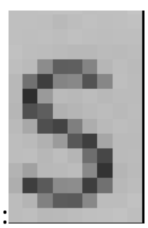
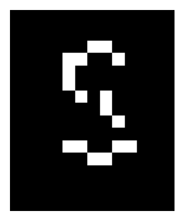
LAB 3 REPORT – Aaron Bruner

The purpose of this lab is to implement thinning, branchpoint and endpoint detection to recognize letters in an image of text. The lab instructions laid out 2 steps for us to follow. The first step was to read the input image, msf image, and ground truth.

We are using the MSF image from lab 3 which is shown above.

Using a threshold value of 200 we can see how it thins out the image.

Original Image:  Image after Thinning: 

For this example, we get a result of 4 end points, 0 branches. TP = 151 and FP = 1109 for this example.

The ideal T is where TP is the highest and so the ideal T should be 244.

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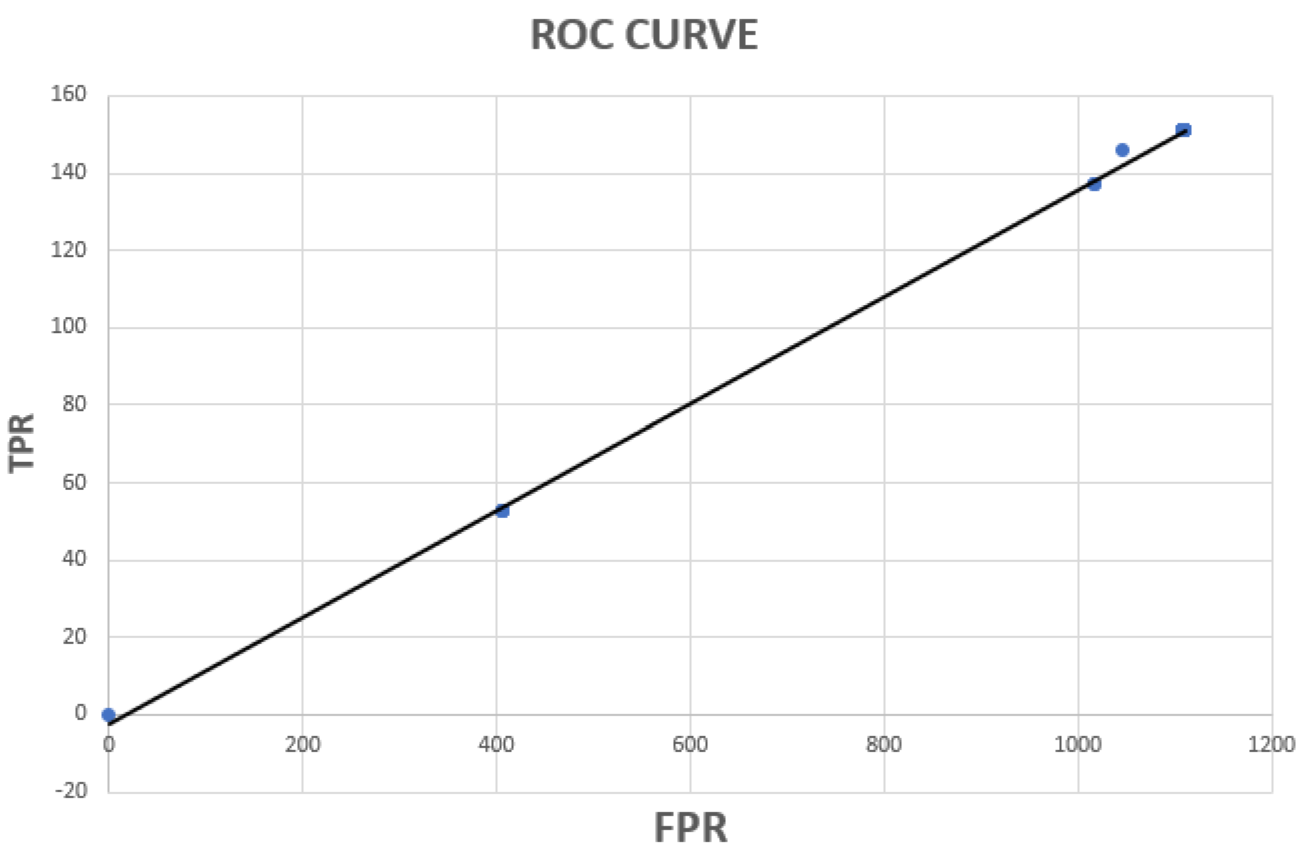

