Wrist MRI Discretization Tools for Finite-Difference Time-Domain Solvers and Analysis

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Antenna, RFID, and Computational EM Group

Overview of Contents

Research Motivation

Strict electronic certification requirements driving aggressive corporate investment in FDTD simulation software

- SAR certification, causing rising overhead costs
- FDTD simulation software limited
- Existing methods focused on cranial
- Electrical Nerve Stimulation for Arthritis Pain

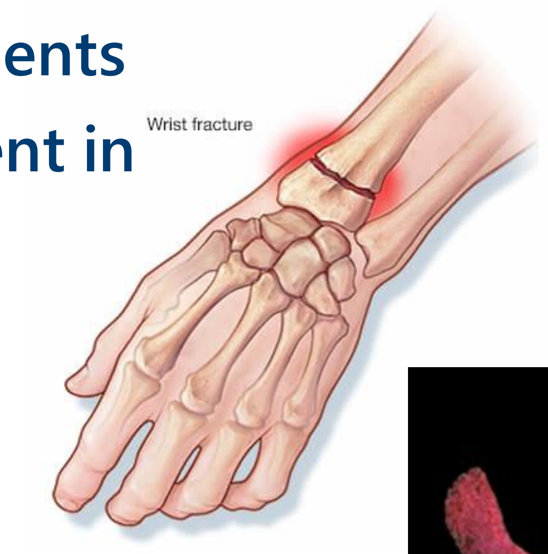

Figure 2 – Wrist Fracture

Figure 1 Coil Demo for Leg-specific MRI Prototype

Sampaio, MD, Marcos Loreto, and Nicholas M. Kolanko, MD. MRI of the wrist. The Journal of Practical Medical Imaging and Management, October 9, 2014. https://www.appliedradiology.com/articles/mri-of-the-wrist

Objectives

1. Develop wrist optimized program
2. FDTD suitable formats
3. Provide higher level accuracy with 2D only
4. Ability to process both color and grayscale
5. Ability to reverse discretization process

Previous Iterations

1998

Atef Z. Elsherbeni
Clayborne D. Taylor, Jr.
The University of Mississippi

Yahya Rahmat-Samii
University of California
Los Angeles

2018

Rachel Lumnitzer
Yiming Chen
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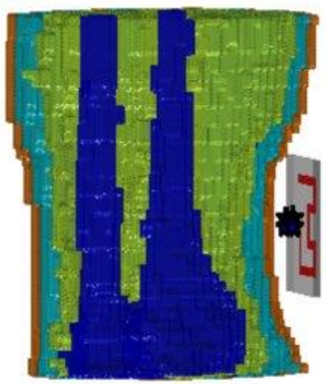
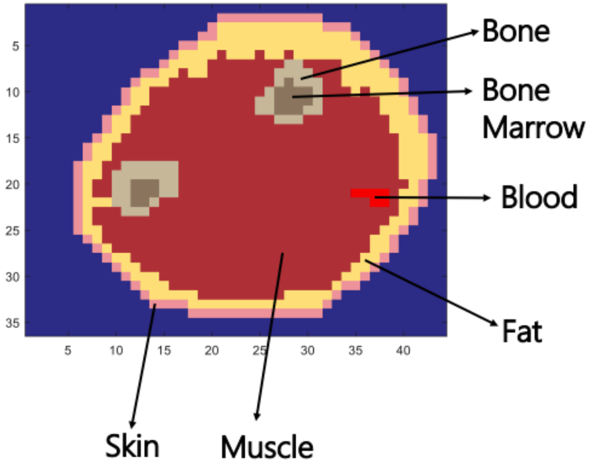
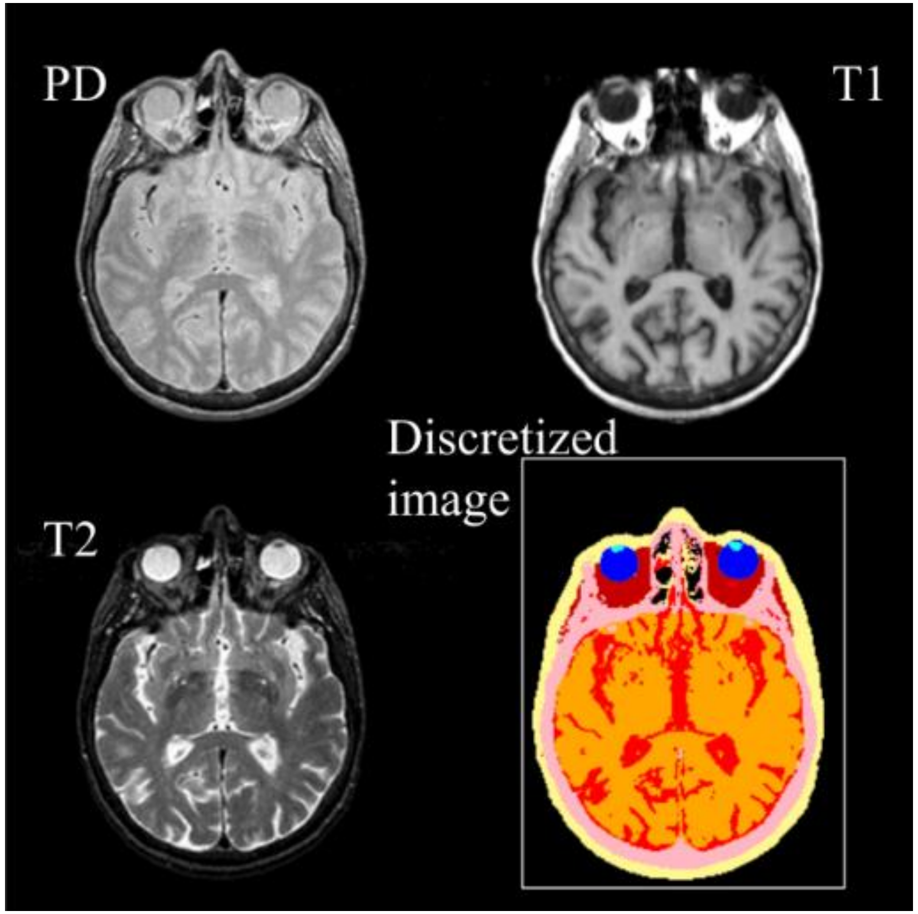
Fatih Kaburcuk
Atef Z. Elsherbeni
Colorado School of Mines







