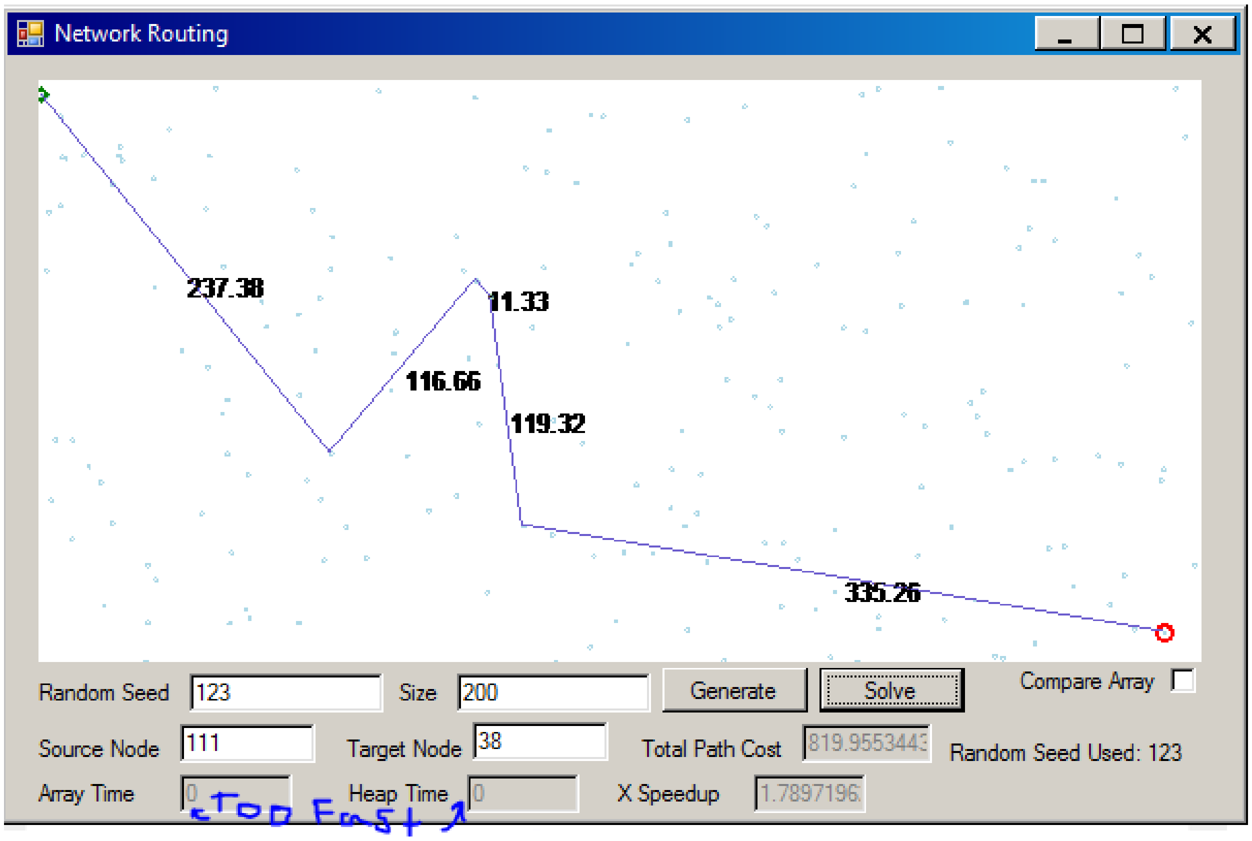
Taylor Cowley
CS 312
Project 3: Dijkstra's Algorithm

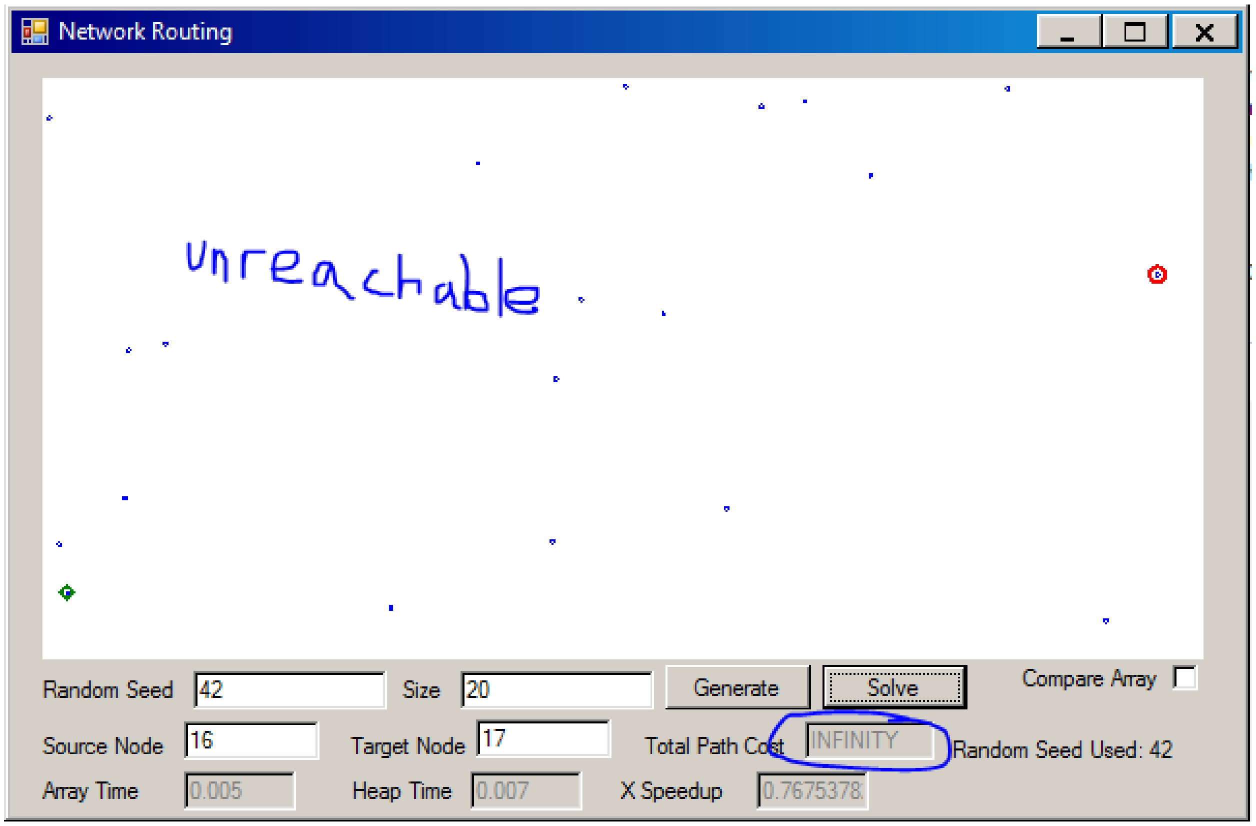
1. See attached code.
2. Code complexity
    a. For the Array,
        i. insert is O(1) because we just put it at the end of the array
        ii. delete-min is O(1) because we just throw away the first index of the array
        iii. decrease-key is O(n) because we bubble-sort the single key to its proper location
    b. For the Heap,
        i. Insert is O(1) because when we insert, we just dump things at the end. (when you insert, the distance is infinity)
        ii. Delete-min is O(logV) because we need to do the whole heap delete-min, where we take out the min, put the last element at the start, then bubble-down.
        iii. Decrease-key is also O(logV) because after the key is decreased, it bubbles-up to its correct location
3. In each case, we might need to cycle through each vector. For each of these cycles, we
    a. Decrease-key the distances at 3 edges – O(1) for array and O(logV) for heap
    b. Delete-min to get the next node- O(V) for array and O(logV) for heap

    Making the final complexity O(V^2) for the array and O(V(logV + logV)) ~ O(VlogV) for the heap
4. Screenshots! For 200 at seed 123, it calculated too quickly to really get times. For 20 at seed 42, it is not reachable, so the distance is INFINITY.



Random Seed 123 Size 200
Source Node 111 Target Node 38 Total Path Cost 819.9553443 Random Seed Used: 123
Array Time 0 Heap Time 0 X Speedup 1.7897196

too Fast!

