Major Technical Project - Term 1 Presentation

Semester 1: August-December 2021

Mentors: Dr Erwin Fuhrer , Dr Arnav Bhavsar

Students: Zaidan Bhat, Aakash Maurya

Project Title

MR simulator to **create tailored datasets** of MR Images for AI Algorithm Development.

Motivation/Background

01 Increasing use of MRI for detection of various anomalies like tumors/cancers , kidney stones, etc.

02 Human error may cause doctors to miss upon detecting these anomalies.

03 Training AI models to detect these anomalies is a challenge due to unavailability of sufficient labelled data.

04 Preparation of this data using real MRI machines is a costly and time intensive process.

05 Patient health/privacy concerns further add to the difficulties in obtaining large amounts of data for training AI/ML models.

Literature Review

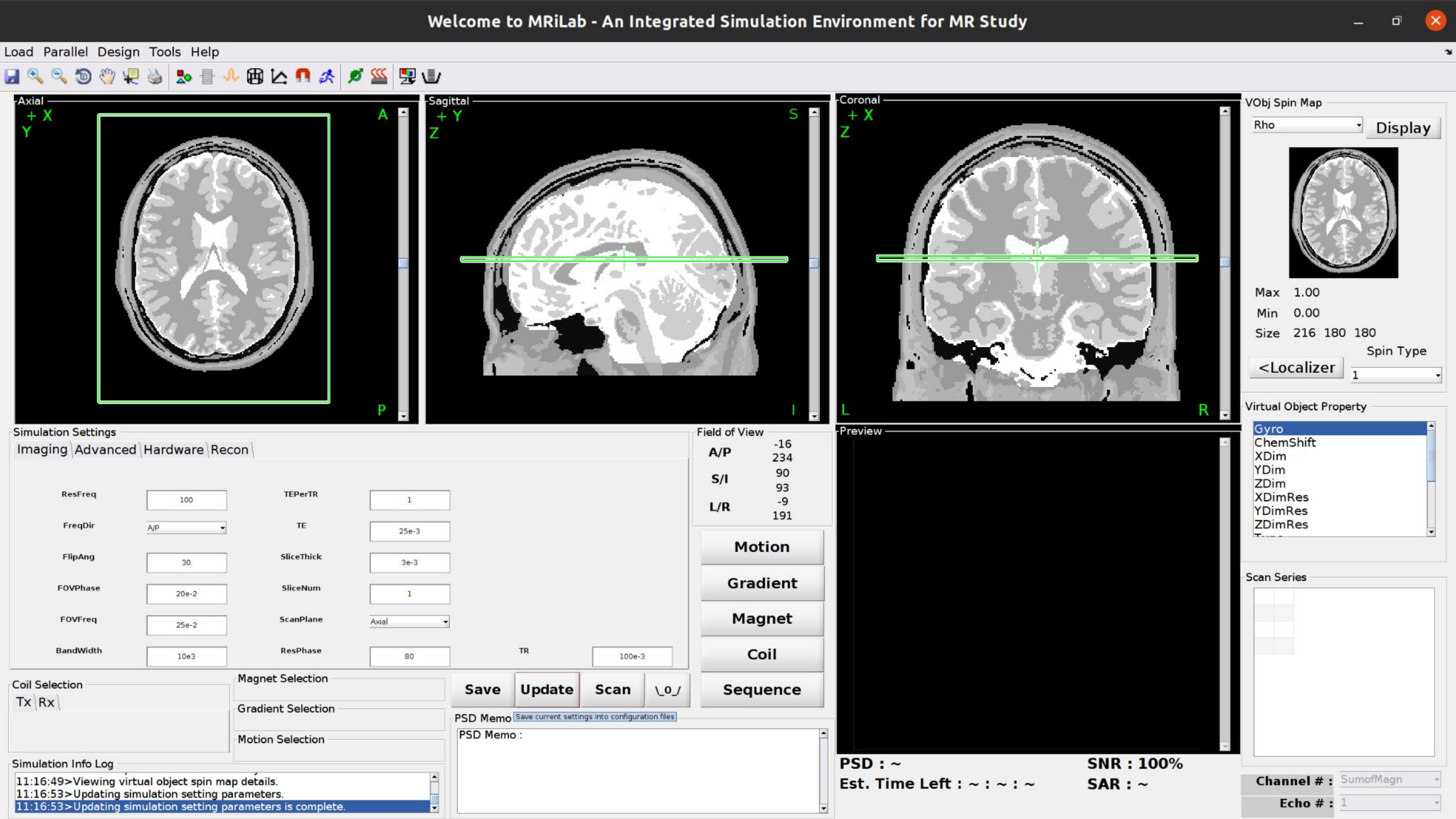
MRiLab is a numerical MRI simulator platform. It uses mathematical models called phantoms to imitate various tissues.

