Student: Pawan Bhatta
Project Due Date: 04/30/2021

Chain Code Algorithm Steps:

```
Step 0: image ← given a Binary Image e.g. a Connected Component Box
        output ← open Chain-Code output file

Step 1: Scan image Left-Right & Top-Bottom
         startingP( i,j ) ← next pixel

Step 2: if startingP( i,j ) > 0 // starting Pixel found
        startRow ← i // row
        startCol ← j // column
        gray-scale ← startingP( i,j ) // pixel value
        currentP( i,j ) ← startingP( i,j )
        lastZero ← 4 //starts with 4 b/c we scan L→R
        output ← startRow , startCol , gray-scale

Step 3: repeat steps 1 to 2 until startingP( i,j ) is found (if found break)

Step 4: direction ← lastZero + 1 // # from 0 to 7 (++lastZero % 8)

Step 5: nextP( i,j ) ← findNextPixel( direction , currentP( i,j ) )

                Step 1: if nextP( i,j ) == 0
                        direction = ++direction % 8
                Step 2: repeat steps 1 until nextP( i,j ) > 0.

 Step 6: output ← direction // direction of nextP( i,j ) set by findNextPixel()
                            // direction is Chain-Code Link
         currentP( i,j ) ← nextP( i,j )
         lastZero ← ZeroTable[ direction - 1 ]

 Step 7: repeat step 4 to 6 until you reach the startingP( i,j )
```

Finding Next Point based on current point and direction value:

```
Step 1: loadNeighborCoord (currentP)

Step 2: chainDir← scan currentP's 8 neighbors counter clockwise from nextQ direction (mod 8)
until a none zero neighbor with the same label as currentCC is found. The row and col of each of
the 8 neighbors are stored in neighborCoord [].

Step 3: returns chainDir
```