A. Elsherbeni and C.D. Taylor, Jr.,"Simulation of Interaction of Electromagnetic Waves with a Human Head," Electrical Engineering Department, University of Mississippi

Procedure

- Start with actual MRI images → (categorize)
- MRI images → (gray scale)
- Assign a grid to the image, set resolution (h value)
- Assign color by tissue
- Export into format suitable for FDTD (MRI) → [R, G, B, X, Y]
- Integrate the discretized images into the FDTD code
- Reverse the entire process

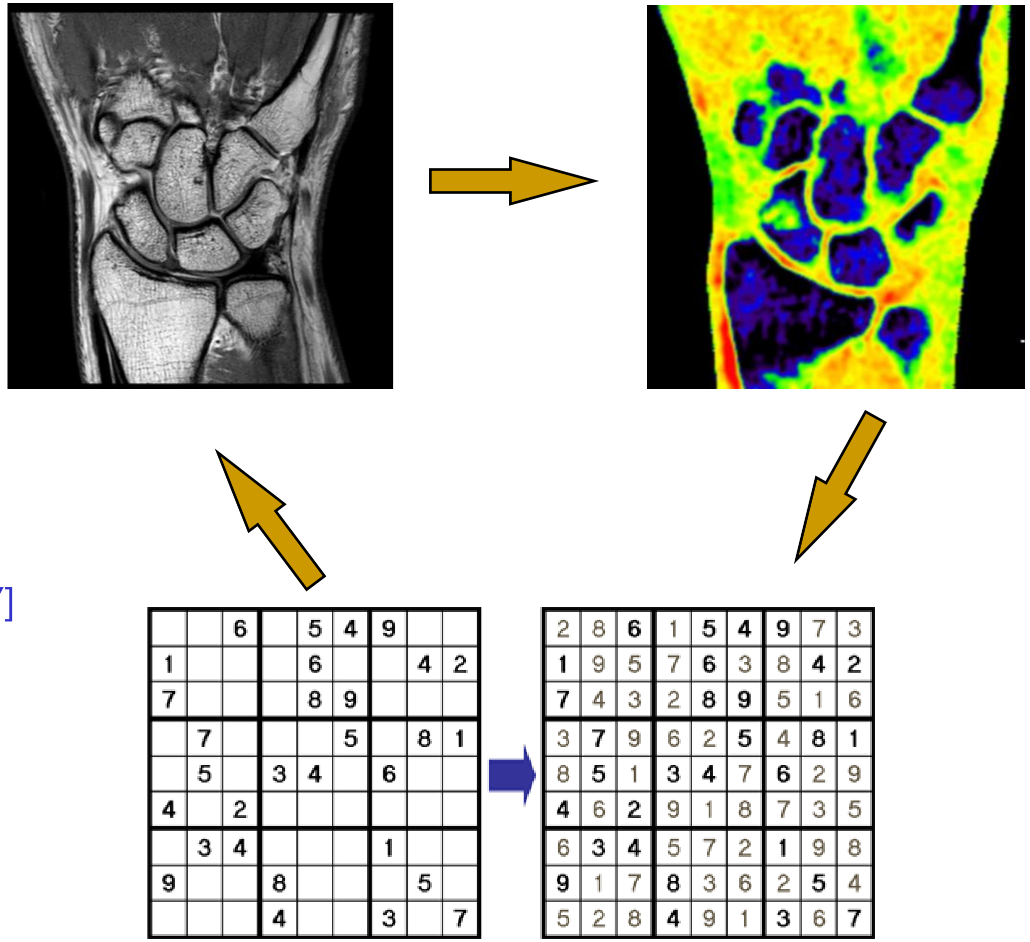


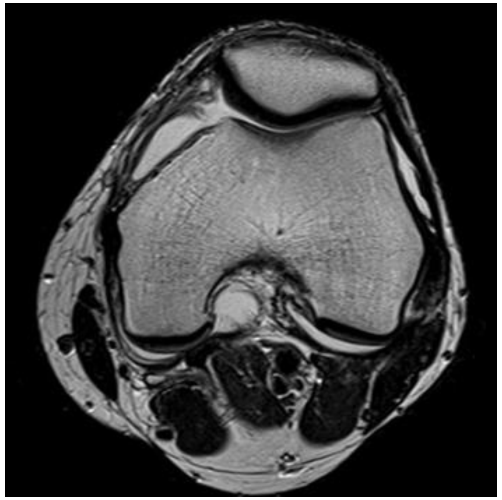
Figure 1. Wrist MRI (from our work). (A) Coronal section with the carpal bones in the dashed yellow box. (B) Zoomed image of the carpal bones. (C) Labeled rendered surfaces of the eight carpal bones.