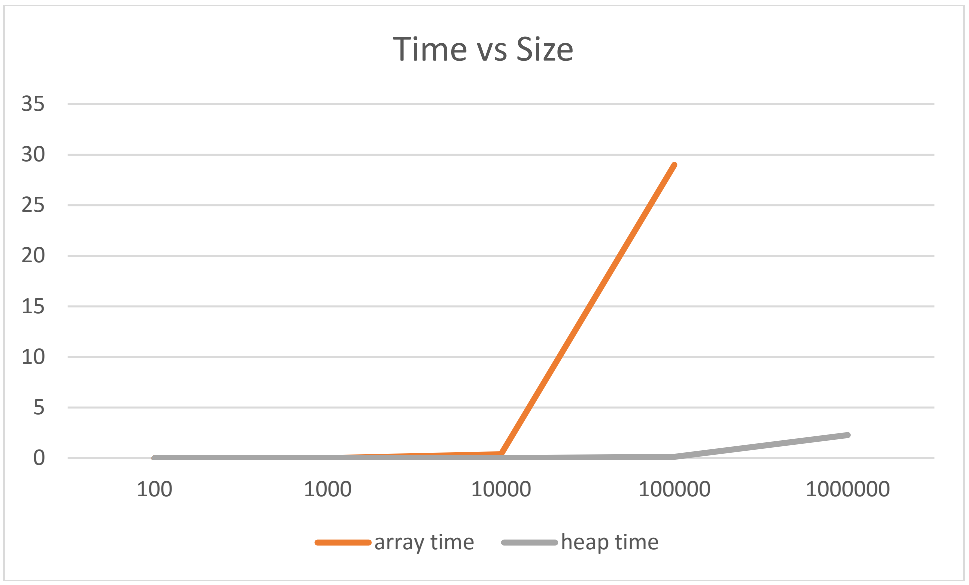


Random Seed 42
Size 20
Source Node 16
Target Node 17
Total Path Cost INFINITY
Random Seed Used: 42
Array Time 0.005
Heap Time 0.007
X Speedup 0.7675378

5. It looks like our complexity calculation is correct- the array time goes up squared relative to the number of nodes, and the heap time goes up by VlogV. It is too bad we ran out of memory; I was hoping for a nicer curve on the heap timing. There are some runs (such as seed 1476 with 100,000 points) that went a lot faster than the others. I expect this means there was an improbably short path between the nodes, and our algorithm found it really fast.

Data table						
Seed	**Size**	**Source**	**Target**	**Array Time**	**Heap Time**	**X Speedup**
1456	100	39	83	0.004	0.084	0.04792
1457	100	59	14	0	0	1.06422
1458	100	95	71	0.005	0.008	0.634
1459	100	82	84	0	0	1.1571
1460	100	3	95	0	0	1.0483
Average				0	0	0.790308
1461	1000	224	259	0.005	0	7.08498
1462	1000	960	439	0.001	0	4.95111
1463	1000	721	972	0.005	0	6.20113
1464	1000	54	805	0.005	0.002	2.48097
1465	1000	905	499	0.006	0.001	5.53367
Average				0.0044	0.0006	5.250372
1466	10,000	9072	3662	0.39	0.011	34.5241

1477	10,000	7164	5481	0.398	0.009	40.9654
1468	10,000	1836	646	0.288	0.005	48.476641
1469	10,000	485	7146	0.365	0.008	43.4262
1470	10,000	4586	1417	0.456	0.013	33.3696
Average				0.3794	0.0092	40.152388
1472	100,000	12752	47962	32.058	0.11	289
1473	100,000	10236	84628	33.272	0.104	317
1474	100,000	62807	70160	35.691	0.177	201
1475	100,000	14029	13496	36.306	0.186	194
1476	100,000	9546	19592	7.614	0.034	220
Average				28.9882	0.1222	244.2
1477	1,000,000	504705	53686	-	2.571	-
1478	1,000,000	396618	860359	-	2.312	-
1479	1,000,000	428806	521130	-	2.16	-
1480	1,000,000	557796	587158	-	2.541	-
1481	1,000,000	887379	192927	-	1.697	-
1482	1,000,000	23816	668763	-	2.424	-
Average				?? 300	2.284166	-
1483	10,000,000	“System.OutOfMemoryException”				



```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Drawing.Drawing2D;
using System.Linq;
using System.Text;
using System.Windows.Forms;

namespace NetworkRouting
{
    public partial class Form1 : Form
    {
        public Form1()
        {
            InitializeComponent();
        }

        private void clearAll()
        {
            startNodeIndex = -1;
            stopNodeIndex = -1;
            sourceNodeBox.Clear();
            sourceNodeBox.Refresh();
            targetNodeBox.Clear();
            targetNodeBox.Refresh();
            arrayTimeBox.Clear();
            arrayTimeBox.Refresh();
            heapTimeBox.Clear();
            heapTimeBox.Refresh();
            differenceBox.Clear();
            differenceBox.Refresh();
            pathCostBox.Clear();
            pathCostBox.Refresh();
            arrayCheckBox.Checked = false;
            arrayCheckBox.Refresh();
            return;
        }

        private void clearSome()
        {
            arrayTimeBox.Clear();
            arrayTimeBox.Refresh();
            heapTimeBox.Clear();
            heapTimeBox.Refresh();
            differenceBox.Clear();
            differenceBox.Refresh();
            pathCostBox.Clear();
            pathCostBox.Refresh();
            return;
        }
        private void generateButton_Click(object sender, EventArgs e)
        {
            int randomSeed = int.Parse(randomSeedBox.Text);
            int size = int.Parse(sizeBox.Text);

            Random rand = new Random(randomSeed);
            seedUsedLabel.Text = "Random Seed Used: " + randomSeed.ToString();

            clearAll();
            this.adjacencyList = generateAdjacencyList(size, rand);
            List<PointF> points = generatePoints(size, rand);
            resetImageToPoints(points);
            this.points = points;
        }

        // Generates the distance matrix.  Values of -1 indicate a missing edge.