Source Code:

```java
import java.io.*;
import java.util.Scanner;

class Image {
    int numRows, numCols, minVal, maxVal;
    int[][] imageAry;
    int[][] boundaryAry;
    int[][] CCAry;

    Image(Scanner imgFile) {
        loadHeader(imgFile);
        zeroFrameImageAry();
        loadImage(imgFile);
    }

    void zeroFrameImageAry() {
        imageAry = new int[numRows + 2][numCols + 2];
    }

    void loadHeader(Scanner imgFile) {
        numRows = imgFile.nextInt();
        numCols = imgFile.nextInt();
        minVal = imgFile.nextInt();
        maxVal = imgFile.nextInt();
    }

    void loadImage(Scanner imgFile) {
        for (int i = 1; i < numRows + 1; i++) {
            for (int j = 1; j < numCols + 1; j++) {
                imageAry[i][j] = imgFile.nextInt();
            }
        }
    }

    void writeHeader(BufferedWriter outFile) throws IOException {
        outFile.write(numRows + " " + numCols + " " + minVal + " " + maxVal + "\n");
    }

    void prettyPrint(BufferedWriter outFile) throws IOException {
        writeHeader(outFile);
        for (int i = 1; i < numRows + 1; i++) {
            for (int j = 1; j < numCols + 1; j++) {
                if (imageAry[i][j] == 0) {
                    outFile.write(". ");
                } else {
                    outFile.write(Integer.toString(imageAry[i][j]) + " ");
                }
            }
            outFile.write("\n");
        }
    }

    void printBoundaryAry(BufferedWriter outFile) throws IOException {
        writeHeader(outFile);
        for (int i = 0; i < numRows; i++) {
            for (int j = 0; j < numCols; j++) {
                outFile.write(Integer.toString(boundaryAry[i][j]) + " ");
            }
            outFile.write("\n");
        }
    }

    void prettyPrintBoundaryAry(BufferedWriter outFile) throws IOException {
        writeHeader(outFile);
        for (int i = 0; i < numRows; i++) {
            for (int j = 0; j < numCols; j++) {
                if (boundaryAry[i][j] == 0) {
                    outFile.write(". ");
                } else {
                    outFile.write(Integer.toString(boundaryAry[i][j]) + " ");
                }
            }
            outFile.write("\n");
        }
    }

    // Give the chainCode file, create an image contains only the boundary of
    // objects in the labelled file
    void constructBoundary(Scanner chainCodeFile) {
        numRows = chainCodeFile.nextInt();
        numCols = chainCodeFile.nextInt();
        minVal = chainCodeFile.nextInt();
        maxVal = chainCodeFile.nextInt();

        boundaryAry = new int[numRows][numCols];

        // initializing whole array to zero
        for (int i = 0; i < numRows; i++) {
            for (int j = 0; j < numCols; j++) {
                boundaryAry[i][j] = 0;
            }
        }

        // reading the chain Code to put pixel values
        while (chainCodeFile.hasNextInt()) {
            int pixelVal = chainCodeFile.nextInt();
            Point startP = new Point(chainCodeFile.nextInt(), chainCodeFile.nextInt());
            boundaryAry[startP.row][startP.col] = pixelVal;
            Point currentP = getNextP(startP, chainCodeFile.nextInt());
            while (!currentP.equals(startP)) {
                boundaryAry[currentP.row][currentP.col] = pixelVal;
                currentP = getNextP(currentP, chainCodeFile.nextInt());
            }
        }

    }

    Point getNextP(Point currentP, int direction) {
        Point returnVal = new Point(0, 0);
        switch (direction) {
        case 0:
            returnVal.update(currentP.row, currentP.col + 1);
            break;
        case 1:
            returnVal.update(currentP.row - 1, currentP.col + 1);
            break;
        case 2:
            returnVal.update(currentP.row - 1, currentP.col);
            break;
        case 3:
            returnVal.update(currentP.row - 1, currentP.col - 1);
            break;
        case 4:
            returnVal.update(currentP.row, currentP.col - 1);
            break;
        case 5:
            returnVal.update(currentP.row + 1, currentP.col - 1);
            break;
        case 6:
            returnVal.update(currentP.row + 1, currentP.col);
            break;
        case 7:
            returnVal.update(currentP.row + 1, currentP.col + 1);
            break;
        default:
            break;
        }

        return returnVal;
    }

}

class CCproperty {
    int numCC, label, numPixels, minRow, minCol, maxRow, maxCol;
    int[][] CCAry;

    CCproperty(Scanner propImgFile) {
```

```java
        int numRows = propImgFile.nextInt();
        int numCols = propImgFile.nextInt();
        int minVal = propImgFile.nextInt();
        int maxVal = propImgFile.nextInt();
        numCC = propImgFile.nextInt();
    }

