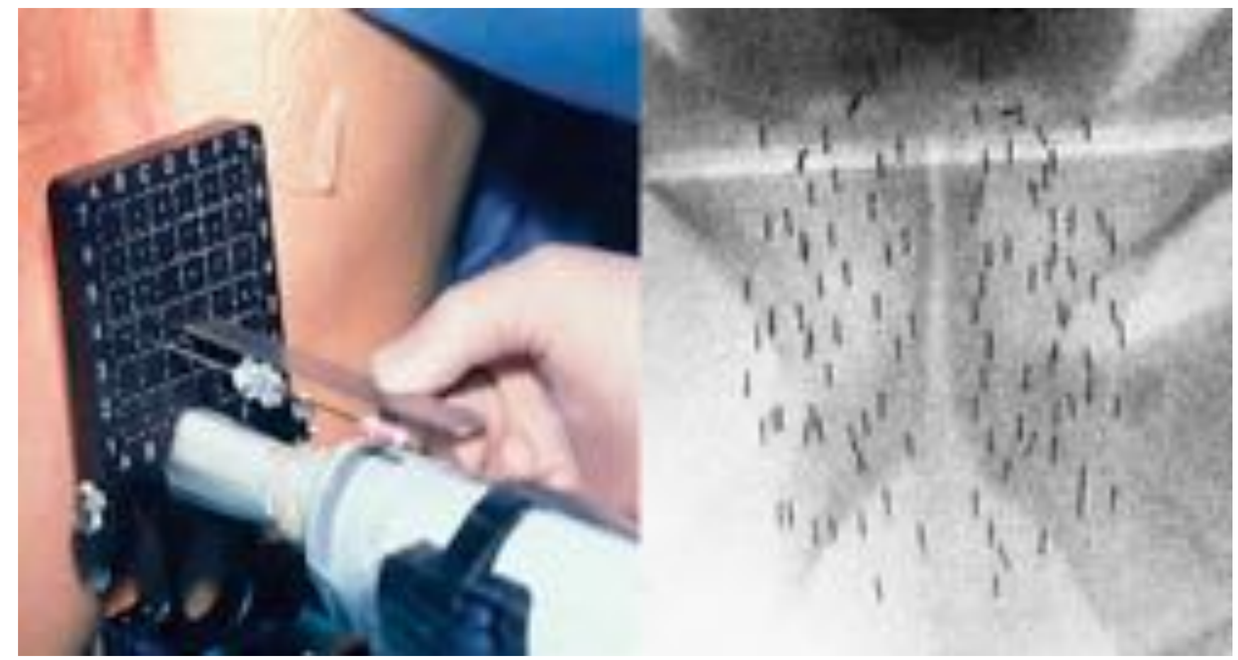


acquisition methods: linear, rotation, fan-like, hand



transrectal ultrasound





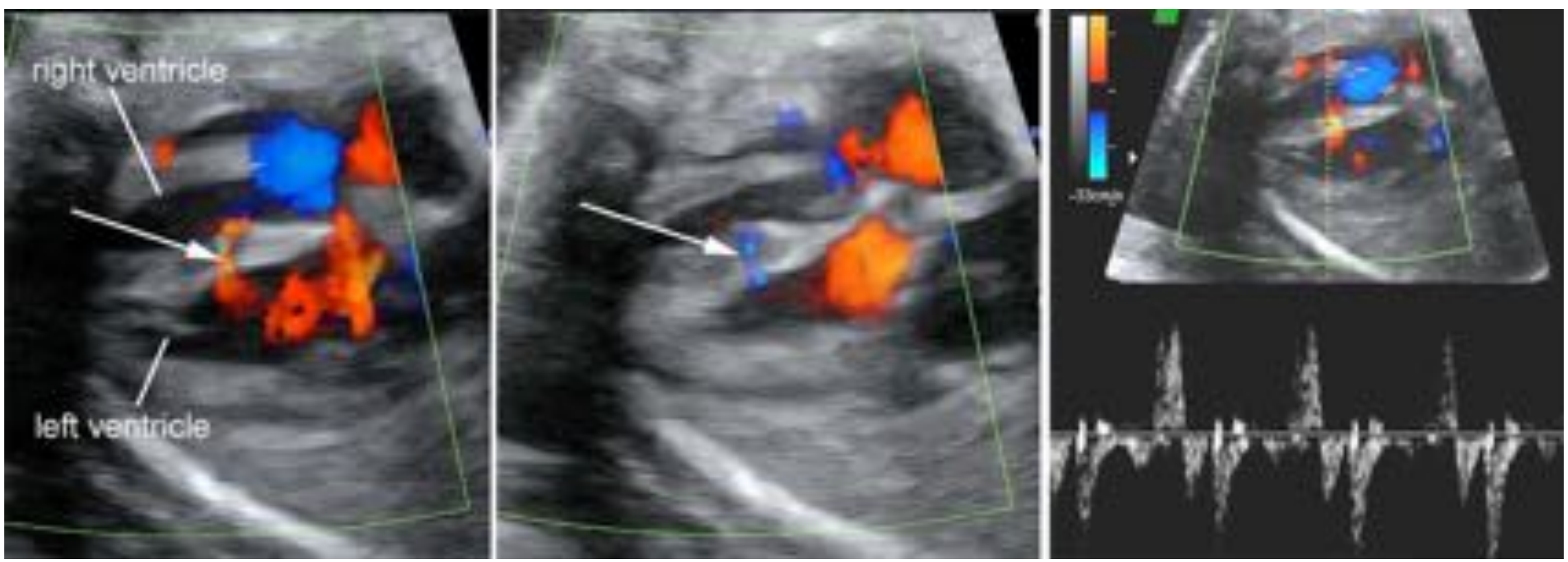
prostate brachytherapy

http://www2.cfpc.ca