          Loopbacks are at a cost of 0.
        private const int MIN_WEIGHT = 1;
        private const int MAX_WEIGHT = 100;
        private const double PROBABILITY_OF_DELETION = 0.35;

        private const int NUMBER_OF_ADJACENT_POINTS = 3;

        private List<HashSet<int>> generateAdjacencyList(int size, Random rand)
        {
            List<HashSet<int>> adjacencyList = new List<HashSet<int>>();

            for (int i = 0; i < size; i++)
            {
                HashSet<int> adjacentPoints = new HashSet<int>();
                while (adjacentPoints.Count < 3)
                {
                    int point = rand.Next(size);
                    if (point != i) adjacentPoints.Add(point);
                }
                adjacencyList.Add(adjacentPoints);
            }

            return adjacencyList;
        }

        private List<PointF> generatePoints(int size, Random rand)
        {
            List<PointF> points = new List<PointF>();
            for (int i = 0; i < size; i++)
            {
                points.Add(new PointF((float) (rand.NextDouble() * pictureBox.Width),
                  (float) (rand.NextDouble() * pictureBox.Height)));
            }
            return points;
        }
        private void resetImageToPoints(List<PointF> points)
        {
            pictureBox.Image = new Bitmap(pictureBox.Width, pictureBox.Height);
            Graphics graphics = Graphics.FromImage(pictureBox.Image);
            Pen pen;

            if (points.Count < 100)
                pen = new Pen(Color.Blue);
            else
                pen = new Pen(Color.LightBlue);
            foreach (PointF point in points)
            {
                graphics.DrawEllipse(pen, point.X, point.Y, 2, 2);
            }

            this.graphics = graphics;
            pictureBox.Invalidate();
        }

        // These variables are instantiated after the "Generate" button is clicked
        private List<PointF> points = new List<PointF>();
        private Graphics graphics;
        private List<HashSet<int>> adjacencyList;
        private double[] distance;                  // Stores the distances of the ⤶
          points
        private int[] previous;                     // Stores how to draw lines


        // Use this to generate paths (from start) to every node; then, just return ⤶
          the path of interest from start node to end node
        private void solveButton_Click(object sender, EventArgs e)
        {
            // This was the old entry point, but now it is just some form interface ⤶
              handling
            bool ready = true;

            if(startNodeIndex == -1)
            {
                sourceNodeBox.Focus();
                sourceNodeBox.BackColor = Color.Red;
                ready = false;
            }
            if(stopNodeIndex == -1)
            {
                if(!sourceNodeBox.Focused)
                    targetNodeBox.Focus();
                targetNodeBox.BackColor = Color.Red;
                ready = false;
            }
            if (points.Count > 0)
            {
                resetImageToPoints(points);
                paintStartStopPoints();
            }
            else
            {
                ready = false;
            }
            if(ready)
            {
                clearSome();
                solveButton_Clicked();  // Here is the new entry point
            }
        }

        private void solveButton_Clicked()
        {
            // *** Implement this method, use the variables "startNodeIndex" and
              "stopNodeIndex" as the indices for your start and stop points,
              respectively ***


            // First do the heap. time it
            System.Diagnostics.Stopwatch stopwatchHEAP =
              System.Diagnostics.Stopwatch.StartNew(); //creates and start the
              instance of Stopwatch

            heapCALCULATE();

            stopwatchHEAP.Stop();
            long heapTicks = stopwatchHEAP.ElapsedTicks;
            double heapSecs = ((double)stopwatchHEAP.ElapsedMilliseconds) / 1000;
            Console.WriteLine("heap ticks:" + heapTicks);
            Console.WriteLine("heap ms:" + heapSecs);
            heapTimeBox.Text = heapSecs.ToString();



            // Then do the array. Time it.
