Major Technical Project - Term 2 Presentation

Semester 2: February-June 2022

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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

Superficial Problems with 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.

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).

Shortcomings

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

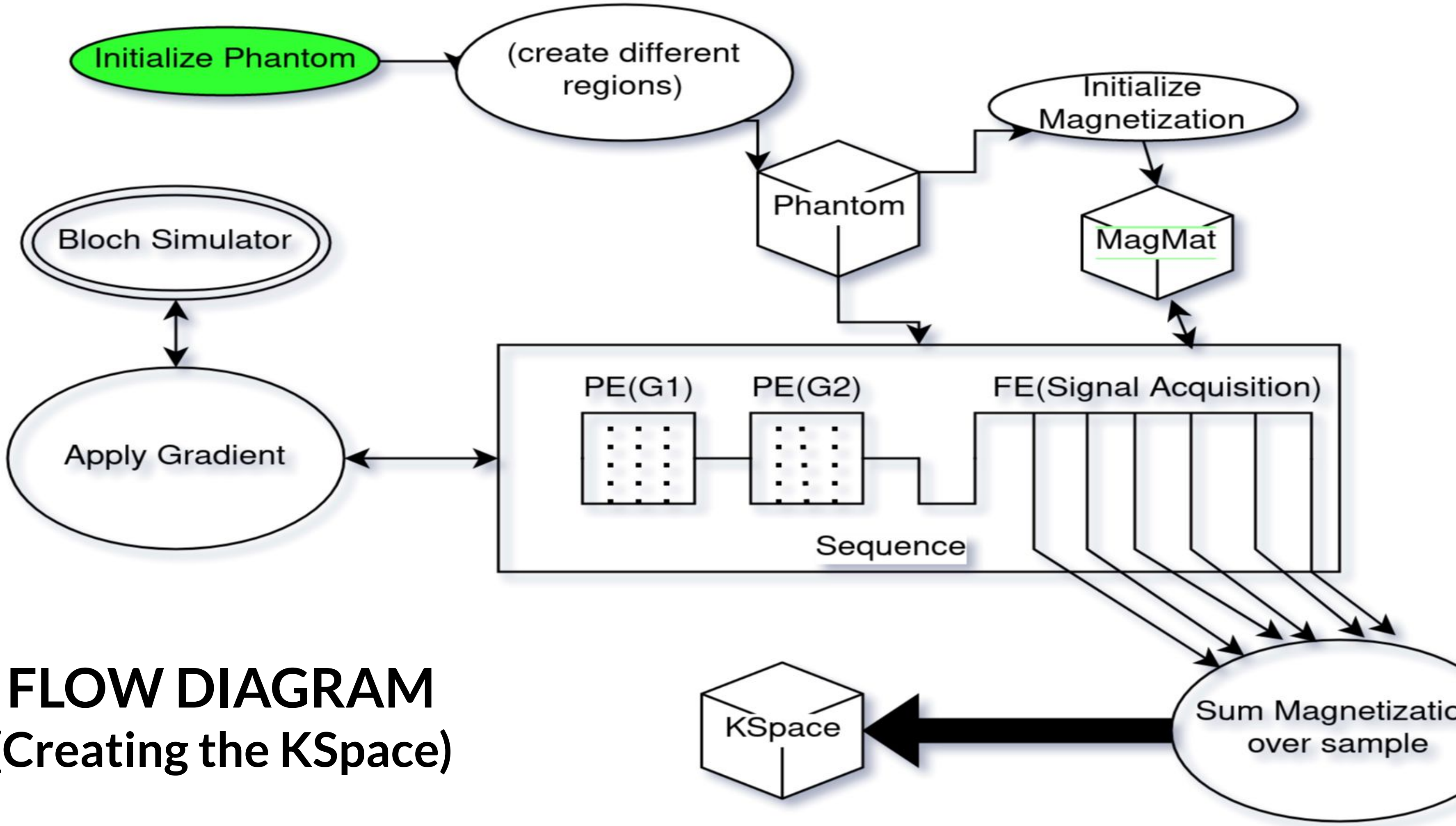
- Perform simulations for certain TE values (TE>=20ms at TR=500ms & α =30°)
- Vary signal (constant signal value) with different TR values at Noise level = 0
- Resemble theoretical signal while varying TR values at any Noise level
- Vary the signal vs flip angle curve for different TR values
- Resemble 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 had multiple computational flaws and hence couldn't model the signal accurately.

Fixing MRiLab Vs Building new MR simulator

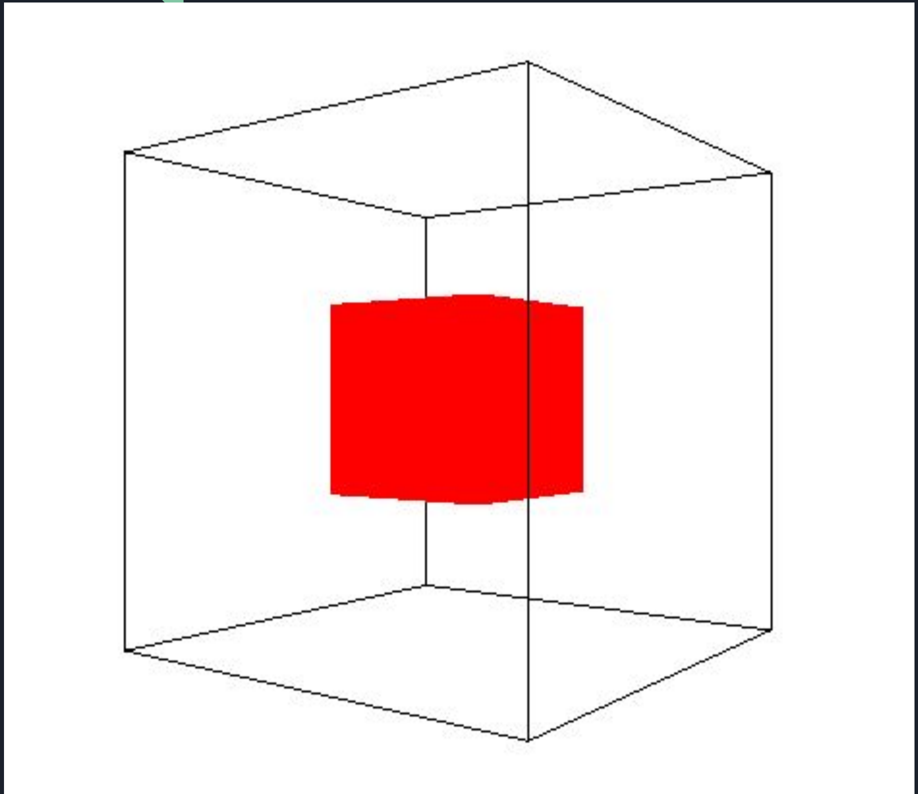
- Working with open-source code
- Simple UI
- Considerations matter diffusion.
- Complex,non-modular low-level language code
- Multiple assumptions
- No reference to the derivation of these equations