MRI Protocol

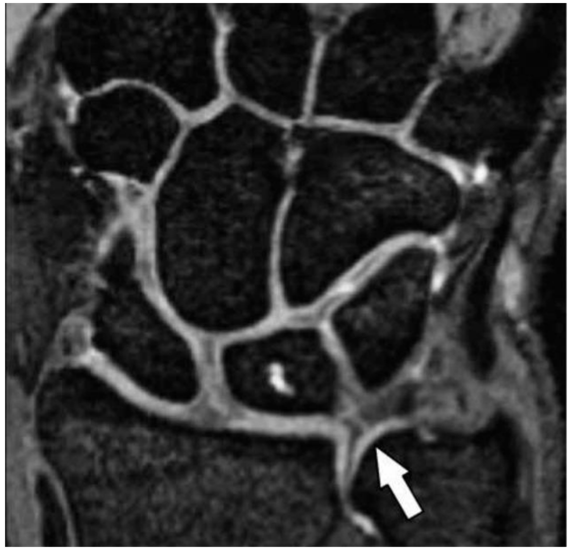
- PD, T1 (LRT), T2 (TRT), GRE
- Fat Suppression

PD

T1



T2



GRE

MRI Protocol

- Increased sophistication of MRI protocol = higher degree of discretization

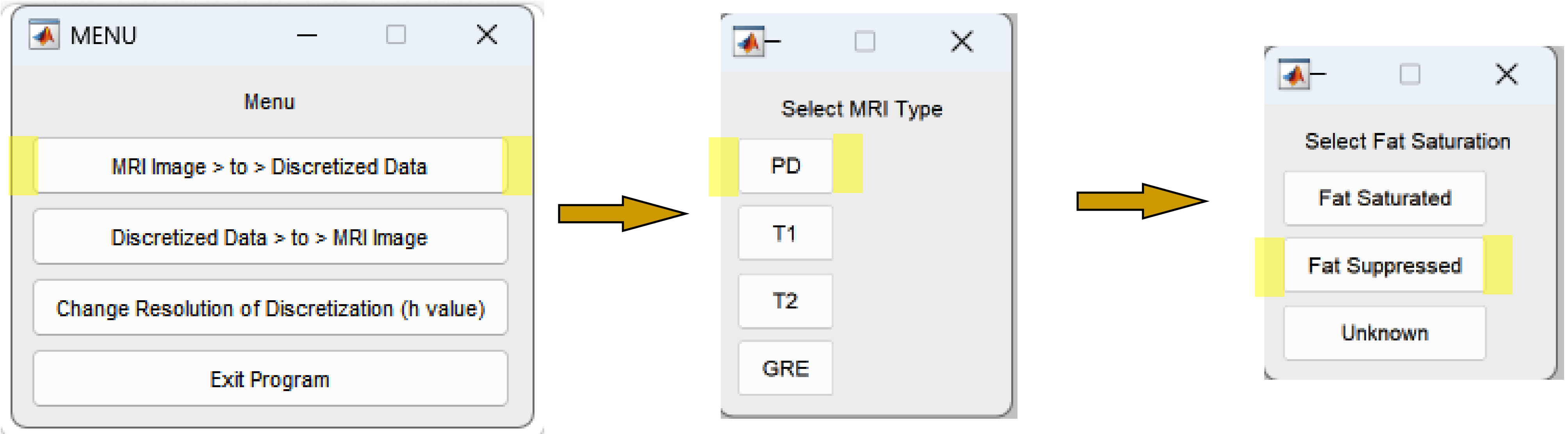
Table 1. MRI protocol

Imaging plane	MRI sequence weighting	Structures optimally assessed
Coronal	Fast spin echo T1 , PD fat sat or STIR and GRE T2*	Bones, intrinsic ligaments, TFCC
Axial	Fast spin echo PD Fat sat and PD (or T1)	Bones, scapholunate ligament, extrinsic ligaments, peri-articular cysts, tendons and nerves
Sagittal	Fast spin echo PD Fat sat	Bones, TFCC, extrinsic ligaments, peri-articular cysts, tendons and nerves

PD – Proton density weighted sequence   Fat sat – spectral fat saturation   GRE – gradient echo

Program Functionality – User Facing Side

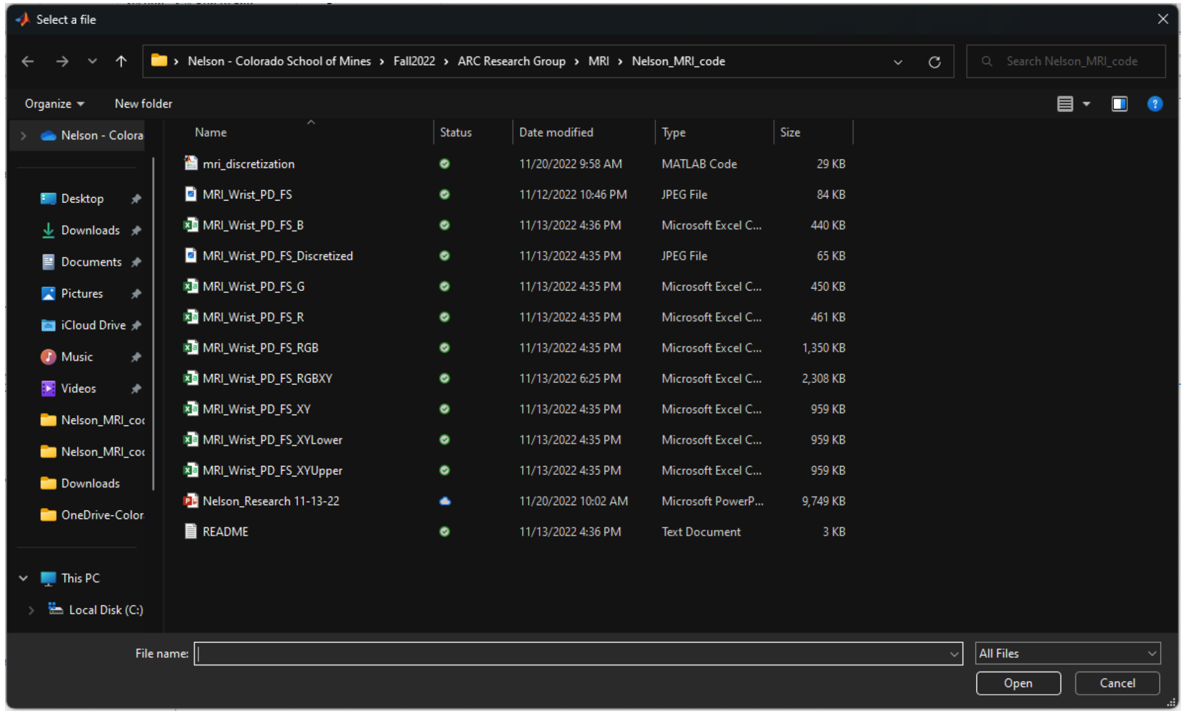
- Menu provides user several options based on MRI type