            System.Diagnostics.Stopwatch stopwatchARRAY =
              System.Diagnostics.Stopwatch.StartNew(); //creates and start the
              instance of Stopwatch

            arrayCALCULATE();

            stopwatchARRAY.Stop();
            long arrayTicks = stopwatchARRAY.ElapsedTicks;
            double arraySecs = ((double)stopwatchARRAY.ElapsedMilliseconds) / 1000;
            Console.WriteLine("array ticks:" + arrayTicks);
            Console.WriteLine("array ms:" + arraySecs);
            arrayTimeBox.Text = arraySecs.ToString();

            differenceBox.Text = ((double)arrayTicks/ (double)heapTicks).ToString();
            //differenceBox.Text = (arraySecs/heapSecs).ToString();

            // now we have answers
            Console.WriteLine("Last node " + stopNodeIndex + " distance: " + distance ⮒
              [stopNodeIndex]);
            int tamp = stopNodeIndex;

            SolidBrush brush = new SolidBrush(Color.Black);     // For writing
            Font font = new Font("Arial", 10);                  // The number
            PointF p = new PointF();                            // next to line
            while (tamp != startNodeIndex) {
                Console.WriteLine(tamp + " connects to ");
                // Draws lines between points
                this.graphics.DrawLine(new Pen(Color.SlateBlue), points[tamp], points ⮒
                  [previous[tamp]]);
                // draw the number next to the line
                string dist = distanceBetweenNodes(points[tamp], points[previous      ⮒
                  [tamp]]).ToString("#.##");
                p.X = (points[tamp].X + points[previous[tamp]].X)/2;    // Gets       ⮒
                  midpoint
                p.Y = (points[tamp].Y + points[previous[tamp]].Y)/2;    // of the line
                this.graphics.DrawString(dist, font, brush, p);         // Draws the  ⮒
                  number
                tamp = previous[tamp];
            }
            Console.WriteLine(tamp);

            pathCostBox.Text = distance[stopNodeIndex].ToString();      // put total  ⮒
              path in
        }

        // A simple function to get the distance between two points
        public static double distanceBetweenNodes(PointF point1, PointF point2) {
            double a = point2.X - point1.X;
            double b = point2.Y - point1.Y;
            return Math.Sqrt(a * a + b * b);
        }

        // Gets the next closest unvisited node. Returns -1 if there is no node to    ⮒
          visit
        // Currently doing a naive search through the entire list every time.
        private int getNextNode(HashSet<int>unvisited, double[] distance) {//         ⮒
          List<double>distance) {
            double currentBest = double.PositiveInfinity;
            int currentBestIndex = -1;

            for (int i = 0; i< distance.Length; i++) {
                if (distance[i] != double.PositiveInfinity && unvisited.Contains(i) &&⮒
                   distance[i] < currentBest) {
                    currentBest = distance[i];
                    currentBestIndex = i;
                }
            }
            return currentBestIndex;
        }

        //
          ****************************************************************************
          ****************
        // This is the priority list array implementation
        int[] priorityArray;                            // Stores the points in distance
          order
        int[] priorityArrayPointers;                    // Points to where in array point
          is
        int priorityArrayIndex;
        private void initPriorityArray() {
            priorityArrayIndex = 0;

            priorityArray = new int[points.Count];
            priorityArrayPointers = new int[points.Count];
            for (int i=0;i<points.Count;i++) {
                priorityArray[i] = i;                   // Make every point its index
                priorityArrayPointers[i] = i;
            }

            priorityArray[0] = startNodeIndex;  // But the highest-priority is start
            priorityArrayPointers[startNodeIndex] = 0;
            priorityArray[startNodeIndex] = 0;  // gotta put zero somewhere
            priorityArrayPointers[0] = startNodeIndex;
        }

        // for debugging. Prints the priority array
        private void printPriorityArray() {
            Console.Write("printing priority array:\n");
            for (int i=0; i < priorityArray.Length; i++) {
                if (i == priorityArrayIndex) {
                    Console.Write("|start| ");
                }
                Console.Write(priorityArray[i] + " ");
            }
            Console.Write("\n\n");


            Console.Write("printing POINTERS:\n");
            for (int i = 0; i < priorityArrayPointers.Length; i++) {
                Console.Write(priorityArrayPointers[i] + " ");
            }
            Console.Write("\n\n");
        }

        // O(1). Don't need to change the array at all.
        private int getNextNodeArray() {
            // Return the next one and increment the index
            if (priorityArray[priorityArrayIndex] == double.PositiveInfinity)
```

```
                return -1;                          // If we can't reach the next 
                  node, give up.
            return priorityArray[priorityArrayIndex++];
        }

        // Given a point id, we need to sort it again in the queue array.
        // It is a bubble sort that only happens in one direction, ever.
