Elie Daou

Assignment #2

Due Monday 6, March 2017

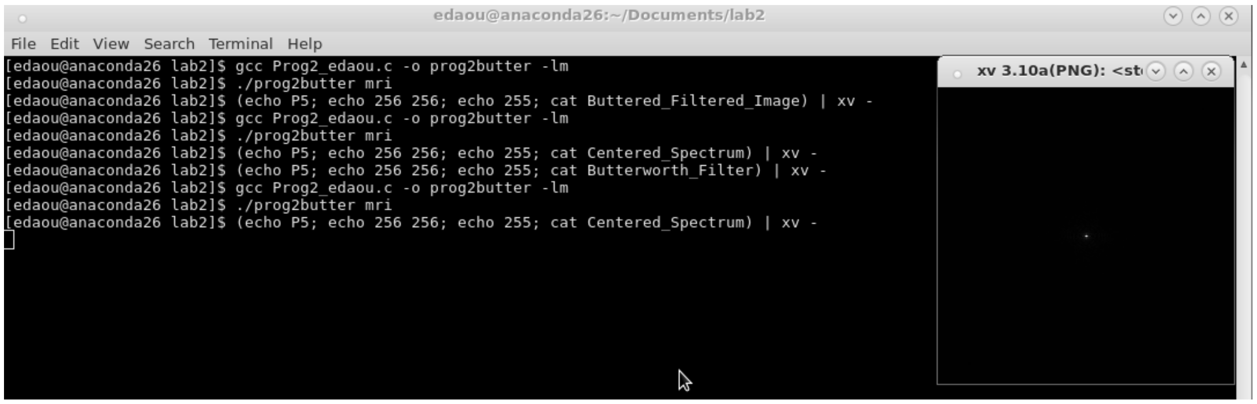
The objective of this assignment was multiple parts. The first part was to properly typecast and otherwise manipulate data using C. The next, was to familiarize ourselves with how to use a Fourier transform function (FFT) to manipulate data in an array. The last part was to create and apply a Butterworth Low Pass Filter.

The background of the assignment is that a Fast Fourier Transform (FFT) can be used to get the spectrum of an image. This can be done in a 2-dimensional array of pixel values. Also, a Butterworth Low Pass Filter can be used to filter an image.

The algorithms used for this lab were implementation of the FFT. A 1-dimensional Fast Fourier Transform function was used to implement a 2-dimenstional transform. First the 1D transform was used on the rows of the image. Next, the 1D transform was used on the columns of the image. The resulting values were then normalized to be within 0 and 255. This normalized array was then centered, so the spectrum was in the center and not the four corners. These values were then typecasted to be unsigned chars and placed back into an output image to view. The next algorithm used was the Butterworth Low Pass Filter. This is an equation that is used on the spectral array. The "buttered" array is then inverse-FFT and placed back into an output image to view.

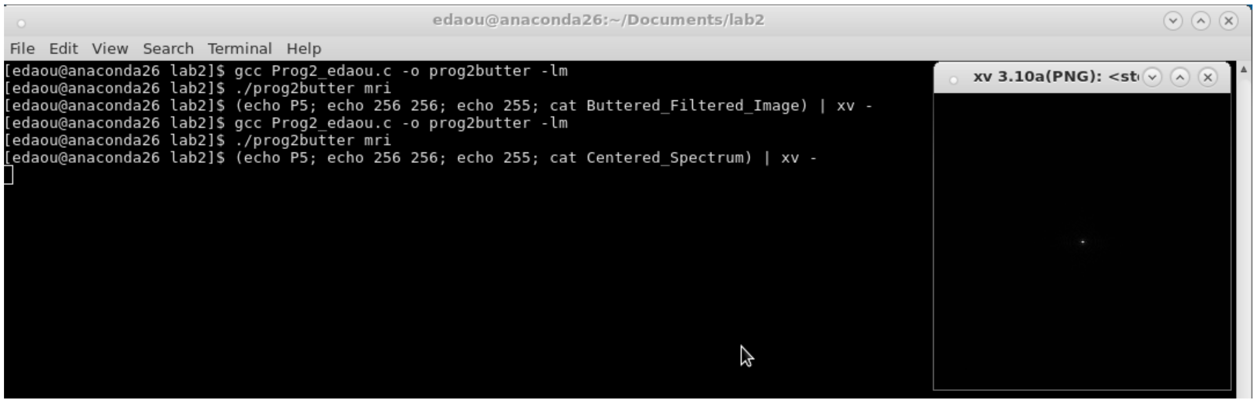
Results

Figure 1 (MRI Spectrum)


edaou@anaconda26:~/Documents/lab2
File Edit View Search Terminal Help
xv 3.10a(PNG): <st

```
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Buttered_Filtered_Image) | xv -
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Centered_Spectrum) | xv -
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Butterworth_Filter) | xv -
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Centered_Spectrum) | xv -
```

