Topic 1: Bio-Medical Imaging
Part II

Jessica Zhang
Department of Mechanical Engineering
Courtesy Appointment in Biomedical Engineering
Carnegie Mellon University
jessicaz@andrew.cmu.edu
http://www.andrew.cmu.edu/user/jessicaz

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Magnetic Resonance Imaging (MRI)

- Unlike CT, MRI doesn't use ionizing radiation to generate cross-sectional images.
- An MRI scanner is a large magnet, a microwave transmitter, a microwave antenna, and several electronic components that decode the signal and reconstruct cross-sectional images from the data.
- The MRI system ranges from $500k to $2M or $3M.

Clinical MRI scanner

Magnetic Resonance Imaging (MRI)

- The bore of an MRI scanner is often up to two meters in length (6-8 feet). Patients are inserted into the middle of the magnetic field.
- The environments for MRI scanners must be shielded for magnetic and radiofrequency interference.
- Large Faraday cages and substantial masses of iron usually surround the magnet and sometimes the entire room about the scanner.

Magnetic Resonance Imaging (MRI)

- In MRI scanning, the patient is placed within a high intensity magnetic field. Field strengths vary from 0.35 Tesla to 1.5 Tesla, about 7,000 to 30,000 times of the earth's magnetic field. (1Tesla = 10,000 Gauss, and the earth's magnetic field is about 0.5 Gauss)

- The induced magnetic field causes the magnetic moments of the hydrogen atoms within the patient to align along the principal direction of the superconducting magnet.

Magnetic Resonance Imaging (MRI)

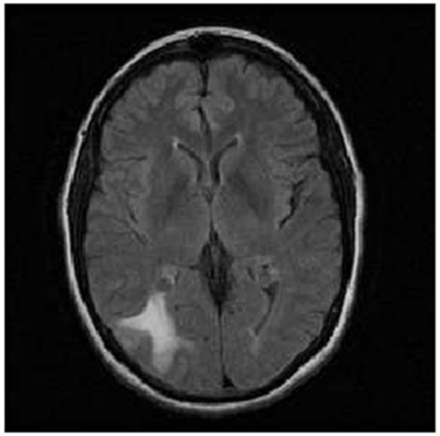
- Low-level radio waves in the microwave frequencies (15-60 MHz) are then transmitted through the patient, causing the magnetic moments of the hydrogen nuclei to resonate and re-emit microwaves after each pulse.

- The microwave emitted by the body are recorded using a radio frequency antenna, filtered, amplified, and reconstructed into tomographic slices.

Magnetic Resonance Imaging (MRI)

- While all of the hydrogen nuclei typically resonate at a frequency fixed by the strength of the induced magnetic field, different tissue types resonate longer than others, allowing the viewer to discriminate among them based on the magnitude of the signal from different points in space over time.

- Unlike CT which always produces transaxial slices, the slices from MRI can be oriented in any plane.



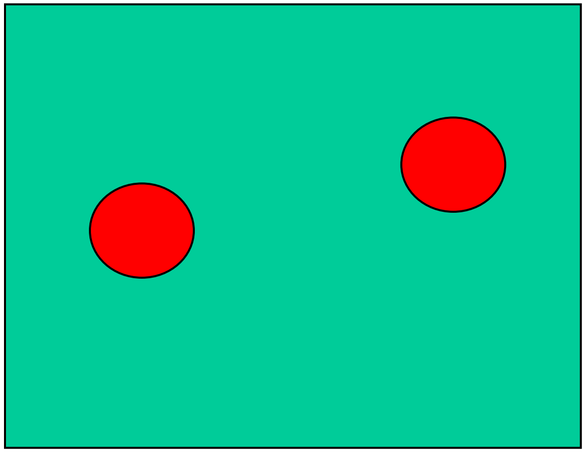
MRI: brain

Magnetic Resonance Imaging (MRI): Weakness

- The output values at each image element are not calibrated to any particular scale. The values will vary depending upon the scan parameters, the patient's size and magnetic characteristics.

