## Submission Information

Course: CS 7375 – Artificial Intelligence

Student Name: Marion Garrett Sisk

Student ID: 000942002

Assignment #: 2

Due Date: 3/21/21

Signature:

Score:

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## Agent Design

The AI agent implemented within this assignment is designed to operate in a specific environment, and complete one task. The agent will solve for a path through a maze, given a starting point, and a goal, or end point. There are four elements to an AI agent: Performance metric(s), Environment, Actuators, and Sensors (or PEAS, as given in the textbook).

The performance metric provides the agent a framework from which to make decisions. In this instance, we are to solve a maze from an arbitrary starting point. The overall idea behind this task is we want to move closer to the goal. In other words, we want to reduce our distance between us and the goal as much as possible with each step taken in the maze. To accomplish this, the agent uses a straight-line distance between the current location and the goal. When deciding where to move next, the agent picks the location with the shortest distance to the goal. Details on how this distance is implemented and computed are described alongside the Environment the agent is designed to work within.

The environment, in its most basic sense, is a grid maze with randomly generated paths. This is implemented using a custom *gridGraph* class. This data structure is based on a graph, where each node of the graph is a “cell” within the grid maze, and each cell has four “walls” which are given as edges between each node. The initial cells and walls are built using the constructor method such that the initial state is a full grid, with each “wall” present around and between each “cell.” Using this initial state, the maze is generated by using a randomized version of Prim’s Algorithm based off the description given in source [1]. This produces a spanning tree that produces “passages” through the “walls” of a “cell” when two are connected through this tree. The effect, when drawn onto the screen, shows a random maze with many short branching corridors. The agent utilizes attributes of each instance of “cell” to determine its state, and which direction to move. The way in which these attributes are examined and implemented is explained subsequently.

The “actuators” implemented within the agent is the process of moving into a cell closer to the goal cell. The choice is made to move into the cell based on the process described in the performance metric.

Lastly, the sensors of this agent include the ability to determine if a cell has been visited before, if a wall is a passage or not, and whether or not the current cell is the goal cell. The combination of these sensing abilities gives the agent the proper percept such that the appropriate decisions with the goal in mind is made.

The way in which the agent works is akin to a greedy algorithm. It makes the best choice based on what is available to it at the moment, though does has some prescience since the location of the goal cell with respect to the current location is known. However, the agent will not know whether a path will result in a dead end until a dead end is reached. Additionally, the agent has issues when the path finding must cross the start cell to begin a new direction. The application handles the error by telling the user to reset the maze and try again. The pseudocode of the algorithm used to implement the agent is given below. Note that straight-line distance is defined as the distance using the Pythagorean theorem, and the differences in the X and Y coordinates between the current cell and the goal cell. This quantity is used to compute the best option and subsequent cell to move forward to.

### Figure 1: AI Agent Pseudocode.

WHILE the current cell is not equal to the goal cell

Mark the current cell as visited

Determine all possible moves

IF there are possible moves available THEN

Compute all distances

Move to cell with shortest distance

PUSH the cell to the path stack

ELSE

POP the current cell off the path stack

END IF

END WHILE

## Output Screenshot

Graphical user interface

Description automatically generated

## Tasks the Agent Can Solve

This particular agent can only solve for a path within a specific data structure. Using this agent outside of this particular environment will result in unpredictable behavior and may not even work at all. Additionally, there was a last-minute addition of a feature that permits the user to see how efficient (or inefficient, as the case may be) the agent is at solving the problem. By using the visit count of each cell that keeps track of how many times the agent accesses that cell, it becomes possible to see where the agent has been and how many times. Below are several screen shots that illustrate this using the 100x100 grid maze. Note that the final solution path is given in blue, but the yellow to red cells indicate where the agent has visited within the maze. The darker the color, the more often the agent has visited a particular cell. It becomes obvious when looking at these images that the agent can be extremely inefficient at solving a maze, and as such suggests there is ample room for improvement in its behavior.

