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Homework 1

Exercise 1

CT and MRI are two important scanning techniques in medical imaging. Please summarize the pros and cons of these two different scanning techniques in terms of

1. **Scanning mechanism**

   A **Computed Tomography** scan is a diagnostic imaging technique that gives the structure of the anatomy. It works by shining X-rays on an object and observing the pattern formed on a detector screen. The structure of the object is then inferred via techniques in computational tomography. In CT scans, x-ray radiation is absorbed at different rates in different tissue types such as bone, muscle, fat. So multiple images taken from different angles are merged to form cross-sectional image slices of bones, blood vessles and soft tissue. CT's primary benefit is the ability to separate anatomical structures at different depths within the body.

   Unlike CT scans, **Magnetic Resonance Imaging** 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 data. In MRI scans, the patient is placed within a high-intensity magnetic field $0.35 - 1.5$ Tesla ($70,00 - 30,000$ times the Earth's magnetic field).

   The introduced magnetic field causes the magnetic moments of the hydrogen atoms within the patient to align along the principal direction of the superconducting magnet. Low-level radio waves (in the microwave range) are then transmitted through the patient causing the magnetic moments of the hydrogen nuclei to resonate and re-emit miecrowaves after each pulse. The microwaves emitted by the body are recorded using a radio frequency antenna, filtered, amplified, and reconstructed into tomographic slices.

   While all of the hydrogen nuclei resonate at the same frequency (dependent on the strength of the magnetic field), different tissue-types resonate longer than other allowing the viewer to discriminate among them based on the magnitude of the signal from different points in space over time. By varying the parameters of the pulse sequence, different contrasts may be generated between tissues.

   An MRI scan captures signal intensity over a period of time, and then converts it to a frequency domain via a Fourier transform to obtain a steady state representation. Every pixel in Fourier space, when inverse-transformed, contributes a single, specific, spatial-frequency to the entire image. A 2D inverse Fourier transform of the resolved fourier modes combines all spatial frequencies.

   Since MRIs capture frequency information, the output frequency intensity at each physical point is not calliberated to any particular scale: the value will vary depending upon scanning parameters, the patient's size, and magnetic characteristics. This lack of absolute scale makes segmentation difficult: unlike x-ray based imaging, there are no physical analogs to what the radiologist is assessing.

2. **Homogeneity, or inhomogeneity** In CT scans, objects absorb x-ray photons at different rates (dense objects absorb more!) and this intensity pattern is captured by the detector. So objects of different density can be visualized.

   MRI scans capture the resonant frequencies of hydrogen atoms in a subject. While all of the hydrogen nuclei resonate at the same frequency (dependent on the strength of the magnetic field), different tissue-types resonate longer than other allowing the viewer to discriminate among them based on the magnitude of the signal from different points in space over time.

3. **Slice orientation (the z direction)**

   CT scans are only able to take transaxial slides, so the source/detector setup makes a complete 360 degree rotation about the subject to obtain a complete set of data from which arbitrary planes may be extracted.

   MRI scans, on the other hand, capture time-varying signal and convert it to frequency space. This allows the radiologist to reconstruct slices along any orientation.

4. **Artifacts**

   It CT-scans, artifacts are caused due to multiple reasons: aliasing artifacts are formed due to the contents of a pixel being distributed across multiple tissue types (partial voluming), blending the absorption characteristics of different materials; patient motion generates a variety of blurring and ring artifacts during reconstruction; finally, artifacts are introduced by x-ray modality, eg embedded dense objects such as dental fixtures, fillings, or bullets lead to beam shadow and streak artifacts.

   MRI scans suffer from the same type artifacts emerging from aliasing errors, patient motion (which is a bigger factor since MRIs take a long time to capture an image). Aliasing artifacts also include Gibbs artifacts, which are due to imperfect approximation of sharp edges by a Fourier transform (for some finite resolution).

   Since MRIs capture frequency information, they can easily be disturbed by the presence of water droplets or moisture in the room. Further, the mass of the patient determines how much radio frequency is absorbed. The distribution of the antenna coverage for both transmission and reception and inhomogeneity is the magnetic field further lead to inconsistent quantitative values and inaccurate geometry within an image.

5. **Facility price**

   CT scans have become affordable due to advances in image acquisition, computational tomography techniques, using smaller and affordable detectors, and combining multiple layers of sensors in the detector ring. The cost of a CT scanner, which is a room-sized x-ray instrument, ranges from $400k to well over a million dollars. A typical CT scanner can generally acquire data for a single slice in a matter of seconds - compared to minutes for an MRI.

   MRI machines, on the other hand, remain very expensive due to the cost of high-power electromagnets for generating strong magnetic fields. The MRI system ranges from $500k to $2 - 3$M. Further, MRI scans capture signals in the time-domain and therefore the time taken to capture a single image on the order of a few minutes.

Exercise 2

Answer the following questions briefly:

1. **Question:** In CT bone is much brighter than soft tissue, while in MRI skin and fat are brighter than bone. Explain why

   Answer: In CT scans, x-rays are shined on an object, which absorbs some of the photons, and the remainder pattern is captured on a detector screen. This pattern is then inverted to get a 2D transaxial representation of the subject, and merged with views taken from different angles. Critically, dense objects such as bone absorb more photos, and, upon inversion, end up becoming brighter.

   MRI scans, on the other hand, measure the radio signals emitted by hydrogen atoms (abundant in fat and water). This is the reason skin and fat are brighter than bone (which is dry) in MRI scans.

2. **Question:** Given a cadaver (very dry), you are asked to scan one knee joint structure, which method would you like to choose? Explain why MRI cannot be used?

   Answer: A CT scan of such an object would result in accurate representation of the different soft-tissue present in the knee joint such as cartilage, tendons, as well as bone. CT scans use x-rays and aren't impacted by the presence or lack thereof of moisture.

   An MRI scan, on the other hand, captures the frequencies emitted by hydrogen atoms. A dry cadaver would lack said hydrogen atoms (which are usually present in water and fat) resulting in an attenuated signal making MRI unfeasible in this situation.