Project #06: Image Processing in F#

Complete By: Wednesday, April 11th @ 11:59pm
Assignment: completion of following exercise
Policy: Individual work only, late work *is* accepted
Submission: electronic submission via Blackboard

Background

You are going to write a program to perform various operations on images stored in PPM format, such as this lovely image of a piece of cake:

There are many image formats you are no doubt familiar with: JPG, PNG, etc. The advantage of PPM is that the file format is human-readable, so you can open PPM files in a text editor. This makes it easier to write programs that manipulate the images, and it also makes it easier to debug your output — you can simply open the image file in a text editor and "see" what's wrong. First some background on PPM files, and then the details of the assignment…

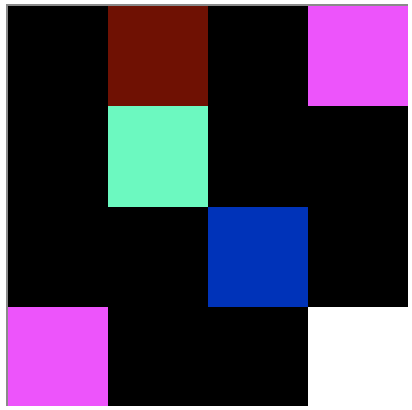
PPM Image Format

The PPM (or Portable Pix Map) image format is encoded in human-readable ASCII text. For those of you who enjoy reading documentation, the formal image specification can be found here [1]. Here is a sample ppm file, representing a very small 4x4 image:

[1] http://netpbm.sourceforge.net/doc/ppm.html

```
P3
4 4
255
0   0   0    100 0   0       0   0   0     255    0  255
0   0   0     0  255 175     0   0   0      0     0   0
0   0   0     0   0   0      0  15  175     0     0   0
255 0  255    0   0   0      0   0   0     255   255 255
```

Here is what this image looks like, magnified 5,000%. Notice it consists of 16 **pixels**, laid out in 4 rows with 4 pixels per row:



You can think of an image as having two parts, a **header** and a **body**. The **header** consists of information about the image such as width and height, GPS location, time, date, etc.. For PPM images, the header is very simple, and has only 4 entries:

```
P3
4 4
255
```

P3 is a "magic number". It indicates what type of PPM image this is (full color, ASCII encoding). For this assignment it will always be the string “P3”. The next two values, **4 4**, represent the *width* and *height* of the image — or more accurately from a programming perspective, the number of **pixels** in one row and the number of **rows** in the image, respectively. The final value, **255**, is the **maximum color depth** for the image. For images in “P3” format, the depth can be any value in the range 0..255.

The **image body** contains the *pixel* data — i.e. the color of each *pixel* in the image. For the image shown above, which is a 4x4 image, we have 4 rows of pixel data:

```
0   0   0    100 0   0       0   0   0     255    0  255
0   0   0     0  255 175     0   0   0      0     0   0
0   0   0     0   0   0      0  15  175     0     0   0
255 0  255    0   0   0      0   0   0     255   255 255
```

Look at this data closely… First, notice the values range from 0 .. maximum color depth (in this case 255). Second, notice that each row contains exactly 12 values, with at least one space between each value. Why

12? Because each row contains 4 **pixels**, but each pixel in PPM format consists of 3 values: the amount of RED, the amount of GREEN, and the amount of BLUE. This is more commonly known as the pixel's **RGB value**. *Black*, the absence of color, has an RGB value of 0 0 0 — the minimum amount of each color. *White*, the presence of all colors, has an RGB value of depth depth depth — the maximum amount of each color. As shown above, notice the first pixel in the 4x4 image is black, and the last pixel is white.

In general a pixel's RGB value is the mix of red, green, and blue needed to make that color. For example, here are some common RGB values, assuming a maximum color depth of 255:

Yellow:	255 255 0
Maroon:	128 0 0
Navy Blue:	0 0 128
Purple:	128 0 128

You can read more about RGB on the web[2]. We will provide you with 5 PPM images to work with. The image shown above is "tiny4by4.ppm". Here are the 5:

- blocks.ppm
- cake.ppm
- square.ppm
- tiny4by4.ppm
- tinyred4by4.ppm

Viewing PPM Images

There's a simple JavaScript program for viewing images on your local computer: under the "Projects" link on the course web page, open "project06-files", download ppmReader.zip, and extract the .html file. Double-click to launch, and select a .PPM file to view — it may chop off the image if it's too big.