    void clearCCAry() {
        for (int i = 0; i < maxRow - minRow; i++) {
            for (int j = 0; j < maxCol - minCol; j++) {
                CCAry[i][j] = 0;
            }
        }
    }

    void loadCCAry(Scanner propImg, int[][] imgAry) {
        label = propImg.nextInt();
        numPixels = propImg.nextInt();
        minRow = propImg.nextInt();
        minCol = propImg.nextInt();
        maxRow = propImg.nextInt();
        maxCol = propImg.nextInt();

        // Initializing CCAry according to the current CC label
        CCAry = new int[maxRow - minRow + 1 + 2][maxCol - minCol + 1 + 2];
        clearCCAry();

        // Copying all the pixel values of a given CC by using bounding box's values
        for (int i = 1; i < maxRow - minRow + 1 + 1; i++) {
            for (int j = 1; j < maxCol - minCol + 1 + 1; j++) {
                CCAry[i][j] = imgAry[i + minRow][j + minCol];
            }
        }
    }

    void prettyPrint(BufferedWriter outFile) throws IOException {
        outFile.write("\n");
        for (int i = 1; i < maxRow - minRow + 1 + 1; i++) {
            for (int j = 1; j < maxCol - minCol + 1 + 1; j++) {
                if (CCAry[i][j] == 0) {
                    outFile.write(". ");
                } else {
                    outFile.write(Integer.toString(CCAry[i][j]) + " ");
                }
            }
            outFile.write("\n");
        }
    }

}
```

```java
class Point {
    int row, col;

    Point(int i, int j) {
        row = i;
        col = j;
    }

    void update(int i, int j) {
        row = i;
        col = j;
    }

    @Override
    public boolean equals(Object obj) {
        if (this == obj)
            return true;
        if ((obj == null) || (obj.getClass() != this.getClass()))
            return false;
        // object must be Point at this point
        Point p = (Point) obj;
        return (row == p.row) && (col == p.col);
    }

    @Override
    public String toString() {
        return "(" + row + "," + col + ")";
    }
}

class ChainCode {
    Point[] neighborCoord;
    int[] zeroTable;
    Point startP;
    Point currentP;// current none zero border pixel
    Point nextP;// next none-zero border pixel
    int lastQ; // Range from 0 to 7; it is the direction of the last zero scanned from
currentP
    int nextDir;// the next scanning direction of currentP's neighbors
    int pChainDir; // chain code direction from currentP to nextP
    CCproperty ccProp;

    ChainCode() {
        zeroTable = new int[] { 6, 0, 0, 2, 2, 4, 4, 6 };
    }

    void getChainCode(CCproperty cc, BufferedWriter chainCodeFile) throws IOException {
        chainCodeFile.write("\n");
        ccProp = cc;
        startP = new Point(1, 1);
        currentP = new Point(1, 1);
        lastQ = 4;
        outerloop: for (int i = 1; i < cc.maxRow - cc.minRow + 1 + 1; i++) {
            for (int j = 1; j < cc.maxCol - cc.minCol + 1 + 1; j++) {
                if (cc.CCAry[i][j] == cc.label) {
                    startP.row = i;
                    startP.col = j;
                    currentP.row = startP.row;
                    currentP.col = startP.col;
                    lastQ = 4;
                    chainCodeFile.write(cc.label + " " + (cc.minRow + i - 1) + " " +
(cc.minCol + j - 1) + " ");
                    break outerloop;
                }
            }
        }

        // at this point we will get our startingPoint

        int count = 0;

        while (count == 0 || !currentP.equals(startP)) {
            count++;
            loadNeigborsCoord(currentP);
            nextDir = ++lastQ % 8;
            pChainDir = findNextP(nextDir, currentP);
            nextP = new Point(neighborCoord[pChainDir].row, neighborCoord[pChainDir].col);
            ccProp.CCAry[nextP.row][nextP.col] = (-1) * ccProp.CCAry[nextP.row][nextP.col];
            chainCodeFile.write(pChainDir + " ");
            if (pChainDir == 0) {
                lastQ = zeroTable[7];
            } else {
                lastQ = zeroTable[pChainDir - 1];
            }
            currentP.row = nextP.row;
            currentP.col = nextP.col;
        }

    }

    // Given currentP's row and col, the method determines and stores the row and
    // col of each of currentP's
    // 8 neighbors (0 to 7 w.r.t the chain-code direction) in neighborCoord[] array.
    void loadNeigborsCoord(Point currentP) {
        neighborCoord = new Point[8];
        neighborCoord[0] = new Point(currentP.row, currentP.col + 1);
        neighborCoord[1] = new Point(currentP.row - 1, currentP.col + 1);
        neighborCoord[2] = new Point(currentP.row - 1, currentP.col);
        neighborCoord[3] = new Point(currentP.row - 1, currentP.col - 1);
        neighborCoord[4] = new Point(currentP.row, currentP.col - 1);