It has a friendly UI to facilitate controlling various parameters like Magnetic field, TE , TR etc. It provides us with multiple tools to design new phantoms and new sequences.

It is written in matlab with computational kernels coded in cpp.

Its uses GPU acceleration and MultiThreading to speed up the simulation process.

Reference: Liu F, Velikina JV, Block WF, Kijowski R, Samsonov AA. Fast Realistic MRI Simulations Based on Generalized Multi-Pool Exchange Tissue Model. *IEEE Trans Med Imaging*. 2017;36(2):527-537. doi:10.1109/TMI.2016.2620961


Welcome to MRiLab - An Integrated Simulation Environment for MR Study
Load Parallel Design Tools Help
Axial
+ X
Y
A
P
Sagittal
+ Y
Z
S
I
Coronal
+ X
Z
L
R
VObj Spin Map
Rho
Display
Max 1.00
Min 0.00
Size 216 180 180
Spin Type
<Localizer
1
Virtual Object Property
Gyro
ChemShift
XDim
YDim
ZDim
XDimRes
YDimRes
ZDimRes
Simulation Settings
Imaging Advanced Hardware Recon
ResFreq 100
TEPerTR 1
FreqDir A/P
TE 25e-3
FlipAng 30
SliceThick 3e-3
FOVPhase 20e-2
SliceNum 1
FOVFreq 25e-2
ScanPlane Axial
BandWidth 10e3
ResPhase 80
TR 100e-3
Field of View
A/P -16 234
S/I 90 93
L/R -9 191
Motion
Gradient
Magnet
Coil
Sequence
Preview
Scan Series
Coil Selection
Tx Rx
Magnet Selection
Gradient Selection
Motion Selection
Save Update Scan _o_/
PSD Memo
Save current settings into configuration files
PSD Memo :
Simulation Info Log
11:16:49>Viewing virtual object spin map details.
11:16:53>Updating simulation setting parameters.
11:16:53>Updating simulation setting parameters is complete.
PSD : ~
Est. Time Left : ~ : ~ : ~
SNR : 100%
SAR : ~
Channel # : SumofMagn
Echo # : 1

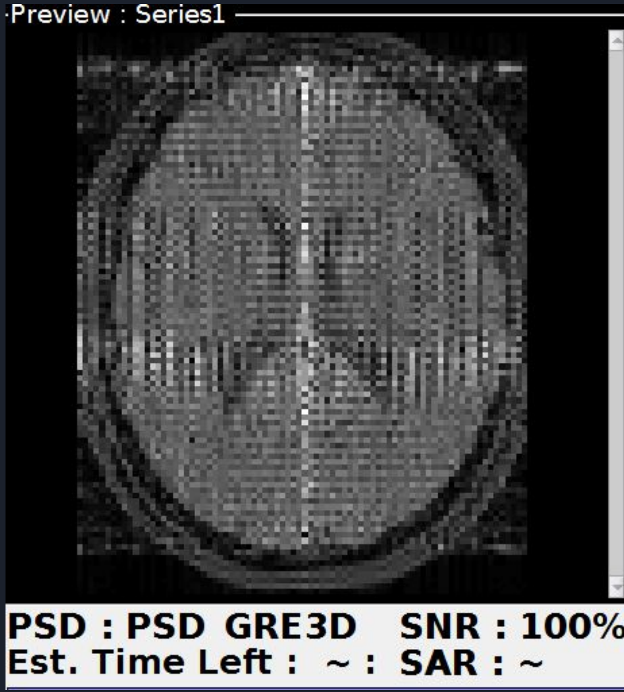
Visible Problems/Limitations of MRiLab

01 Artifacts and mass distortions for certain ranges of values of various parameters .

02 Change in parameters which should ideally affect the SNR(signal to noise ratio) does not seem to have any effect.

03 No functionality to manually add tumors and or anomalies to the MR images.

04 T1 and T2* times of materials depend on static magnetic field strength. If this feature is included it needs to be analysed.