On Windows you can view PPM images using Irfanview [3], a free image utility. If the installation fails, note that I had to download the installer and then *run as administrator* for it to install properly on Windows: right-click on setup program and select "run as administrator". Irfanview will also allow you to convert your own images to PPM so you work on your own pictures — keep in mind that you may need to resize your images to be smaller before converting to PPM, otherwise the PPM files become quite large (since they are ASCII). Save your image in PPM format, checking the option for "ASCII" format.

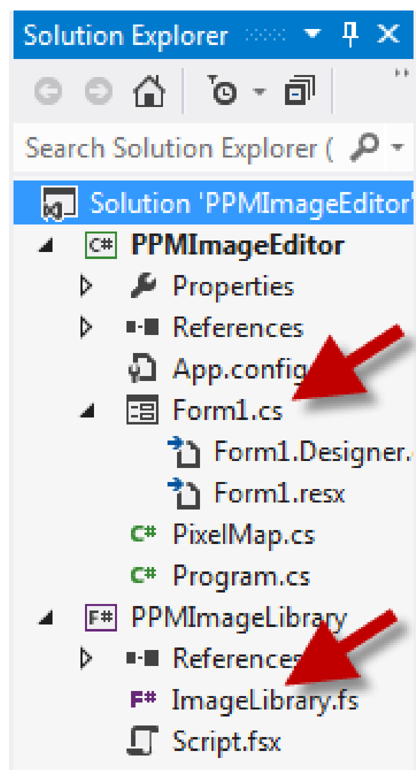
Keep in mind you can also "view" PPM files in your local text editor: File menu, Open command, and then browse to the file and open it — you will see lots of integers :-) If you don't see the PPM files listed in the Open File dialog, try selecting "All files" from the drop-down.

[2] http://www.rapidtables.com/web/color/RGB_Color.htm
[3] http://www.irfanview.com/

Getting Started

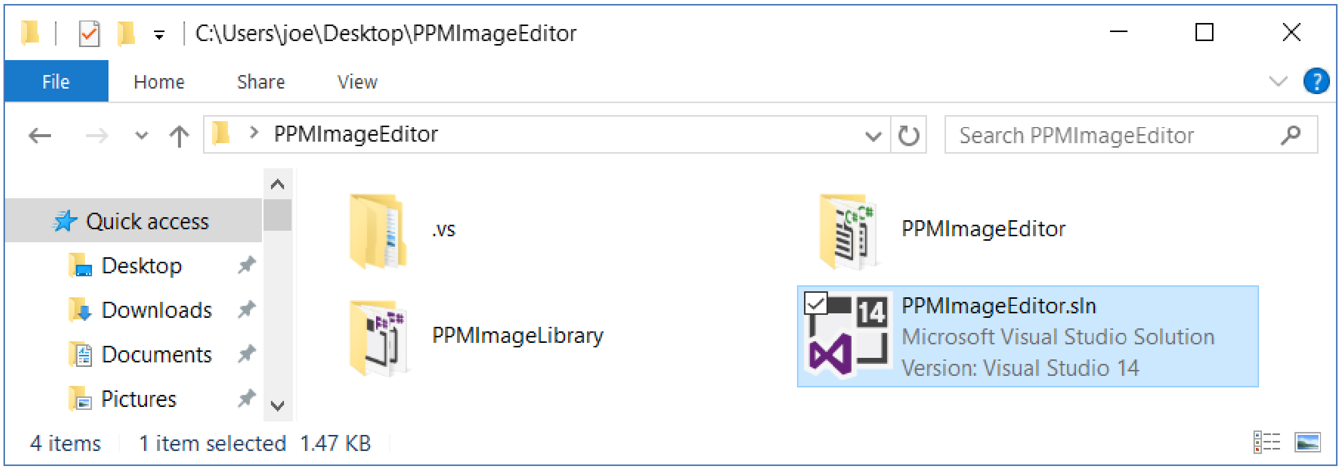
To make life more interesting (and realistic), we are going to be working with a GUI-based, multi-language application. Here's a snapshot:

The Visual Studio solution contains 2 parts ("projects"), one representing the GUI front-end written in C#, and the image processing code representing the back-end written in F#. This is depicted in Visual Studio's solution explorer, as shown on the right. When you want to work on the F# code, you'll open the "ImageLibrary.fs" file. If you want to see the GUI-based C# code, you can open "Form1.cs" — there should be no reason to modify this code, but you might want to review in case you're curious (you'll be writing this type of code soon enough).