Graphical user interface, application, map

Description automatically generatedMap

Description automatically generated

Graphical user interface, application, map

Description automatically generatedGraphical user interface, application

Description automatically generated

## Video Demonstration

A video demonstration of the application can be found at the following YouTube link:

<https://youtu.be/IZ10ZvcHrn0>

## GitHub Repository

All source files and associated binary files can be found on my personal GitHub page at:

<https://github.com/mgarrettsisk/mazeSolver>

## References

[1] <https://en.wikipedia.org/wiki/Maze_generation_algorithm#Randomized_Prim's_algorithm>

## Source Code

### main.java

package assignment01;  
  
import javafx.application.Application;  
import javafx.fxml.FXMLLoader;  
import javafx.scene.Parent;  
import javafx.scene.Scene;  
import javafx.stage.Stage;  
  
public class Main extends Application {  
  
 @Override  
 public void start(Stage primaryStage) throws Exception{  
 Parent root = FXMLLoader.*load*(getClass().getResource("mainWindow.fxml"));  
 primaryStage.setTitle("CS 7375 - Assignment #1");  
 primaryStage.setScene(new Scene(root, 600, 600));  
 primaryStage.setResizable(false);  
 primaryStage.show();  
 }  
  
 public static void main(String[] args) {  
 *launch*(args);  
 }  
}

### aiAgent.java

package assignment01;  
  
import java.util.ArrayList;  
import java.util.LinkedList;  
  
public class aiAgent {  
 // attributes  
 private gridGraph.cell goalCell;  
 private final LinkedList<gridGraph.cell> solutionPathStack = new LinkedList<>();  
 private final ArrayList<gridGraph.cell> possibleMoves = new ArrayList<>();  
  
 // constructor methods  
 aiAgent(){  
 // null constructor  
 }  
 aiAgent(gridGraph.cell startCell, gridGraph.cell goalCell) {  
 // this constructor takes a start cell and goal cell and solves the maze, producing a solutionPath  
 // first, push the start cell onto the solutionPathStack list  
 this.solutionPathStack.push(startCell);  
 // second, set the goal cell attribute  
 this.setGoalCell(goalCell);  
  
 }  
 // public methods  
 public void solveMaze() {  
 // this method actually does the solving, and creates the solution path along the stack  
 // define starting cell  
 gridGraph.cell currentCell = this.solutionPathStack.peek();  
 while (!(currentCell.equals(goalCell))) {  
 // determine which cells can be moved to  
 currentCell.visit();  
 determinePossibleMoves(currentCell);  
 if (possibleMoves.isEmpty()) {  
 // if no possible moves at this cell, pop off current cell from stack and repeat for previous cell  
 solutionPathStack.pop();  
 currentCell = solutionPathStack.peek();  
 //System.out.println("Stack size reduced by one. New Size: " + solutionPathStack.size());  
 } else {  
 // else choose the best possible move, and add the new cell to the stack and redo loop  
 currentCell = computeBestMove(possibleMoves, goalCell);  
 solutionPathStack.push(currentCell);  
 //System.out.println("X: " + currentCell.getX() + "; Y: " + currentCell.getY());  
 //System.out.println("Stack size increased by one. New Size: " + solutionPathStack.size());  
 }  
 }  
 }  
  