Semester 1:

Benchmarking MRiLab .

Run Experiments on MRiLab and compare the results obtained with expected results computed using standard equations. (For Spoiled Gradient Echo Sequence)

Derive conclusions from the comparisons made in the above step,

Semester 2:

Try to fix problems and irregularities found in semester 1.

Add functionality to simulate tumors in the phantoms.

Experiments Conducted

- All Experiments were conducted using the Spoiled Gradient Echo Sequence.
- All experiments were conducted for two Phantoms , Brain High Resolution Phantom and the Water-Fat Phantom.
- All Experiments were conducted for three noise levels. Noise Level 0, 5, 10.

1. Vary TE while keeping all other parameters constant (TE = 5 - 100 ms; steps: 10 ms (5,10,20,30,....) , TR = 500 ms, FA = 30°).
2. Vary TR while keeping all other parameters constant (TR = 25 - 500 ms; steps: 25 ms) , TE = 5 ms, FA = 30°).
3. Vary FA while keeping all other parameters constant (FA 5° - 90°, steps: 5°; TE = 5 ms, TR = 500ms).
4. Vary FA while keeping all other parameters constant (FA 5° - 90°, steps: 5°; TE = 5 ms, TR = 40ms).

Theoretical Signal

- The theoretical signal depends on the following properties of material:
  - **ρ** which is the Proton Density
  - $\mathbf{T_1}$ for the given tissue material
  - $\mathbf{T_2^*}$ for the given tissue material
- The theoretical signal also depends on the following parameters:
  - ***α*** which is the flip angle
  - **TR** which is the repetition time
  - **TE** which is the echo time

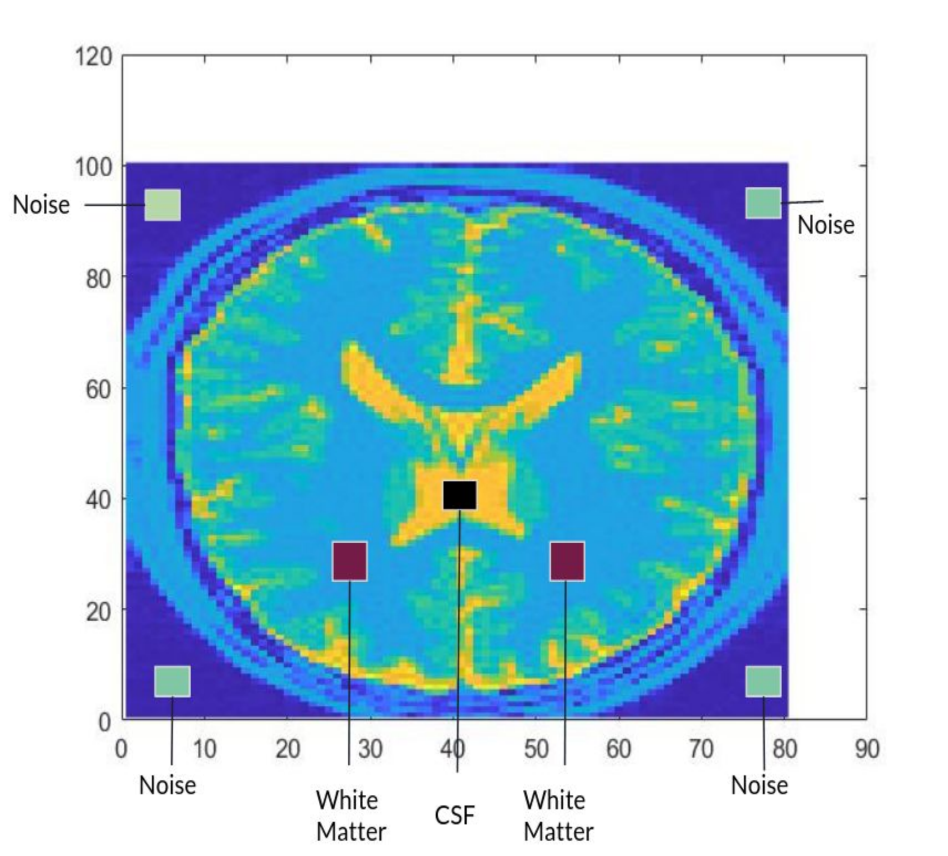
$$\text{Signal} = \rho \frac{\sin\alpha \cdot [1 - \exp(-\mathrm{TR}/\mathrm{T}_1)] \cdot \exp(-\mathrm{TE}/\mathrm{T}_2^*)}{1 - \cos\alpha \exp(-\mathrm{TR}/\mathrm{T}_1)}$$