Categorization enables program to assign a different tissue assignment protocol based on categorization, increasing accuracy of discretization

Program Functionality – User Facing Side

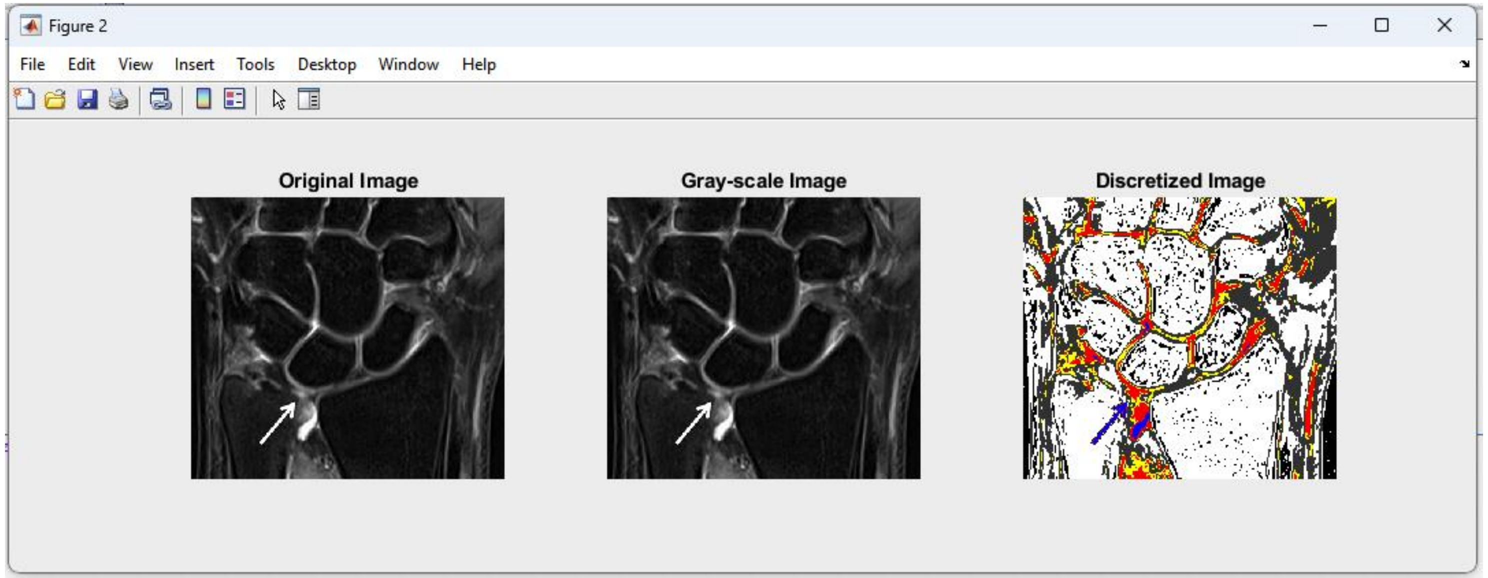
- Program works with system OS to provide user GUI for file selections:



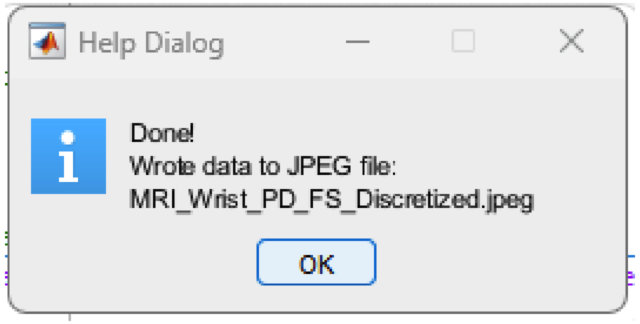
User selects MRI image from any folder

Program Functionality – User Facing Side

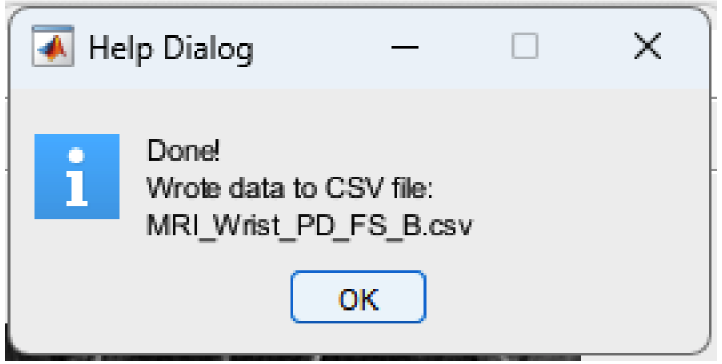
- Program displays image processing montage and exports files:



Montage



JPEG Confirmation



CSV Confirmation

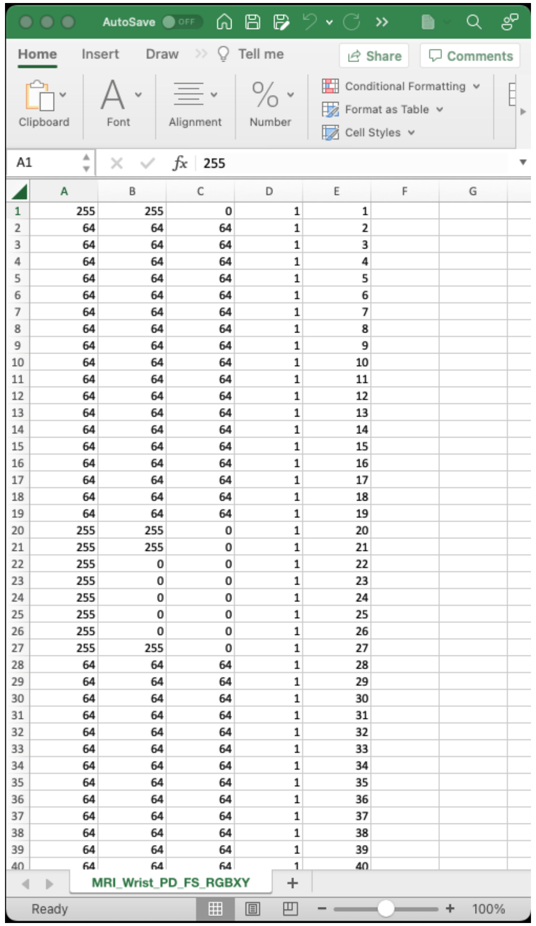
Program Functionality – User Facing Side

