Computational MR imaging
Laboratory 1: MRI pulse sequences and image contrast

Report is due on Wednesday the week after the lab session at 23:59. Send your report by email to Bruno Riemenschneider (bruno.riemenschneider@fau.de) and Florian Knoll (florian.knoll@fau.de).

Learning objectives

- Recall and improve familiarity of the MR contrast generation process.
- Recall and improve familiarity with MR pulse sequences and the k-space concept.
- Simulate image contrasts from generated by pulse sequences using a numerical brain phantom.
- Design an acquisition process for quantitative T2 fitting, and perform the numerical fits to estimate the parameters.

1. Inspect the digital brain phantom (Aubert-Broche, Neuroimage 2006)

1.1. Load the file digital_brain_phantom.mat.

1.2. Display the regions Cerebrospinal Fluid (CSF, label=1) Gray Matter (GM, label=2) and White Matter (WM=3).

1.3. Display the predefined T1, T2 and Proton Density (PD) values for these three regions.

2. Simulate MR image contrast from pulse sequences

2.1. Spin Echo Proton density weighted (PDw):

2.1.1. Assume a 90º excitation and a 180º refocusing pulse.

2.1.2. Use the Spin-Echo signal equation from Bernstein eq 14.57.

2.1.3. Choose repetition time (TR) and echo time (TE) accordingly. Hint: Consider the T1 and T2 values of GM and WM.

2.1.4. Spin Echo T1 weighted: Use the same signal equation as for PDw, adjust TR and TE accordingly.

2.1.5. Spin Echo T2 weighted: Use the same signal equation as for PDw, adjust TR and TE accordingly.

2.2. Water signal suppression with inversion recovery (FLAIR sequence):

2.2.1. Use the signal equation from Bernstein eq 14.32, or from section 8, inverstion recovery imaging, of Joseph Hornak's "Basics of MRI" e-book: https://www.cis.rit.edu/htbooks/mri/inside.htm. Assume a 180º inversion pulse.

2.2.2. Choose TR, TE and Inversion time (TI) accordingly. Hint: Determine the nulling TI for CSF according to Bernstein eq 14.36

2.3. MPRAGE: This sequence uses an inversion preparation pulse to emphasize the contrast between GM and WM in the brain, and is the most commonly used T1 weighted sequence in neuroimaging.

2.3.1. Use the eqs 1 to 3b from Noeth, NMR Biomed (2015).

2.3.2. Set TR, TI, Flip Angle (FA) and Echo Spacing (ES) accordingly.

3. **Quantitative T2 parameter mapping**
   3.1. To increase realism, we add noise to the simulated data in this part.
      3.1.1. Use the provided fft2c function to simulate k-space from the generated image.
      3.1.2. Add real and imaginary gaussian noise to the k-space signal so that the SNR is approximately 50. Hint: Use the l2-norm of the k-space signal to approximate the signal energy, and then set the standard deviation of the noise accordingly.
      3.1.3. Reconstruct the noise-corrupted image by using the provided ifft2c function, and extract only the real part of the image.

   3.2. T2 mapping for CSF, GM and WM: Use a spin-echo sequence (see section 2) with multiple TEs. Why is that a good choice?
      3.2.1. Choose the number of TEs that you want to use. Explain your choice.
      3.2.2. Set TR and the multiple TEs accordingly. You can use either different or the same sequence parameters for all three tissues. What is the advantage and disadvantage of either choice?
      3.2.3. Fit a quantitative model of the form s(t) = a*(exp(-t/b))
      3.2.4. to your data. Which parts of the MRI signal equation do these parameters represent? You can use the signal either from a region of interest or a single pixel. Are there advantages and disadvantages in either choice?

4. **K-Space trajectories**
   Consider three popular k-space acquisition trajectories. Cartesian, radial and spiral (see **Figure 1**). Sketch the gradient waveforms that generate these k-space trajectories. Hint: Remember that:

$$k_y = \int_0^t G_y d\tau$$
$$k_x = \int_0^t G_x d\tau$$
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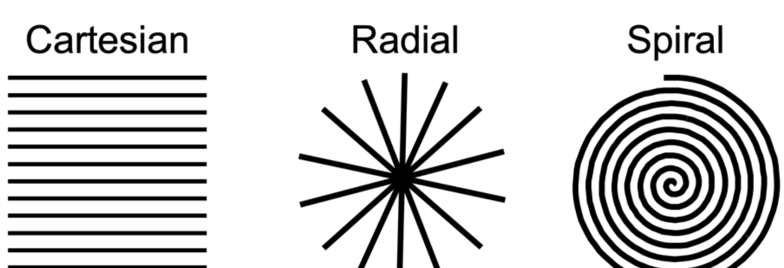

Figure 1: Cartesian, radial and spiral k-space trajectories