Source Code:

```
/* File  : lab3.c
   Author: Aaron Bruner
   Class : ECE - 4310 : Introduction to Computer Vision
   Term  : Fall 2022

   Description: The purpose of this lab is to implement thinning, branchpoint and endpoint
detection to recognize letters in an image of text.

   Required Files:
    * parenthood.ppm
    * parenthood_e_template.ppm
    * parenthood_gt.txt
    * msf_e.ppm

   Bugs:
    * Currently none
*/

#define True 1
#define False 0
#define DEBUG False
#define T 255 // Upper limit for thresholding

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <time.h>

struct groundTruth {
    char letter;
    int  x; // COLUMN
    int  y; // ROW
};

unsigned char* readImage( int* ROWS, int* COLS, char* source);
unsigned char* createImage(int size);
void thin(unsigned char* srcImage);
void edgeNonEdgeTransitions(unsigned char* img, int *transitions, int *neighbors, int *passNum4,
int r, int c);
void branchEndPoints(unsigned char* img, int* isE);

char* sourceImageDir    = "parenthood.ppm";
char* templateImageDir  = "parenthood_e_template.ppm";
char* groundTruthDir    = "parenthood_gt.txt";
char* msfeImageDir      = "msf_e.ppm";

int main(int argc, char* argv[])
{
    unsigned char* sourceImage, *templateImage, *msf_eImage, *thresholdImage;
    struct groundTruth* truth;
    char temp, gtLetter;
    int temp1, temp2, fileRows = 0; // Number of rows in the ground truth file
    int i = 0, j = 0, sourceROWS, sourceCOLS, templateROWS, templateCOLS, msfe_ROWS, msfe_COLS;
    int dr = 7, dc = 4, found = False, TP = 0, FP = 0, threshLocation = 0, isE = False, endBranch
= 0, eRows = 15, eCols = 9;
    int gtR = 0, gtC = 0, index = 0, end = 0, branch = 0;
    FILE* fpt, *TPFPfpt;

    /*
*/
```

```
    /*                  STEP 1: Read in source, msf image and ground truth
*/
    /*      * User provides no arguments (argc == 1) then we default to specified files
*/
    /*      * User provides 4 arguments  (argc == 5) then we open provided files
*/
    /* ──────────────────────────────────────────────────────────────────────────
*/

    //printf("Step 1:\n");
    if (argc == 1) {
        //printf("Performing matched filter on images [%s] and [%s] using ground truth [%s] and
MSF image [%s]\n", sourceImageDir, templateImageDir, groundTruthDir, msfeImageDir);

        //printf("\t* Reading in source image...");
        sourceImage = readImage(&sourceROWS, &sourceCOLS, sourceImageDir);
//printf("\t[SUCCESS]\n");
        //printf("\t* Reading in template image...");
        templateImage = readImage(&templateROWS, &templateCOLS, templateImageDir);
//printf("\t[SUCCESS]\n");
        //printf("\t* Reading in MSF_e image...");
        msf_eImage = readImage(&msfe_ROWS, &msfe_COLS, msfeImageDir); //printf("\t[SUCCESS]\n");

        // Read in CSV/TXT file
        //printf("\t* Opening ground truth file...");
        fpt = fopen(groundTruthDir, "r");
        //fpt == NULL ? printf("Failed to open %s\n", groundTruthDir), exit(0) :
printf("\t[SUCCESS]\n");
    }
    else if (argc == 5)
    {
        printf("Performing matched filter on images [%s] and [%s] using ground truth [%s] and MSF
image [%s]\n", argv[1], argv[2], argv[4], argv[3]);

        printf("\t* Reading in source image...");
        sourceImage = readImage(&sourceROWS, &sourceCOLS, argv[1]); printf("\t[SUCCESS]\n");
        printf("\t* Reading in template image...");
        templateImage = readImage(&templateROWS, &templateCOLS, argv[2]); printf("\t[SUCCESS]\n");
        printf("\t* Reading in MSF_e image...");
        msf_eImage = readImage(&msfe_ROWS, &msfe_COLS, argv[3]); printf("\t[SUCCESS]\n");

        // Read in CSV/TXT file
        printf("\t* Opening ground truth file...");
        fpt = fopen(argv[4], "r");
        fpt == NULL ? printf("Failed to open %s\n", argv[3]), exit(0) : printf("\t[SUCCESS]\n");
    }
    else
    {
        printf("Incorrect number of arguments...\nUsage: ./lab2 (sourceImage.ppm)
(templateImage.ppm) (msf_e.ppm) (groundTruth.txt)\n");
        exit(0);
    }

    while ((i = fscanf(fpt, "%c %d %d\n", &temp, &temp1, &temp2)) && !feof(fpt))
        if (i == 3) fileRows += 1;
    //printf("\t* Found %d number of rows in the ground truth file\n", fileRows);

    //printf("\t* Allocating space for ground truth file...");
    truth = calloc(fileRows, sizeof(struct groundTruth)); //printf("\t[SUCCESS]\n");

    rewind(fpt); // Return to the beginning of the file
```