- The values are not constant over the entire scan space since inhomogeneity in the magnetic field causes pixels that may represent the same tissue, but located some distance apart to give different signals.

- This lack of an absolute scale for a dataset makes segmentation difficult.



Magnetic Resonance Imaging (MRI)

- Unlike *x*-ray-based imaging, there are no physical analogs to what the viewer is seeing.
- An MRI device measures the radio signals emitted by drops of water over time. Usually skin and fat are much brighter than bone which has virtually no signal at all.
- Segmentation and classification are much harder for MRI data.
- Sampling resolution: 256x256 or 512x512
- Spatial resolution is primarily dependent on the strength of the gradient magnets and their ability to separate the slices along their gradient directions.

Magnetic Resonance Imaging (MRI)

- CT uses *x*-rays, a type of ionizing radiation, to acquire its images.
- MRI uses non-ionizing radio frequency (RF) signals to acquire its images.
- MRI has excellent soft-tissue contrast.

Magnetic resonance image showing a median sagittal cross section through a human head.

Artifacts in MRI

- Like CT, MRI also has artifacts introduced by partial voluming, patient motion, and aliasing (introduced by sampling and reconstruction).

- MRI doesn't have *x*-ray-related artifacts, it has its own host of radio and magnetic artifacts.

- The mass of the patient will affect how well the material absorbs the radiofrequency energies.

- The distribution of the antenna coverage for both transmission and reception and inhomogeneity in the induced magnetic field lead to inconsistent quantitative values and even inaccurate geometry within an image.

Advances in MRI

- Studies in perfusion and diffusion of various agents across the body (e.g., drug delivery in coronary arteries) are being enabled by new capabilities in fast imaging. These studies can illuminate blood flow, creating high-resolution images of vascular structure.
- Functional MRI (fMRI) has been introduced not only to record the patient's anatomy, but also the physiological functions of the tissues, largely used to map the cerebral cortex of the brain.
- The complex pulse sequences of Diffusion Tensor Imaging (DTI) are beginning to reveal the direction and course of nerve bundles deep within the white matter of the brain, providing new research areas of tractography and patient specific anatomical analysis.

Nuclear Medicine

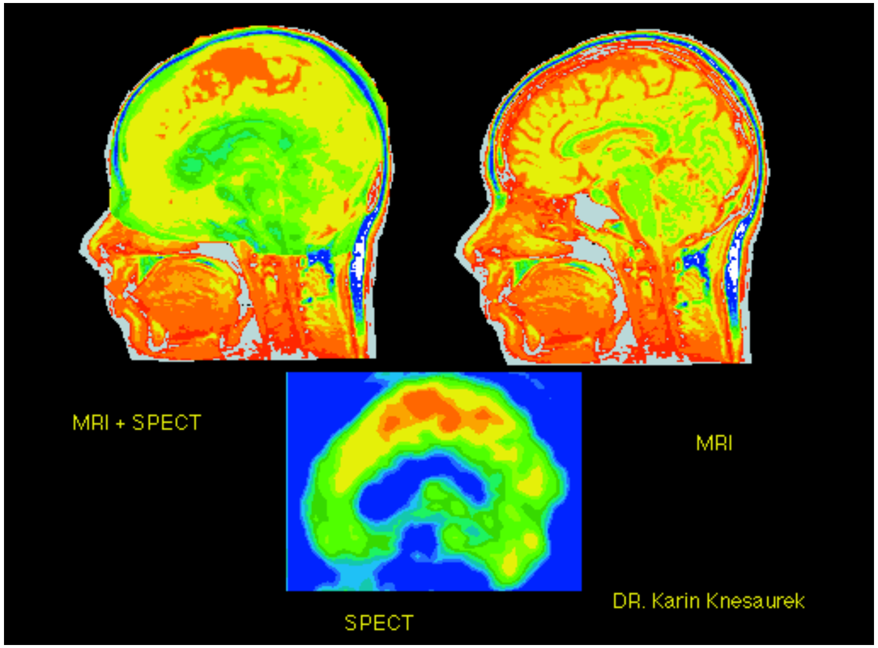
- In nuclear medicine imaging, a radioactive source is injected into the patient and the distribution of that source is measured using a detector array to catch and quantify the radiation emitted from the body.