https://myhealth.alberta.ca/

Doppler ultrasound

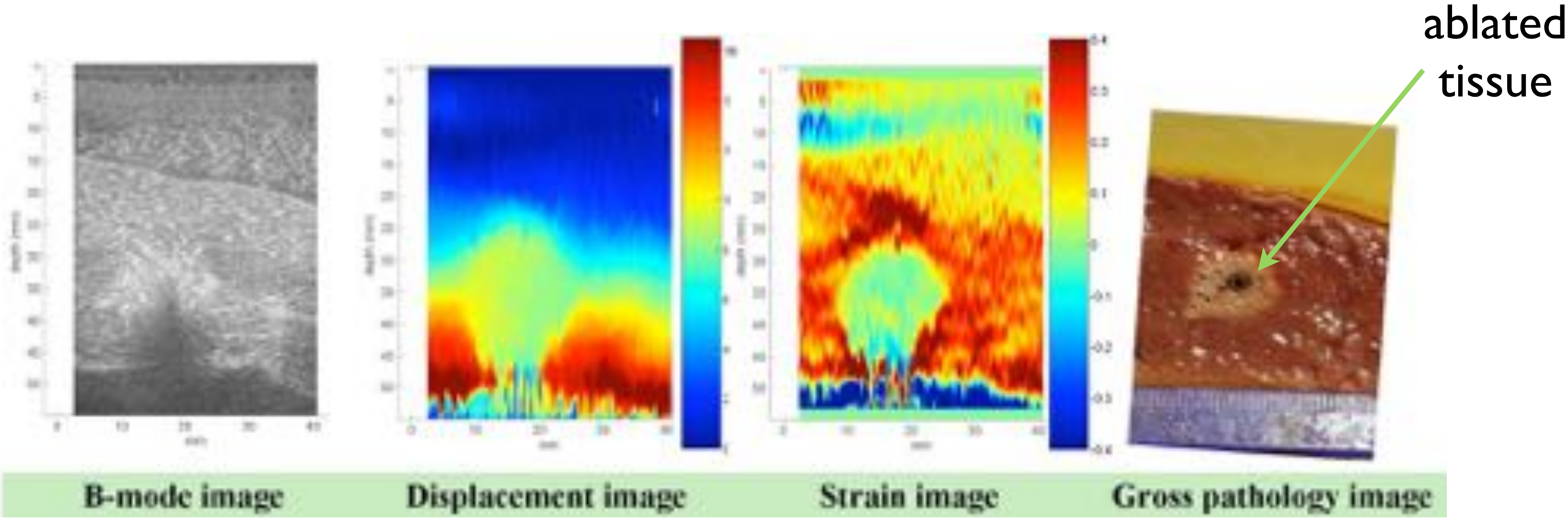
employs the Doppler effect to determine whether structures (typically blood) are moving towards or away from the probe, and their relative velocity