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    //printf("\t* Scanning in values from ground truth file...");
    for (i = 0; i <= fileRows && !feof(fpt); i++)
    {
        fscanf(fpt, "%c %d %d\n", &truth[i].letter, &truth[i].x, &truth[i].y);
    }
    fclose(fpt);
    //printf("\t[Read in %d rows]\n", i - 1);

    /* ──────────────────────────────────────────────────────────────────────
*/
    /*    STEP 2: Looping through the following steps for a range of T
*/
    /*      a) Loop through the ground truth letter locations
*/
    /*          i) Check a 9x15 pixel area centered at the ground truth location. If any pixel in
*/
    /*              the msf image is greater then the threshold, consider the letter "detected".
*/
    /*              If none of the pixels in the 9 x 15 area are greater than the threshold,
*/
    /*              consider the letter "not detected".
*/
    /*         ii) If the letter is "not detected" continue to the next letter
*/
    /*        iii) Create a 9 x 15 pixel image that is a copy of the area centered at the ground
*/
    /*              truth location(center of letter) from the original image.
*/
    /*         iv) Threshold this image at 128 to create a binary image.
*/
    /*          v) Thin the thresholded image down to single-pixel wide components.
*/
    /*         vi) Check all remaining pixels to determine if they are branch-points or endpoints.
*/
    /*        vii) If there are not exactly 1 branch-point and 1 endpoint, do not further consider
*/
    /*             this letter(it becomes “not detected”)
*/
    /*      b) Count up the number of FP (letters detected that are not 'e') and TP (number of
*/
    /*          letters detected that are 'e').
*/
    /*      c) Output the total TP and FP for each T.
*/
    /* ──────────────────────────────────────────────────────────────────────
*/

    //printf("Step 2:\n");
    thresholdImage = createImage(eCols * eRows);
    // Open to write to clear file
    TPFPfpt = fopen("TPFP.txt", "w"); TPFPfpt == NULL ? (printf("Failed to open TPFP.txt.\n"),
exit(0)) : TPFPfpt;

    // Threshold values
    for (i = 0; i <= T; i++, branch = end = TP = FP = found = isE = False)
    {
        // File rows from the GT
        for (j = 0; j < fileRows; j++)
        {
            gtLetter = truth[j].letter; gtR = truth[j].y; gtC = truth[j].x;
```

```
            // iii)
            for (int r = -dr; r <= dr; r++)
            {
                for (int c = -dc; c <= dc; c++, index++)
                {
                    if (msf_eImage[(r + gtR) * msfe_COLS + (c + gtC)] > i) found = True;
                    thresholdImage[index] = sourceImage[(r + gtR) * sourceCOLS + (c + gtC)];
                }
            }

