

## Hands-on Lab

### Image Processing

A digital image is a collection of pixel data. A pixel has a location and value. The location is the row and column in the image whereas the value represents the color at that location. This lab introduces the reading, processing, and writing of digital image using ANSI C (GCC) and RAW image file standard. By using ANSI C, the underlying algorithms should be platform independent. RAW images are standard uncompressed binary files. The net effect is a brief but focused introduction to image processing which is the pre-cursor to robotic computer vision.

**Preliminary:** Code Blocks, IrfanView, and Pixel Former

Before doing this lab, tutorials on Code Blocks, IrfanView and Pixelformer should be completed: These software allows one to: write C programs for image processing (Code Blocks); create bitmap images (Pixelformer); and create RAW files and view results (IrfanView).

**Concept 1:** Thresholding images (Read and Write RAW files) `threshold1_0a.c`

Thresholding reads an image and writes a black-and-white output image. This is important because working with a binary image (i.e. a pixel is either black or white) often simplifies image understanding (e.g. detecting edges, calculating area and centroids, and object counting). Thresholding is thus a “Hello World” example for image processing. Figure 1A lists main for `threshold1_0a.c` threshold a 256-by-256 grayscale image.

Unlike JPEG, PNG and other image files, RAW files are uncompressed and have no headers. One simply reads the binary file one byte at a time using a loop.

```
// FILE: threshold1_0a.c - Works!
// DATE: 02/21/20 08:34
// AUTH: P.Oh
// DESC: Output is threshold of Input image

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

struct Image {
    int Rows, Cols; // image's number of rows and columns
    unsigned char *Data; // pointer to image data
}; // end of struct Image

int main() {

    FILE *ofile;
    struct Image In, Out; // Declare input and output images

    // Assumes RAW image is 256-by-256 bytes and allocate memory for images
    In.Rows = Out.Rows = In.Cols = Out.Cols = 256;
    In.Data = (unsigned char *)calloc(In.Rows, In.Cols);
    Out.Data = (unsigned char *)calloc(Out.Rows, Out.Cols);

    Img_in(&In);
    Img_threshold(&In, &Out);
    Img_out(&Out);

} // end of main
```

Figure 1A: main for `threshold1_0a.c`

## Image Processing

In `main`, the yellow-highlight shows that data being allocated. It's assumed that the RAW image will have 256 rows and 256 columns of 1-byte pixels. Next, `main` calls 3 functions to respectively read an input image, process it, and write the output image.

### Step 1: Reading a RAW image

```
void Img_in(struct Image *Img) {
    FILE *ifile;
    int i;

    // NB: Assumes RAW image file 256 x 256 size
    // Open file for binary reading
    // Assumes RAW file in same directory as this C-program
    ifile = fopen("cameraMan.raw", "rb"); // read binary file

    // Read directly into the image array
    for(i=0; i < Img->Rows; ++i)
        fread(Img->Data + i*Img->Cols, Img->Cols, 1, ifile);

    fclose(ifile);
} // end Img_in
```

**Figure 1B: `Img_in` function**

The function `Img_in` is used to read a RAW file (**Figure 1B**). As input, it takes a pointer to an `Image` structure. This function begins with `fopen` to open the desired input RAW image file (`cameraMan.raw` in this case). The row-column format is used to store pixel data as a vector. This is implemented by a single `for` loop and moves the pointer through the image file. The function ends by closing the file. Recall the structure variable `Image` is a global one, so other functions will be able to access this variable.

### Step 2: Processing the RAW image

```
void Img_threshold(struct Image *In, struct Image *Out) {

    long i, j;
    int val, thresholdValue;
    unsigned char *tmp;

    thresholdValue = 50;

    for(i=0; i<In->Rows; ++i) {
        for(j=0; j<In->Cols; ++j) {
            val = *(In->Data + i*In->Rows + j);
            if(val < thresholdValue) {
                val = 0;
            }
            else {
                val = 255;
            }
            tmp = Out->Data + i*Out->Rows + j;
            *tmp = (unsigned char)val;
        }
    };
} // end Img_threshold
```

**Figure 1C: `Img_threshold` function**

## Image Processing

The function `Img_threshold` is used to implement thresholding (**Figure 1C**). As inputs, this function takes pointers to the `Image` structures (input and output `Image` structures).