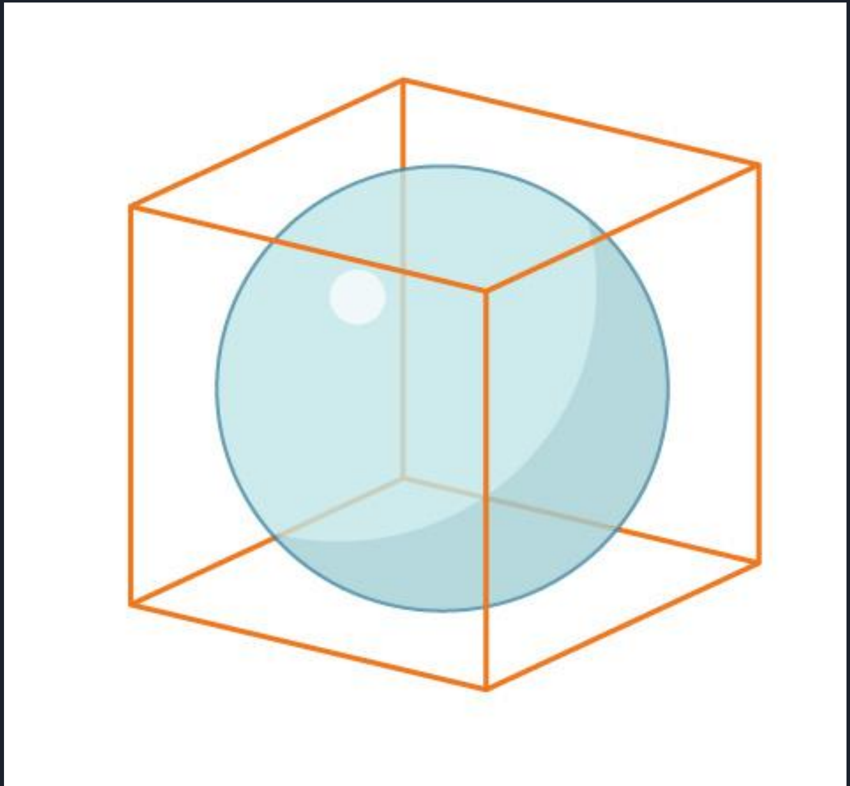
- We can create a modular simulator which will provide more flexibility and scope for improvement.
- New sequences can easily be incorporated.
- Easily readable python code.
- Adding a UI should be easy because of Modularity.
- Open Source



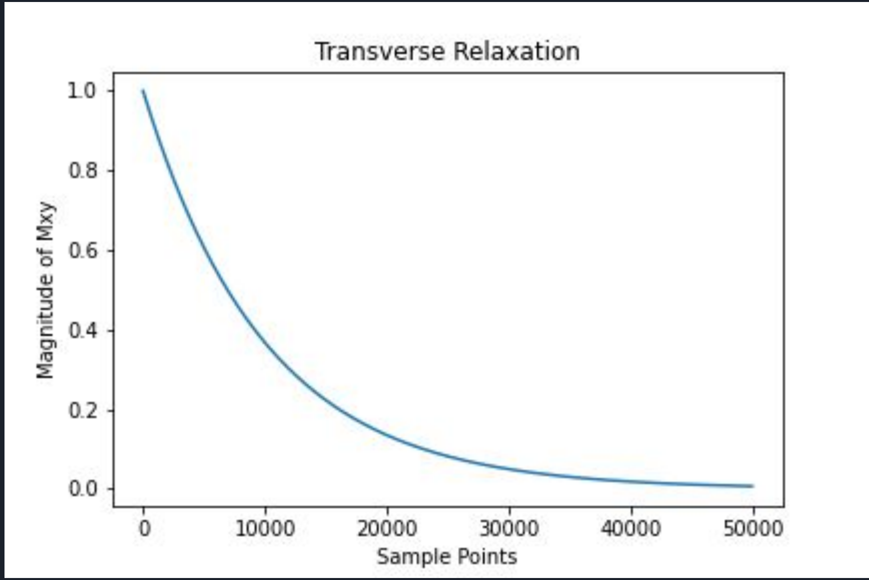
FLOW DIAGRAM
(Creating the KSpace)