- In CT, the radiation source's location is external and known, while in nuclear medicine, the source is internal and its distribution is unknown.

Nuclear Medicine

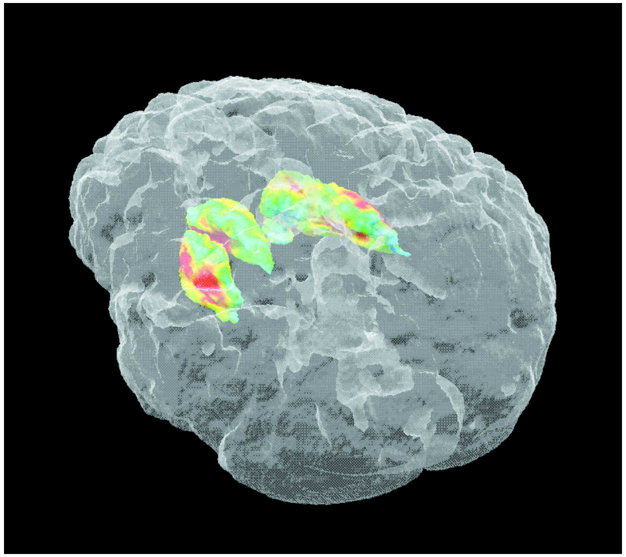
- Nuclear medicine allows clinician to image the physiological activity (the biological activity) of the patient, rather than just the geometry of the patient's anatomy.
- Nuclear medicine produces images with fairly low resolution and a high amount of noise. This is due to our inability to use high radiation doses because of the consequences of high doses of radiation to the patient.

MRI and SPECT head sagittal slices of the same patient and the co-registrated (MRI + SPECT) image. The lesion on the top of the skull is more prominent in the composite image, although it can be visualized in both modalities.



Nuclear Medicine

- Two common types of 3D nuclear medicine are Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET).
- SPECT utilizes radiotracers that emit photons while decaying. The radioactive agents have half-lives measured in hours and can be easily generated or transported to the clinic.
- PET uses radioactive isotopes that decay by positron emission. The half-lives of the isotopes are often measured in minutes, necessitating their production at the clinic.



Co-registered 3D viz of the brain and basal ganglia. The brain viz is from an MRI study, while the basal ganglia viz is depicting PET of some metabolism rate (Courtesy of PET Laboratory at Mount Sinai Medical Center, New York).

Ultrasound

- Medical ultrasonography uses high frequency sound waves (3-10 megahertz) that are reflected by tissue to varying degrees to produce a 2D image on a TV monitor.
- Ultrasound studies the function of moving structures in real-time, but provides less anatomical information than CT or MRI.
- Very safe to use (no ionizing radiation), cheap and quick to perform.

Ultra-Sound: A fetus head in a womb

Ultrasound

- The same device that is used to create the acoustic signal, a transducer, is then used to measure the returning echo information. Partial reflections are created by interfaces between areas of differing acoustical impedance.

- Ultrasound is similar to the SONAR systems used in maritime and undersea naval imaging.

Ultrasound

- The sonographer places the probe against the patient and moves it to obtain images of various parts of the body.
- Most ultrasound machines consist of a linear array of transducers, and produce an image representing a pie-shaped slice of the body.

Ultra-Sound: A fetus in a womb

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Fluoroscopy

- Radiography is the use of *x*-rays to view internal structure of objects.
- Similar to radiography, fluoroscopy produces real-time images of internal structure of the body.
- Fluoroscopy employs a constant of input *x*-rays.