The threshold value is set (50 in this case) in the variable `thresholdValue`. The nested `for`-loops then reads each pixel of the input image data and stores the pixel value in the variable `val` and compared to `thresholdValue`.

Recall that 8-bit pixel data ranges in values from 0 (black) to 255 (white). Setting `thresholdValue` closer to 0 means that the darkest pixels are set black, while all other pixels are set white. The value of resulting threshold is then set to the pointer `tmp` which stores the data in the global structure variable `Out`.

### Step 3: Write the RAW image

```
void Img_out(struct Image *Out) {
    FILE *ofile;
    int i;

    // Open (or create) binary file for writing
    ofile = fopen("thresholdOutput.raw", "wb");
    // Output the image by rows
    for(i=0; i < Out->Rows; ++i)
        fwrite(Out->Data + i*Out->Cols, Out->Cols, 1, ofile);

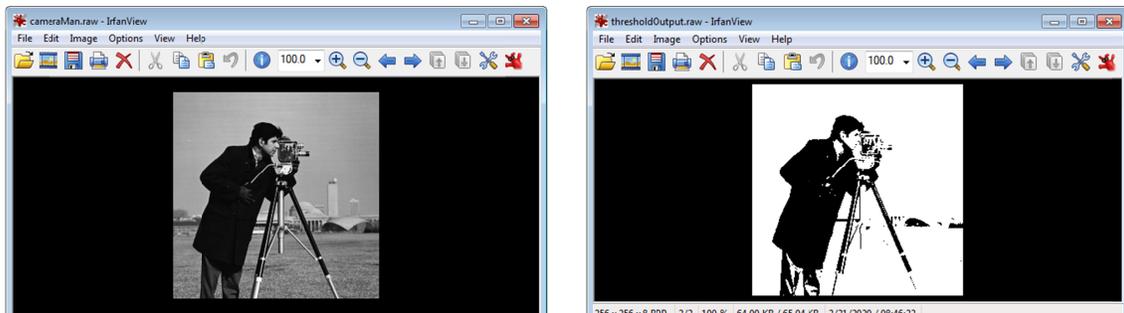
    fclose(ofile);
} // end Img_out
```

**Figure 1D: `Img_out` function**

The function `Img_out` takes an `Image` structure (**Figure 1D**). It opens a file (`thresholdOutput.raw` in this case) and proceeds with a `for`-loop and `fwrite` to write the data to the file. The function ends by closing the file.

### Step 4: Threshold a RAW image file

Combine **Figures 1A** thru **1D** into a single file named `threshold1_0a.c`. Make sure that the input image file (`cameraMan.raw`) is in the same folder as `threshold1_0a.c`. Compile and execute to generate the output file. View `thresholdOutput.raw` with `IrfanView` (**Figure 1E**).



**Figure 1E: Original `cameraMan.raw` file (left) processed with `threshold1_0a.c` with `thresholdValue` set to 50. Note that for that value, only the darkest pixels remain black.**