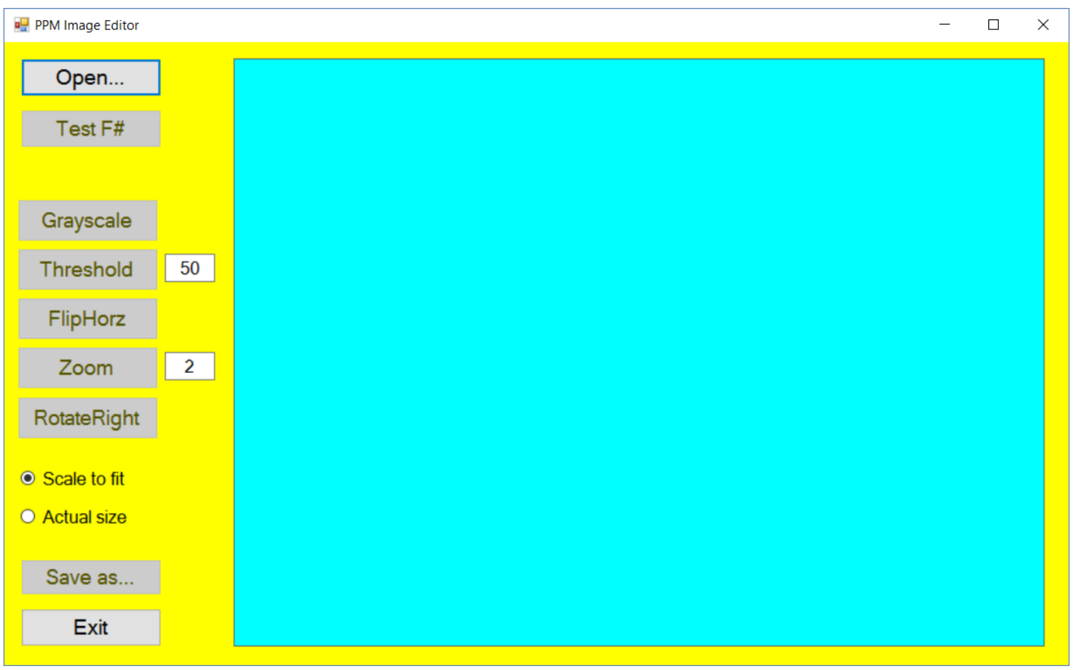


To get started, browse to the course web page, open the "Projects" folder, and drill down into "project06-files". Download "[PPMImageEditor.zip]", which is a .zip file of the PPM Image Editor application. After the download, double-click on the .zip file to open, and *extract* the folder by dragging to your desktop. Close and discard the .zip file. Open the folder you extracted, which represents the entire Visual Studio solution to the program. You should see the following:

<< screenshot on next page >>

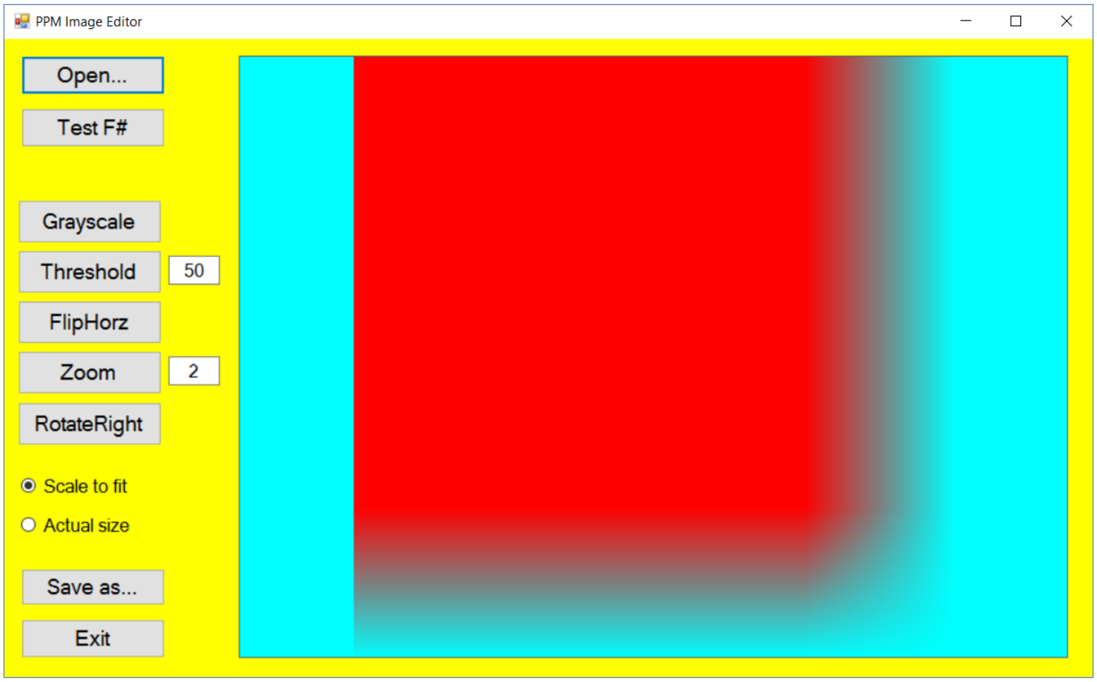


Now open the program in Visual Studio by double-clicking the **Visual Studio Solution** (.sln) file highlighted above. Once in Visual Studio, run with debugging by pressing F5. The program should compile and run successfully, and you'll see the GUI:

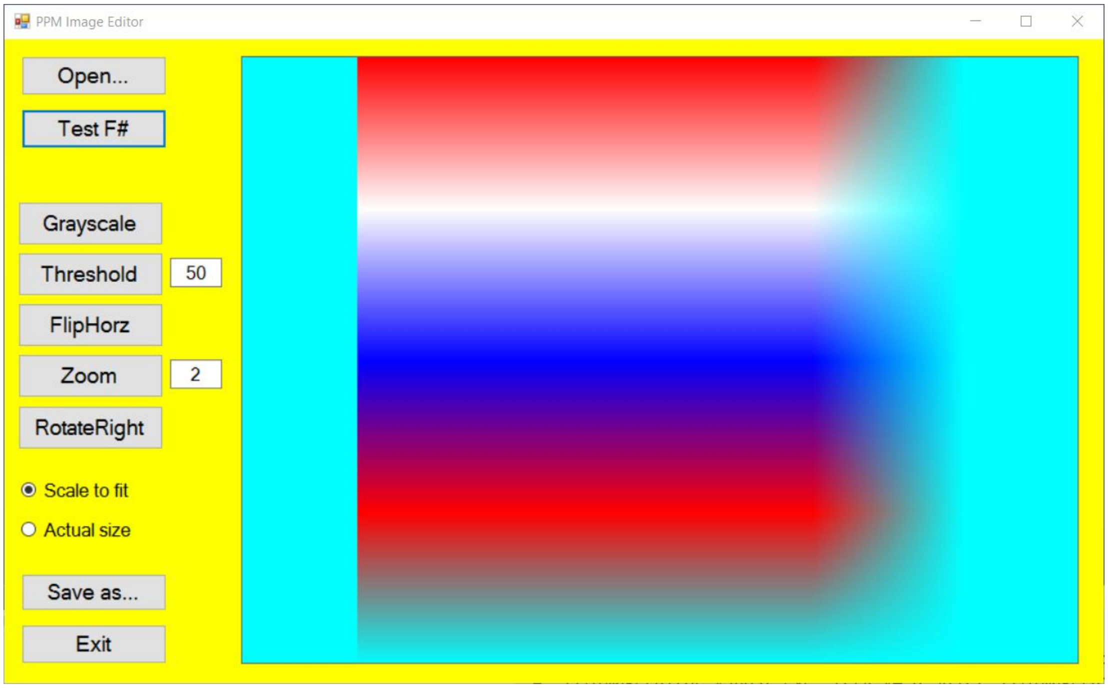


Click the **Open** button — the sample PPM files are already installed in the bin\Debug sub-folder of the GUI project (PPMImageEditor). Selected the simplest file, "tinyred4by4.ppm". This is a tiny image, but the GUI stretches the image to fill the image area, so you'll see something like this:

<< screenshot on next page >>



Finally, click the "Test F#" button, and if you look carefully, you'll notice that the 3 lines of the image are changed to be red, white, and blue. Open other images such as "cake.ppm", and test F#...



As provided, the GUI (graphical user interface) is completely written for you — each button calls an F# function defined in a separate library. Your job is to implement the functions in this library, as discussed in the next section.