        // O(n)
        private void reprioritizeArray(int changed) {
            int currentPriorityIndex = priorityArrayPointers[changed];
            // While our current thing has a higher priority than what came before it
            while (distance[priorityArray[currentPriorityIndex]] < distance
              [priorityArray[currentPriorityIndex-1]]
                && currentPriorityIndex > priorityArrayIndex) {
                // We need to swap our current thing with the thing before.
                int temp = priorityArray[currentPriorityIndex];
                priorityArray[currentPriorityIndex] = priorityArray
                  [currentPriorityIndex - 1];
                priorityArray[currentPriorityIndex - 1] = temp;

                // And fix the pointers
                priorityArrayPointers[changed] = priorityArrayPointers
                  [changed]-1;   // our current thing moved up one
                priorityArrayPointers[priorityArray[currentPriorityIndex]] =
                  priorityArrayPointers[priorityArray[currentPriorityIndex]] + 1;   //
                   Other thing moved back one

                currentPriorityIndex--;     // We are going back on the array
            }
        }

        // Takes O(V^2)
        private void arrayCALCULATE()
        {
            // We make our sets.
            HashSet<int> visited = new HashSet<int>();
            HashSet<int> unvisited = new HashSet<int>();

            // And our distance list
            distance = new double[points.Count];

            // And our graph-following list
            previous = new int[points.Count];


            // Now we need to set up our unvisited set and distance list
            for (int i = 0; i < points.Count; i++)
            {    // Go through all our points
                unvisited.Add(i);                       // Add that point to the 
                  unvisited set
                distance[i] = double.PositiveInfinity;  // distances are infinity
                previous[i] = -1;                       // Tree is not at all 
                connected at the start
            }

            // FOR THE PRIORITYARRAY IMPLEMENTATION
            initPriorityArray();                        // Need to init our array

            visited.Add(startNodeIndex);                // Start by visiting the first ↩
               node
            unvisited.Remove(startNodeIndex);           // So it isn't unvisited      ↩
              anymore
            distance[startNodeIndex] = 0;               // Distance to the start node ↩
              is zero!

            int currentNode = currentNode = getNextNodeArray(); //                    ↩
              startNodeIndex;           // Start at the beginning!

            //Can happen up to O(V) times
            while (!visited.Contains(stopNodeIndex))
            {  // As soon as we've visited the end node, we've won!
                // 2. For all the (unvisited) nodes it can go to, update their        ↩
                  distance if it is now less from the current node

                // Only ever happens 3x max. O(1)
                foreach (int outNode in adjacencyList[currentNode])
                {
                    if (unvisited.Contains(outNode)     // If outNode is not yet      ↩
                      visited and the new distance is less than the current distance
                        && distanceBetweenNodes(points[currentNode], points[outNode]) ↩
                      + distance[currentNode] < distance[outNode]
                        )
                    {
                        // Store the new distance!
                        distance[outNode] = distanceBetweenNodes(points[currentNode], ↩
                      points[outNode]) + distance[currentNode];
                        previous[outNode] = currentNode;// Set up graph.

                        //Takes O(V)
                        reprioritizeArray(outNode);     // Gotta fix outNode's        ↩
                      priority now.
                    }
                }


                // 1. visit the next closest unvisited node
                // O(1)
                currentNode = getNextNodeArray();
                if (currentNode == -1)
                {
                    Console.WriteLine("CANNOT VISIT ANY MORE NODES");
                    return;
                }
                visited.Add(currentNode);               // We are now visiting this   ↩
```

```
                  node
                unvisited.Remove(currentNode);          // so it is not unvisited any ⮐
                  more
            }
        }

        // End the priority list array implementation
        //                                                                            ⮐
          **************************************************************************** ⮐
          ****************



        //                                                                            ⮐
          **************************************************************************** ⮐
          ****************
        // This is the HEAP implementation
        int[] priorityHeap;                         // Doing our heap as an array!
        int[] priorityHeapPointers;                 // Where in the array is any given⮐
           point
        int priorityHeapLAST;                       // Used for deleteMin- index of   ⮐
          last thing in the heap
        private void initPriorityHeap() {
            priorityHeapLAST = points.Count;        // Just the last thing [shrugs]
            priorityHeap = new int[points.Count+1]; // Because we start at index 1
            priorityHeapPointers = new int[points.Count];
            for (int i=0;i<points.Count;i++) {
                priorityHeap[i + 1] = i;            // +1 because we are 1-indexing it
                priorityHeapPointers[i] = i+1;      // Things are at +1 their own     ⮐
                  index.