        neighborCoord[5] = new Point(currentP.row + 1, currentP.col - 1);
        neighborCoord[6] = new Point(currentP.row + 1, currentP.col);
        neighborCoord[7] = new Point(currentP.row + 1, currentP.col + 1);
    }

    int findNextP(int direction, Point p) {
        int i = p.row;
        int j = p.col;

        int loop = 0;
        while (loop < 8) {
            switch (direction) {
            case 0:
                if (ccProp.CCAry[i][j + 1] > 0 || ccProp.CCAry[i][j + 1] == -1)
                    return 0;
                break;
            case 1:
                if (ccProp.CCAry[i - 1][j + 1] > 0 || ccProp.CCAry[i - 1][j + 1] == -1)
                    return 1;
                break;
            case 2:
                if (ccProp.CCAry[i - 1][j] > 0 || ccProp.CCAry[i - 1][j] == -1)
                    return 2;
                break;
            case 3:
                if (ccProp.CCAry[i - 1][j - 1] > 0 || ccProp.CCAry[i - 1][j - 1] == -1)
                    return 3;
                break;
            case 4:
                if (ccProp.CCAry[i][j - 1] > 0 || ccProp.CCAry[i][j - 1] == -1)
                    return 4;
                break;
            case 5:
                if (ccProp.CCAry[i + 1][j - 1] > 0 || ccProp.CCAry[i + 1][j - 1] == -1)
                    return 5;
                break;
            case 6:
                if (ccProp.CCAry[i + 1][j] > 0 || ccProp.CCAry[i + 1][j] == -1)
                    return 6;
                break;
            case 7:
                if (ccProp.CCAry[i + 1][j + 1] > 0 || ccProp.CCAry[i + 1][j + 1] == -1)
                    return 7;
                break;
            default:
                break;
            }
            direction = ++direction % 8;
            loop++;
```

```java
        }
        return 0;
    }

    public static void main(String[] args) throws IOException {
        String labelFileName = args[0] + ".txt";
        FileReader labelFileReader = null;
        BufferedReader labelFileBuffReader = null;
        Scanner labelFile = null;

        String propFileName = args[1] + ".txt";
        FileReader propFileReader = null;
        BufferedReader propFileBuffReader = null;
        Scanner propFile = null;

        String chainCodeFileName = args[0] + "_chainCode.txt";
        FileWriter chainCodeFileWriter = null;
        BufferedWriter chainCodeFile = null;

        String boundaryFileName = args[0] + "_Boundary.txt";
        FileWriter boundaryFileWriter = null;
        BufferedWriter boundaryFile = null;

        String chainCodeInputFileName = args[0] + "_chainCode.txt";
        FileReader chainCodeInputReader = null;
        BufferedReader chainCodeInputBuffReader = null;
        Scanner chainCodeInput = null;

        try {
            labelFileReader = new FileReader(labelFileName);
            labelFileBuffReader = new BufferedReader(labelFileReader);
            labelFile = new Scanner(labelFileBuffReader);

            propFileReader = new FileReader(propFileName);
            propFileBuffReader = new BufferedReader(propFileReader);
            propFile = new Scanner(propFileBuffReader);

            chainCodeFileWriter = new FileWriter(chainCodeFileName);
            chainCodeFile = new BufferedWriter(chainCodeFileWriter);

            boundaryFileWriter = new FileWriter(boundaryFileName);
            boundaryFile = new BufferedWriter(boundaryFileWriter);

            Image img = new Image(labelFile);
            // img.prettyPrint(chainCodeFile);

            CCproperty ccProp = new CCproperty(propFile);

            img.writeHeader(chainCodeFile);
            for (int i = 0; i < ccProp.numCC; i++) {
                ccProp.loadCCAry(propFile, img.imageAry);
                ChainCode chainCode = new ChainCode();
                // ccProp.prettyPrint(chainCodeFile);
                chainCode.getChainCode(ccProp, chainCodeFile);
            }

            // Closing chain Code file
            if (chainCodeFile != null)
                chainCodeFile.close();

            // Reopening the Chain Code file
            chainCodeInputReader = new FileReader(chainCodeInputFileName);
            chainCodeInputBuffReader = new BufferedReader(chainCodeInputReader);
            chainCodeInput = new Scanner(chainCodeInputBuffReader);

            img.constructBoundary(chainCodeInput);
            img.printBoundaryAry(boundaryFile);
            img.prettyPrintBoundaryAry(boundaryFile);
            if (chainCodeInput != null) {
                chainCodeInput.close();
            }
        } finally {
            if (labelFile != null)
                labelFile.close();
            if (propFile != null)
                propFile.close();

            if (boundaryFile != null)
                boundaryFile.close();

        }
    }

}
```