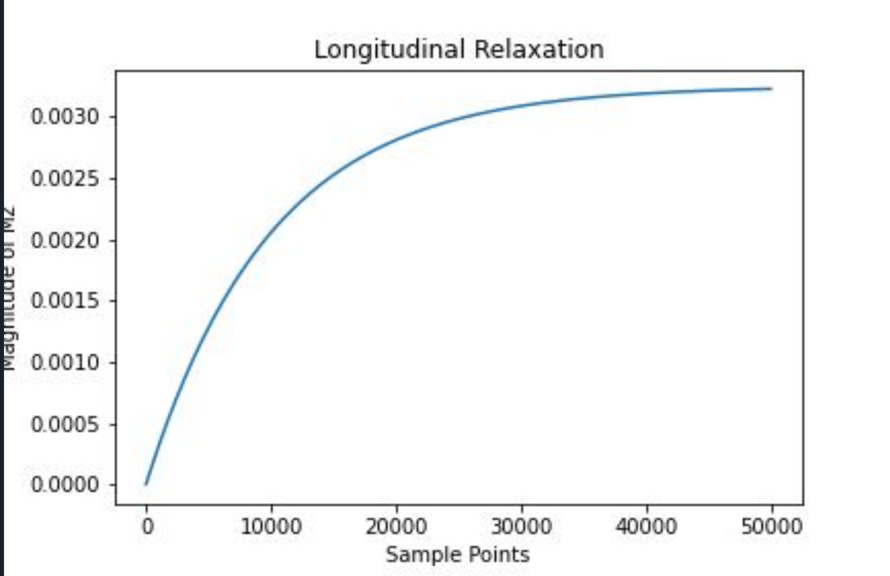
PHANTOMS



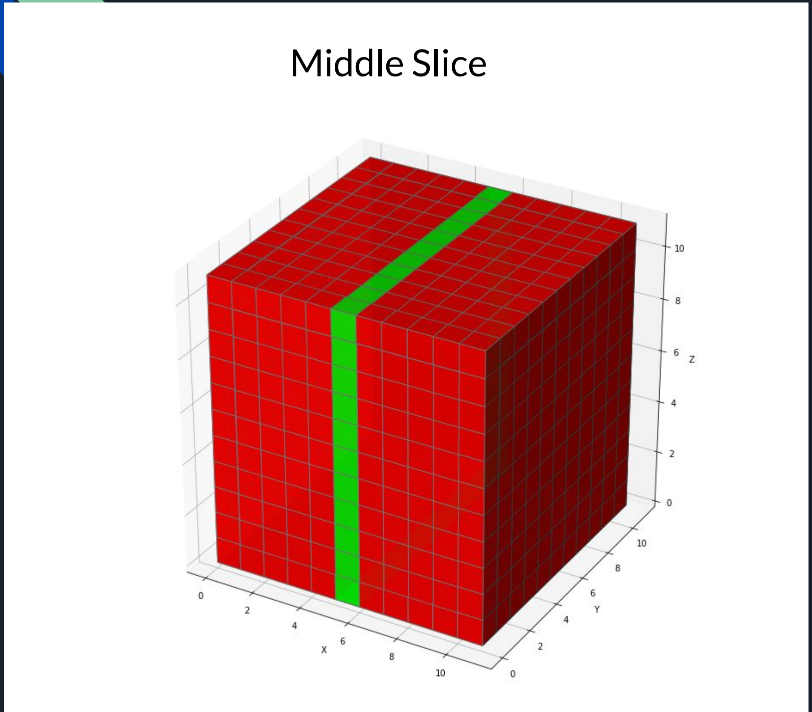


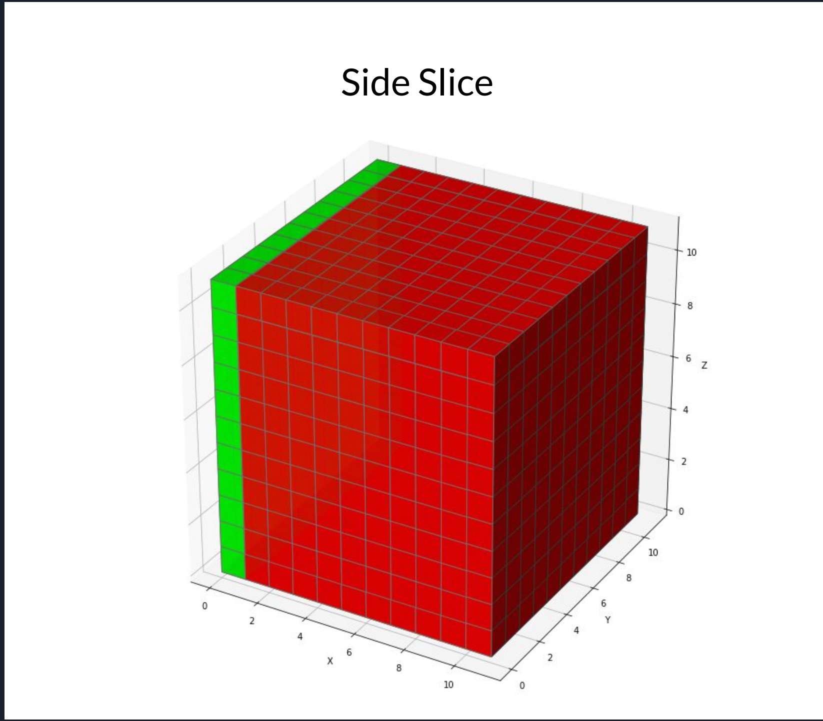
Relaxation (T1 and T2) (VOXEL LEVEL)