            }
            priorityHeap[0] = -1;                   // Error value
            priorityHeap[1] = startNodeIndex;       // swap start node
            priorityHeapPointers[startNodeIndex]=1; // and 0
            priorityHeap[startNodeIndex + 1] = 0;
            priorityHeapPointers[0] = startNodeIndex + 1;
        }

        // This is deleteMin for our heap,
        // O(log(V))
        private int getNextNodeHeap() {
            // 1 Replace root with last node
            int highestPriority = priorityHeap[1];
            priorityHeap[1] = priorityHeap[priorityHeapLAST];
            priorityHeapPointers[highestPriority] = priorityHeapLAST;
            priorityHeapPointers[priorityHeap[1]] = 1;
            priorityHeap[priorityHeapLAST] = highestPriority;

            // 2 Remove the last node
            priorityHeapLAST--;                     // Cause we do this

            // 3 Swap new root with its child until correct position
            int l, r;
            int currentIndex = 1;

            while (true) {                              // We only escape by breaking
                if (currentIndex * 2 > priorityHeapLAST) {
                    break;                              // current has no children
                } else if (currentIndex * 2 == priorityHeapLAST) {
                    l = priorityHeap[currentIndex * 2];
                    if (distance[l] < distance[priorityHeap[currentIndex]]) {
                        // l is higher priority than current!
                        // SWAP
                        swapHeap(currentIndex * 2, currentIndex);
                    }
                    break;                              // won't be no more children
                }
                l = priorityHeap[currentIndex * 2];
                r = priorityHeap[(currentIndex * 2) + 1];
                if (distance[l] < distance[r]) {
                    // l is higher priority than r
                    if (distance[l] < distance[priorityHeap[currentIndex]]) {
                        // l is higher priority than current!
                        // SWAP
                        swapHeap(currentIndex*2, currentIndex);
                        currentIndex = currentIndex * 2;
                    } else {
                        break;
                    }
                } else {
                    // r is higher (or equal) priority than r
                    if (distance[r] < distance[priorityHeap[currentIndex]]) {
                        // r is higher priority than current!
                        // SWAP
                        swapHeap((currentIndex*2)+1, currentIndex);
                        currentIndex = currentIndex * 2+1;
                    } else {
                        break;
                    }
                }
            }

            if (distance[highestPriority] == double.PositiveInfinity) {
                return -1;
            }
            return highestPriority;
        }

        // Swaps two nodes of the heap
        // O(1)
        private void swapHeap(int a, int b) {
            int temp = priorityHeap[a];
            priorityHeap[a] = priorityHeap[b];
            priorityHeap[b] = temp;
            priorityHeapPointers[temp] = b;
            priorityHeapPointers[priorityHeap[a]] = a;
        }

        // This reprioritizes the point IDed by changed
        // O(log(V))
        private void reprioritizeHeap(int changed) {

            int currentIndex = priorityHeapPointers[changed];
            while (true) {
                if (currentIndex / 2 == 0) {
                    // can't get higher priority than this
                    return;
                }

                if (distance[priorityHeap[currentIndex]] < distance[priorityHeap 
                  [currentIndex/2]]) {
                    // The current node is higher priority than its parent!
                    swapHeap(currentIndex, currentIndex / 2);
                    currentIndex = currentIndex / 2;
                } else {
                    return;
                }
            }
        }

        private void printHeap()
        {
            Console.Write("printing heap:\n");
            for (int i = 0; i < priorityHeap.Length; i++)
            {
                if (i == priorityHeapLAST)
                {
                    Console.Write("|end| ");
                }
                Console.Write(priorityHeap[i] + " ");
            }
            Console.Write("\n\n");


            Console.Write("printing POINTERS:\n");
            for (int i = 0; i < priorityHeapPointers.Length; i++)
            {
                Console.Write(priorityHeapPointers[i] + " ");
            }
            Console.Write("\n\n");
        }

        // O(logV) things happening O(V) times?
        // O(VlogV)
        private void heapCALCULATE() {
            // We make our sets.
            HashSet<int> visited = new HashSet<int>();
            HashSet<int> unvisited = new HashSet<int>();

            // And our distance list
            distance = new double[points.Count];

            // And our graph-following list
            previous = new int[points.Count];


            // Now we need to set up our unvisited set and distance list
            for (int i = 0; i < points.Count; i++)
            {    // Go through all our points
                unvisited.Add(i);                      // Add that point to the      ⮒
                  unvisited set
                distance[i] = double.PositiveInfinity;  // distances are infinity
                previous[i] = -1;                      // Tree is not at all         ⮒
                  connected at the start
            }

            initPriorityHeap();

            visited.Add(startNodeIndex);                // Start by visiting the first⮒
               node
            unvisited.Remove(startNodeIndex);           // So it isn't unvisited      ⮒
              anymore
            distance[startNodeIndex] = 0;               // Distance to the start node ⮒
              is zero!