Outputs

Image_1:

```
Labeled Image

20 31 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 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 0 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 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 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 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 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 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 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 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 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 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 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 0 0 0 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 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



Property File

20 31 0 1
1
1
119
2 9
18 21
```

Result of: Chain Coding

```
20 31 0 1
1 2 14 5 5 5 5 5 6 0 0 0 0 0 7 6 6 5 4 4 4 4 4 6 7 0 7 7 7 6 0 0 2 1 1 1 0
1 2 4 4 4 4 4 3 2 2 1 0 0 0 0 0 2 3 3 3 3 3 4 4
```

Result of: Boundary Construction from the above Chain Code

```
20 31 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 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 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 1 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 1 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 1 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 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 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 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 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 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 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 1 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 1 1 0 0 0 0 0 0 0 1 1 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 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 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 1 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 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
```

```
20 31 0 1
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . 1 1 1 . . . . . . . . . . . . . .
. . . . . . . . . . . . . 1 . . . 1 . . . . . . . . . . . . .
. . . . . . . . . . . . 1 . . . . . 1 . . . . . . . . . . . .
. . . . . . . . . . . 1 . . . . . . . 1 . . . . . . . . . . .
. . . . . . . . . . 1 . . . . . . . . . 1 . . . . . . . . . .
. . . . . . . . . 1 . . . . . . . . . . . 1 . . . . . . . . .
. . . . . . . . . 1 1 1 1 1 1 . 1 1 1 1 1 1 . . . . . . . . .
. . . . . . . . . . . . . . . 1 . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . 1 . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . 1 . . . . . . . . . . . . . . .
. . . . . . . . . 1 1 1 1 1 1 . 1 1 1 1 1 1 . . . . . . . . .
. . . . . . . . . 1 . . . . . . . . . . . 1 . . . . . . . . .
. . . . . . . . . . 1 1 . . . . . . . 1 1 . . . . . . . . . .
. . . . . . . . . . . . 1 . . . . . 1 . . . . . . . . . . . .
. . . . . . . . . . . . . 1 . . . 1 . . . . . . . . . . . . .
. . . . . . . . . . . . . . 1 . 1 . . . . . . . . . . . . . .
. . . . . . . . . . . . . . 1 1 1 . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
```

Image_2:

```
Labeled Image
20 40 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 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 2 2 2 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 2 2 2 2 2 0 0 0 0 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 2 2 2 2 2 2 2 0 0 0 0 0 0
0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 2 2 2 2 2 2 2 2 2 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 2 2 2 2 2 2 2 2 2 2 2 0 0 0 0
0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 2 2 2 2 2 2 2 2 2 2 2 0 0 0 0
0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 2 2 2 2 2 2 2 2 2 2 2 0 0 0 0
0 0 0 0 1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 2 2 2 2 2 2 2 2 2 0 0 0 0 0
0 0 0 0 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 2 2 2 2 2 2 2 0 0 0 0 0 0
0 0 0 0 1 1 1 1 1 1 1 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 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 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 3 3 3 3 3 3 3 3 3 3 3 3 3 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 3 3 3 3 3 3 3 3 3 3 3 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 0 0 0 3 3 3 3 3 3 3 3 3 3 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 3 3 3 3 0 3 3 3 3 3 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 1 1 1 1 0 0 0 0 3 3 3 3 0 0 3 3 3 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 1 1 1 0 0 0 3 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 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
Property File

20 40 0 3
3
1
172
2 4
19 20
2
73
2 25
10 35
3
68
12 23
19 37
```