Selecting Slices for Representation

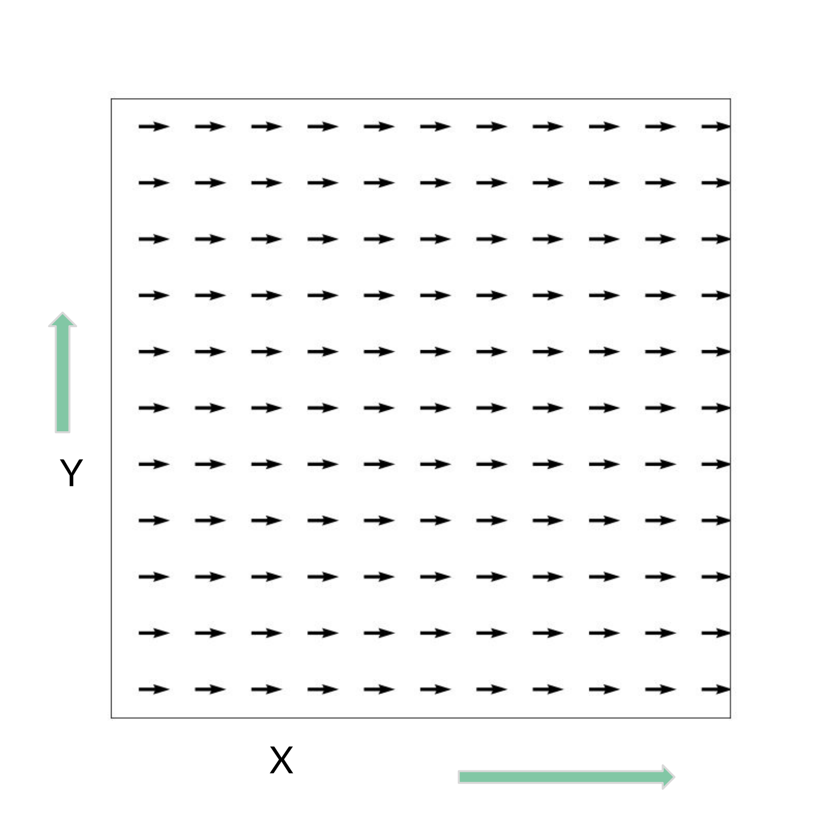




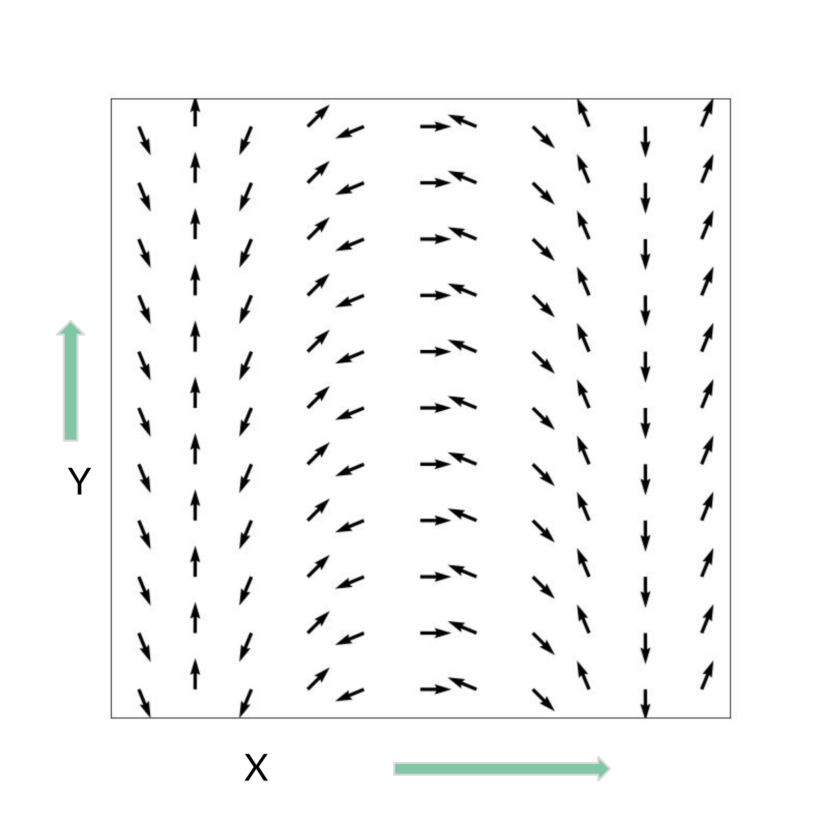
Note: Since we will only be dealing with symmetric phantoms in this presentation the axis of slice selection shall not make a difference in how the corresponding KSpace slice looks.

GRADIENTS (Full water Phantom)

Before Application of Gradient along X

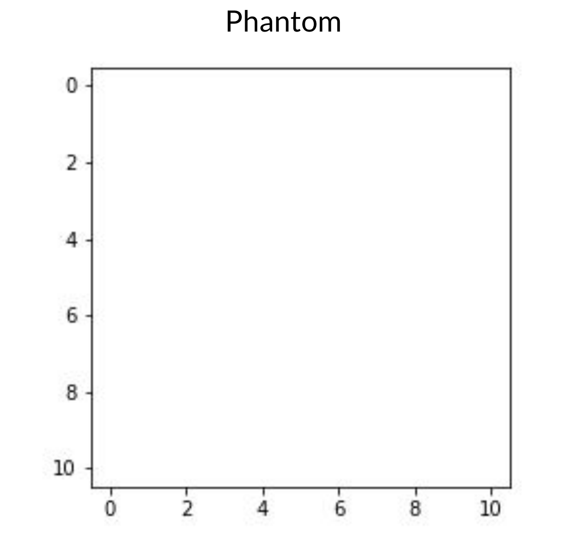


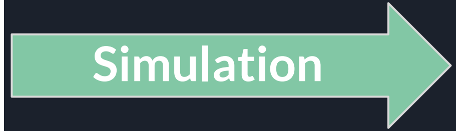
After Application of Gradient along X

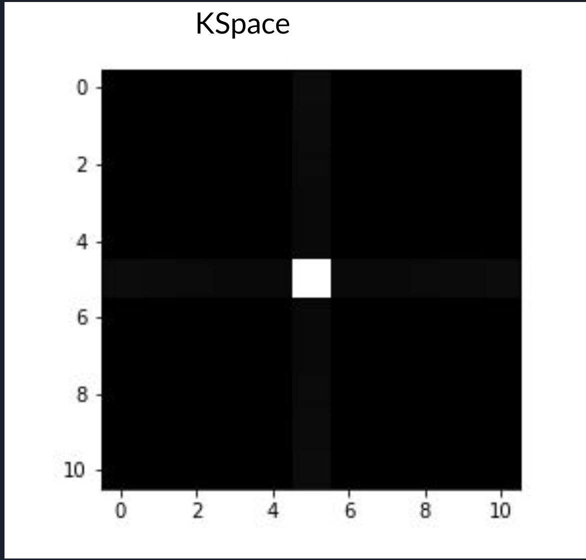


KSpace (Example 1)

Full water Phantom (Proton density 1 throughout)