            int currentNode = getNextNodeHeap();

            // This goes O(V) times
            while (!visited.Contains(stopNodeIndex))
            {  // As soon as we've visited the end node, we've won!
                // 2. For all the (unvisited) nodes it can go to, update their        ⮒
                  distance if it is now less from the current node
                foreach (int outNode in adjacencyList[currentNode])
                {
                    if (unvisited.Contains(outNode)     // If outNode is not yet      ⮒
                      visited and the new distance is less than the current distance
                        && distanceBetweenNodes(points[currentNode], points[outNode]) ⮒
                      + distance[currentNode] < distance[outNode]
                        )
                    {
                        // Store the new distance!
                        distance[outNode] = distanceBetweenNodes(points[currentNode], ⮒
                      points[outNode]) + distance[currentNode];
                        previous[outNode] = currentNode;// Set up graph.

                        // max O(logV)
                        reprioritizeHeap(outNode);
                    }
                }


                // 1. visit the next closest unvisited node
                // Max O(logV)
                currentNode = getNextNodeHeap();
                if (currentNode == -1)
                {
                    Console.WriteLine("CANNOT VISIT ANY MORE NODES");
                    return;
                }
                visited.Add(currentNode);                 // We are now visiting this
                  node
                unvisited.Remove(currentNode);            // so it is not unvisited any
                  more
            }
        }

        // end HEAP implementation
        //
          ****************************************************************************
          ****************



        private Boolean startStopToggle = true;
        private int startNodeIndex = -1;
        private int stopNodeIndex = -1;
        private void pictureBox_MouseDown(object sender, MouseEventArgs e)
        {
            if (points.Count > 0)
            {
                Point mouseDownLocation = new Point(e.X, e.Y);
                int index = ClosestPoint(points, mouseDownLocation);
                if (startStopToggle)
                {
                    startNodeIndex = index;
                    sourceNodeBox.ResetBackColor();
                    sourceNodeBox.Text = "" + index;
                }
                else
                {
                    stopNodeIndex = index;
                    targetNodeBox.ResetBackColor();
                    targetNodeBox.Text = "" + index;
                }
                resetImageToPoints(points);
                paintStartStopPoints();
            }
        }

        private void sourceNodeBox_Changed(object sender, EventArgs e)
        {
            if (points.Count > 0)
            {
                try{ startNodeIndex = int.Parse(sourceNodeBox.Text); }
                catch { startNodeIndex = -1; }
                if (startNodeIndex < 0 | startNodeIndex > points.Count-1)
                    startNodeIndex = -1;
                if(startNodeIndex != -1)
                {
                    sourceNodeBox.ResetBackColor();
                    resetImageToPoints(points);
                    paintStartStopPoints();
                    startStopToggle = !startStopToggle;
                }
            }
        }

        private void targetNodeBox_Changed(object sender, EventArgs e)
        {
            if (points.Count > 0)
            {
                try { stopNodeIndex = int.Parse(targetNodeBox.Text); }
                catch { stopNodeIndex = -1; }
                if (stopNodeIndex < 0 | stopNodeIndex > points.Count-1)
                    stopNodeIndex = -1;
                if(stopNodeIndex != -1)
                {
                    targetNodeBox.ResetBackColor();
                    resetImageToPoints(points);
                    paintStartStopPoints();
                    startStopToggle = !startStopToggle;
                }
            }
        }

        private void paintStartStopPoints()
        {
            if (startNodeIndex > -1)
            {
                Graphics graphics = Graphics.FromImage(pictureBox.Image);
                graphics.DrawEllipse(new Pen(Color.Green, 6), points
                  [startNodeIndex].X, points[startNodeIndex].Y, 1, 1);
                this.graphics = graphics;
                pictureBox.Invalidate();
            }

            if (stopNodeIndex > -1)
            {
                Graphics graphics = Graphics.FromImage(pictureBox.Image);
                graphics.DrawEllipse(new Pen(Color.Red, 2), points[stopNodeIndex].X -
                  3, points[stopNodeIndex].Y - 3, 8, 8);
                this.graphics = graphics;
                pictureBox.Invalidate();
            }
        }

        private int ClosestPoint(List<PointF> points, Point mouseDownLocation)
        {
            double minDist = double.MaxValue;
            int minIndex = 0;

            for (int i = 0; i < points.Count; i++)
            {
                double dist = Math.Sqrt(Math.Pow(points[i].X-mouseDownLocation.X,2) + ↩
                  Math.Pow(points[i].Y - mouseDownLocation.Y,2));
                if (dist < minDist)
                {
                    minIndex = i;
                    minDist = dist;
                }
            }

            return minIndex;
        }
    }
}
```