Figure 2 (MRI Spectrum)

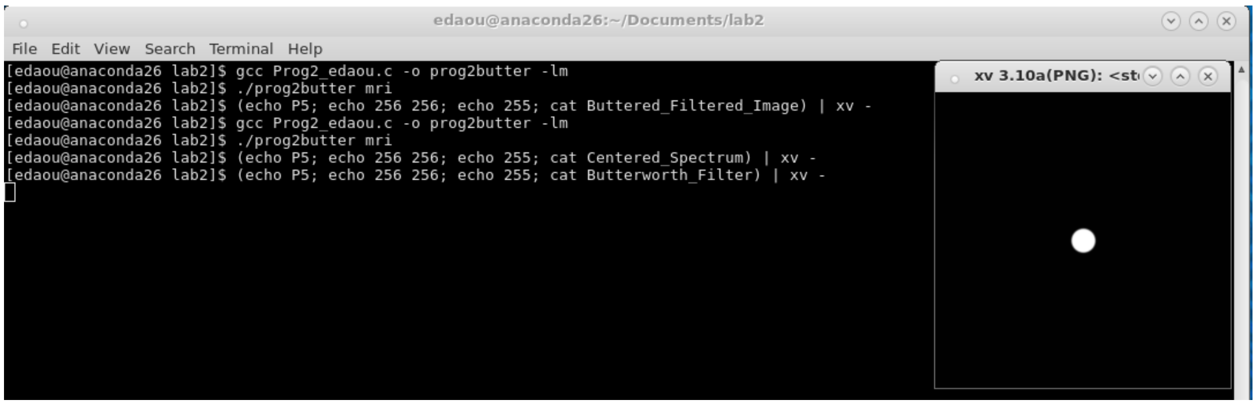


edaou@anaconda26:~/Documents/lab2
File Edit View Search Terminal Help
xv 3.10a(PNG): <st

```
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Buttered_Filtered_Image) | xv -
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Centered_Spectrum) | xv -
```

Figure 1 and figure 2 seem identical, but in fact they are the outputs of the program running at two different times. Figure 1 is run when D0 (for the Butterworth Filter) is set to 10, and figure 2 is when D0 is set to 50. They look identical because they are. The Butterworth Filter does not affect the spectral analysis at all.

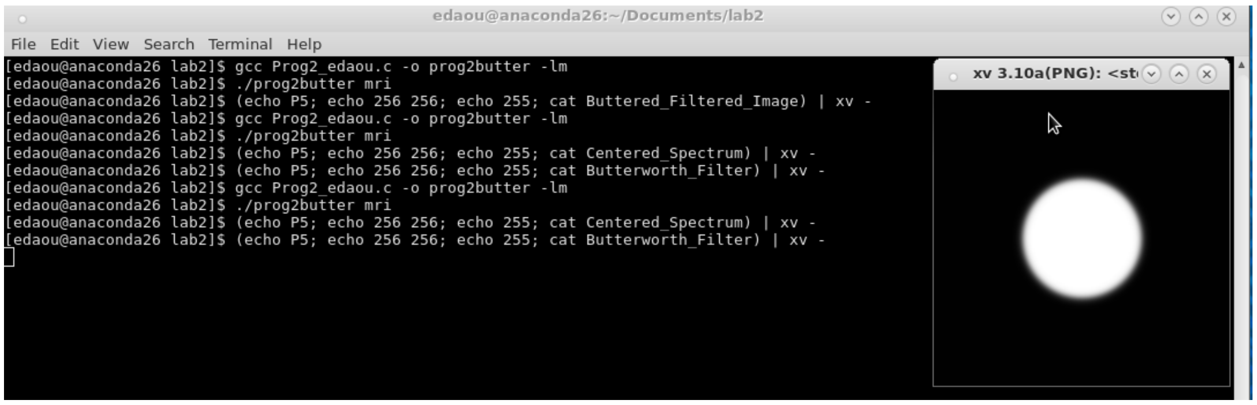
Figure 3 (BLPF D0=10)



edaou@anaconda26:~/Documents/lab2
File Edit View Search Terminal Help
xv 3.10a(PNG): <st

```
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Buttered_Filtered_Image) | xv -
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Centered_Spectrum) | xv -
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Butterworth_Filter) | xv -
```