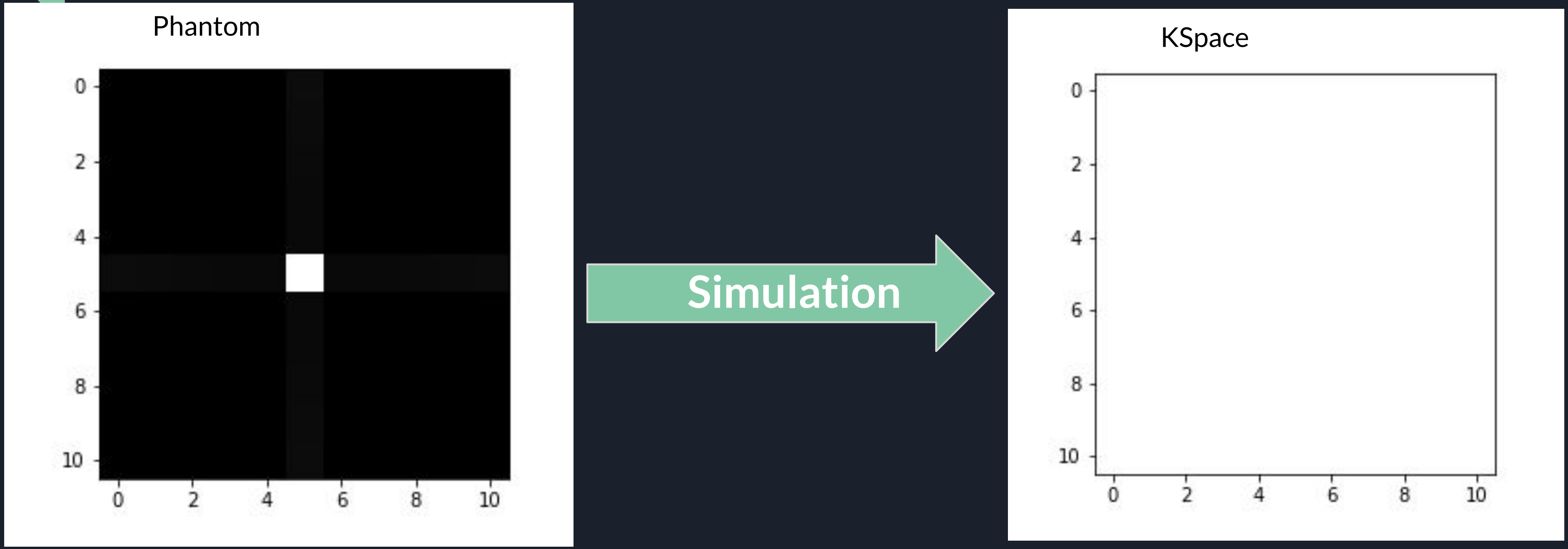






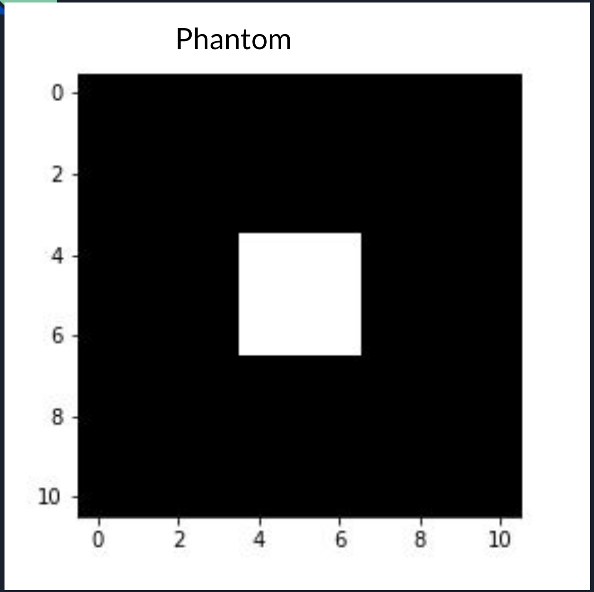
KSpace (Example 1)

Single Voxel Water Phantom(Proton density 0 except in centre)

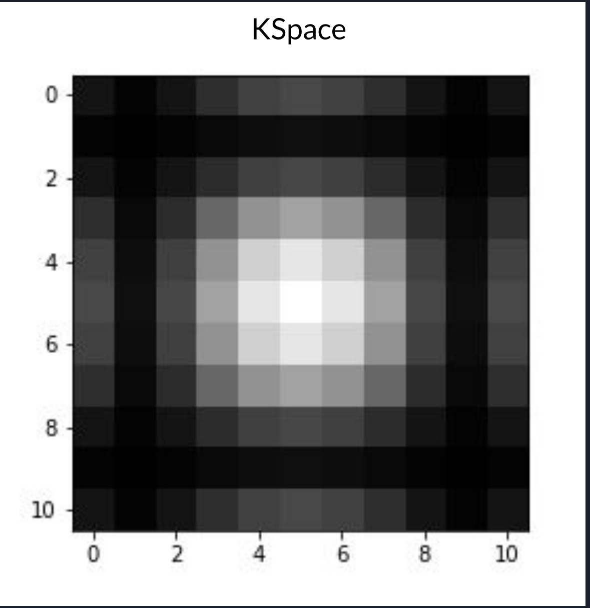


KSpace (Example 1)

