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Section: Image Processing

Project: **Project 5 - Image Compression via 8 Connected**

Due Date: Oct 29th

Algorithm Steps

```
step 0:
        inFile, outFile1, deBugFile ⍰ open via argv[]
        numRows, numCols, minVal, maxVal ⍰ read from inFile
        dynamically allocate ZFAry with extra 2 rows and 2 cols
        dynamically allocate skeletonAry with extra 2 rows and 2 cols
Step 1: skeletonFileName <- argv [1] + "_skeleton.txt"
Step 2: skeletonFile <- open (skeletonFileName)
Step 3: deCompressedFileName <- argv [1] + "_deCompressed.txt"
Step 4: deCompressedFile <- open (deCompressedFileName)
Step 5:  setZero (ZFAry)
        setZero(skeletonAry)
Step 6: loadImage (inFile, ZFAry)
Step 7: Distance8 (ZFAry, outFile1, deBugFile) // Perform distance transform.
Step 8: imageCompression (ZFAry, skeletonAry, skeletonFile, outFile1, deBugFile) // Perform lossless compression
Step 9: close skeletonFile
Step 10: reopen skeletonFile

Step 11: setZero (ZFAry)

Step 12: loadSkeleton (skeletonFile, ZFAry, deBugFile)

Step 13: imageDeCompression (ZFAry, outFile1, deBugFile) // Perform decompression

Step 14: deCompressFile <— output numRows, numCols, newMinVal, newMaxVal

Step 15: threshold (ZFAry, deCompressFile,1)

Step 16: close all files
```