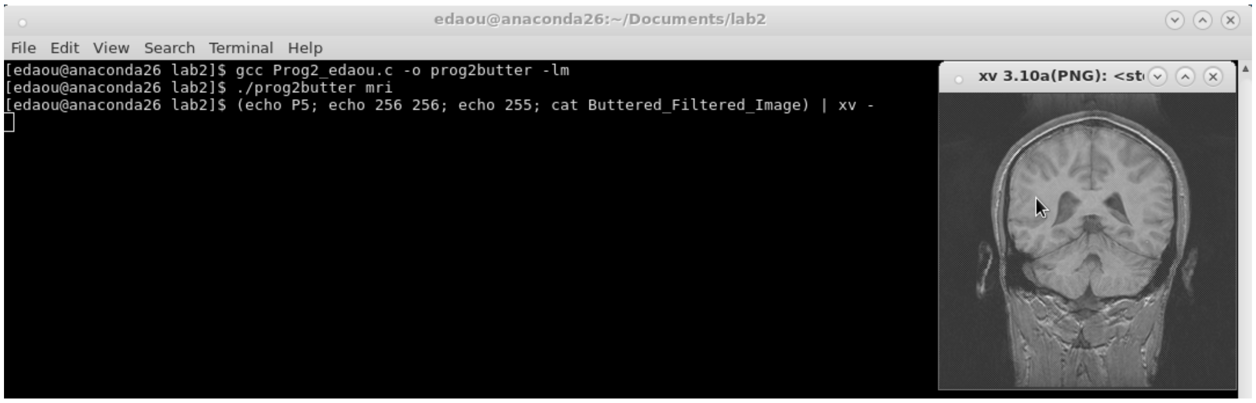
Figure 4 (BLPF D0=50)



edaou@anaconda26:~/Documents/lab2
File Edit View Search Terminal Help
xv 3.10a(PNG): <st

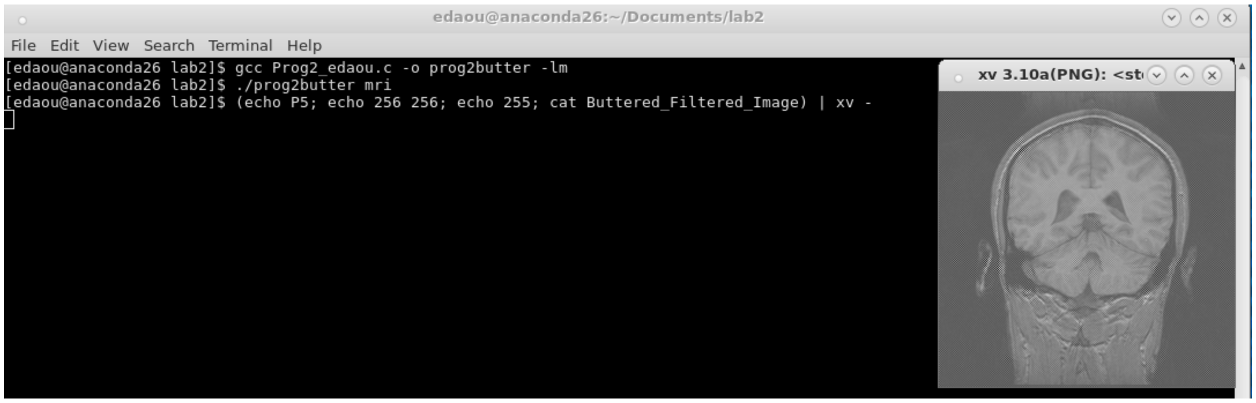
```
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Buttered_Filtered_Image) | xv -
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Centered_Spectrum) | xv -
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Butterworth_Filter) | xv -
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Centered_Spectrum) | xv -
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Butterworth_Filter) | xv -
```

Figure 5 (Image after BLPF D0=10)


edaou@anaconda26:~/Documents/lab2
File Edit View Search Terminal Help
xv 3.10a(PNG): <st