Result of: Chain Coding

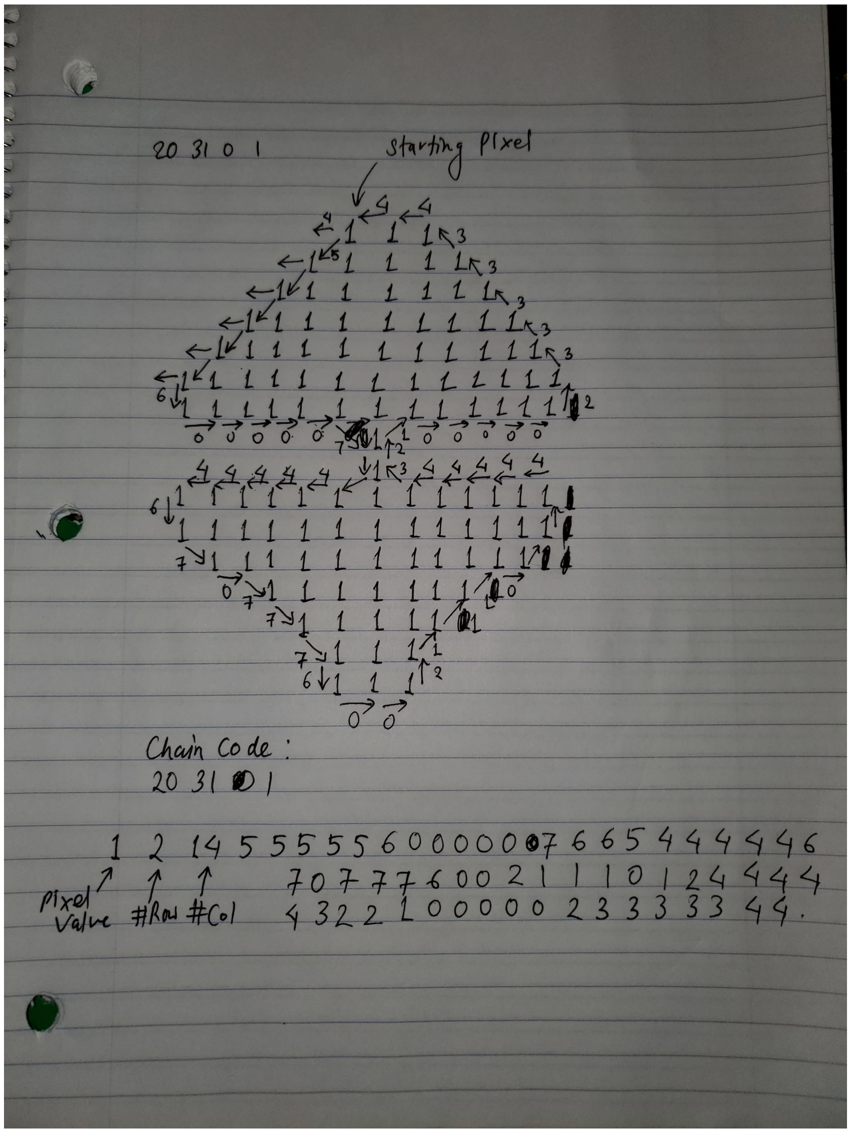
```
20 40 0 3
1 2 7 5 4 5 7 0 7 5 4 4 6 6 6 6 6 6 6 7 7 7 0 7 6 1 1 1 0 0 7 0 7 7 1 3 2 1 0 2 2 2 3
3 2 3 3 2 2 6 6 5 5 5 5 5 3 3 2 2 2 2 2 2 2 4 3
2 2 29 5 5 5 5 6 6 7 7 0 0 0 0 0 0 1 1 2 2 3 3 3 3 4 4
3 12 23 7 7 5 5 6 6 7 2 1 0 2 1 7 7 0 0 1 1 1 0 1 1 4 4 4 4 4 4 4 4 4 4 4 4 4 4
```