            // iv)
            for (index = 0; index < eRows * eCols; index++) thresholdImage[index] =
thresholdImage[index] > 128 ? 0 : 255;

            // v)
            thin(thresholdImage);

            // vi)
            branchEndPoints(thresholdImage, &isE);

            // b)
            found ? (gtLetter == 'e' ? TP++ : FP++) : (isE ? (gtLetter == 'e' ? TP++ : TP) : FP);
        }
        // c)
        fprintf(TPFPfpt, "%d %d %d\n", i, TP, FP);
    }

    fclose(TPFPfpt);
    /* ───────────────────────────────────────────────────────────────────────────
*/
}

/// <summary>
/// This is a thinning algorithm designed based on both the lecture notes 'Edge properties' and
the
/// Zhang-Suen thinning algorithm found at the link below.
/// https://rosettacode.org/wiki/Zhang-Suen_thinning_algorithm#C
///
/// This function uses a helper function edgeNonEdgetransitions which detects if there are any
edge pixes
/// and returns them in the variables transitionCount, neighborCount and passNum4 for each row and
column.
/// </summary>
/// <param name="srcImage">The source image which is a 9x15 which contains a letter to be
thinned</param>
void thin(unsigned char* srcImage)
{
    const int rowE = 15, colE = 9;
    const unsigned char ON = 255, OFF = 0;
    int erasure = True, transitionCount = 0, neighborCount = 0, passNum4 = 0;
    unsigned char* copy = createImage(rowE * colE);

    //Lecture notes: Edge properties | Describes the Zhang-Suen thinning algorithm
    // https://rosettacode.org/wiki/Zhang-Suen_thinning_algorithm#C
    // P9   P2  P3      _   A   _
    // P8   P1  P4      C   X   B
    // P7   P6  P5      _   D   _
    //1. Pass through the image looking at each pixel X.
    do
    {
```

```
        for (int i = 0; i < rowE * colE; i++) copy[i] = (unsigned char)0; // Reset the copy image
to all black pixels
        erasure = False; // Only repeat if we find a marked pixel

        for (int r = 1; r < rowE; r++)
        {
            for (int c = 1; c < colE; c++, transitionCount = 0, neighborCount = 0)
            {
                //2. Count the number of edge->non-edge transitions in CW (or CCW) order around
the pixel X (r,c)
                // Only need to check pixes that are ON
                if (srcImage[r * colE + c] != OFF) edgeNonEdgeTransitions(srcImage,
&transitionCount, &neighborCount, &passNum4, r, c);
                //5. The edge pixel is marked for erasure if it has
                //      a) exactly 1 edge->non - edge transition,
                //      b) 2 <= edge neighbors <= 6, and
                //      c) passes item #4
                if (transitionCount == 1 && neighborCount >= 3 && neighborCount <= 7 && passNum4
== 1)
                {
                    // Mark pixel for erasure
                    copy[r * colE + c] = ON;
                    erasure = True;
                }
            }
        }
        //6. Once all pixels have been scanned, erase those marked, and repeat
        //      (back to step 1) until no pixels are marked for erasure.
        for (int index = 0; index < colE * rowE; index++)
        {
            copy[index] == ON ? srcImage[index] = OFF : False;
        }
    } while (erasure == True);

    // Free the copy image
    free(copy);
    return;
}

/// <summary>
/// Determining if the letter is 'e' if it has one end and one branch
/// </summary>
/// <param name="img">The image of the letter in which we are scanning</param>
/// <param name="isE">Logical bool which is either true if the letter is 'e' and false if it is
not</param>
void branchEndPoints(unsigned char* img, int *isE)
{
    const int rowE = 15, colE = 9;
    const unsigned char ON = 255, OFF = 0;
    int edge = 0, last = False, branch = 0, end = 0;
    unsigned char N = OFF, E = OFF, S = OFF, W = OFF, NE = OFF, SE = OFF, SW = OFF, NW = OFF;