Computation of Signal/Noise

64 pixels from 4 patches for noise

16 pixels for CSF signal

32 pixels from 2 patches for White Matter Signal



Signal to Noise Ratio (SNR) in MRiLab

- The SNR Computation of MRiLab is flawed.
- It uses the following equation, which does not changes on varying TE, TR, Flip angle.
- The problem was verified by manually calculating the SNR using the patches.
- Computation of Signal itself has multiple flaws (shown in future slides).

$$SNR = B0 \times RFreq \times RPhase \times RSlice \times \frac{\sqrt{ResFreq \times ResPhase \times SliceNum \times NEX}}{NoiseLevel \times \sqrt{BandWidth}}$$

where,

B0 = Magnetic Field; Noise Level = User-input std deviation of noise;
RFreq = FOV Freq/ResFreq; RPhase = FOV Phase/ResPhase; RSlice = SliceThick.

Noise computation model of MRiLab

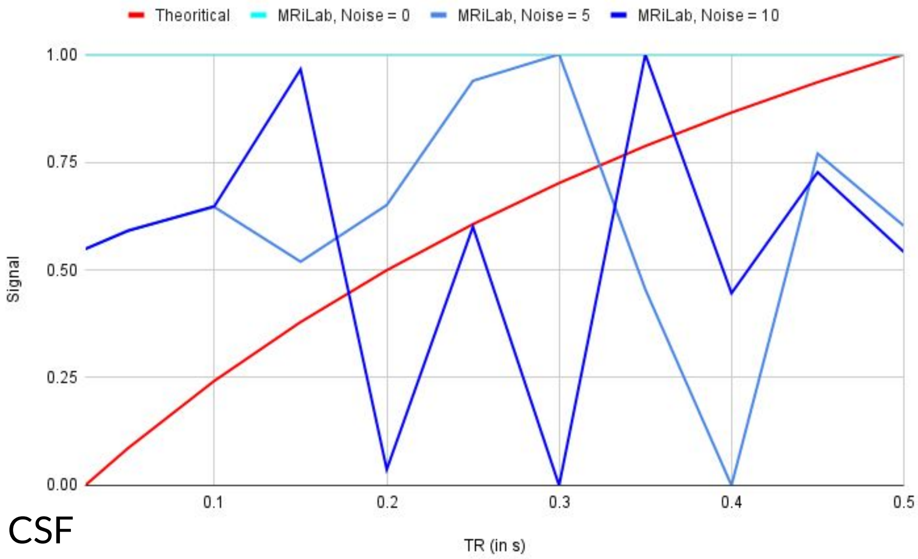
- Added noise is a Gaussian Noise with zero mean and user-defined standard deviation
- This standard deviation is referred to as Noise Level
- Noise is added to acquired k-space data

$$Noise = \frac{\frac{NoiseLevel}{NoiseRef} \times \sqrt{\frac{BandWidth}{BWRef}}}{\frac{B0}{B0Ref} \times \frac{RFreq \times RPhase \times RSlice}{VolRef} \times \sqrt{\frac{NEX}{NEXRef} \times \frac{ResFreq \times ResPhase \times SliceNum}{ADCRef}}}$$