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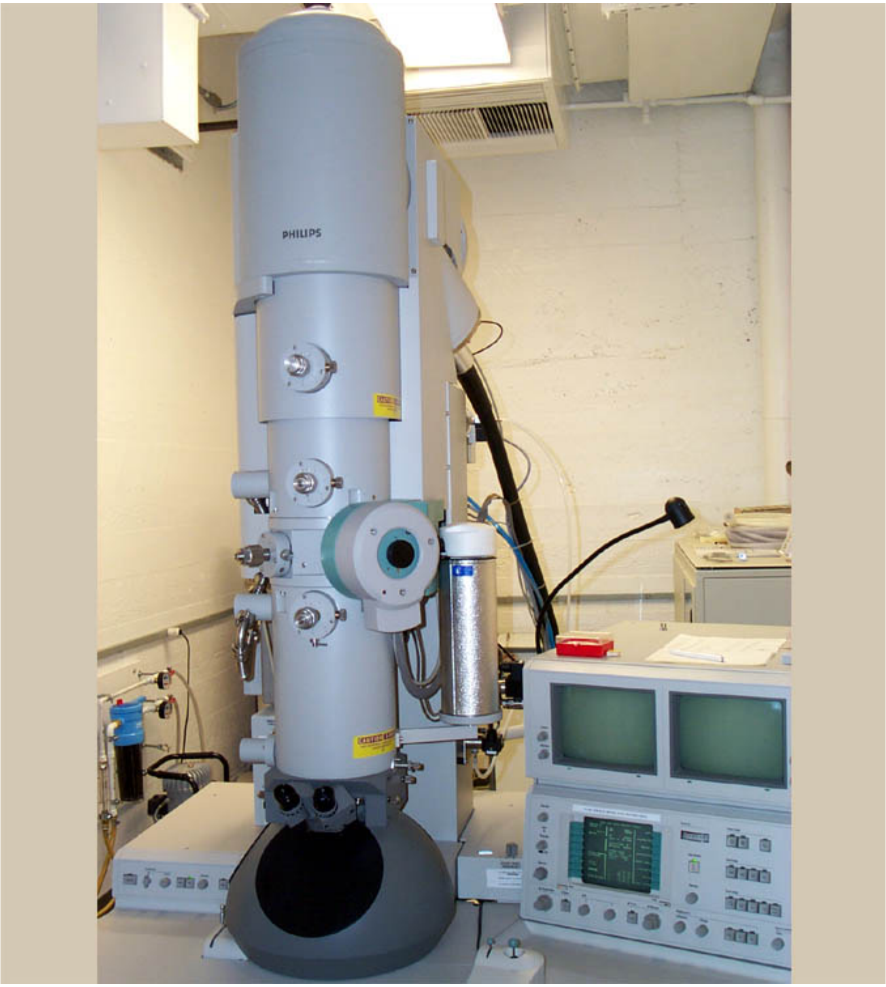
Electron Microscope

- EM is a type of microscope that uses electrons to illuminate a specimen and create an enlarged image.

- Cryo-electron microscopy (cryo-EM) is a form of EM where the sample is studied at cryogenic temperatures (generally liquid nitrogen temperatures). Cryo-EM is developing popularity in structural biology.



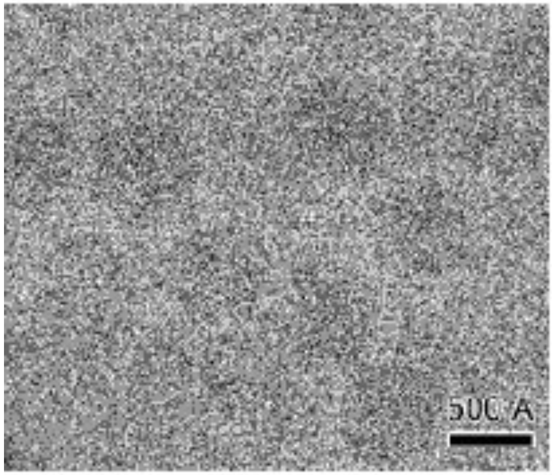
Philips/FEI CM200, Field emission gun equipped with 1Kx1K Tietz CCD camera.

How cold is liquid nitrogen?

- Under normal atmospheric pressure, **nitrogen** can exist as a **liquid** between the **temperatures** of 63 K and 77.2 K (-346ºF and -320.44ºF, or -210ºC and -195ºC).