    //Lecture notes: Edge properties
    // P9   P2  P3      _   A   _
    // P8   P1  P4      C   X   B
    // P7   P6  P5      _   D   _
    for (int r = 1; r < rowE; r++)
    {
        for (int c = 1; c < colE; c++, edge = 0)
        {
```

```
            //2. Count the number of branch and end points in CW (or CCW) order around the pixel X 
(r,c)
            // Only need to check pixes that are ON
            if (img[r * colE + c] == ON)
            {
                // Checking in a clockwise rotation of the following image (r,c)
                // NW  N  NE    |   (-1,-1)  (-1,0)  (-1,+1)    |   (-9,-1)  (-9,0)  (-9,+1)
                //  W  X  E     |   ( 0,-1)  (0, 0)  ( 0,+1)    |   ( 0,-1)  (0, 0)  ( 0,+1)
                // SW  S  SE    |   (+1,-1)  (+1,0)  (+1,+1)    |   (+9,-1)  (+9,0)  (+9,+1)
                //  We'll check North -> North East -> East -> South East -> South -> South West -
> West -> North West
                //  Moving up one row = -9  |   Moving down one row = +9    |   Moving left = -1 
|   Moving right = +1
                N = img[(r - 1) * colE + c];  NE = img[(r - 1) * colE + (c + 1)];
                E = img[r * colE + (c + 1)];  SE = img[(r + 1) * colE + (c + 1)];
                S = img[(r + 1) * colE + c];  SW = img[(r + 1) * colE + (c - 1)];
                W = img[r * colE + (c - 1)];  NW = img[(r - 1) * colE + (c - 1)];

                //3. Count the number of edge neighbor pixels
                // Check N  edges
                N  == ON ? last = True : (last = False);
                // Check NE edges
                NE == ON ? last = True : ((last == True ? edge++ : edge), last = False);
                // Check E edges
                E  == ON ? last = True : ((last == True ? edge++ : edge), last = False);
                // Check SE edges
                SE == ON ? last = True : ((last == True ? edge++ : edge), last = False);
                // Check S  edges
                S  == ON ? last = True : ((last == True ? edge++ : edge), last = False);
                // Check SW edges
                SW == ON ? last = True : ((last == True ? edge++ : edge), last = False);
                // Check W  edges
                W  == ON ? last = True : ((last == True ? edge++ : edge), last = False);
                // Check NW edges
                NW == ON ? last = True : ((last == True ? edge++ : edge), last = False);
                // Check NW -> N edges
                N && last ? edge++ : edge;

                // https://stackoverflow.com/questions/63938495/branch-points-of-the-skeleton
                // Endpoint     -- has exactly   one edge->non-edge transition
                // Branchpoint  -- has more than two edge->non-edge transitions
                edge == 1 ? end++ : end;
                edge > 2 ? branch++ : branch;
            }
        }
    }
    // Part vii)
    (end == 1 && branch == 1) ? *isE = True : (*isE = False);

    return;
}

/// <summary>
/// Checking for edge->non-edge transitions in a clockwise motion centered at X which is r,c
/// </summary>
/// <param name="img">The 9 x 15 image we're looping over</param>
/// <param name="transitions">The number of Edge to non-edge transitions</param>
/// <param name="neighbors">Count of neighboring pixels (on)</param>
/// <param name="r"></param>
/// <param name="c"></param>
```

```
void edgeNonEdgeTransitions(unsigned char* img, int *transitions, int *neighbors, int *passNum4,
int r, int c)
{
    const int COLS = 9;
    const unsigned char ON = 255, OFF = 0;
    int last = False;
    unsigned char N = OFF, E = OFF, S = OFF, W = OFF, NE = OFF, SE = OFF, SW = OFF, NW = OFF;
    // Checking in a clockwise rotation of the following image (r,c)
    // NW  N  NE    |   (-1,-1)  (-1,0)  (-1,+1)    |   (-9,-1)  (-9,0)  (-9,+1)
    //  W  X  E     |   ( 0,-1)  (0, 0)  ( 0,+1)    |   ( 0,-1)  (0, 0)  ( 0,+1)
    // SW  S  SE    |   (+1,-1)  (+1,0)  (+1,+1)    |   (+9,-1)  (+9,0)  (+9,+1)
    //  We'll check North -> North East -> East -> South East -> South -> South West -> West ->
North West
    //  Moving up one row = -9  |   Moving down one row = +9    |   Moving left = -1    |   Moving
right = +1
    N = img[(r - 1) * COLS + c]; NE = img[(r - 1) * COLS + (c + 1)];
    E = img[r * COLS + (c + 1)]; SE = img[(r + 1) * COLS + (c + 1)];
    S = img[(r + 1) * COLS + c]; SW = img[(r + 1) * COLS + (c - 1)];
    W = img[r * COLS + (c - 1)]; NW = img[(r - 1) * COLS + (c - 1)];