Video: https://www.youtube.com/watch?v=kaJNpfPy-PE

Source Code:

```
//

//  main.cpp

//  CS381_Image_Processing_Project5_Distance_Transform

//

//  Created by Jingshi Liu on Oct/28/2023.

//



#include <iostream>

#include <fstream>


using namespace std;

namespace Util{

    static int** getArray(int rows, int cols){
```

```
    int** array = new int*[rows];
    for(int i = 0; i < rows; i++){
        array[i] = new int[cols];
        for(int j = 0; j < cols; j++){
            array[i][j] = 0;
        }
    }
    return array;
}

static int min(int a, int b){
    return a < b ? a : b;
}

static int max(int a, int b){
    return a > b ? a : b;
}

static int findMin(int* array, int length){
    int min = array[0];
    for(int i = 0; i < length; i++){
        if(array[i] < min){
            min = array[i];
        }
    }
    return min;
}

static int findMax(int* array, int length){
    int max = array[0];
    for(int i = 0; i < length; i++){
        if(array[i] > max){
            max = array[i];
        }
```

```cpp
        }
        return max;
    }
}

class ImageCompression{
public:
    int numRows,
        numCols,
        minVal,
        maxVal,
        newMinVal,
        newMaxVal;
    int** ZFAry;
    int** skeletonAry;

    ImageCompression(ifstream& inFile){
        inFile >> numRows >> numCols >> minVal >> maxVal;
        ZFAry = Util::getArray(numRows + 2 , numCols + 2);
        skeletonAry = Util::getArray(numRows + 2, numCols + 2);

        loadImage(inFile);
    }

    void setZero(int** array){
        for(int i = 0; i < numRows + 2; i++){
            for(int j = 0; j < numCols + 2; j++){
                array[i][j] = 0;
            }
        }
    }

    void loadImage(ifstream& inFile){
        int pixelVal;
        for(int i = 1; i < numRows + 1; i++){
            for(int j = 1; j < numCols + 1; j++){
                inFile >> pixelVal;
                ZFAry[i][j] = pixelVal;
            }
        }
    }

    void imageReformat(int** image, ofstream& outFile){
        outFile << numRows << " " << numCols << " " << newMinVal << " " << newMaxVal << '\n';
        string str;
        int curWidth,
            pixelWidth = to_string(newMaxVal).length();

        for(int r = 1; r < numRows + 1; r++){
            for(int c = 1; c < numCols + 1; c++){
                outFile << image[r][c];
                str = to_string(image[r][c]);
                curWidth = str.length();
                while(curWidth < pixelWidth){
                    outFile<<' ';
                    curWidth++;
                }
                outFile<<' ';
            }
            outFile << '\n';
        }
    }

    void loadSkeleton(ifstream& inFile){
        int row, col, pixelVal;
        while(inFile >> row >> col >> pixelVal){
            ZFAry[row][col] = pixelVal;
        }
```

```
}

void distance8(ofstream& outFile, ofstream& debugFile){
    debugFile << "Entering distance8() method" << endl;
    distance8Pass1(debugFile);

    outFile<<"Distance Transform 8 Pass 1"<<endl;
    imageReformat(ZFAry, outFile);
    distance8Pass2(debugFile);

    outFile<<"\n\nDistance Transform 8 Pass 2"<<endl;
    imageReformat(ZFAry, outFile);
    debugFile << "Exiting distance8() method" << endl;
}

void distance8Pass1(ofstream& debugFile){
    debugFile << "Entering distancePass1() method" << endl;
    for(int i = 1; i < numRows + 1; i++){
        for(int j = 1; j < numCols + 1; j++){
            if (ZFAry[i][j] == 0) continue;
            int neighbors[4] = {ZFAry[i - 1][j - 1],
                              ZFAry[i - 1][j],
                              ZFAry[i - 1][j + 1],
                              ZFAry[i][j - 1]};
            ZFAry[i][j] = 1 + Util::findMin(neighbors, 4);
            newMaxVal = Util::max(ZFAry[i][j], newMaxVal);
            newMinVal = Util::min(ZFAry[i][j], newMinVal);
        }
    }
    debugFile << "Exiting distancePass1() method" << endl;
}

void distance8Pass2(ofstream& debugFile){
    debugFile << "Entering distancePass2() method" << endl;
    newMaxVal = 0;
    for(int i = numRows; i > 0; i--){
        for(int j = numCols; j > 0; j--){
            if (ZFAry[i][j] == 0) continue;
            int neighbors[4] = {ZFAry[i][j + 1],
                                ZFAry[i + 1][j - 1],
                                ZFAry[i + 1][j],
                                ZFAry[i + 1][j + 1]};
            ZFAry[i][j] = Util::min(ZFAry[i][j], 1 + Util::findMin(neighbors, 4));
            newMaxVal = Util::max(ZFAry[i][j], newMaxVal);
            newMinVal = Util::min(ZFAry[i][j], newMinVal);
        }
    }
    debugFile << "Exiting distancePass2() method" << endl;
}

void imageCompression(ofstream& skeletonFile, ofstream& outFile, ofstream& debugFile){
    debugFile << "Entering imageCompression() method" << endl;
    computeLocalMaxima(debugFile);
    outFile<< "\n\nLocal Maxima Skeleton of the image" << endl;
    imageReformat(skeletonAry, outFile);
    extractSkeleton(skeletonFile, debugFile);