3*3*3 cube inside 11*11*11 cube



Simulation



Parallelization of K Space acquisition

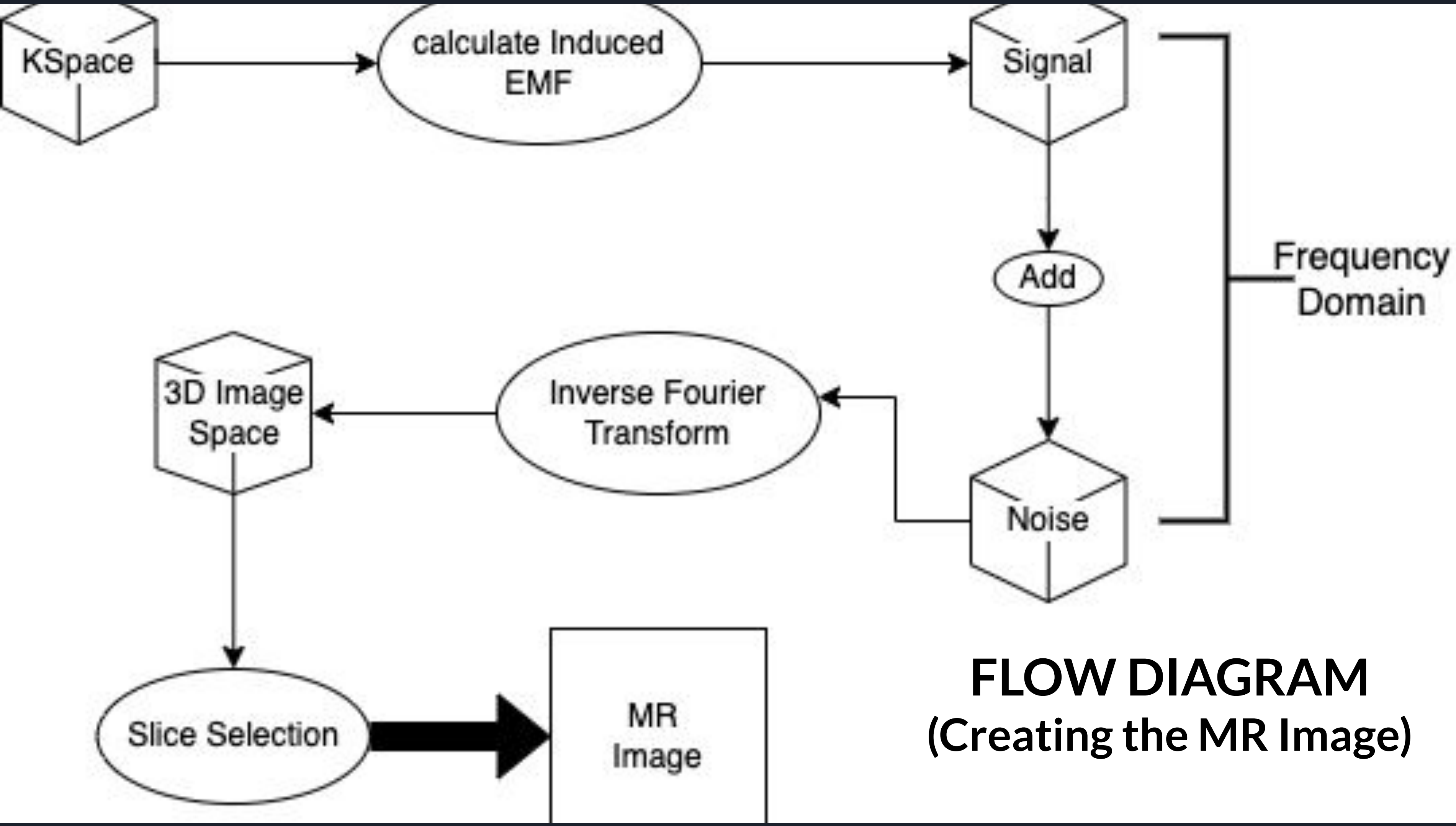
1: Since the simulation is computationally intensive we have utilized pool processing to parallelize the process and reduce the execution time.

2: Application of gradients itself is a very heavy task since you simulate bloch equations for each voxel independently.

3: This simulator can utilize all available CPU's on a machine.

4: The number of times we run through the gradients is NOP*NOP*NOP (Number Of Pixels)

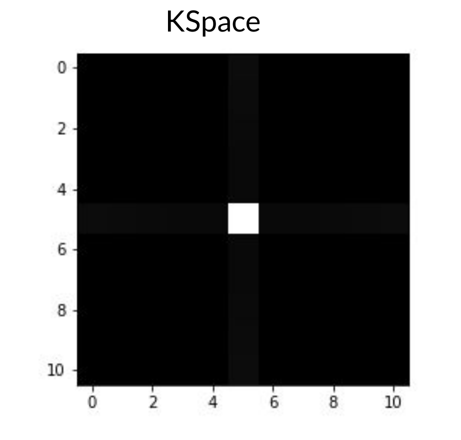
5: We divide these tasks equally among the available processors in the machine.



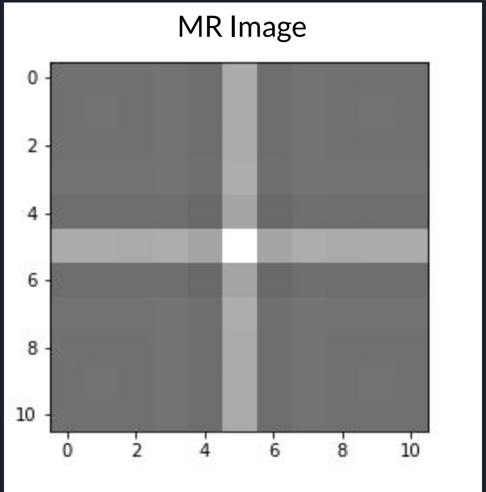
FLOW DIAGRAM
(Creating the MR Image)

MR Image from K-Space (Example 1)

Full water Phantom (Proton density 1 throughout)

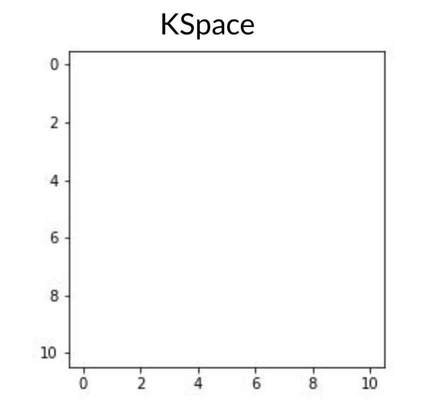


Reconstruction

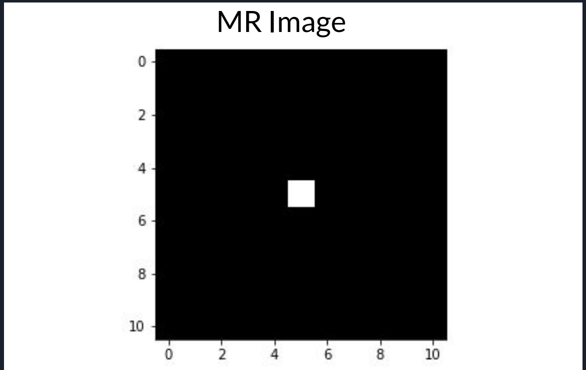


MR Image from K-Space (Example 2)