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

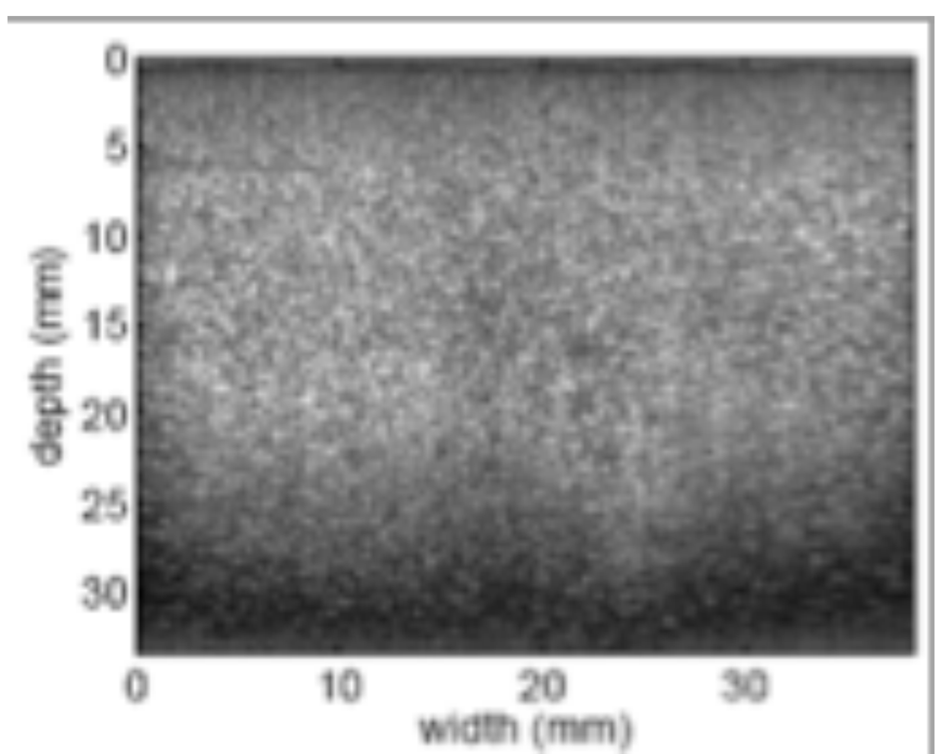
http://www.glowm.com/

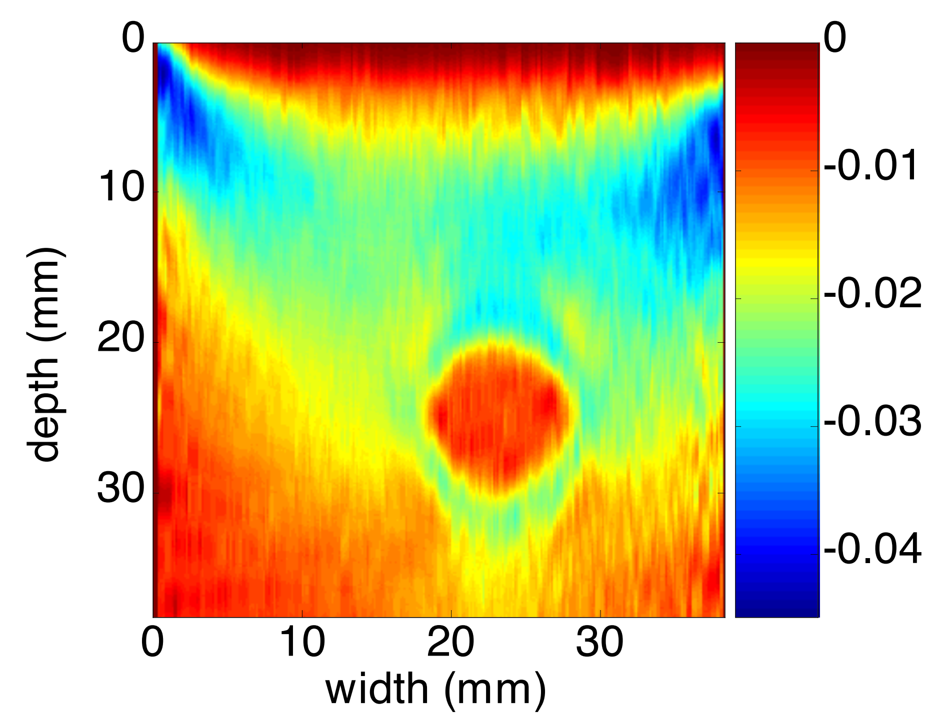
ultrasound elastography



Freehand palpation elastograms

Boctor, Rivaz, Fleming, Foroughi, Fichtinger, Hager (2008)





discussion

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

caution!

when introducing robotic (or any) technology into the interventional suite, you should consider what imaging modalities are already used and available

there is a conflict between the potential for improving a procedure and the practical limitations in changing the workflow and resources required to perform the procedure

Modality	Intra-operative Availability	Accessability	Data Dimensionality
Computed Tomography (CT)	available (not widespread)	high	3D
Magnetic Resonance Imaging (MRI)	available (not widespread)	high	3D
X-ray	available	high	2D projection
functional Magnetic Resonance Imaging (fMRI)	not available	moderate	3D
Positron Emission Tomography (PET)	not available	moderate	3D
Single Photon Emission Computed Tomography (SPECT)	not available	moderate	3D
X-ray Fluoroscopy	available	high	2D projection
C-arm CT	available	low	3D
Ultrasound (US)	available	high	2D
optical imaging	available	high	2D projection

Table 1: Classification of imaging devices according to their availability for intra-operative use, their accessability to physicians around the world, the dimensionality of the data they acquire and the type of information conveyed by the images.

Image-Guided Procedures: A Review, by Ziv Yaniv and Kevin Cleary (2006)