- Results:

JPEG

1. [R, G, B, X, Y]
2. [R, G, B]
3. [X, Y]
4. [X_{LOWER},Y_{LOWER}]
5. [X_{UPPER},Y_{UPPER}]
6. [R]
7. [G]
8. [B]

8 FDTD Suitable Formats



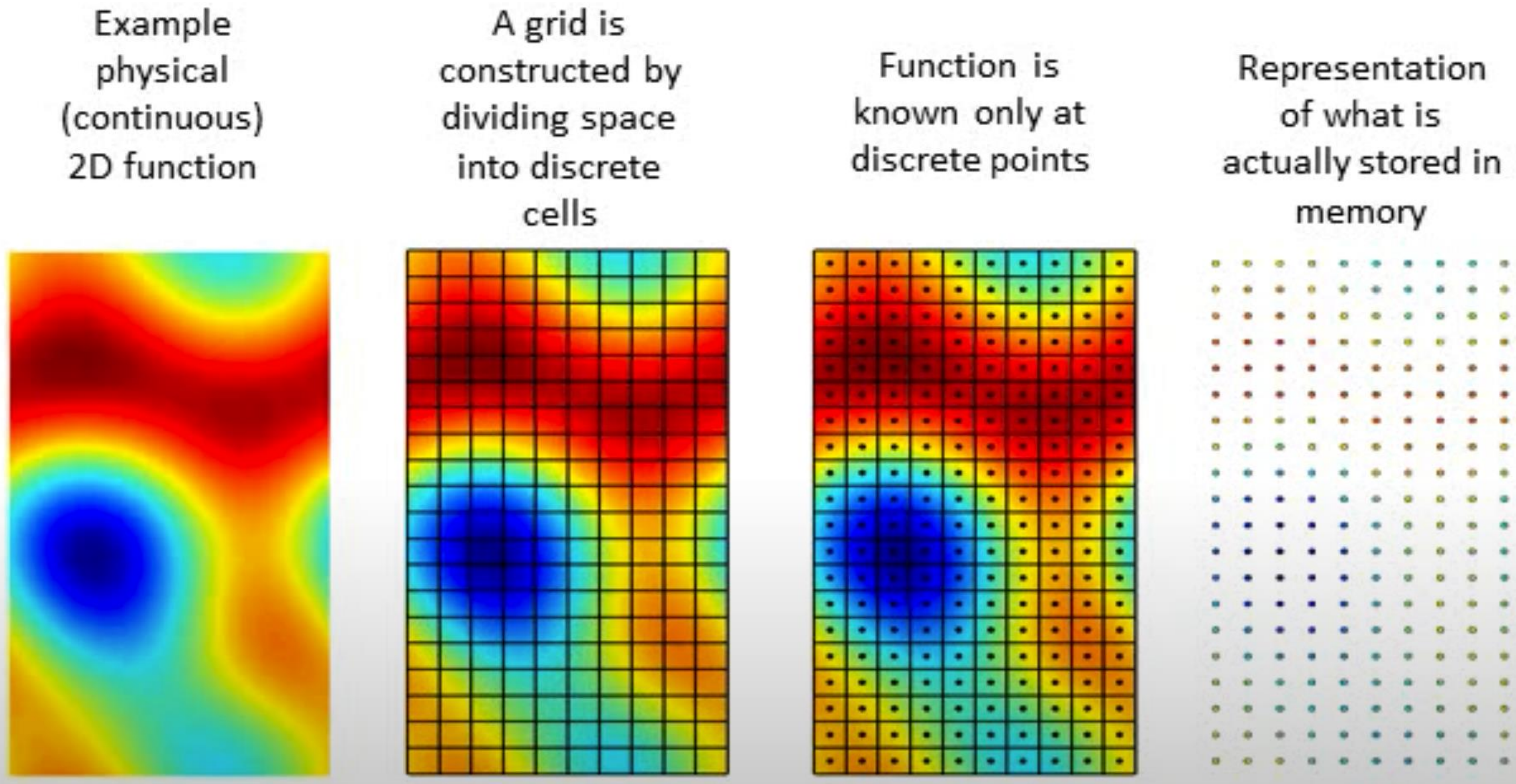
	A	B	C	D	E
1	255	255	0	1	1
2	64	64	64	1	2
3	64	64	64	1	3
4	64	64	64	1	4
5	64	64	64	1	5
6	64	64	64	1	6
7	64	64	64	1	7
8	64	64	64	1	8
9	64	64	64	1	9
10	64	64	64	1	10
11	64	64	64	1	11
12	64	64	64	1	12
13	64	64	64	1	13
14	64	64	64	1	14
15	64	64	64	1	15
16	64	64	64	1	16
17	64	64	64	1	17
18	64	64	64	1	18
19	64	64	64	1	19
20	255	255	0	1	20
21	255	255	0	1	21
22	255	0	0	1	22
23	255	0	0	1	23
24	255	0	0	1	24
25	255	0	0	1	25
26	255	0	0	1	26
27	255	255	0	1	27
28	64	64	64	1	28
29	64	64	64	1	29
30	64	64	64	1	30
31	64	64	64	1	31
32	64	64	64	1	32
33	64	64	64	1	33
34	64	64	64	1	34
35	64	64	64	1	35
36	64	64	64	1	36
37	64	64	64	1	37
38	64	64	64	1	38
39	64	64	64	1	39
40	64	64	64	1	40