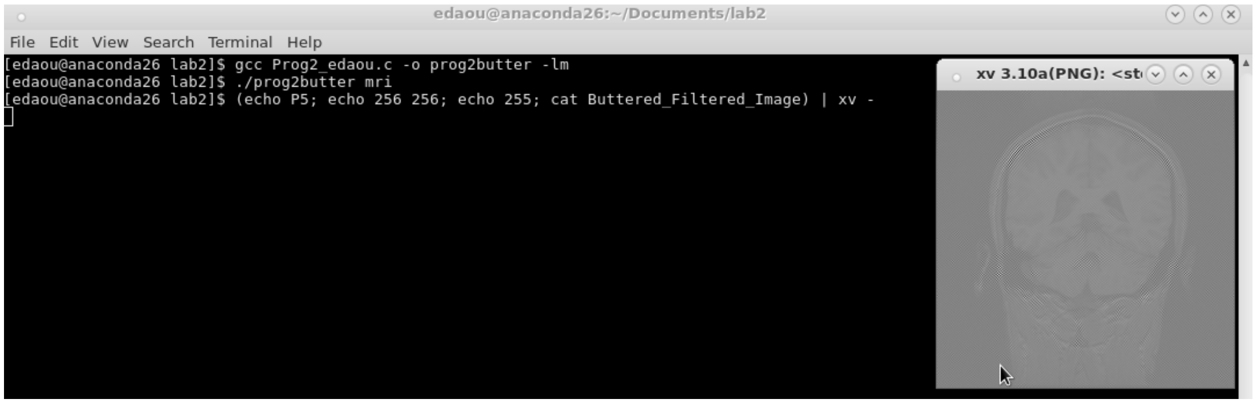
```
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Buttered_Filtered_Image) | xv -
```

Figure 6 (Image after BLPF D0=20)


edaou@anaconda26:~/Documents/lab2
File Edit View Search Terminal Help
xv 3.10a(PNG): <st

```
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Buttered_Filtered_Image) | xv -
```

Figure 7 (Image after BLPF D0=50)


edaou@anaconda26:~/Documents/lab2
File Edit View Search Terminal Help
xv 3.10a(PNG): <st

```
[edaou@anaconda26 lab2]$ gcc Prog2_edaou.c -o prog2butter -lm
[edaou@anaconda26 lab2]$ ./prog2butter mri
[edaou@anaconda26 lab2]$ (echo P5; echo 256 256; echo 255; cat Buttered_Filtered_Image) | xv -
```

The only real observations I have from this lab is that it is very easy to mess up the filters and the spectral analysis. I produced more outputs that were simply just “noise” than I would care to admit. I spent many hours banging my head against the wall trying to make this work. The order in which you apply certain filters and normalizations is extremely important.

In conclusion, this lab was very hard. However, after many hours of work, I am very excited about the implications of these filters and how they can be applied to other image processing projects.