Single Voxel Water Phantom(Proton density 0 except in centre)

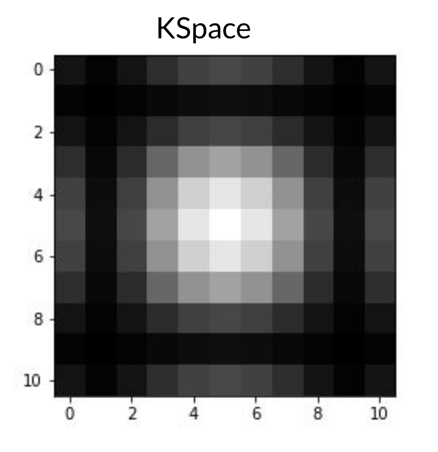


Reconstruction

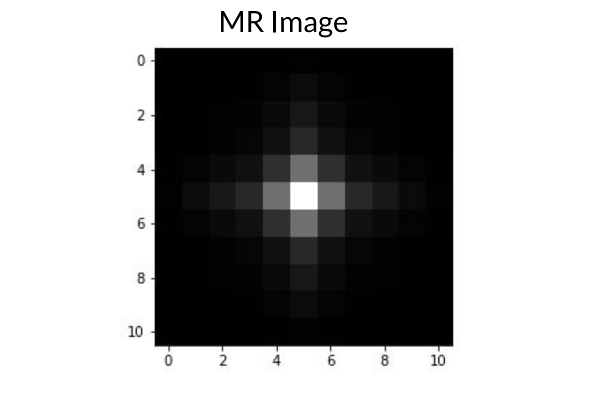


MR Image from K-Space (Example 3)

3*3*3 cube inside 11*11*11 cube



Reconstruction



Probable Reasons for Artifacts

1. Limitations of Discrete Fourier Transform such as leakage

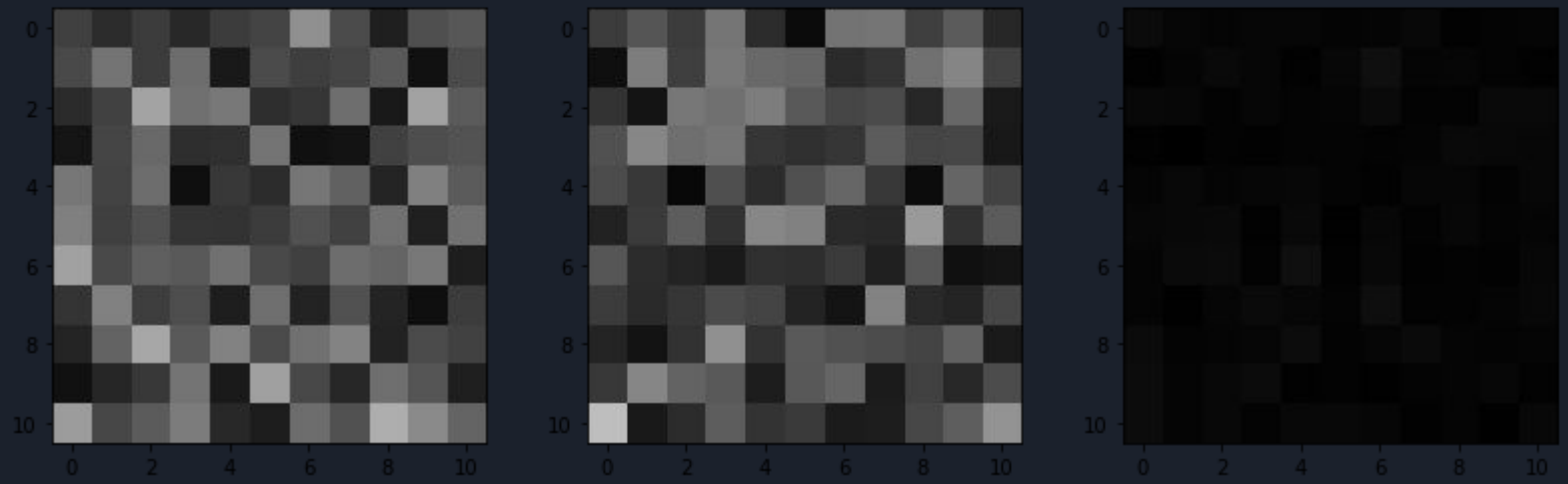
2. Slight difference in the values of constant

3. Error in Gradient calculation process

Effect on Noise by varying Proton Density

[First slice of the 3D image]