CSV

Entire process can be reversed in like manner

Program Functionality – Backend Code

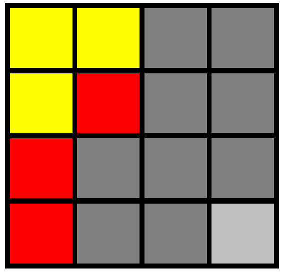
Representing functions on a grid



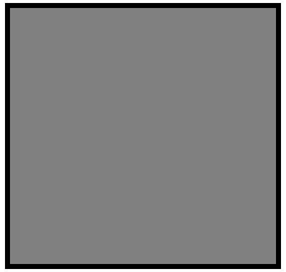
Program Functionality – Backend Code

2 grids assigned. 1st grid is for quantization of cell material (from previous iteration):

- Based on the desired resolution, each cell will contain several material types.
- Each material type is counted in the cell.
- The greatest occurring material will be selected as the material type for this cell.



Original area of
3 bone cells
3 fluid cells
9 air cells
1 cartilage cell



Quantized
to 1 air cell

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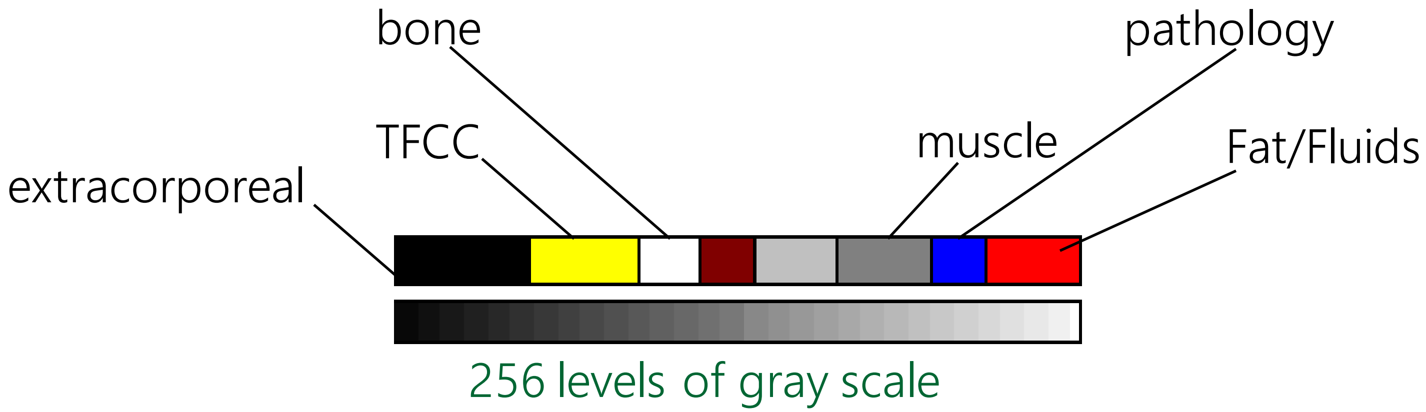
Program Functionality – Backend Code

Tissue assignment methodology:

- The ASCII pixel data are converted to integers
- The 256 levels in each pixel are interpreted as one of 6 different materials including free space.
- Each material type is considered to have an exclusive interval for a quick conversion.

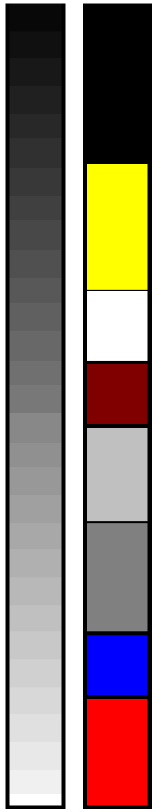


A. Elsherbeni and C.D. Taylor, Jr.,"Simulation of Interaction of Electromagnetic Waves with a Human Head," Electrical Engineering Department, University of Mississippi

Program Functionality – Backend Code

Tissue assignment methodology (For PD FS assignment protocol):

Tissue Type	Gray Level	Color
extracorporeal/free space	0-9	black
bone	10-49	white
muscle & tendons	50-99	Dark grey
TFCC	100-119	yellow
fat & fluids	120-229	red
pathological issue	230-255	blue