Your Assignment

The provided GUI interacts with the user, and opens the selected image file. It reads the image data, and builds a list of lists of tuples — an F# **`(int*int*int) list list`** to be precise. This data structure is then passed over to the F# library for manipulation, and a new image is returned for display. Your job is to write the functions in the F# library that perform the image manipulation.

In Visual Studio, open the "ImageLibrary.fs" file. Your job is to implement the following 5 functions as defined below: **Grayscale**, **Threshold**, **FlipHorizontal**, **Zoom**, and **RightRotate90**. Do not change the API in any way: do not add parameters, do not change their types, etc. We will be grading your F# library against our own test suite, and so your API must match what is given below.

```
module PPMImageLibrary

#light

//
// DebugOutput:
//
// Outputs to console, which appears in the "Output" window pane of
// Visual Studio when you run with debugging (F5).
//
let rec private OutputImage (image:(int*int*int) list list) =
  match image with
  | [] -> printfn "**END**"
  | hd::tl -> printfn "%A" hd
              OutputImage tl

let DebugOutput(width:int, height:int, depth:int, image:(int*int*int) list list) =
  printfn "**HEADER**"
  printfn "W=%A, H=%A, D=%A" width height depth
  printfn "**IMAGE**"
  OutputImage image


//
// TransformFirstThreeRows:
//
// An example transformation: replaces the first 3 rows of the given image
// with a row of Red, White and Blue pixels (go USA :-).
//
let rec BuildRowOfThisColor row color =
  match row with
  | []     -> []
  | hd::tl -> color :: BuildRowOfThisColor tl color

let TransformFirstThreeRows(width:int, height:int, depth:int, image:(int*int*int) list list) =
  let row1 = List.head image
  let row2 = List.head (List.tail image)
  let row3 = List.head (List.tail (List.tail image))
  let tail = List.tail (List.tail (List.tail image))
  let newRow1 = BuildRowOfThisColor row1 (255,0,0)      // red:
  let newRow2 = BuildRowOfThisColor row2 (255,255,255)  // white:
  let newRow3 = BuildRowOfThisColor row3 (0,0,255)      // blue:
```

```
  let newImage = newRow1 :: newRow2 :: newRow3 :: tail
  newImage

//
// WriteP3Image:
//
// Writes the given image out to a text file, in "P3" format.  Returns true if successful,
// false if not.
//
let Flatten (SL:string list) =
  List.reduce (fun s1 s2 -> s1 + " " + s2) SL

let Image2ListOfStrings (image:(int*int*int) list list) =
  List.map (fun TL -> List.map (fun (r,g,b) -> r.ToString()+" "+g.ToString()+" "+b.ToString()+" ") TL) image
  |> List.map Flatten

let rec WriteP3Image(filepath:string, width:int, height:int, depth:int, image:(int*int*int) list list) =
  let L = [ "P3" ] @
          [ System.Convert.ToString(width); System.Convert.ToString(height) ] @
          [ System.Convert.ToString(depth) ] @
          (Image2ListOfStrings image)
  System.IO.File.WriteAllLines(filepath, L)
  true  // success

//
// Grayscale:
//
// Converts the image into grayscale and returns the resulting image as a list of lists.
// Conversion to grayscale is done by averaging the RGB values for a pixel, and then
// replacing them all by that average. So if the RGB values were 25 75 250, the average
// would be 116, and then all three RGB values would become 116 – i.e. 116 116 116.
//
let rec Grayscale(width:int, height:int, depth:int, image:(int*int*int) list list) =
  image

//
// Threshold
//
// Thresholding increases image separation --- dark values become darker and light values
// become lighter.  Given a threshold value in the range 0 < threshold < MaxColorDepth,
// all RGB values > threshold become the max color depth (white) while all RGB values
// <= threshold become 0 (black).  The resulting image is returned.
//
let rec Threshold(width:int, height:int, depth:int, image:(int*int*int) list list, threshold:int) =
  image

//
// FlipHorizontal:
//
// Flips an image so that what’s on the left is now on the right, and what’s on
// the right is now on the left. That is, the pixel that is on the far left end
// of the row ends up on the far right of the row, and the pixel on the far right
// ends up on the far left. This is repeated as you move inwards toward the center
// of the row.
//
let rec FlipHorizontal(width:int, height:int, depth:int, image:(int*int*int) list list) =
  image
```