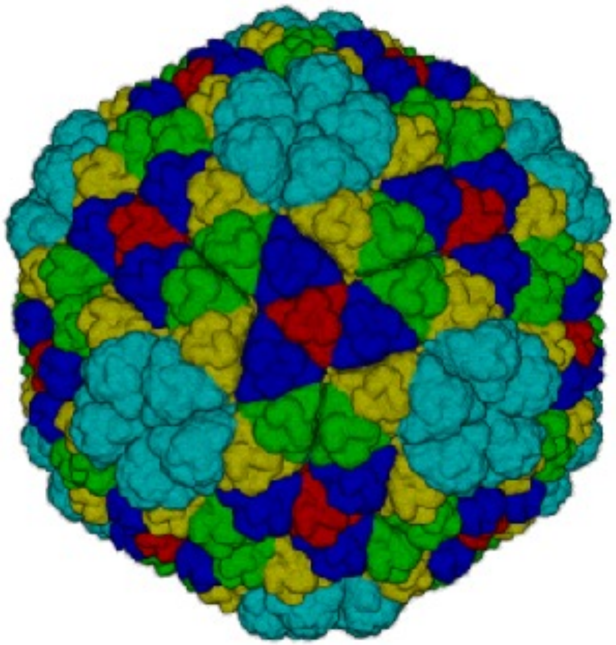
- Below 63 K, **nitrogen** freezes and becomes a solid. Above 77.2 K, **nitrogen** boils and becomes a gas.

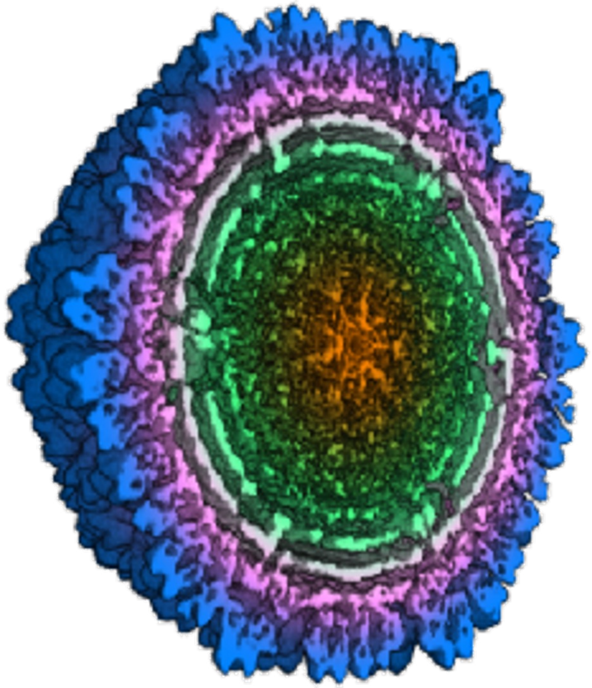
Cryo-EM



- Cryo-electron microscopy (cryo-EM) and computer reconstruction techniques are used to determine the structure of subcellular complexes, e.g., rice dwarf virus (RDV).

icosahedral polygon (20 faces)





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Acquisition, Analysis and Visualization

- Most acquisition of medical data is not optimized for 3D representation.
- The single easiest method for improving visualization is to use better acquisition techniques.
- There is a trade-off between image quality and acceptable dose.
- An even deeper understanding of the clinical findings of a case is required to validate a 3D visualization.

Summary

- There are multiple imaging modalities with differing strengths and weaknesses in imaging anatomy vs. physiology and hard tissue vs. soft tissue.
- This requires registration and alignment of multimodal data.
- Differences in size and resolution of imaging data lead to multiscale methods.

Image Processing

- **Contrast enhancement** – improving contrast
- **Filtering** – removing noise
- **Classification and Segmentation** – partitioning an image into contiguous regions with cohesive properties.
- **Registration** – aligning multiple data streams or images, permitting the fusion of different information creating a more powerful diagnostic tool than any single image alone.

References

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- Wilhelm Burger and Mark J. Burge (2007). Digital Image Processing: An Algorithmic Approach Using Java. Springer. ISBN 1846283795 and ISBN 3540309403