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Course: ECE 4310
Lab #5

Active Contours

In this project the student was to implement the Active Contour algorithm. The student was provided with a PPM image named “hawk.ppm” and text file containing a list of 42 initial contour points called “initial_contour.txt”. The student was to use these two files in order to complete the following requirements:

1. Read gray scale PPM “hawk.ppm” image
2. Read initial contour points from “initial_contour.txt” file.
3. Draw a “+” shape in a 7x7 window based on the initial contour points on the original PPM gray scale image.
4. Implement Active Contour Algorithm based on initial contour points.
    1. The Active contour algorithm used 2 Internal Energies and 1 External Energy.
        1. First Internal Energy
            1. The first internal energy calculation was based on calculating the square of the distances between the contour points in a 7x7 window.
            2. It should be noted that it was assumed that the contour encloses the area, therefore the last contour point was connected to the first contour point to calculate the First Internal Energy.
        2. Second Internal Energy
            1. The second internal energy calculation was based on:
                1. Calculating the average distance between all contour points.
                2. Taking the square difference between the ravage and the distance between the current contour point and the next contour point.
                3. It should be noted that it was assumed that the contour encloses the area, therefore the last contour point was connected to the first contour point to calculate the Second Internal Energy.
        3. External Energy
            1. The external energy was calculated by obtaining the gradient magnitude of the original image which was calculated by convolution with a Sobel template
        4. Normalization
            1. Each of the Energies calculated in a 7x7 window were normalized by finding the maximum and minimum value of that size window and then re-scaling each window to a min-max value of 0 and 1 respectively.
        5. New Contour Points
            1. After normalization of all Energy windows, the new contour points were calculated by finding the minimum value after the summation of all values in the 7x7 window of the three energies.
        6. Repeat Algorithm
            1. The Active Contour algorithm was run a total of 30 iterations with the purpose of obtaining the best contour points.

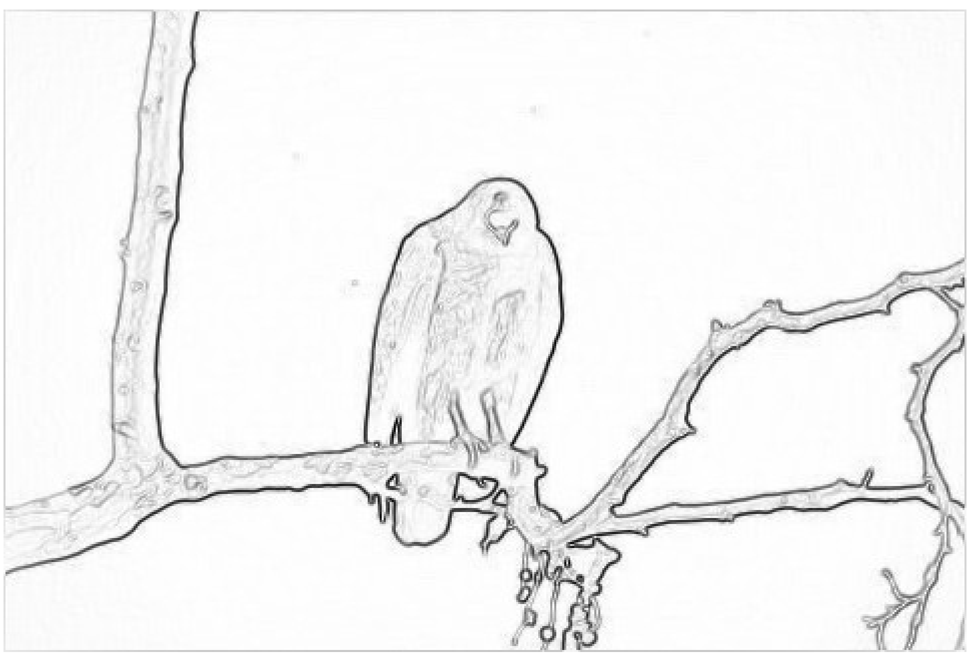
All C code can be seen at the end of the report.