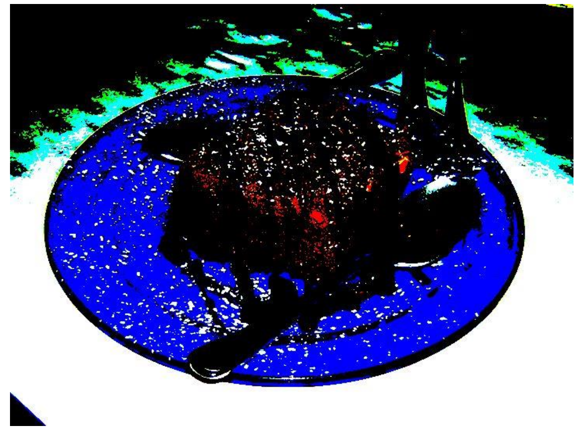
```
//
// Zoom:
//
// Zooms the image by the given zoom factor, which is an integer 0 < factor < 5.
// The function uses the nearest neighbor approach where each pixel P in the original
// image is replaced by a factor*factor block of P pixels.  For example, if the zoom
// factor is 4, then each pixel is replaced by a 4x4 block of 16 identical pixels.
// The nearest neighbor algorithm is the simplest zoom algorithm, but results in
// jagged images.  The resulting image is returned.
//
let rec Zoom(width:int, height:int, depth:int, image:(int*int*int) list list, factor:int) =
  image

//
// RotateRight90:
//
// Rotates the image to the right 90 degrees.
//
let rec RotateRight90(width:int, height:int, depth:int, image:(int*int*int) list list) =
  image
```

Here is more information about the functions you need to write… Use whatever features you want in F#, except functions that perform direct image manipulations. Strive for efficient solutions using the techniques we have discussed in class; any function that takes over a minute to execute is considered unacceptable and thus wrong. And of course, do *not* use imperative style programming — no mutable variables, no arrays, and no for loops.

1. **Grayscale**(`width:int, height:int, depth:int,` image:(int*int*int) list list): converts the image into grayscale and returns the resulting image as a list of lists. Conversion to grayscale is done by averaging the RGB values for a pixel, and then replacing them all by that average. So if the RGB values were 25 75 250, the average would be 116, and then all three RGB values would become 116 — i.e. 116 116 116. Here's the cake in gray:

2. **Threshold**(`width:int, height:int, depth:int,` image:(int*int*int) list list, threshold:int): thresholding increases *image separation* --- dark values become darker and light values become lighter. Given a **threshold** value in the range 0 < threshold < MaxColorDepth, all RGB values > threshold become the max color depth (e.g. white). And all RGB values <= threshold become 0 (e.g. black). Given a grayscale image, after thresholding the image becomes black and white. For example, given the cake image, the left is the result with a threshold value of 50, and the right with a threshold value of 200:



3. **FlipHorizontal**(`width:int, height:int, depth:int,` image: (int*int*int) list list): flips an image so that what's on the left is now on the right, and what's on the right is now on the left. That is, the pixel that is on the far left end of the row ends up on the far right of the row, and the pixel on the far right ends up on the far left. This is repeated as you move inwards toward the center of the row; remember to preserve RGB order for each pixel as you flip — you flip pixels, not individual RGB colors. Here's the cake flipped horizontally:

4. **Zoom**(`width:int, height:int, depth:int,` image: (int*int*int) list list, factor:int): zooms the image by the given zoom **factor**, which you may assume is an integer 0 < factor < 5. [*Given the file format of PPM images, they grow in size very quickly, so large zoom factors are impractical here.*] There are many zoom algorithms, use the **nearest neighbor** approach where each pixel P in the original image is replaced by a factor*factor block of P pixels. For example, if the zoom factor is 4, then each pixel is replaced by a 4x4 block of 16 identical pixels. The nearest neighbor algorithm is the simplest zoom algorithm, but results in jagged images… The cake image is 720x540; a zoom factor of 4 yields an image that is 2880x2160, but looks exactly the same (only bigger, and more jagged). When viewed in an image viewer, it will appear 4x bigger. However, when viewed in the provided GUI, it will appear exactly the same since by default the image is "Scaled to fit"; switch to "Actual size" and you'll see the effect of the zoom.