Source Code:

```
/*
 * Program 2 - Elie Daou
 * Due Monday 6 March, 2017 9:00am
 * This program reads an input file and outputs 4 files
 * 1. The spectrum of that file
 * 2. The original output file, after it has gone through FFT2d/ FFT2d^-1
 * 3. The butterworth filter
 * 4. The original image after it has had the butterworth filter applied to
it.
 */

#include <math.h>
#include <stdlib.h>
#include <stdio.h>


#define SWAP(a,b) tempr=(a);(a)=(b);(b)=tempr

int const n = 256;

// This is the 1D FFT given to us. It was not modified at all.
four1(data,nn,isign)
float data[];
int nn,isign;
{
    int n,mmax,m,j,istep,i;
    double wtemp,wr,wpr,wpi,wi,theta;
    float tempr,tempi;
    n=nn << 1;
    j=1;
    for (i=1;i<n;i+=2) {
        if (j > i) {
            SWAP(data[j],data[i]);
            SWAP(data[j+1],data[i+1]);
        }
        m=n >> 1;
        while (m >= 2 && j > m) {
            j -= m;
            m >>= 1;
        }
        j += m;
    }
    mmax=2;
    while (n > mmax) {
        istep=2*mmax;
        theta=6.28318530717959/(isign*mmax);
        wtemp=sin(0.5*theta);
        wpr = -2.0*wtemp*wtemp;
        wpi=sin(theta);
        wr=1.0;
        wi=0.0;
        for (m=1;m<mmax;m+=2) {
            for (i=m;i<=n;i+=istep) {
                j=i+mmax;
                tempr=wr*data[j]-wi*data[j+1];
                tempi=wr*data[j+1]+wi*data[j];
                data[j]=data[i]-tempr;
                data[j+1]=data[i+1]-tempi;
                data[i] += tempr;
                data[i+1] += tempi;
            }
            wr=(wtemp=wr)*wpr-wi*wpi+wr;
            wi=wi*wpr+wtemp*wpi+wi;
        }
        mmax=istep;
    }
}

// get the minimum and maximum of the array to be able to normalize it
float getMaximumOfArray(float **inputtedArray);
float getMinimumOfArray(float **inputtedArray);

//find the magnitude of the FFT (real and imaginary combined)
void findMagnitude(float **inputArray, float **outputArray);

// do fourier transform in 2D
void four2d(float **inArray);

// do inverse fourier in 2D
void four2dInverse(float **inArray);

// normalize the data based on 255 being the max possible value
void normalize(float **inputArray, float **outputArray, float min, float
max);

// function to output the files
void outputFile(char nameOfFile[256], float **dataArray);

// main function
void main(int argc, char *argv[]){
    int row, column;
    //dynamic memory allocation is sooooo0o0o00o0o much better, easier to
pass into funtions and clean to work with. be careful with segmentation
faults!!!
    float **data, **spectrum, **newSpectrum, **realValuesOnly, **butter,
**newButter, **butteredSpectrum, **centeredSpectrum;
    char outputFileName[256];
    unsigned char pixel;                // represent one pixel at a time, to
be able to typecast
    FILE *input;
    int D0 = 50;
    int smoothness = 30; //"smoothness factor" or "gradient"

    float minimum;           // minimum pixel value to normalize
    float maximum;          // maximum pixel value to normalize


    // 2-d array to hold original image data
    data =(float**) calloc (n, sizeof (float *));
    for (row = 0; row < n; row++) {
        data[row] = (float *) calloc (n, sizeof (float));
    }

    // spectrum array to hold fourier transform image data
    spectrum =(float**) calloc (n, sizeof (float *));
    for (row = 0; row < n; row++) {
        spectrum[row] = (float *) calloc (2*n, sizeof (float));
    }

    // new spectrum to hold the combined spectrum data
    newSpectrum =(float**) calloc (n, sizeof (float *));
    for (row = 0; row < n; row++) {
        newSpectrum[row] = (float *) calloc (n, sizeof (float));
    }
    // Store and output the centered spectrum
    centeredSpectrum =(float**) calloc (n, sizeof (float *));
    for (row = 0; row < n; row++) {
        centeredSpectrum[row] = (float *) calloc (n, sizeof (float));
    }

    // holds real data to output from the FFT
    realValuesOnly =(float**) calloc (n, sizeof (float *));
    for (row = 0; row < n; row++) {
        realValuesOnly[row] = (float *) calloc (n, sizeof (float));
    }
    // the butterworth LPF
    butter =(float**) calloc (n, sizeof (float *));
    for (row = 0; row < n; row++) {
        butter[row] = (float *) calloc (n, sizeof (float));
    }
    // normalized butterworth filter to be outputted
    newButter =(float**) calloc (n, sizeof (float *));
    for (row = 0; row < n; row++) {
        newButter[row] = (float *) calloc (n, sizeof (float));
    }
    //take the spectrum through the LPF
    butteredSpectrum =(float**) calloc (n, sizeof (float *));
    for (row = 0; row < n; row++) {
        butteredSpectrum[row] = (float *) calloc (2*n, sizeof (float));
    }

    // Read the inputted image to data, same as lab 1
    input = fopen(argv[1], "rb");