RESULTS

Original gray-scale PPM image

Original gray-scale PPM image with Initial Contour Points

Sobel Edge Gradient Magnitude Image



Inverted Sobel Edge Gradient Magnitude Image

Original gray-scale PPM image with Final Contour Points

Initial Contour Points PPM Image vs Final Contour Points Image

FINAL CONTOUR POINTS TABLE

COLS	ROWS
266	104
272	114
275	123
277	133
278	143
278	154
275	167
270	180
266	191
262	201
255	213
254	226
246	237
235	234
225	239
226	249
221	260
212	266
199	266
195	255
194	245
185	242
177	237
185	223
180	211
181	201
182	190
183	180
184	170
186	160
188	147
193	134
196	125
199	116
206	109
214	105
222	100
230	94
237	87
246	84
256	86
264	96

```c
/*
    NAME: RODRIGO IGNACIO ROJAS GARCIA
    LAB#: 5
*/

// LIBRARY SECTION
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <math.h>

// DEFINE SECTION
#define MAXLENGTH 256
#define MAXITERATION 30
#define SQUARE(x) ((x) * (x))
#define WINDOWSIZE 7

/* READS IN IMAGE */
unsigned char *read_in_image(int rows, int cols, FILE *image_file)
{
    // VARIABLE DECLARATION SECTION
    unsigned char *image;

    image = (unsigned char *)calloc(rows * cols, sizeof(unsigned char));

    fread(image, sizeof(unsigned char), rows * cols, image_file);

    fclose(image_file);

    return image;
}

/* CREATES AND SAVES FILE AS A PPM IMAGE */
void save_image(unsigned char *image, char *file_name, int rows, int cols)
{
    // VARIABLE DECLARATION SECTION
    FILE *file;

    file = fopen(file_name, "w");
    fprintf(file, "P5 %d %d 255\n", cols, rows);
    fwrite(image, rows * cols, sizeof(unsigned char), file);
    fclose(file);
}

/* EXTRACTS INFORMATION FROM INITIAL CONTOUR TEXT FILE*/
void read_initial_countour(char *file_name, int **contour_rows, int **contour_cols,
int *file_size)
{
    // VARIABLE DECLARATION SECTION
    FILE *file;
    int i = 0;
    int cols, rows;
    char c;
    cols = rows = 0;
    *file_size = 0;

    // OBTAINS FILE LENGTH AND REWINDS IT TO BEGINNING
    file = fopen(file_name, "r");
    if (file == NULL)
    {
        printf("Error, could not read in initial contour text file\n");
        exit(1);
```

```
    }

    while((c = fgetc(file)) != EOF)
    {
        if (c == '\n')
        {
            *file_size += 1;
        }
    }
    rewind(file);

    // ALLOCATES MEMORY
    *contour_rows = calloc(*file_size, sizeof(int *));
    *contour_cols = calloc(*file_size, sizeof(int *));

    // EXTRACTS THE INITIAL COLUMNS AND ROWS OF INITIAL CONTOUR TEXT FILE
    while((fscanf(file, "%d %d\n", &cols, &rows)) != EOF)
    {
        (*contour_rows)[i] = rows;
        (*contour_cols)[i] = cols;
        i++;
    }

    fclose(file);
}

/* OUTPUTS INITIAL HAWK IMAGE WITH THE CONTOURS  */
void draw_contour(unsigned char *image, int image_rows, int image_cols, int
**contour_rows, int **contour_cols, int arr_length, char *file_name)
{
    // VARIABLE DECLARATION SECTION
    unsigned char *output_image;
    int rows, cols;
    int i = 0;

    output_image = (unsigned char *)calloc(image_rows * image_cols, sizeof(unsigned
char));

    // COPIES ORIGINAL IMAGE TO OUTPUT IMAGE
    for (i = 0; i < (image_rows * image_cols); i++)
    {
        output_image[i] = image[i];
    }

    // DRAW "+" ON IMAGE
    for (i = 0; i < arr_length; i++)
    {
        rows = (*contour_rows)[i];
        cols = (*contour_cols)[i];

        // "|" ON COLS
        output_image[(rows - 3)*image_cols + cols] = 0;
        output_image[(rows - 2)*image_cols + cols] = 0;
        output_image[(rows - 1)*image_cols + cols] = 0;
        output_image[(rows - 0)*image_cols + cols] = 0;
        output_image[(rows + 1)*image_cols + cols] = 0;
        output_image[(rows + 2)*image_cols + cols] = 0;
        output_image[(rows + 3)*image_cols + cols] = 0;

        // "-" ON ROWS
        output_image[(rows * image_cols) + (cols - 3)] = 0;
        output_image[(rows * image_cols) + (cols - 2)] = 0;
```

```
        output_image[(rows * image_cols) + (cols - 1)] = 0;