## Exercises

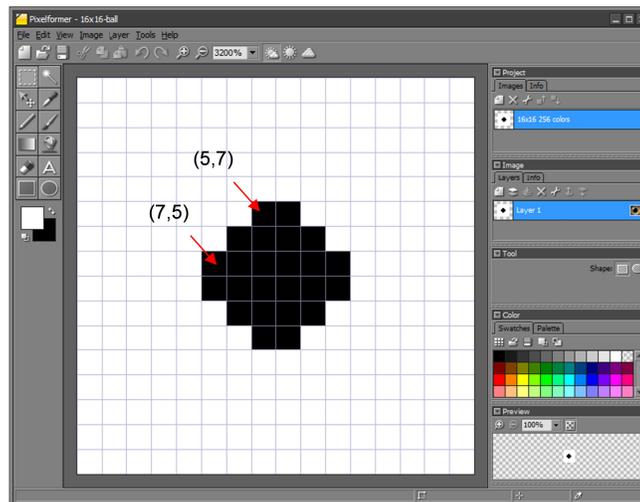
- 1.1 Write a program to threshold a RAW grayscale image (e.g. cameraMan.raw) so that only the whitest pixels remain white.
- 1.2 Write a program to reads a RAW mage file (e.g. cameraMan.raw) and outputs the inverse (i.e. a negative).

## Concept 2: Areas and Centroids - `areaCentroid1_0.c`

From lecture, the area is defined as the number of pixels (of a specific value) in the image. The centroid of an image is calculated as  $X_c = \frac{1}{A} \sum_{i=1}^N X$  and  $Y_c = \frac{1}{A} \sum_{i=1}^N Y$  where  $X_c$  and  $Y_c$  are the centroid coordinates,  $X$  and  $Y$  are the  $i$ th pixel's coordinates, and  $A$  is the area of the object.

**Step 1:** Write the function to calculate the image's area

**Figure 2A** is a 16x16 RAW test image (`16x16-ballRaw.raw`).



**Figure 2A:** Pixelformer was used to create a 16x16 image with white (value = 255) background and black (value = 0) pixels to create the ball. Counting the number of black pixels, the area of this image should be 24.

```
float area(struct Image *In, int x1, int y1,
           int x2, int y2, unsigned char ObjVal) {
    // returns calculated area of a RAW image
    long i, j;
    float areaValue = 0.0; // although this is an int, will use for float division

    for(i=x1; i <= x2; ++i)
        for(j=y1; j <= y2; ++j) {
            if(pix(In, i, j) == ObjVal)
                areaValue = areaValue + 1.0;
        }
    return(areaValue);
} // end function area
```

**Figure 2B:** Function to calculate the image's area

## Image Processing

The listing in **Figure 2B** takes an `Image` structure, the starting row and column of the image, the ending row and column of the image, and the desired pixel value (`ObjVal`). The nested for-loop compares the Image's pixel value to `ObjVal`. If it matches, then `areaValue` is incremented. Technically, `areaValue` is an integer (i.e. whole number of pixels). However, for calculating the centroid later, `areaValue` is declared as a float.

To increase the code's readability, `pix(In, i, j)` is used to denote the (i,j) pixel of the input Image. This variable is `#defined` as a global variable.

### Step 2: Write the function to calculate the image's centroid

```
struct coord centroid(struct Image *In, int x1,
                    int y1, int x2, int y2,
                    unsigned char ObjVal) {
    // returns calculated centroid (as struct) of RAW image
    long i, j;
    float calculatedArea;
    int xSum, ySum;
    struct coord calculatedCentroid;

    calculatedArea = area(In, x1, y1, x2, y2, ObjVal);

    if(calculatedArea == 0) {
        calculatedCentroid.x = -1; calculatedCentroid.y = -1;
        return(calculatedCentroid);
    };

    xSum = ySum = 0;

    for(i=x1; i<=x2; ++i)
        for(j=y1; j<=y2; ++j) {
            if(pix(In, i, j) == ObjVal) {
                xSum += j;
                ySum += i;
            }
        }

    calculatedCentroid.x = xSum/calculatedArea;
    calculatedCentroid.y = ySum/calculatedArea;

    return(calculatedCentroid);
} // end function centroid
```

**Figure 2C:** Listing for function centroid

The `centroid` function (**Figure 2C**) takes on the same parameters as the `area` function. It returns a structure `coord` which is declared as a global variable. This structure will contain the x and y location of the calculated centroid.