    for (row = 0; row < n; row++) {
        for (column = 0; column < n; column++) {
            fread(&pixel, sizeof(char), 1, input);
            data[row][column]= (float)pixel;
        }
    }

    // close input image since it's not needed anymore
    fclose(input);

    // store data into spectrum because you can't use FFT without losing the
info passed into it
    for (row = 0; row < n; row++) {
        for (column = 0; column < n; column++) {
            spectrum[row][column*2] = data[row][column];
        }
    }

    four2d(spectrum);

    // find the magnitude of the fourier transform
    findMagnitude(spectrum, newSpectrum);

    // This way of centering the information didn't work, but i kept it in
because i did try it and i can't figure out why it won't work

    /*for (row=0; row<n; row++) {
        for (column=0; column<n; column++) {
            centeredSpectrum[row][column] = newSpectrum[row][column] * pow((-
1), (row+column));
        }
    }

    maximum = getMaximumOfArray(centeredSpectrum);
    minimum = getMinimumOfArray(centeredSpectrum);

    // normalize the data based on the max and min values with the new max
being 255
    normalize(centeredSpectrum, centeredSpectrum, minimum, maximum);*/

    // find the max and min values pre-normalization
    maximum = getMaximumOfArray(newSpectrum);
    minimum = getMinimumOfArray(newSpectrum);

    // normalize the data based on the max and min values with the new max
being 255
```

```
    normalize(newSpectrum, newSpectrum, minimum, maximum);

    // center the normalized data.
    for (row=0; row<n/2; row++) {
        for (column=0; column<n/2; column++) {
            float temp = newSpectrum[row][column];
            centeredSpectrum[row][column] = newSpectrum[row+n/2][column+n/2];
            centeredSpectrum[row+n/2][column+n/2] = temp;

            temp = newSpectrum[row + n/2][column];
            centeredSpectrum[row + n/2][column] =
newSpectrum[row][column+n/2];
            centeredSpectrum[row][column+n/2] = temp;
        }
    }

    // save the centered spectrum
    sprintf(outputFileName, "Centered_Spectrum");
    outputFile(outputFileName, centeredSpectrum);

    // make the butterworth filter, just the BLPF equation
    for (row=0; row<n; row++) {
        for (column=0; column<n; column++) {
            float center = sqrt(((column-128)*(column-128)) + ((row-
128)*(row-128)));
            butter[row][column] = 1/(1+(sqrt(2)-
1)*pow((center/D0),smoothness));
        }
    }

    // repeat steps for min/ max/ normalize for the butterworth filter
    maximum = getMaximumOfArray(butter);
    minimum = getMinimumOfArray(butter);

    normalize(butter, newButter, minimum, maximum);

    // output the butterworth filter
    sprintf(outputFileName, "Butterworth_Filter");
    outputFile(outputFileName, newButter);

    // apply the butterworth filter to the spectrum
    for (row=0; row<n; row++) {
        for (column=0; column<n; column++) {
            butteredSpectrum[row][column*2] = spectrum[row][column*2] *
newButter[row][column];
            butteredSpectrum[row][column*2+1] = spectrum[row][(column*2)+1] *
newButter[row][column];
        }
    }

    // reverse the FFT2D for both the buttered and unbuttered spectrum
    four2dInverse(spectrum);
    four2dInverse(butteredSpectrum);

    // ignore all the imaginary numbers and only save the real values
    for (row=0; row<n; row++) {
        for (column=0; column<2*n; column++) {
            if (column%2 == 0) {
                realValuesOnly[row][column/2] = spectrum[row][column];
            }
        }
    }

    // get the max and min to be able to normalize (we do this every time)
    maximum = getMaximumOfArray(realValuesOnly);
    minimum = getMinimumOfArray(realValuesOnly);

    // normalize so you can......
    normalize(realValuesOnly, realValuesOnly, minimum, maximum);

    // ...... properly output the data. told you it happens a lot. that's why
there's a function for it.
    sprintf(outputFileName, "Inverted_Original_Image");
    outputFile(outputFileName, realValuesOnly);

    // do that again for the buttered spectrum
    for (row=0; row<n; row++) {
        for (column=0; column<2*n; column++) {
            if (column%2 == 0) {
                realValuesOnly[row][column/2] =
butteredSpectrum[row][column];
            }
        }
    }

    // and again. min/ max/ normalize/ output
    maximum = getMaximumOfArray(realValuesOnly);
    minimum = getMinimumOfArray(realValuesOnly);

    normalize(realValuesOnly, realValuesOnly, minimum, maximum);

    sprintf(outputFileName, "Buttered_Filtered_Image");
    outputFile(outputFileName, realValuesOnly);


    // free up all dynamically allocated memory
    for (row=0; row< n; row++) {
        free(data[row]);