    debugFile << "Exiting imageCompression() method" << endl;
}

void computeLocalMaxima(ofstream& debugFile) {
    debugFile << "Entering computeLocalMaxima() method" << endl;
    for (int i = 1; i < numRows + 1; i++) {
        for (int j = 1; j < numCols + 1; j++) {
            if (ZFAry[i][j] == 0) continue;
            int neighbors[8] = {ZFAry[i - 1][j - 1],
                                ZFAry[i - 1][j],
                                ZFAry[i - 1][j + 1],
                                ZFAry[i][j - 1],
                                ZFAry[i][j + 1],
                                ZFAry[i + 1][j - 1],
                                ZFAry[i + 1][j],
                                ZFAry[i + 1][j + 1]};
            int max = Util::findMax(neighbors, 8);
            if (ZFAry[i][j] >= max) {
                skeletonAry[i][j] = ZFAry[i][j];
            }
        }
        debugFile << "Exiting computeLocalMaxima() method" << endl;
    }
}

void extractSkeleton(ofstream& skeletonFile, ofstream& debugFile){
    debugFile << "Entering extractSkeleton() method" << endl;
    for (int i = 1; i < numRows + 1; i++) {
        for (int j = 1; j < numCols + 1; j++) {
            if(skeletonAry[i][j] == 0) continue;
            skeletonFile<< i << " " << j << " " << skeletonAry[i][j] << endl;
        }
    }
    debugFile << "Exiting extractSkeleton() method" << endl;
}

void imageDecompression(ofstream &outFile, ofstream &debugFile){
    debugFile << "Entering imageDecompression() method" << endl;
    expansionPass1(debugFile);
    outFile<<"\n\nExpansion Pass 1"<<endl;
    imageReformat(ZFAry, outFile);

    expansionPass2(debugFile);
    outFile<<"\n\nExpansion Pass 2"<<endl;
    imageReformat(ZFAry, outFile);
    debugFile << "Exiting imageDecompression() method" << endl;
```

```
}

void expansionPass1(ofstream& debugFile){
    debugFile << "Entering expansionPass1() method" << endl;
    for(int i = 1; i < numRows + 1; i++){
        for(int j = 1; j < numCols + 1; j++){
            if(ZFAry[i][j] > 0) continue;
            int neighbors[8] = {ZFAry[i - 1][j - 1],
                                ZFAry[i - 1][j],
                                ZFAry[i - 1][j + 1],
                                ZFAry[i][j - 1],
                                ZFAry[i][j + 1],
                                ZFAry[i + 1][j - 1],
                                ZFAry[i + 1][j],
                                ZFAry[i + 1][j + 1]};
            ZFAry[i][j] = Util::max(ZFAry[i][j], Util::findMax(neighbors, 8) - 1);
        }
    }
    debugFile << "Exiting expansionPass1() method" << endl;
}

void expansionPass2(ofstream& debugFile){
    debugFile << "Entering expansionPass2() method" << endl;
    for(int i = numRows; i > 0; i--){
        for(int j = numCols; j > 0; j--){
            int neighbors[8] = {ZFAry[i - 1][j - 1],
                                ZFAry[i - 1][j],
                                ZFAry[i - 1][j + 1],
                                ZFAry[i][j - 1],
                                ZFAry[i][j + 1],
                                ZFAry[i + 1][j - 1],
                                ZFAry[i + 1][j],
                                ZFAry[i + 1][j + 1]};
            ZFAry[i][j] = Util::max(ZFAry[i][j], Util::findMax(neighbors, 8) - 1);
            }
        }
        debugFile << "Exiting expansionPass2() method" << endl;
    }

    void threshold(int threshold, ofstream &outFile){
        outFile << numRows << " " << numCols << " " << minVal << " " << threshold << '\n';
        for(int i = 1; i < numRows + 1; i++){
            for(int j = 1; j < numCols + 1; j++){
                if(ZFAry[i][j] >= threshold){
                    outFile << 1 << " ";
                }else{
                    outFile << 0 << " ";
                }
            }
            outFile<< '\n';
        }
    }
};



// --------------------------------------- Main Function---------------------------------------//

int main(int argc, const char* argv[]){
    ifstream inFile(argv[1]);
    ofstream outFile(argv[2]),
             debugFile(argv[3]),
             skeletonFile((string)argv[1] + "_skeleton.txt"),
             decompressedFile((string)argv[1] + "_decompressed.txt");
    // compress image and output to skeletonFile
    ImageCompression* imageCompression = new ImageCompression(inFile);
    imageCompression->distance8(outFile, debugFile);
    imageCompression->imageCompression(skeletonFile, outFile, debugFile);
    skeletonFile.close();


    // load skeleton file and decompress
    ifstream skeletonInFile((string)argv[1] + "_skeleton.txt");
    imageCompression->setZero(imageCompression->ZFAry);
    imageCompression->loadSkeleton(skeletonInFile);

    imageCompression->imageDecompression(outFile, debugFile);
    imageCompression->threshold(1, decompressedFile);

    inFile.close();
    outFile.close();
    debugFile.close();
    skeletonInFile.close();
    decompressedFile.close();
    return 0;
}
```