        output_image[(rows * image_cols) + (cols - 0)] = 0;
        output_image[(rows * image_cols) + (cols + 1)] = 0;
        output_image[(rows * image_cols) + (cols + 2)] = 0;
        output_image[(rows * image_cols) + (cols + 3)] = 0;
    }

    // SAVES IMAGE WITH CONTOUR POINTS EXPRESSED AS "+"
    save_image(output_image, file_name, image_rows, image_cols);

    free(output_image);
}

/* CALCULATES THE MINIMUM AND MAXIMUM VALUE IN EACH PIXEL */
void find_min_and_max_int(int *convolution_image, int image_rows, int image_cols, int
*min, int *max)
{
    // VARIABLE DECLARATION SECTION
    int i;

    *min = convolution_image[0];
    *max = convolution_image[0];
    for (i = 1; i < (image_rows * image_cols); i++)
    {
        if (*min > convolution_image[i])
        {
            *min = convolution_image[i];
        }
        if (*max < convolution_image[i])
        {
            *max = convolution_image[i];
        }
    }
}

/* CALCULATES THE MINIMUM AND MAXIMUM VALUE OF EACH PIXEL ON WINDOW */
void find_min_and_max_float(float *convolution_image, int image_rows, int image_cols,
float *min, float *max)
{
    // VARIABLE DECLARATION SECTION
    int i, j, k;

    *min = convolution_image[0];
    *max = convolution_image[0];

    for(i = 1; i < (image_rows-1); i++)
    {
        for(j = 1; j < (image_cols-1); j++)
        {
            k = (i * image_cols) + j;
            if (*min > convolution_image[k])
            {
                *min = convolution_image[k];
            }
            if (*max < convolution_image[k])
            {
                *max = convolution_image[k];
            }
        }
    }
}
```

```c
/* NORMALIZE UNSIGNED CHAR INPUT IMAGE, RETURNS NORMALIZED IMAGE */
unsigned char *normalize_unsigned_char(int *convolution_image, int image_rows, int
image_cols, int new_min, int new_max, int min, int max)
{
    // Variable Declaration Section
    unsigned char *normalized_image;
    int i;

    // Allocate memory
    normalized_image = (unsigned char *)calloc(image_rows * image_cols,
sizeof(unsigned char));

    for (i = 0; i < (image_rows * image_cols); i++)
    {
        if (min == 0 && max == 0)
        {
            normalized_image[i] = 0;
        }
        else
        {
            normalized_image[i] = ((convolution_image[i] - min)*(new_max - new_min)/
(max-min)) + new_min;
        }
    }

    return normalized_image;
}

/*  NORMALIZE FLOAT INPUT IMAGE, RETURNS NORMALIZED IMAGE */
float *normalize_float(float *convolution_image, int image_rows, int image_cols, float
new_min, float new_max, float min, float max)
{
    float *normalized_image;
    int i;

    normalized_image = (float *)calloc(image_rows * image_cols, sizeof(float));

    for (i = 0; i < (image_rows * image_cols); i++)
    {
        normalized_image[i] = ((convolution_image[i] - min)*(new_max - new_min)/(max-
min)) + new_min;
    }

    return normalized_image;
}

/* OUTPUTS NORMALIZED SOBEL IMAGE AND RETURNS UN-NORMALIZED SOBEL IMAGE */
float *sobel_edge_detector(unsigned char *image, int image_rows, int image_cols)
{
    // VARIABLE DECLARATION SECTION
    int *convolution_image;
    float *sobel_image;
    unsigned char *normalized_image;
    int i, j, rows, cols;
    int index1 = 0;
    int index2 = 0;
    int x = 0;
    int y = 0;
    int min = 0;
    int max = 0;

    // X and Y KERNELS
```

```
    int g_x[9] =    {-1, 0, 1,
                    -2, 0, 2,
                    -1, 0, 1};

    int g_y[9] =    {-1, -2, -1
                    , 0, 0, 0,
                    1, 2, 1};

    // ALLOCATE MEMORY
    convolution_image = (int *)calloc(image_rows * image_cols, sizeof(int));
    sobel_image = (float *)calloc(image_rows * image_cols, sizeof(float));

    // COPY ORIGINAL IMAGE
    for (i = 0; i < (image_rows * image_cols); i++)
    {
        convolution_image[i] = image[i];
    }

    // CONVOLUTE INPUT IMAGE WITH X AND Y KERNELS
    for (rows = 1; rows < (image_rows - 1); rows++)
    {