The nested for-loop compares the image's pixel to the desired pixel value (`ObjVal`). When equal, the column and row values of that pixel are accumulated in `xSum` and `ySum` respectively. The centroid is then calculated by dividing those accumulated sums by the image's area (`calculatedArea`) and returned.

### Step 3: Write main program to call area and centroid functions and print results

**Figure 2D** shows the full listing of `areaCentroid1_0.c`. The yellow highlights show the `#defined` variable `pix(In, i, j)` and global structure variable `coord`. Much like Concept 1's `threshold1_0a.c`, the functions `Img_in` (**Figure 1B**) and `struct Image` are used.

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```
// FILE: areaCentroid1_0.c - Works!
// DATE: 02/26/20 09:44
// AUTH: P.Oh
// DESC: Report area and centroid of RAW image
// REFS: areaCentroid0_lb.c

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

#define pix(Im, x, y) *(Im->Data + (x)*Im->Cols + (y))
#define WHITE 255
#define BLACK 0

struct Image {
    int Rows, Cols; // image's number of rows and columns
    unsigned char *Data; // pointer to image data
}; // end of struct Image

struct coord {
    float x, y; // result's row and column coordinates
};

void Img_in(struct Image *Img) {
    FILE *ifile;
    int i;

    // NB: Assumes RAW image file 256 x 256 size
    // Open file for binary reading
    // Assumes RAW file in same directory as this C-program
    ifile = fopen("16x16-ballRaw.raw", "rb"); // read binary file

    // Read directly into the image array
    for(i=0; i < Img->Rows; ++i)
        fread(Img->Data + i*Img->Cols, Img->Cols, 1, ifile);

    fclose(ifile);
} // end Img_in

void Img_out(struct Image *Out) {
    FILE *ofile;
    int i;

    // Open (or create) binary file for writing
    ofile = fopen("thresholdOutput.raw", "wb");
    // Output the image by rows
    for(i=0; i < Out->Rows; ++i)
        fwrite(Out->Data + i*Out->Cols, Out->Cols, 1, ofile);

    fclose(ofile);
} // end Img_out

float area(struct Image *In, int x1, int y1,
           int x2, int y2, unsigned char ObjVal) {
    // returns calculated area of a RAW image
    long i, j;
    float areaValue = 0.0; // although this is an int, will use for float division

    for(i=x1; i <= x2; ++i)
        for(j=y1; j <= y2; ++j) {
            if(pix(In, i, j)==ObjVal)
                areaValue = areaValue + 1.0;
        }
    return(areaValue);
} // end function area
```

**Figure 2D:** Full listing of `areaCentroid1_0.c`

## Image Processing

```
struct coord centroid(struct Image *In, int x1,
                    int y1, int x2, int y2,
                    unsigned char ObjVal) {
    // returns calculated centroid (as struct) of RAW image
    long i, j;
    float calculatedArea;
    int xSum, ySum;
    struct coord calculatedCentroid;

    calculatedArea = area(In, x1, y1, x2, y2, ObjVal);

    if(calculatedArea == 0) {
        calculatedCentroid.x = -1; calculatedCentroid.y = -1;
        return(calculatedCentroid);
    };

    xSum = ySum = 0;

    for(i=x1; i<=x2; ++i)
        for(j=y1; j<=y2; ++j) {
            if(pix(In, i, j) == ObjVal) {
                xSum += j;
                ySum += i;
            }
        }

    calculatedCentroid.x = xSum/calculatedArea;
    calculatedCentroid.y = ySum/calculatedArea;

    return(calculatedCentroid);
} // end function centroid

int main() {

    struct Image In; // Declare input and output images
    struct coord centroidCoordinates;

    int areaImage;

    // Assumes RAW image is 16-by-16 bytes and allocate memory
    In.Rows = 16;
    In.Cols = 16;
    In.Data = (unsigned char *)calloc(In.Rows, In.Cols);