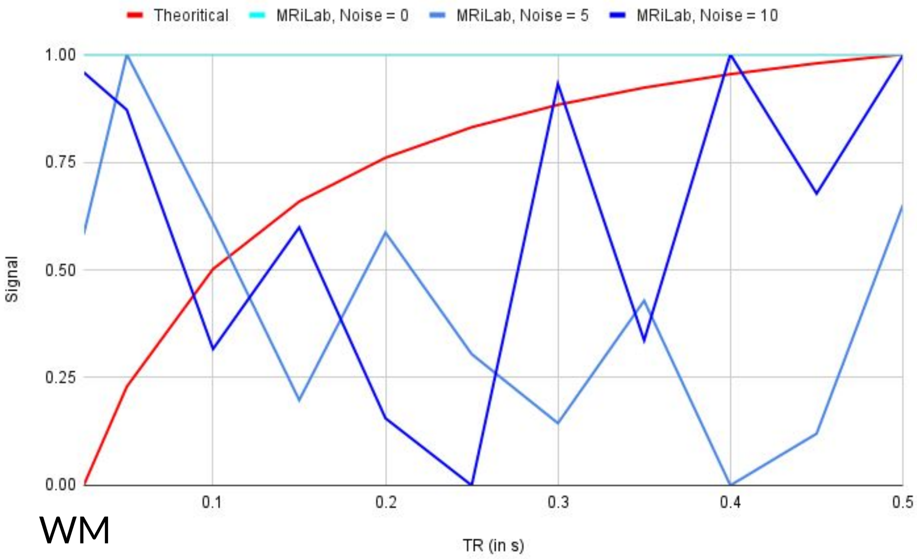
where,

BWRef = 1e3; NoiseRef = 1; B0Ref = 1.5; VolRef = 1e − 9; NEXRef = 1;
ADCRef = 1e4; RFreq = FOV Freq/ResFreq; RPhase = FOV Phase/ResPhase; RSlice = SliceThick.