Program Output

Image 1 Input File

```
40 22 0 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
```

```
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

Image 1 OutFile

```
Distance Transform 8 Pass 1

40 22 0 7

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0

0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0

0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0

0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0

0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 1 1 2 2 3 3 4 4 5 5 5 4 4 3 3 2 2 1 1 0

0 0 0 1 2 3 3 4 4 5 5 6 5 5 4 4 3 3 2 2 0 0

0 0 0 0 1 2 3 4 5 5 6 6 6 5 5 4 4 3 3 0 0 0
```

```
0 0 0 0 0 1 2 3 4 5 6 7 6 6 5 5 4 4 0 0 0 0
0 0 0 0 0 0 1 2 3 4 5 6 7 6 6 5 5 0 0 0 0 0
0 0 0 0 0 0 0 1 2 3 4 5 6 7 6 6 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 2 3 4 5 6 7 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 2 3 4 5 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 2 3 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0
0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0
0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0
0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0
0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0
0 0 1 1 2 2 3 3 4 4 5 5 5 4 4 3 3 2 2 1 1 0
0 0 0 1 2 3 3 4 4 5 5 6 5 5 4 4 3 3 2 2 0 0
0 0 0 0 1 2 3 4 5 5 6 6 6 5 5 4 4 3 3 0 0 0
0 0 0 0 0 1 2 3 4 5 6 7 6 6 5 5 4 4 0 0 0 0
0 0 0 0 0 0 1 2 3 4 5 6 7 6 6 5 5 0 0 0 0 0
0 0 0 0 0 0 0 1 2 3 4 5 6 7 6 6 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 2 3 4 5 6 7 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 2 3 4 5 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 2 3 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
```

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
Distance Transform 8 Pass 2

40 22 0 5

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0

0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0

0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0

0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0

0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 1 1 2 2 3 3 4 4 5 5 5 4 4 3 3 2 2 1 1 0

0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0

0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0

0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0

0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
```

```
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0

0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0

0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0

0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0

0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 1 1 2 2 3 3 4 4 5 5 5 4 4 3 3 2 2 1 1 0

0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0

0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0

0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0

0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0



Local Maxima Skeleton of the image

40 22 0 5

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0
0 0 1 0 2 0 3 0 4 0 5 5 5 0 4 0 3 0 2 0 1 0
0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0
```

```
0 0 1 0 2 0 3 0 4 0 5 5 5 0 4 0 3 0 2 0 1 0
0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
Expansion Pass 1
40 22 0 5
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 2 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 2 2 2 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 2 3 2 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 3 3 3 2 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 2 3 4 3 2 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 2 4 4 4 3 2 1 0 0 0 0 0 0
0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0
0 0 1 1 2 2 3 3 4 4 5 5 5 4 4 3 3 2 2 1 1 0
```

```
0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0

0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0

0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0

0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 2 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 2 2 2 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 2 3 2 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 3 3 3 2 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 2 3 4 3 2 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 2 4 4 4 3 2 1 0 0 0 0 0 0

0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 1 1 2 2 3 3 4 4 5 5 5 4 4 3 3 2 2 1 1 0

0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0

0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0

0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0

0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0
```

```
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0


Expansion Pass 2
40 22 0 5
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0
0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0
0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0
0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0
0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0
0 0 1 1 2 2 3 3 4 4 5 5 5 4 4 3 3 2 2 1 1 0
0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0
0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0
0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0
0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0
0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
```

```
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0

0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0

0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0

0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0

0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 1 1 2 2 3 3 4 4 5 5 5 4 4 3 3 2 2 1 1 0

0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0

0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0

0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0

0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0

0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

Image 1 Skeleton File

```
2 12 1

4 12 2
```

```
6 12 3

8 12 4

10 12 5

11 3 1

11 5 2

11 7 3

11 9 4

11 11 5

11 12 5

11 13 5

11 15 4

11 17 3

11 19 2

11 21 1

12 12 5

14 12 4

16 12 3

18 12 2

20 12 1

21 12 1

23 12 2

25 12 3

27 12 4

29 12 5

30 3 1

30 5 2
```

```
30 7 3
30 9 4
30 11 5
30 12 5
30 13 5
30 15 4
30 17 3
30 19 2
30 21 1
31 12 5
33 12 4
35 12 3
37 12 2
39 12 1
```

Image 1 DecompressedFile