        for (cols = 1; cols < (image_cols - 1); cols++)
        {
            x = 0;
            y = 0;
            for (i = -1; i < 2; i++)
            {
                for (j = -1; j < 2; j++)
                {
                    index1 = (image_cols * (rows + i)) + (cols + j);
                    index2 = 3*(i + 1) + (j + 1);
                    x += (image[index1] * g_x[index2]);
                    y += (image[index1] * g_y[index2]);
                }
            }
            index1 = (image_cols * rows) + cols;
            convolution_image[index1] = sqrt((SQUARE(x) + SQUARE(y)));
            sobel_image[index1] = sqrt((SQUARE(x) + SQUARE(y)));
        }
    }

    // FIND MINIMUM AND MAXIMUM VALUES IN CONVOLUTED IMAGE
    find_min_and_max_int(convolution_image, image_rows, image_cols, &min, &max);

    // NORMALIZES CONVOLUTED IMAGE FROM RANGE OF 0-255 IN ORDER TO SAVE AS PPM
    normalized_image = normalize_unsigned_char(convolution_image, image_rows,
image_cols, 0, 255, min, max);
    save_image(normalized_image, "hawk_sobel_image.ppm", image_rows, image_cols);

    // INVERTS NORMALIZED IMAGE IN ORDER TO SAVE AS PPM
    for (i = 0; i < (image_rows * image_cols); i++)
    {
        normalized_image[i] = 255 - normalized_image[i];
    }
    save_image(normalized_image, "hawk_sobel_inverted_image.ppm", image_rows,
image_cols);

    // FREE ALLOCATED MEMORY
    free(normalized_image);
    free(convolution_image);

    return sobel_image;
```

```
}

/* ACTIVE CONTOUR ALGORITHM APPLIED TO ORIGINAL IMAGE */
void active_contour(unsigned char *image, float *sobel_image, int image_rows, int
image_cols, int **contour_rows, int **contour_cols, int arr_length)
{
    // VARIABLE DECLARATION SECTION
    float *inverted_sobel;
    float *first_internal_energy;
    float *second_internal_energy;
    float *external_energy;
    float *sum_energies;
    float min, max, new_min, new_max;
    float *first_internal_energy_normalized, *second_internal_energy_normalized,
*external_energy_normalized;
    float average_distance_x = 0;
    float average_distance_y = 0;
    float average_distance = 0;
    int i, j, k, l, rows, cols;
    int index = 0;
    int index2 = 0;
    int index3 = 0;
    int new_x[arr_length];
    int new_y[arr_length];
    int temp = 0;
    new_min = 0.0;
    new_max = 1.0;


    // ALLOCATE MEMORY
    first_internal_energy = (float *)calloc(49, sizeof(float));
    second_internal_energy = (float *)calloc(49, sizeof(float));
    external_energy = (float *)calloc(49, sizeof(float));
    sum_energies = (float *)calloc(49, sizeof(float));
    inverted_sobel = (float *)calloc(image_rows * image_cols, sizeof(float));

    // FIND MINIMUM AND MAXIMUM VALUE OF SOBEL IMAGE
    find_min_and_max_float(sobel_image, image_rows, image_cols, &min, &max);

    // Creates an invereted Sobel image for External Energy calculation
    for ( i = 0; i < (image_rows * image_cols); i++)
    {
        inverted_sobel[i] = sobel_image[i];
        inverted_sobel[i] = (float)max - inverted_sobel[i];
    }

    // Calculates first Internal Energy
    for (l = 0; l < MAXITERATION; l++)
    {

        average_distance_x = 0.0;
        average_distance_y = 0.0;
        average_distance = 0.0;

        // CALCULATES THE AVERAGE DISTANCE BETWEEN CONTOUR POINTS
        for (i = 0; i < arr_length; i++)
        {
            if ((i + 1) < arr_length)
            {
                average_distance_x = SQUARE((*contour_cols)[i] - (*contour_cols)[i +
1]);
                average_distance_y = SQUARE((*contour_rows)[i] - (*contour_rows)[i +
```

```
1]);
            }
            else
            {
                average_distance_x = SQUARE((*contour_cols)[i] - (*contour_cols)[0]);
                average_distance_y = SQUARE((*contour_rows)[i] - (*contour_rows)[0]);
            }
            average_distance +=sqrt(average_distance_x + average_distance_y);
            new_x[i] = 0;
            new_y[i] = 0;
        }