    Img_in(&In);
    areaImage = area(&In, 0, 0, (In.Rows-1), (In.Cols-1), BLACK);
    printf("Area of 16x16 image is: %d\n", areaImage);

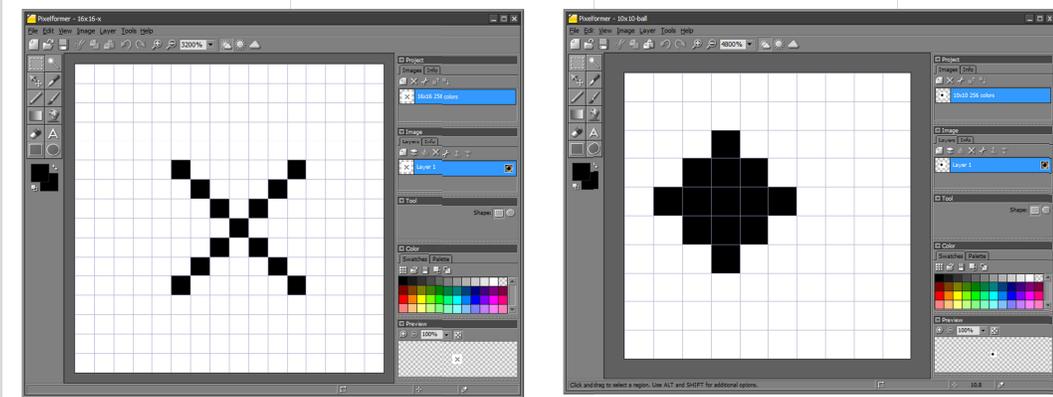
    centroidCoordinates = centroid(&In, 0, 0, (In.Rows-1), (In.Cols-1), BLACK);
    printf("Centroid is (x,y) = (%3.3f, %3.3f)\n", centroidCoordinates.x,
    centroidCoordinates.y);

} // end of main
```

**Figure 2D continued:** Full listing of areaCentroid1\_0.c

## Exercises

2.1 Modify `areaCentroid1_0.c` to read a 16x16 RAW image `16x16-x-Raw.raw`. What are the values of the area and centroid?



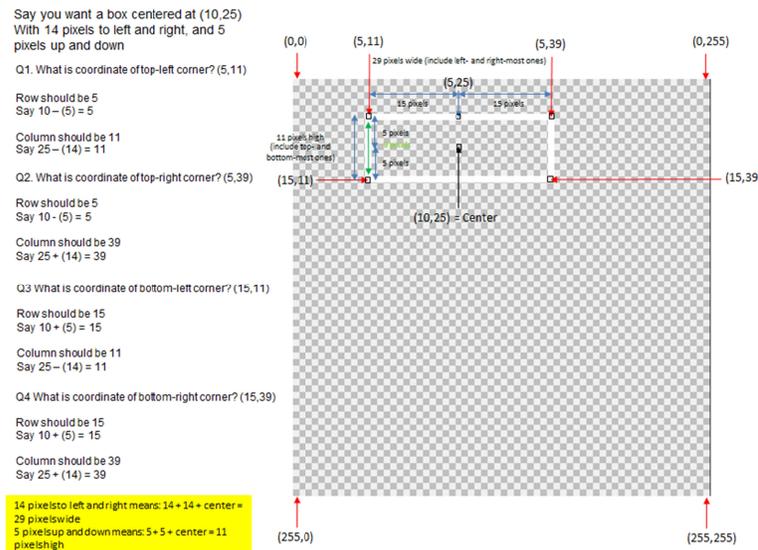
`16x16-x-Raw.raw` (left) and `10x10-ballRaw.raw` (right)

2.2 Use Pixelformer to create a 16x16 image of a white ball on black background and use IrfanView to create an equivalent RAW image. Hand-calculate the area and centroid. Write a C program to report the area and centroid. Compare with your hand-calculations.

2.3 Modify `areaCentroid1_0.c` to read a 10x10 RAW image `10x10-ballRaw.raw`. What are the values of the area and centroid?

## Concept 3: Drawing white box - `whiteBox1_0.c`

A white pixel has a value of 255. This concept creates an output image that draws a white rectangle, at a desired location of the input image. Calculations were given in lecture **Figure 3A**.



**Figure 3A:** From lecture, the rectangle's width and height and center yield equations

## Image Processing

### Step 1: Write a function `Img_DrawBox` that takes an input and output image