Theoretical Vs Actual Normalised Signal on varying TR

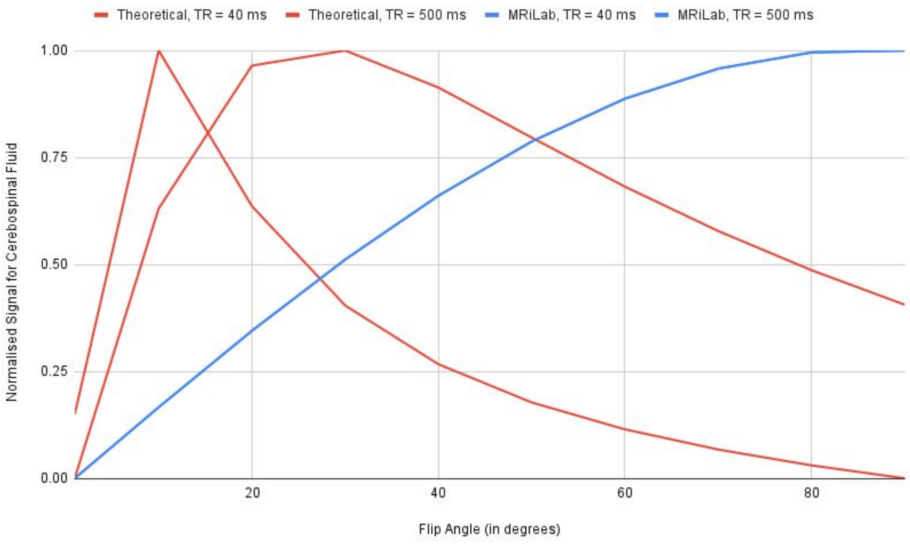


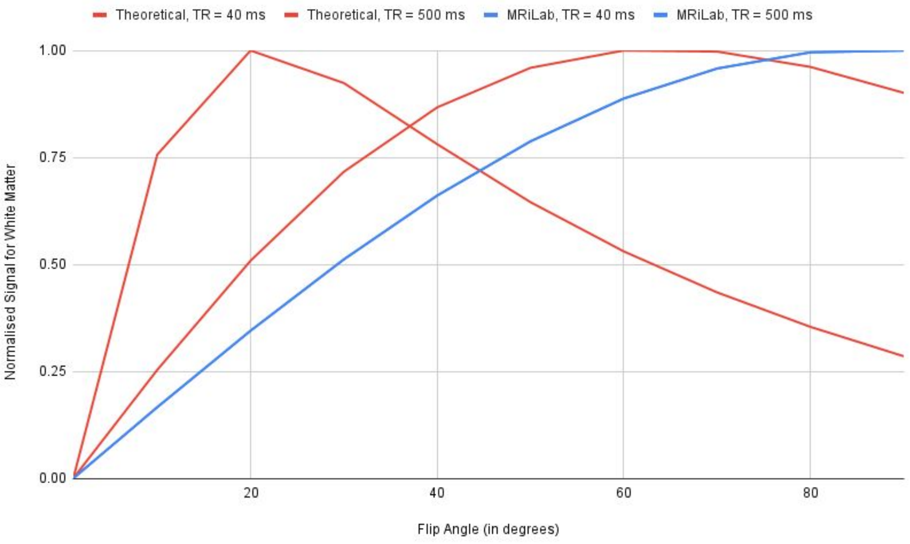
CSF



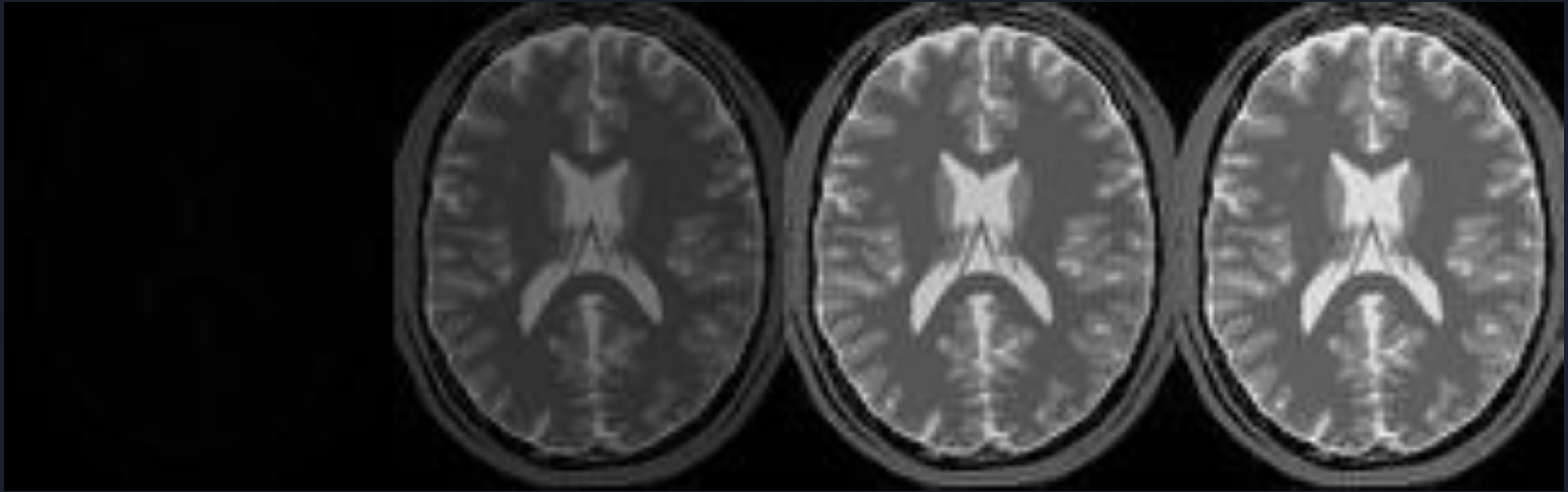
WM

Theoretical Vs Actual Normalised Signal on varying Flip Angle





MRiLab Simulated images on increasing flip angle (left to right)