        average_distance /= arr_length;

        for (i = 0; i < arr_length; i++)
        {
            rows = (*contour_rows)[i];
            cols = (*contour_cols)[i];
            index = 0;

            // FIRST AND SECOND INTERNAL ENERGY AND EXTERNAL ENERGY CALCULATED
            for (j = (rows - 3); j <= (rows + 3); j++)
            {
                for (k = (cols - 3); k <= (cols + 3); k++)
                {
                    if ((i + 1) < arr_length)
                    {
                        first_internal_energy[index] = SQUARE(k - (*contour_cols)[i +
1]) + SQUARE(j - (*contour_rows)[i + 1]);
                        second_internal_energy[index] =
SQUARE(sqrt(first_internal_energy[index]) - average_distance);
                        index2 = (j * image_cols) + k;
                        external_energy[index] = SQUARE(inverted_sobel[index2]);
                    }
                    else
                    {
                        first_internal_energy[index] = SQUARE(k - (*contour_cols)[0])
+ SQUARE(j - (*contour_rows)[0]);
                        second_internal_energy[index] =
SQUARE(sqrt(first_internal_energy[index]) - average_distance);
                        index2 = (j * image_cols) + k;
                        external_energy[index] = SQUARE(inverted_sobel[index2]);

                    }
                    index++;
                }
            }

            // FINDS MINIMUM AND MAXIMUM VALUES OF EACH ENERGY AND NORMALIZES TO
VALUE OF 0 AND 1
            find_min_and_max_float(first_internal_energy, WINDOWSIZE, WINDOWSIZE,
&min, &max);
            first_internal_energy_normalized = normalize_float(first_internal_energy,
WINDOWSIZE, WINDOWSIZE, new_min, new_max, min, max);
            find_min_and_max_float(second_internal_energy, WINDOWSIZE, WINDOWSIZE,
&min, &max);
            second_internal_energy_normalized =
normalize_float(second_internal_energy, WINDOWSIZE, WINDOWSIZE, new_min, new_max,
min, max);
            find_min_and_max_float(external_energy, WINDOWSIZE, WINDOWSIZE, &min,
&max);
            external_energy_normalized = normalize_float(external_energy, WINDOWSIZE,
WINDOWSIZE, new_min, new_max, min, max);
```

```
            // CALCULATES THE ENERGY
            for (j = 0; j < 49; j++)
            {
                sum_energies[j] = first_internal_energy_normalized[j] +
second_internal_energy_normalized[j] + external_energy_normalized[j];
            }

            // FREES MEMORY
            free(first_internal_energy_normalized);
            free(second_internal_energy_normalized);
            free(external_energy_normalized);

            // DETERMINES THE LOWEST VALUE FOR NEW POINTS
            min = sum_energies[0];
            index = 0;
            for (j = 0; j < 49; j++)
            {
                if (min > sum_energies[j])
                {
                    min = sum_energies[j];
                    index = j;
                }
            }

            // DETERMINES ROW AND COLUMN FOR NEW POINT BASED ON INDEX
            temp = 0;
            index2 = (index / WINDOWSIZE); // row
            if (index2 < 3)
            {
                temp = (*contour_rows)[i] - abs(index2 - 3);
                new_y[i] = temp;
            }
            else if (index2 > 3)
            {
                temp = (*contour_rows)[i] + abs(index2 - 3);
                new_y[i]  = temp;
            }
            else
            {
                new_y[i] = (*contour_rows)[i];
            }


            index3 = (index % WINDOWSIZE); // col
            if (index3 < 3)
            {
                new_x[i] = (*contour_cols)[i] - abs(index3 - 3);

            }
            else if (index3 > 3)
            {
                new_x[i] = (*contour_cols)[i] + abs(index3 - 3);
            }
            else
            {
                new_x[i] = (*contour_cols)[i];
            }
        }

        // SETS NEW POINTS
        for (i = 0; i < arr_length; i++)
```