```
void Img_DrawBox(struct Image *In, struct Image *Out) {

    long i, j;
    int val;
    unsigned char *tmp;

    // original example: 29, 11, 10, 25
    int boxColWidth = 29; // [pix] hence 14 pixels to the left and right of center
    int boxRowHeight = 11; // [pix] hence 5 pixels upwards and downwards from center
    int boxRowCenter = 10; // [pix]
    int boxColCenter = 25; // [pix]
    int boxTopLeftRowCorner, boxTopLeftColCorner;
    int boxTopRightRowCorner, boxTopRightColCorner;
    int boxBottomLeftRowCorner, boxBottomLeftColCorner;
    int boxBottomRightRowCorner, boxBottomRightColCorner;

    boxTopLeftRowCorner = boxRowCenter - ((boxRowHeight-1)/2); // 10 - (11-1)/2 = 5 NB: minus
one because don't count center pixel
    boxTopLeftColCorner = boxColCenter - ((boxColWidth-1)/2);
    printf("Box Top Left corner is (%d, %d)\n", boxTopLeftRowCorner, boxTopLeftColCorner);

    boxTopRightRowCorner = boxRowCenter - ((boxRowHeight-1)/2);
    boxTopRightColCorner = boxColCenter + ((boxColWidth-1)/2);
    printf("Box Top Right corner is (%d, %d)\n", boxTopRightRowCorner, boxTopRightColCorner);
    boxBottomLeftRowCorner = boxRowCenter + ((boxRowHeight-1)/2);
    boxBottomLeftColCorner = boxColCenter - ((boxColWidth-1)/2);
    printf("Box Bottom Left corner is (%d, %d)\n", boxBottomLeftRowCorner,
boxBottomLeftColCorner);
    boxBottomRightRowCorner = boxRowCenter + ((boxRowHeight-1)/2);
    boxBottomRightColCorner = boxColCenter + ((boxColWidth-1)/2);
    printf("Box Bottom Right corner is (%d, %d)\n", boxBottomRightRowCorner,
boxBottomRightColCorner);

    for(i=0; i<In->Rows; ++i) {
        for(j=0; j<In->Cols; ++j) {
            val = *(In->Data + i*In->Rows + j);
            if( (i==boxTopLeftRowCorner || i==boxBottomLeftRowCorner) ) {
                // OK, we're on box's top or bottom row
                if( (j>=boxTopLeftColCorner && j<=boxTopRightColCorner) ||
(j>=boxBottomLeftColCorner && j<=boxBottomRightColCorner) ){
                    // Draw top OR bottom line
                    val = 255; // make row white between left and right side
                }; // otherwise just keep the original value of val
            }; // end if that checks for box's top or bottom row