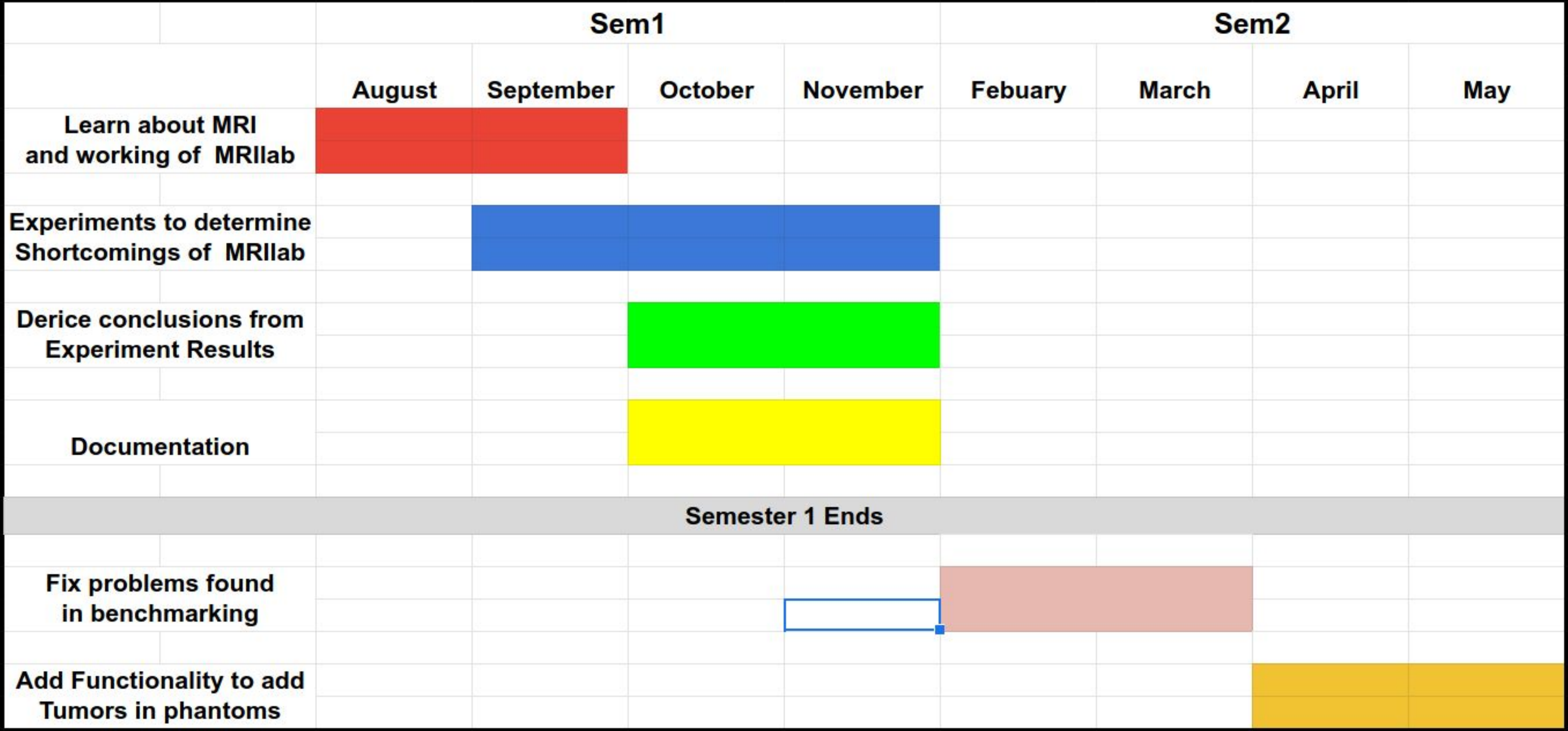
Shortcomings

MRiLab (Spoiled Gradient Echo Sequence) was found to be unable to:

- Perform simulations for certain TE values (TE>=20ms at TR=500ms & α =30°)
- Vary signal (constant signal value) with different TR values at Noise level = 0
- Resemble theoretical signal while varying TR values at any Noise level
- Vary the signal vs flip angle curve for different TR values
- Resemble theoretical signal while varying flip angle values
- Resemble basic MRI concept of maximum signal at Ernst angle while varying flip angle

For the Spoiled Gradient Echo Sequence, we conclude that the MRiLab simulations couldn't model the signal accurately.

Since, the MRiLab simulations had multiple computation flaws in calculation of Signal, in the next semester we'll try to fix the computation of Signal.


Sem1
Sem2
August
September
October
November
Febuary
March
April
May
Learn about MRI and working of MRIlab
Experiments to determine Shortcomings of MRIlab
Derice conclusions from Experiment Results
Documentation
Semester 1 Ends
Fix problems found in benchmarking
Add Functionality to add Tumors in phantoms

References

1. F. Liu, J. V. Velikina, W. F. Block, R. Kijowski and A. A. Samsonov, "Fast Realistic MRI Simulations Based on Generalized Multi-Pool Exchange Tissue Model," in IEEE Transactions on Medical Imaging, vol. 36, no. 2, pp. 527-537, Feb. 2017, doi: 10.1109/TMI.2016.2620961.
2. Willemink MJ, Koszek WA, Hardell C, et al. Preparing Medical Imaging Data for Machine Learning. *Radiology*. 2020;295(1):4-15. doi:10.1148/radiol.2020192224
3. Kohli, M.D., Summers, R.M. & Geis, J. Medical Image Data and Datasets in the Era of Machine Learning—Whitepaper from the 2016 C-MIMI Meeting Dataset Session. *J Digit Imaging* **30,** 392–399 (2017). https://doi.org/10.1007/s10278-017-9976-3