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        {
            (*contour_cols)[i] = new_x[i];
            (*contour_rows)[i] = new_y[i];
        }

    }

    // DRAWS CONTOUR WITH FINAL POINTS
    draw_contour(image, image_rows, image_cols, contour_rows, contour_cols,
arr_length, "hawk_final_contour.ppm");

    // CREATE FILE WITH FINAL CONTOUR POINTS
    FILE *file;
    file = fopen("final_contour_points.csv", "w");
    fprintf(file, "COLS,ROWS\n");
    for(i = 0; i < arr_length; i++)
    {
        fprintf(file, "%d,%d\n", (*contour_cols)[i], (*contour_rows)[i]);
    }
    fclose(file);

    // FREE ALLOCATED MEMORY
    free(first_internal_energy);
    free(second_internal_energy);
    free(external_energy);
    free(sum_energies);
    free(inverted_sobel);
}

int main(int argc, char *argv[])
{
    // VARIABLE DECLARATION SECTION
    FILE *image_file;
    int IMAGE_ROWS, IMAGE_COLS, IMAGE_BYTES;
    char file_header[MAXLENGTH];
    unsigned char *input_image;
    float *sobel_image;
    int *contour_rows, *contour_cols;
    int file_size;

    /* CHECKS THAT USER ENTERED THE CORRECT NUMBER OF PARAMETERS */
    if (argc != 3)
    {
        printf("Usage: ./executable image_file.ppm initial_contour_file.txt");
        exit(1);
    }

    /* OPEN IMAGE */
    image_file = fopen(argv[1], "rb");
    if (image_file == NULL)
    {
        printf("Error, could not read input image\n");
        exit(1);
    }
    fscanf(image_file, "%s %d %d %d\n", file_header, &IMAGE_COLS, &IMAGE_ROWS,
&IMAGE_BYTES);
    if ((strcmp(file_header, "P5") != 0) || (IMAGE_BYTES !=  255))
    {
        printf("Error, not a greyscale 8-bit PPM image\n");
        fclose(image_file);
        exit(1);
    }
```

```
    /* ALLOCATE MEMORY AND READ IN INPUT IMAGE */
    input_image = read_in_image(IMAGE_ROWS, IMAGE_COLS, image_file);

    /* EXTRACT INFORMATION FROM INITIAL CONTOUR TEXT FILE */
    read_initial_countour(argv[2], &contour_rows, &contour_cols, &file_size);

    /* DRAW INITIAL CONTOUR "+" ON INPUT IMAGE */
    draw_contour(input_image, IMAGE_ROWS, IMAGE_COLS, &contour_rows, &contour_cols,
file_size, "hawk_initial_contour.ppm");

    /* UN-NORMALIZED SOBEL IMAGE */
    sobel_image = sobel_edge_detector(input_image, IMAGE_ROWS, IMAGE_COLS);

    /* CONTOUR ALGORITHM */
    active_contour(input_image, sobel_image, IMAGE_ROWS, IMAGE_COLS, &contour_rows,
&contour_cols, file_size);

    /* FREE ALLOCATED MEMORY */
    free(input_image);
    free(sobel_image);
    free(contour_rows);
    free(contour_cols);

    return 0;
}
```