5. **RotateRight90**(`width:int, height:int, depth:int,` image:int list list): rotates the image to the right 90 degrees. The list returned by this function will have different dimensions than the original list passed in. Here's the cake rotated right 90 degrees:

The parameters to the F# functions should be self-explanatory. For example, the **RightRotate90** function takes the image *width*, *height*, *depth*, and the *image data*. The image data is the interesting one… The format is a list of lists of tuples, where each tuple denotes the RGB values for that pixel. For example, on page 2 we presented the file format for the "tiny4by4.ppm" image:

```
P3
4 4
255
0  0  0    100 0  0       0  0  0     255   0 255
0  0  0     0 255 175     0  0  0      0    0  0
0  0  0     0  0  0       0 15 175     0    0  0
255 0 255   0  0  0       0  0  0     255  255 255
```

The image data passed to the F# Image Library in this case is a list of 4 lists, one sub-list per row. Each row is a sub-list of tuples (R, G, B), where R, G, and B are color values 0..depth:

```
[ [ (0,0,0);     (100,0,0);   (0,0,0);    (255,0,255)   ] ;
  [ (0,0,0);     (0,255,175); (0,0,0);    (0,0,0)       ] ;
  [ (0,0,0);     (0,0,0);     (0,15,175); (0,0,0)       ] ;
  [ (255,0,255); (0,0,0);     (0,0,0);    (255,255,255) ] ]
```

Note each sub-list contains the same number of pixels — 4 in this case. You must work with this format for communication between the GUI front-end and the F# back-end; you cannot change the data structure.

Each button in the GUI calls a different function in the F# library. If you want to look at how an F# function is called from the C# code, do the following:

1. View the *PPMImageEditor* project in Visual Studio (solution explorer window, upper-right)
2. Double-click on Form1.cs to view the main window in "Design" mode.
3. The "form" opens, which is the application's main window. Double-click on a button...
4. The click event handler is opened for that button in "coding" mode.
5. The code you see is executed when the button is clicked by the user at run-time

For debugging, click in the left-margin of the F# code to set a breakpoint, run (F5), and start exploring when the breakpoint is reached. There is also some C# code that will print the state of the image data before and after the call to an F# function. To enable this code:

6. View the C# event handling code for the button in question
7. Uncomment the code that calls *PPMImageLibrary.DebugOutput*
8. Run (F5), and view the contents of the Output Debug window (View menu, Output, select Debug from dropdown).

Electronic Submission to Blackboard under "Assignments, Projects, Project 06"

Before you submit, make sure your name appears in a header comment at the top of the F# source file, something like

```
//
// F#-based PPM image library.
//
// <<YOUR NAME HERE>>
// U. of Illinois, Chicago
// CS341, Spring 2018
// Project 06
//
```

Then close Visual Studio and locate the top-level project folder that for your project, i.e. PPMImageEditor. Right-click on this top-level folder, Send to, and select "Compressed (zipped) folder". The result will be a single archive (.zip) file that you submit to Blackboard under "Projects", "P06 PPM Image Editor".

You may submit on BB as many times as you want before the due date, but we grade the last version submitted. This implies that if you submit a version before the due date and then another after the due date, we will grade the version submitted after the due date — we will *not* grade both and then give you the better grade. We grade the last one submitted. In general, do not submit after the due date unless you had a non-working program before the due date.

Policy

Late work *is* accepted. You may submit as late as 24 hours after the deadline for a penalty of 25%. After 24 hours, no submissions will be accepted.

All work is to be done individually — group work is not allowed. While I encourage you to talk to your peers and learn from them (e.g. your "iClicker teammates" or Piazza), this interaction must be superficial with regards to all work submitted for grading. This means you *cannot* work in teams, you cannot work side-by-side, you cannot submit someone else's work (partial or complete) as your own. The University's policy is described here:

http://www.uic.edu/depts/dos/docs/Student%20Disciplinary%20Policy.pdf .

In particular, note that you are guilty of academic dishonesty if you extend or receive any kind of unauthorized assistance. Absolutely no transfer of program code between students is permitted (paper or electronic), and you may not solicit code from family, friends, or online forums. Other examples of academic dishonesty include emailing your program to another student, copying-pasting code from the internet, working in a group on a homework assignment, and allowing a tutor, TA, or another individual to write an answer for you. It is also considered academic dishonesty if you click someone else's iClicker with the intent of answering for that student, whether for a quiz, exam, or class participation. Academic dishonesty is unacceptable, and penalties range from failure to expulsion from the university; cases are handled via the official student conduct process described at http://www.uic.edu/depts/dos/studentconductprocess.shtml .