    //3. Count the number of edge neighbor pixels
    // Check N  edges
    N  == ON ? ((*neighbors)++, last = True) : (last = False);
    // Check NE edges
    NE == ON ? ((*neighbors)++, last = True) : ((last == True ? (*transitions)++ : *transitions),
last = False);
    // Check E edges
    E  == ON ? ((*neighbors)++, last = True) : ((last == True ? (*transitions)++ : *transitions),
last = False);
    // Check SE edges
    SE == ON ? ((*neighbors)++, last = True) : ((last == True ? (*transitions)++ : *transitions),
last = False);
    // Check S  edges
    S  == ON ? ((*neighbors)++, last = True) : ((last == True ? (*transitions)++ : *transitions),
last = False);
    // Check SW edges
    SW == ON ? ((*neighbors)++, last = True) : ((last == True ? (*transitions)++ : *transitions),
last = False);
    // Check W  edges
    W  == ON ? ((*neighbors)++, last = True) : ((last == True ? (*transitions)++ : *transitions),
last = False);
    // Check NW edges
    NW == ON ? ((*neighbors)++, last = True) : ((last == True ? (*transitions)++ : *transitions),
last = False);
    // Check NW -> N edges
    (N && last) ? (*transitions)++ : (*transitions);
    //4. Check that at least one of the North, East, or (West and South) are not edge pixels
    //      A or B or (C and D) != edge
    (N == OFF || E == OFF || (S == OFF && W == OFF)) ? (*passNum4 = True) : (*passNum4 = False);

    return;
}

/// <summary>
/// The readImage function is designed to take a file name as the source and reads all of the data
into a new image.
/// </summary>
/// <param name="ROWS"> Number of rows in the source image </param>
/// <param name="COLS"> Number of columns in the source image </param>
/// <param name="source"> File name that we're needing to open and read data from </param>
/// <returns> The function returns an array of values which makes up our image </returns>
```

```
unsigned char* readImage(int* ROWS, int* COLS, char* source)
{
    int BYTES, readHeaderReturn;
    static char header[80];

    // Open image for reading
    FILE *fpt = fopen(source, "rb");
    if (fpt == NULL) {
        printf("Failed to open file (%s) for reading.\n", source);
        exit(0);
    }

    /* read image header (simple 8-bit greyscale PPM only) */
    if (fscanf(fpt, "%s %d %d %d\n", header, &*COLS, &*ROWS, &BYTES) != 4 || strcmp(header, "P5")
!= 0 || BYTES != 255)
    {
        fclose(fpt);
        printf("Image header corrupted.\n");
        exit(0);
    }

    unsigned char* destination = createImage((*ROWS)*(*COLS)); // Create an empty image that is
large enough for ROWS x COLS bytes

    fread(destination, 1, (*ROWS) * (*COLS), fpt);
    fclose(fpt);

    return destination;
}

/// <summary>
/// createImage allocates memory for our image array.
/// </summary>
/// <param name="size"> Number of bytes that are needing to be allocated for our image </param>
/// <returns> An array with 'size' number of bytes allocated for our image use</returns>
unsigned char* createImage(int size)
{
    unsigned char* newImage = (unsigned char*)calloc(size, sizeof(unsigned char));
    if (newImage == NULL) {
        printf("Unable to allocate %d bytes of memory.\n", size);
        exit(0);
    }

    return newImage;
}
```