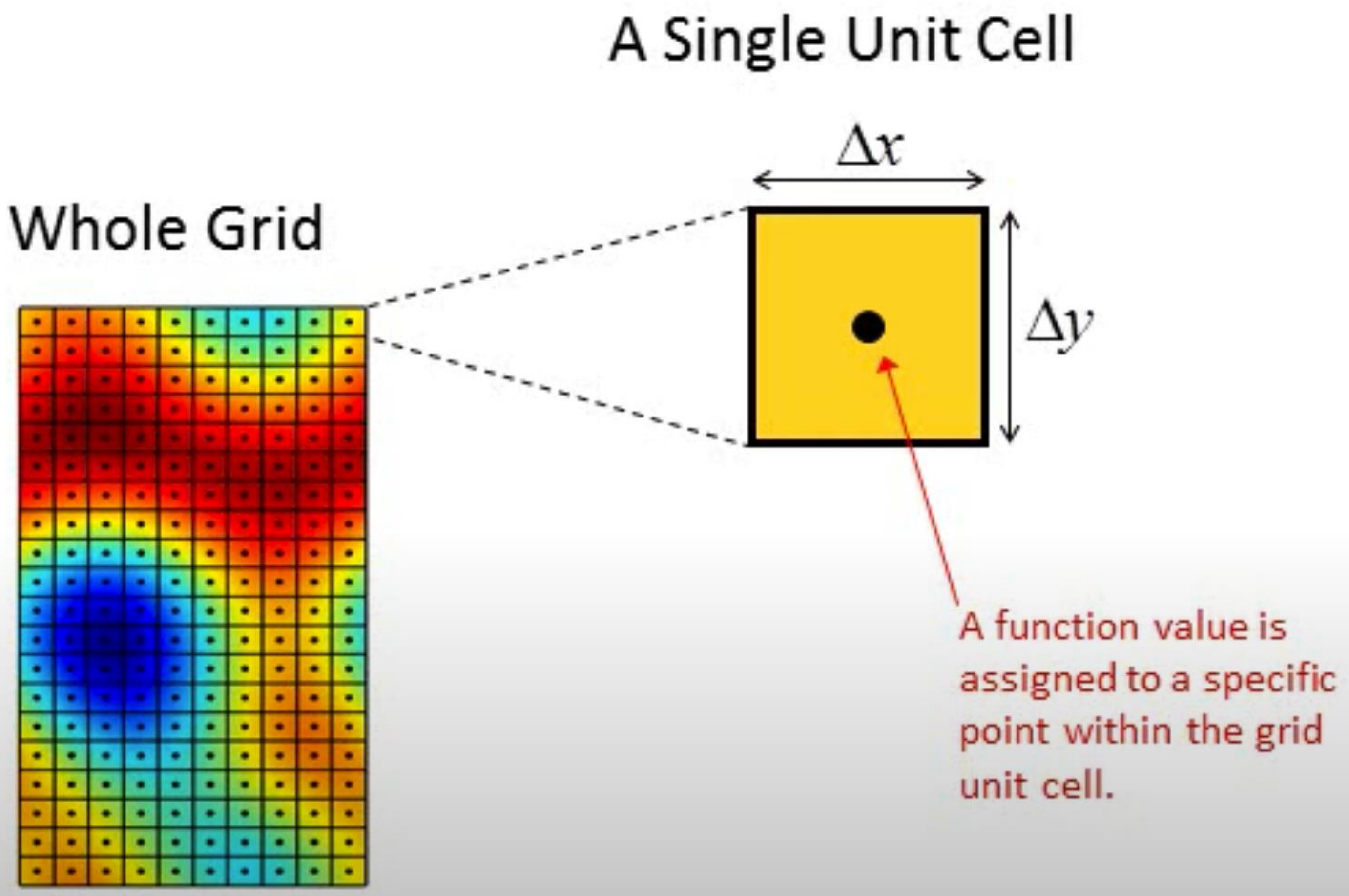


Program Functionality – Backend Code

```
%% Resynthesize image based on tissue
% by assigning tissue to colors

   if PD == true % image is a PD
       if fatSuppressed == true
               % Extracorporeal -> Black
               linearInd = find(grayImage>=0 & grayImage<=9);
               redChannel = grayImage;
               redChannel(linearInd) = 0;
               greenChannel = grayImage;
               greenChannel(linearInd) = 0;
               blueChannel = grayImage;
               blueChannel(linearInd) = 0;
               outImage = cat(3, redChannel, greenChannel, blueChannel);


               % Muscle -> Dark Grey
               linearInd = find(grayImage>=50 & grayImage<=99);
               redChannel(linearInd) = 64;
               greenChannel(linearInd) = 64;
               blueChannel(linearInd) = 64;
               outImage = cat(3, redChannel, greenChannel, blueChannel);
```