        free(spectrum[row]);
        free(newSpectrum[row]);
        free(realValuesOnly[row]);
        free(butter[row]);
        free(newButter[row]);
        free(butteredSpectrum[row]);
        free(centeredSpectrum[row]);
    }
    free(data);
    free(spectrum);
    free(newSpectrum);
    free(realValuesOnly);
    free(butter);
    free(newButter);
    free(butteredSpectrum);
    free(centeredSpectrum);

}

// get the maximum of an array, self explanatory
float getMaximumOfArray(float **inputtedArray){
    int row, column;
    int n = 256;
    float max;
    max = inputtedArray[0][0];
    for (row=0; row<n; row++) {
        for (column=0; column<n; column++) {
            if (inputtedArray[row][column] > max) {
                max = inputtedArray[row][column];
            }
        }
    }
    return max;
}
// same with the minimum, self- explanatory
float getMinimumOfArray(float **inputtedArray){
    int row, column;
    int n = 256;
    float min;
    min = inputtedArray[0][0];
    for (row=0; row<n; row++) {
        for (column=0; column<n; column++) {
            if (inputtedArray[row][column] < min) {
                min = inputtedArray[row][column];
            }
        }
    }
    return min;
}
// to get the maginitude it's the sqrt of the real^2 times the imaginary^2
void findMagnitude(float **inputArray, float **outputArray){
    int n = 256;
    int row, column;
    for ( row=0; row<n; row++) {
        for (column=0; column<n; column++) {
            outputArray[row][column] = sqrt(pow(inputArray[row][2*column], 2)
+ pow(inputArray[row][(2*column)+1], 2));
        }
    }
}

// find the min and the max, then scale it up/ down into the range of 0-255,
because those are our pixel ranges
void normalize(float **inputArray, float **outputArray, float min, float
max){
    int n = 256;
    int row, column;
    for ( row=0; row<n; row++) {
        for (column=0; column<n; column++) {
            outputArray[row][column] = 255 * (inputArray[row][column] -
min)/(max - min);
            outputArray[row][column] = ceil(outputArray[row][column]);
        }
    }
}

// we do the FFT2D twice, i think, so it's only logical to make it's own
function
void four2d(float **inArray){
    int row, column;
    int n = 256;
    float *temp;

    temp =(float*) calloc (2*n, sizeof (float ));
    // for each row, pass it into the FFT
    for (row = 0; row < n; row ++) {
        for (column = 0; column <2*n; column++) {
            temp[column] = inArray[row][column];
        }
        four1(temp-1, n, 1);
        for (column=0; column<2*n; column++) {
            inArray[row][column] = temp[column];
        }
    }

    // now column by column because that's the rule, hombre
    for (column = 0; column<n; column++) {
        for (row=0; row<n; row++) {
            temp[row*2] = inArray[row][column*2];
            temp[(row*2)+1] = inArray[row][(column*2)+1];
        }
        four1(temp-1, n, 1);
        for (row=0; row<n; row++) {
            inArray[row][column*2] = temp[row*2];
            inArray[row][(column*2)+1] = temp[(row*2)+1];
        }
    }
    free(temp);

}

void four2dInverse(float **inArray){
    int row, column;
    int n = 256;
    float *temp;

    temp =(float*) calloc (2*n, sizeof (float ));
    // time for inverse fourier transform
    //start with columns, since you started fourier with rows
    for (column = 0; column<n; column++) {
        for (row=0; row<n; row++) {
            temp[row*2] = inArray[row][column*2];
            temp[(row*2)+1] = inArray[row][(column*2)+1];
        }
        four1(temp-1, n, -1);
        for (row=0; row<n; row++) {
            inArray[row][column*2] = temp[row*2];
            inArray[row][(column*2)+1] = temp[(row*2)+1];
        }
    }

    // next do the rows chica, because that's what you did first and this
rule isn't made to be broken
    for (row=0; row<n; row++) {
        for (column=0; column<n; column++) {
            temp[(column*2)] = inArray[row][(column*2)];
            temp[(column*2)+1] = inArray[row][(column*2)+1];
        }
        four1(temp-1, n, -1);
        for (column=0; column<2*n; column++) {
            inArray[row][column] = temp[column];
        }
    }
    free(temp);

}

// the most boring funtion here, all it does it outputs a file of bits.....
yay
void outputFile(char nameOfFile[256], float **dataArray){
    unsigned char pixel;
    FILE *outputFile;
    int column, row;
    int n = 256;
    outputFile = fopen(nameOfFile, "wb");
    for (row=0; row<n; row++) {
        for (column=0; column<n; column++) {
            pixel = (unsigned char)(dataArray[row][column]); // this is the
typecasting everyone was worried about
            fwrite(&pixel, sizeof(char), 1, outputFile);
        }
    }
    fclose(outputFile);
}
```