            if( j==boxTopLeftColCorner || j==boxTopRightColCorner ) {
                // OK, we're on left or right side
                if( (i>=boxTopLeftRowCorner && i<=boxBottomLeftRowCorner) ||
(i>=boxTopRightRowCorner && i<=boxBottomRightRowCorner) ) {
                    // Draw left OR right line
                    val = 255; // make column white between top and bottom row
                };
            }; // end if that checks for box's left or right side
            tmp = Out->Data + i*Out->Rows + j;
            *tmp = (unsigned char)val;
        };
    };
} /
```

**Figure 3B:** Listing for `Img_DrawBox`

The function begins by assigning values for the desired rectangle. The resulting corners are then calculated. The nested `for`-loop contains `if`-statements. These check for pixel location of the rectangle's corners. When the row and column counters (`i` and `j` respectively) match the

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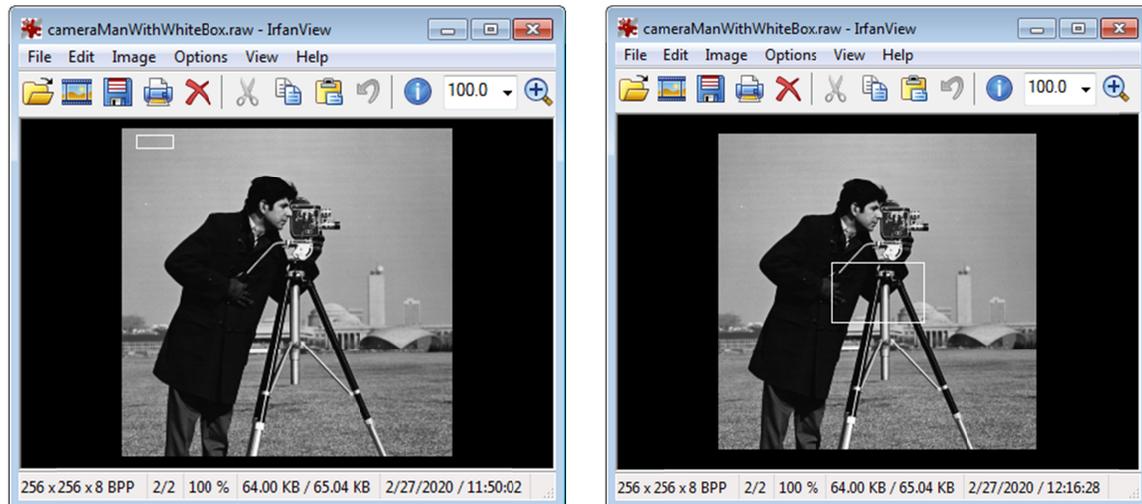
corner, then white pixels are assigned for the top and bottoms horizontal lines and left and right vertical lines.

**Step 2:** Add your function to `main` (see **Figure 3C**) which also contains functions `Img_out` and `Img_in` to create a program called `whiteBox1_0.c`.

```
int main() {  
  
    FILE *ofile;  
    struct Image In, Out; // Declare input and output images  
  
    // Initialize image parameters and allocate memory  
    In.Rows = Out.Rows = 256;  
    In.Cols = Out.Cols = 256;  
    In.Data = (unsigned char *)calloc(In.Rows, In.Cols);  
    Out.Data = (unsigned char *)calloc(Out.Rows, Out.Cols);  
    ofile = fopen("cameraManWithWhiteBox.raw", "wb");  
  
    Img_in(&In);  
    Img_DrawBox(&In, &Out);  
    Img_out(&Out);  
  
} // end of main
```

Figure 3C: Program `whiteBox1_0.c` main function

**Step 3:** Run your program with input image (`cameraMan.raw`) to generate output image (`cameraManWithWhiteBox.raw` (**Figure 3D left**)).



**Figure 3D: Output image** `cameraManWithWhiteBox.raw` with rectangle centered at (10, 25), 29 pixels wide and 11 pixels tall (left). Rectangle centered in the image (right).

## Exercises

- 3.1 Create an output image with a white rectangle centered in the image (like shown in **Figure 3D right**), defined by your desired rectangle height and width.
- 3.2 Create an output image with a white box (rectangle height and width are the same), centered in the image.
- 3.3 Modify your program in 3.2 to also have diagonal lines spanning from the top-left corner to the bottom-right corner, and from the top-right corner to the bottom-left corner.

Congratulations! You can read input images, perform calculations, and draw output images – the basics of Image Processing and Computer Vision!