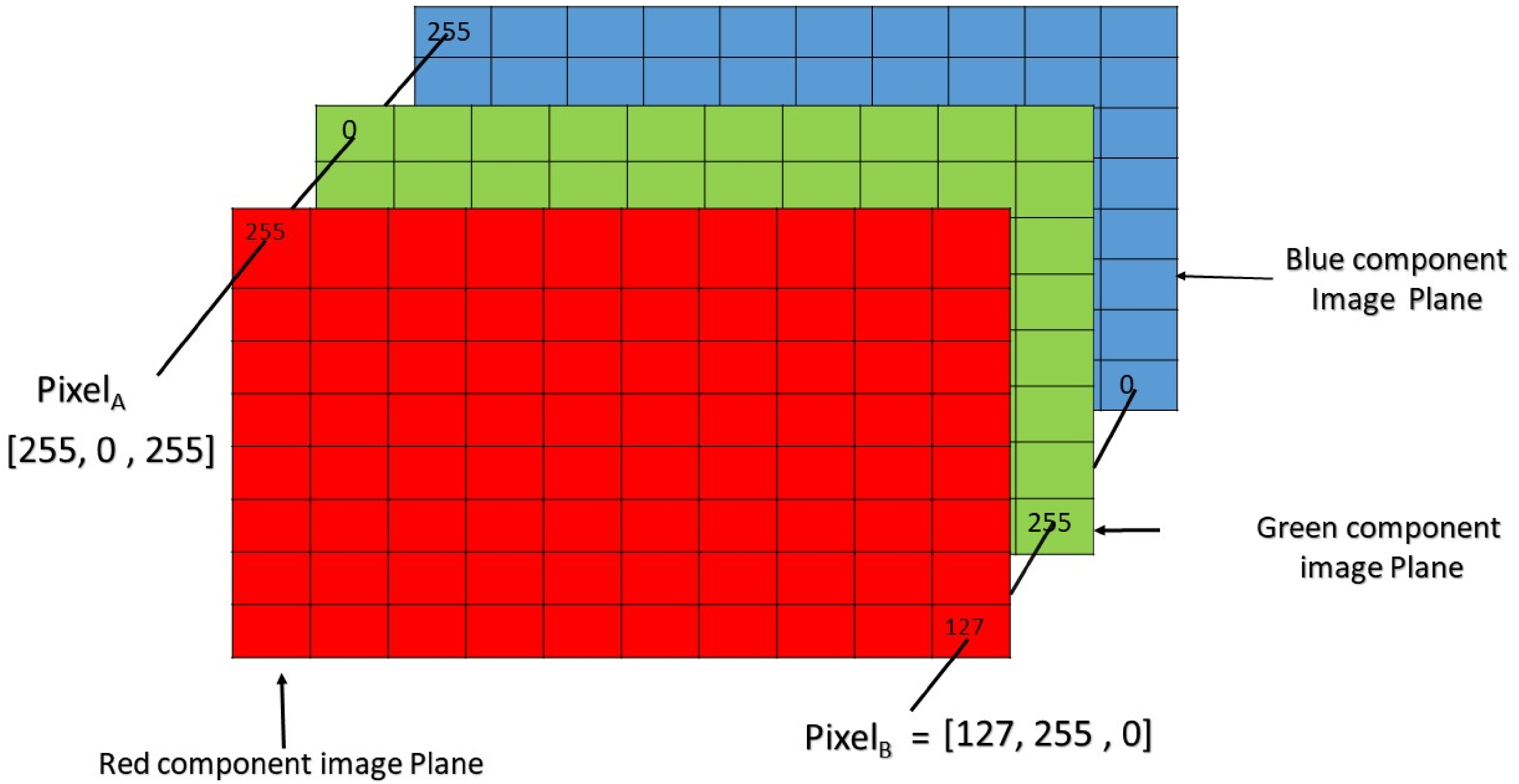
Program Functionality – Backend Code

FDTD Export based on 2nd grid:



Program Functionality – Backend Code

Rearange image array into format suitable for FDTD -> 8 Matrices



Pixel of an RGB image are formed from the corresponding pixel of the three component images

Program Functionality – Backend Code

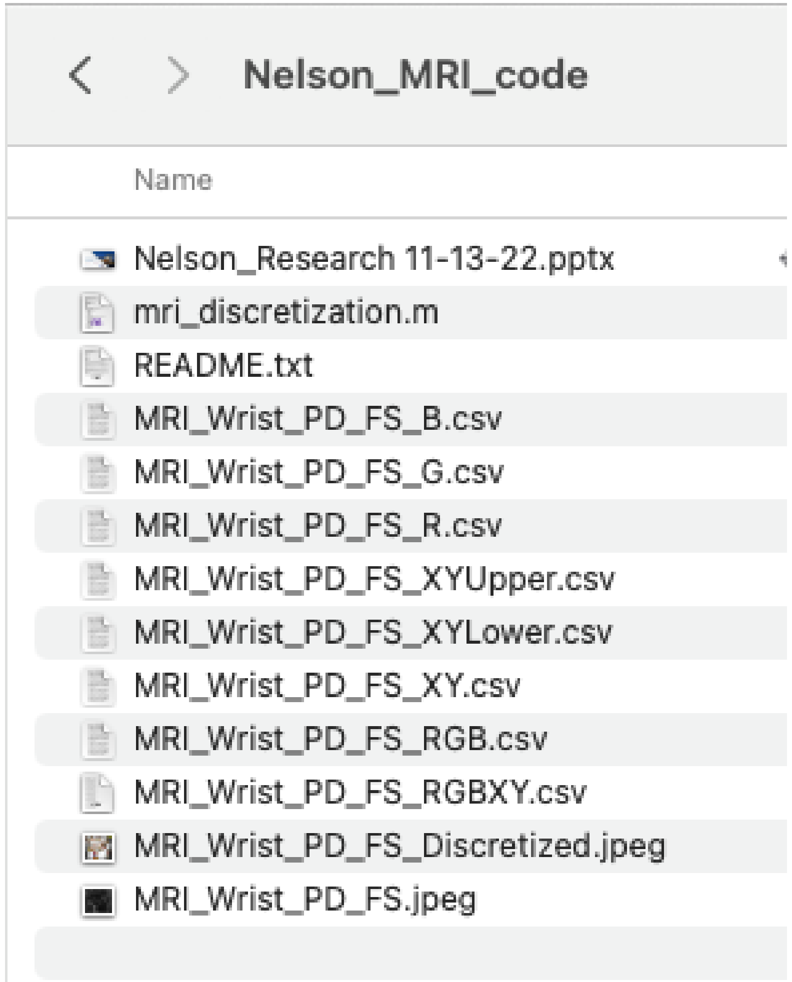
```
%% Rearange image array into format suitable for FDTD -> 8 Matrices contained in CSV or TXT 1. [R, G, B,
[rows, columns, numberOfColorChannels] = size(outImage);
[x, y] = meshgrid(1:columns, 1:rows);
% Extract the individual red, green, and blue color channels.
% Need to cast to double or else x and y will be clipped to 255 when we concatenate them.
if numberOfColorChannels == 1
    % Leave as gray scale.
    % Get array listing [r, g, b, x, y].  Using (:) will turn all the 2-D arrays into column vectors.
    finalImage = [outImage(:), x(:), y(:)];
else
    redChannel = double(outImage(:, :, 1));
    greenChannel = double(outImage(:, :, 2));
    blueChannel = double(outImage(:, :, 3));

    %% Get array listing [r, g, b, x, y].  Using (:) will turn all the 2-D arrays into column vectors.
    %Extract all matrices and combine 1. [R, G, B, X, Y]
    finalImage = [redChannel(:), greenChannel(:), blueChannel(:), x(:), y(:)];

    %Extract R, G, B color matrices and combine  2. [R, G, B]
    finalImageRGB = [redChannel(:), greenChannel(:), blueChannel(:)];

    %Extract X, Y coordinate matrices and combine  3. [X, Y]
    finalImageXY = [x(:), y(:)];

    %Extract X lower bound, Y lower bound coordinate matrices and combine  4. [X Lower, Y Lower]
    [i] = finalImageXY(:,1);
    [j] = finalImageXY(:,2);
    finalImageXYLower = [i, j+1];
```

Program Functionality – User Facing Side

- Results:

1. [R, G, B, X, Y]
2. [R, G, B]
3. [X, Y]
4. [X_{LOWER},Y_{LOWER}]
5. [X_{UPPER},Y_{UPPER}]
6. [R]
7. [G]
8. [B]

8 FDTD Suitable Formats



Entire process can be reversed in like manner

Next Steps

- MRI Discretization Protocols to be Expanded
  - Tissue assignment protocol will be further sophisticated to take advantage of deeper MRI protocols
- Integration into FDTD
- App?