Result of: Boundary Construction from the above Chain Code

```
20 40 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 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 2 2 2 0 0 0 0 0 0 0 0
0 0 0 0 0 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 2 0 0 0 0 0 0 0
0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 2 0 0 0 0 0 0
0 0 0 0 0 1 1 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 2 0 0 0 0 0
0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 2 0 0 0 0
0 0 0 0 1 1 1 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 2 0 0 0 0
0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 2 0 0 0 0
0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 2 0 0 0 0 0
0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 2 2 2 2 2 2 2 0 0 0 0 0 0
0 0 0 0 1 0 0 0 0 0 1 0 1 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 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 0 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 3 0 0 0 0 0 0 0 0 0 0 0 3 0 0 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 3 0 0 0 0 0 0 0 0 3 3 0 0 0 0
0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 3 0 0 3 0 0 0 0 0 3 0 0 0 0 0 0
0 0 0 0 0 0 1 0 0 0 0 0 1 1 1 0 0 0 1 0 0 0 0 3 0 0 3 0 3 0 0 0 3 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 1 0 0 1 0 0 0 1 1 0 1 0 0 0 0 3 0 3 3 0 0 3 3 3 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 1 0 1 0 0 0 3 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 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
20 40 0 3
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
. . . . . . . 1 . . . . . . . . . . . . . . . . . . . . . 2 2 2 . . . . . . . .
. . . . . 1 1 . 1 1 . . . . . . . . . . . . . . . . . . 2 . . . 2 . . . . . . .
. . . . 1 . . . . 1 . . . . . . . . . . . . . . . . . 2 . . . . . 2 . . . . . .
. . . . . 1 1 . . 1 . . . . . . 1 . . . . . . . . . 2 . . . . . . . 2 . . . . .
. . . . . . . 1 . 1 . . . . . . 1 . . . . . . . . 2 . . . . . . . . . 2 . . . .
. . . . 1 1 1 . . 1 . . . . . . 1 . . . . . . . . 2 . . . . . . . . . 2 . . . .
. . . . 1 . . . . 1 . . . . . 1 . 1 . . . . . . . 2 . . . . . . . . . 2 . . . .
. . . . 1 . . . . 1 . . . . 1 . . . 1 . . . . . . . 2 . . . . . . . 2 . . . . .
. . . . 1 . . . . 1 . . . 1 . . . . 1 . . . . . . . . 2 2 2 2 2 2 2 . . . . . .
. . . . 1 . . . . . 1 . 1 . . . . . . 1 . . . . . . . . . . . . . . . . . . . .
. . . . 1 . . . . . . 1 . . . . . . . . 1 . . 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 . .
. . . . 1 . . . . . . . . . . . . . . . 1 . . . 3 . . . . . . . . . . . 3 . . .
. . . . 1 . . . . . . . . . . . . . . . 1 . . . . 3 . . . . . . . . 3 3 . . . .
. . . . . 1 . . . . . . . . . . . . . 1 1 . . . 3 . . 3 . . . . . 3 . . . . . .
. . . . . . 1 . . . . . 1 1 1 . . . 1 . . . . 3 . . 3 . 3 . . . 3 . . . . . . .
. . . . . . . 1 1 . . 1 . . . 1 1 . 1 . . . . 3 . 3 3 . . 3 3 3 . . . . . . . .
. . . . . . . . . 1 1 . . . . . . 1 . 1 . . . 3 3 . . . . . . . . . . . . . . .
. . . . . . . . . 1 . . . . . . . . 1 . . . . . 3 . . . . . . . . . . . . . . .
```

Hand Tracing to check the validity of chain code produced for Data_1 above:



Chain Code:
20 31 0 1

```
1 2 14 5 5 5 5 5 6 0 0 0 0 0 7 6 6 5 4 4 4 4 4 6
            7 0 7 7 7 6 0 0 2 1 1 1 0 1 2 4 4 4 4
            4 3 2 2 1 0 0 0 0 0 2 3 3 3 3 3 4 4.
```