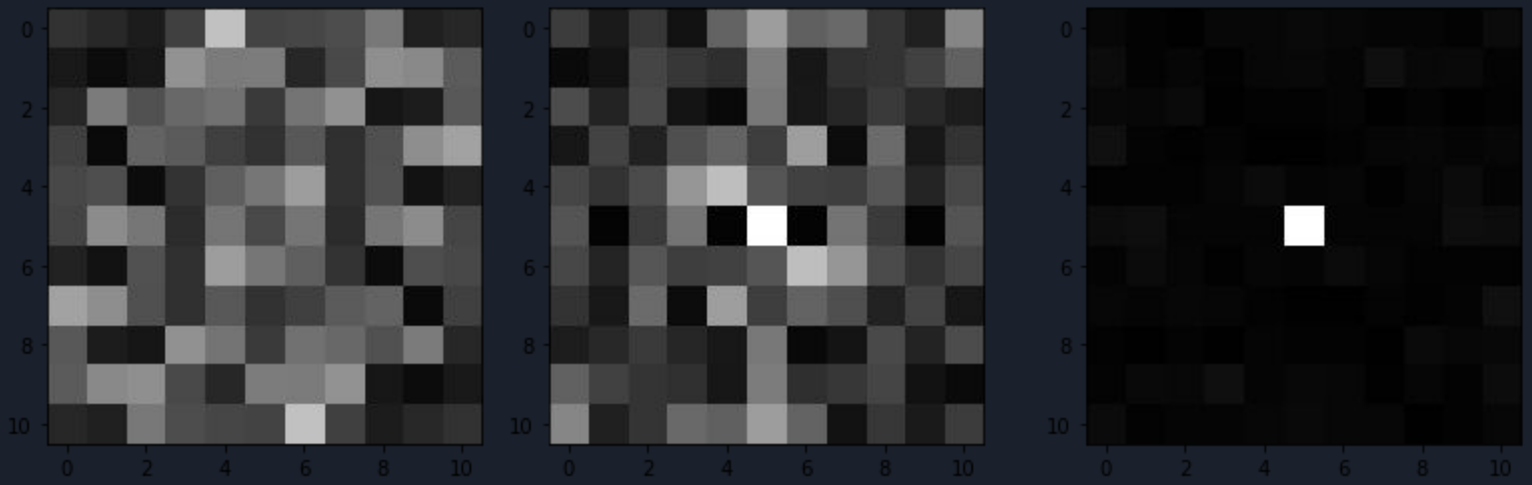
Proton Density (ρ) increasing moving from left to right: 1, 50, 500 in E-10 m^{-3}



Effect on Noise by varying Proton Density

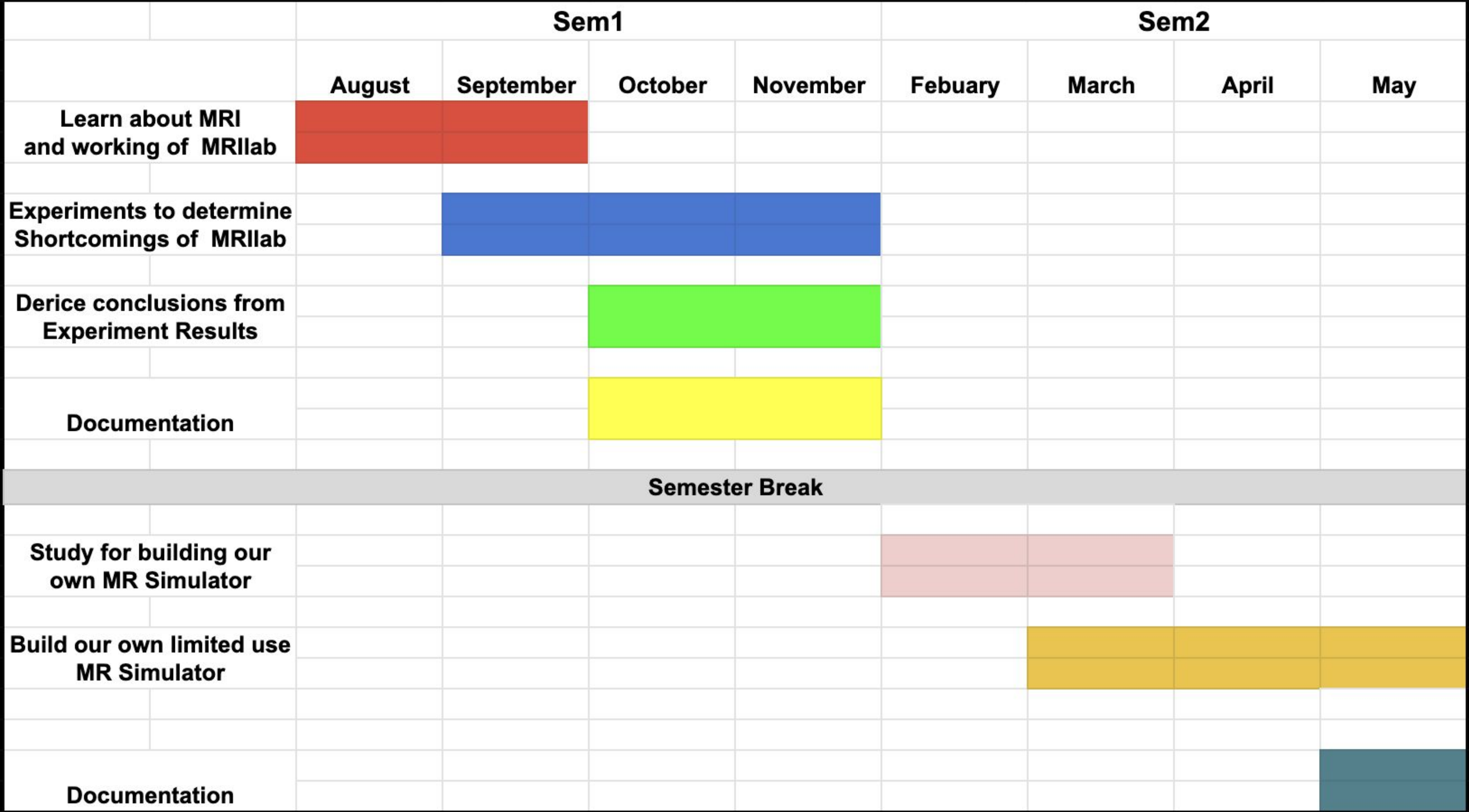
[Center slice of the 3D image]

Proton Density (ρ) increasing moving from left to right: 1, 50, 500 in E-10 m^{-3}



Conclusion

1. The simulator we created is still not complete, there are a lot of complex phenomenon like diffusion that have not been implemented yet.
2. However since the code is modular changes can be made in specific parts of code to introduce more advanced features.
3. There is scope for improving efficiency of the simulator by changing various things eg: how the gradients are applied.
4. The simulator due to its simplistic nature, easily readable modular code, and the code for visualization makes it a great tool for learning how MRI works.


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 Break
Study for building our own MR Simulator
Build our own limited use MR Simulator
Documentation

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