Quantitative and Functional Imaging Name:_____
BME 4420/7450
Final Exam—Fall 2022
Due by Tuesday, Dec 13, at 11:59pm.

In answering these questions, you may consult any course materials (e.g., your class notes, posted lecture slides, and project procedures/reports). You may also use any books and internet sources, however, you must cite these in your answers. These other sources should not be necessary, but you are free to use them if you find them helpful. Under no circumstances should you discuss any aspect of the exam with anyone else until after the due date (of course you can discuss the questions with me if they are unclear to you). Please submit your answers on Brightspace as a single PDF file with the name "Exam_", followed by your name.

1. Briefly explain how each of the following operations would affect image quality (15 points).
   a. Multiplying all pixel intensities by 10.
   b. Averaging pixel intensities over a 3x3 neighborhood. This produces an image with pixel intensity at each position (x,y) equal to the average intensity in a region in the original image defined by {(x+i, y+j), where $|i|,|j| \leq 1$}.
   c. Using linear interpolation to halve the pixel size in both x and y, and hence double the image size (e.g., from 256x256 to 512x512).

2. Define the following terms and briefly explain how they are measured and why they are useful (20 points):
   a. NMR relaxation times (T_1 and T_2)
   b. Diffusion anisotropy
   c. Perfusion
   d. Partition coefficient (λ)—also known as the distribution volume of a tracer

3. Medical imaging techniques typically have a spatial resolution on the order of millimeters. Explain how it is possible to use these methods to gain information about tissue constituents at much smaller length scales, for example on the molecular (10^{-6} mm), cellular (~10^{-3} mm) and capillary (~10^{-2} mm) scales. For each of these length scales, include an example from ultrasound, CT, PET or MRI. (15 points)

4. In an fMRI experiment, tissue T_2^* changes in voxels with increased neuronal activity (due to the BOLD effect). The signal intensity from a given voxel is

$$S = S_0 \cdot e^{-T_E/T_2^*} \qquad [1]$$

where T_E is the time (after spin excitation) at which the image data are acquired and T_2^* is the transverse relaxation time constant (including the dephasing effects of B_0 field

inhomogeneities). The image contrast, ΔS, produced by the time-constant change, ΔT_2^*, is given by

$$\Delta S = \frac{dS}{dT_2^*} \cdot \Delta T_2^* .$$

The time T_E is an experimental parameter under your control. (20 points)

a. Use Eq. [1] to express ΔS as a function of T_E (as well as T_2^* and ΔT_2^*).
b. What value of T_E would you choose to maximize the BOLD contrast, ΔS, in your experiment?
c. Find an expression for the fractional signal change, $\Delta S/S$, under this optimal condition, in terms of ΔT_2^*.
d. In an fMRI experiment, $T_E = 50$ ms and $\Delta S/S = 1\%$ in the activated region (assume that T_E is optimized). What is the change in tissue T_2^* due to the BOLD effect in this case?

5. The last image analysis project (Project 8) examined the binding of a radioactive tracer (fallypride) to the dopamine (D2) receptor. Suppose you want to evaluate a new drug that binds to and blocks the dopamine receptor—this is called a dopamine *antagonist*, because it blocks the action of dopamine (several antipsychotic medications are in this class of drugs). The new drug is not visible on PET scans. How could you use the radiotracer to determine how much of the new drug is binding to dopamine receptors? Outline the steps of your experiment, including image analysis. (10 points)

For graduate credit (extra-credit for undergraduate credit)

6. Suppose you are hired to analyze signal changes in an fMRI brain activation experiment. You find that there is a strong variation in signal around 0.2 Hz, and you suspect this is due to respiratory motion of the chest wall (which slightly changes the B_0 magnetic field in the head). (20 points total)
   a). You decide to try to filter out the respiratory signal changes, assuming a respiratory rate of 0.2 Hz. Why would this improve the sensitivity of the fMRI experiment? Describe the steps you would use to do this.
   b). Although the filtering method above improves the data, you are not completely satisfied with the results. You take a deep breath and think about what to do next. In a flash of insight, you realize that respiration is not perfectly periodic, and some inhalation/exhalation cycles are significantly longer or shorter than the mean, which implies that the respiratory spectrum is probably not a single, narrow peak with fixed frequency during the entire experiment. Fortunately, someone on the team recorded the circumference of the subject's chest (call this variable *s*) as a function of time during the experiment (this was measured with a stretch-sensitive belt around the subject's chest). You decide to use the measurements of *s* to improve your estimates of brain activation signal changes. As a first step, you develop a model of how signal intensity

in the brain is related to *s*. Let the signal intensity of the pixel in row *i* and column *j* be written *I(i,j)*, You choose a polynomial to model the influence of *s* on *I(i,j)*:

$$I(i,j) = a_0 + a_1 s + a_2 s^2 + \cdots$$

Describe how you would determine the coefficients a_i. Are these likely to have the same values in all pixels?

c). Describe the steps you would use to analyze the fMRI data, including the approach of part 'b'. This should be a (brief) set of procedures, but similar in outline to those of the analysis projects you've done in this course. You don't have to include MATLAB commands but should summarize each conceptual step.

Please sign the following Honor code statement:
I have not given or received help on this examination that in any way conflicts with the Vanderbilt University honor code.

Signed:_____ Date:_____