```
40 22 0 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
```

```
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
```

```
0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

Image 1 debugFile

```
Entering distance8() method
Entering distancePass1() method
Exiting distancePass1() method
Entering distancePass2() method
Exiting distancePass2() method
Exiting distance8() method
Entering imageCompression() method
Entering computeLocalMaxima() method
Exiting computeLocalMaxima() method
Exiting computeLocalMaxima() method
Exiting computeLocalMaxima() method
Exiting computeLocalMaxima() method
Exiting computeLocalMaxima() method
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Exiting computeLocalMaxima() method
Exiting computeLocalMaxima() method
Exiting computeLocalMaxima() method
Exiting computeLocalMaxima() method
Exiting computeLocalMaxima() method
Entering extractSkeleton() method
Exiting extractSkeleton() method
Exiting imageCompression() method
Entering imageDecompression() method
Entering expansionPass1() method
Exiting expansionPass1() method
Entering expansionPass2() method
Exiting expansionPass2() method
Exiting imageDecompression() method
```

Image 2 Input File

```
49 64 0 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

Image 2 OutFile

```
Distance Transform 8 Pass 1

49 64 0 9

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 2 2 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 2 2 3 2 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 2 2 3 3 3 2 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 2 2 3 3 4 3 3 2 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 2 2 3 3 4 4 4 3 3 2 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 2 2 3 3 4 4 5 4 4 3 3 2 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 2 2 3 3 4 4 5 5 5 4 4 3 3 2 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 2 3 3 4 4 5 5 6 5 5 4 4 3 3 2 2 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 2 3 4 5 5 6 6 6 5 5 4 4 3 3 0 0 0 0 0 0 0 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 0 0

0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 1 2 3 4 5 6 7 6 6 5 5 4 4 0 0 0 0 0 0 0 0 1 2 3 3 3 3 3 3 3 3 3 3 3 3 3 2 1 0 0

0 0 0 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 0 0 0 0 0 1 2 3 4 5 6 7 6 6 5 5 0 0 0 0 0 0 0 0 0 1 2 3 4 4 4 4 4 4 4 4 4 4 4 3 2 1 0 0

0 0 0 1 2 3 3 3 3 3 3 3 3 3 3 3 3 3 2 1 0 0 0 0 0 0 1 2 3 4 5 6 7 6 6 0 0 0 0 0 0 0 0 0 0 1 2 3 4 5 5 5 5 5 5 5 5 5 4 3 2 1 0 0

0 0 0 1 2 3 4 4 4 4 4 4 4 4 4 4 4 3 2 1 0 0 0 0 0 0 0 1 2 3 4 5 6 7 0 0 0 0 0 0 0 0 0 0 0 1 2 3 4 5 6 6 6 6 6 6 6 5 4 3 2 1 0 0

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Expansion Pass 1

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Image 2 Skeleton File

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6 31 2

8 31 3

10 31 4

12 31 5

13 22 1
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13 24 2
13 26 3
13 28 4
13 30 5
13 31 5
13 32 5
13 34 4
13 36 3
13 38 2
13 40 1
14 31 5
16 31 4
18 31 3
19 51 6
19 52 6
19 53 6
19 54 6
19 55 6
19 56 6
19 57 6
20 31 2
21 9 6
21 10 6
21 11 6
21 12 6
21 13 6
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21 14 6
21 15 6
22 31 1
22 49 4
22 50 4
22 58 4
22 59 4
23 31 1
23 49 4
23 59 4
25 31 2
25 48 3
25 49 3
25 59 3
25 60 3
26 48 3
26 60 3
27 31 3
28 47 2
28 48 2
28 60 2
28 61 2
29 31 4
29 47 2
29 61 2
31 31 5
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31 46 1

31 47 1

31 61 1

31 62 1

32 22 1

32 24 2

32 26 3

32 28 4

32 30 5

32 31 5

32 32 5

32 34 4

32 36 3

32 38 2

32 40 1

32 46 1

32 62 1

33 31 5

35 31 4

37 31 3

39 31 2

41 31 1
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Image 2 DecompressedFile

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Image 2 debugFile

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Entering distance8() method
Entering distancePass1() method
Exiting distancePass1() method
Entering distancePass2() method
Exiting distancePass2() method
Exiting distance8() method
Entering imageCompression() method
Entering computeLocalMaxima() method
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Entering extractSkeleton() method

Exiting extractSkeleton() method

Exiting imageCompression() method

Entering imageDecompression() method

Entering expansionPass1() method

Exiting expansionPass1() method

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Exiting expansionPass2() method

Exiting imageDecompression() method
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