 public void setGoalCell(gridGraph.cell inputCell) {  
 // method sets the attribute for the goal cell  
 this.goalCell = inputCell;  
 }  
 public gridGraph.cell getGoalCell() {  
 // returns the cell object of the goal as provided in the input  
 return this.goalCell;  
 }  
 public void setCurrentCell(gridGraph.cell inputCell) {  
 // method to set the current cell attribute  
 this.solutionPathStack.push(inputCell);  
 }  
 public gridGraph.cell getCurrentCell() {  
 // returns the current cell on which the AI agent is acting  
 return this.solutionPathStack.peekLast();  
 }  
 public void setPreviousCell(gridGraph.cell inputCell) {  
 // method to keep track of previous cell. Adds the inputCell to the top of the solutionPathStack  
 this.solutionPathStack.push(inputCell);  
 }  
 public gridGraph.cell getPreviousCell() {  
 // method pops the top cell off the solutionPath stack  
 return this.solutionPathStack.pop();  
 }  
 public LinkedList<gridGraph.cell> getSolutionPath() {  
 // method returns the list of cells that compose the solution path from start to finish  
 return this.solutionPathStack;  
 }  
 // private methods  
 private void determinePossibleMoves(gridGraph.cell inputCell) {  
 // this method takes a cell as input, and adds the cells that are possible to move to to the possibleMoves array  
 // clear the array first, such that there are no other cells present  
 this.possibleMoves.clear();  
 // examine each wall and add the neighboring cell to the possible moves list if the wall is a passage  
 if (inputCell.getTopWall().isPassage()) {  
 gridGraph.cell topNeighbor = inputCell.getNeighbors()[0];  
 if (topNeighbor.getVisitCount() == 0) {  
 this.possibleMoves.add(topNeighbor);  
 }  
 }  
 if (inputCell.getRightWall().isPassage()) {  
 gridGraph.cell rightNeighbor = inputCell.getNeighbors()[1];  
 if (rightNeighbor.getVisitCount() == 0) {  
 this.possibleMoves.add(rightNeighbor);  
 }  
 }  
 if (inputCell.getBottomWall().isPassage()) {  
 gridGraph.cell bottomNeighbor = inputCell.getNeighbors()[2];  
 if (bottomNeighbor.getVisitCount() == 0) {  
 this.possibleMoves.add(bottomNeighbor);  
 }  
 }  
 if (inputCell.getLeftWall().isPassage()) {  
 gridGraph.cell leftNeighbor = inputCell.getNeighbors()[3];  
 if (leftNeighbor.getVisitCount() == 0) {  
 this.possibleMoves.add(leftNeighbor);  
 }  
 }  
 }  
 private gridGraph.cell computeBestMove(ArrayList<gridGraph.cell> inputCellList, gridGraph.cell goalCell) {  
 // this method takes the current possible moves list, and the goal cell as inputs, and determines which cell  
 // should be used next in the path  
 int goalXpos = goalCell.getX();  
 int goalYpos = goalCell.getY();  
 int outputIndex = -1;  
 gridGraph.cell outputCell = null;  
 double shortestDistance = -1.0;  
 // find the index of the cell with the shortest straight line distance to goal  
 for (int listIndex = 0; listIndex < inputCellList.size(); listIndex++) {  
 // get the current (x,y) coordinates of neighbor cell  
 int currentXpos = inputCellList.get(listIndex).getX();  
 int currentYpos = inputCellList.get(listIndex).getY();  
 // compute the pythagorean distance between the current cell and the goal cell  
 double radicand = Math.*pow*((goalXpos - currentXpos),2) + Math.*pow*((goalYpos - currentYpos),2);  
 double distance = Math.*sqrt*(radicand);  
 if (shortestDistance == -1.0) {  
 // this is the first cell, and we set the shortest distance as the distance  
 shortestDistance = distance;  
 outputIndex = listIndex;  
 } else if (distance <= shortestDistance) {  
 // the newly computed distance is shorter, so set the shortest distance and the output index  
 shortestDistance = distance;  
 outputIndex = listIndex;  
 }  
 }  
 if (outputIndex == -1) {  
 return null;  
 } else {  
 outputCell = inputCellList.get(outputIndex);  
 return outputCell;  
 }  
 }  
}

### gridGraph.java

package assignment01;  
  
import java.util.ArrayList;  
  
public class gridGraph {  
  
 // Attributes  
 ArrayList<cell> cells = new ArrayList<>();  
 ArrayList<wall> walls = new ArrayList<>();  
  
 // Constructor Methods  
 gridGraph(int x, int y) {  
 // constructor method that creates the data structure  
 generateGraphStructure(x, y);  
 }  
 // Public Methods  
 public cell getCell(int index) {  
 // returns a cell object given a particular index on the cells ArrayList.  
 return cells.get(index);  
 }  
 public int getCellsSize() {  
 // returns the cardinality of the cells set  
 return cells.size();  
 }  
 public wall getWall(int index) {  
 // returns a wall object given a particular index on the walls ArrayList  
 return walls.get(index);  
 }  
 public int getWallsSize() {  
 // returns the cardinality of the walls set  
 return walls.size();  
 }  
 // Private Methods  
 private void generateGraphStructure(int xSize, int ySize) {  
 /\* this method takes a 2D size parameter (as two separate integer values) and populates the data structure with  
 the following arrangement:  
 Each "pixel" in the graph structure is a cell. Each cell has at most four walls. To generate every  
 "pixel" we must iterate over the size of the canvas given as inputs to this method.  
 \*/  
 for (int yIndex = 1; yIndex <= ySize; yIndex++) {  
 for (int xIndex = 1; xIndex <= xSize; xIndex++) {  
 int[] currentPosition = {xIndex, yIndex};  
 cells.add(new cell(currentPosition));  
 }  
 }  
 /\*  
 The next step in the creation is to generate all the appropriate walls in the grid. There are four walls per  
 cell, however the method will place only the right and bottom walls by default. This leaves the outside and  
 corner cells requiring special consideration. This arrangement will avoid creation of duplicates and will  
 prevent needing to run a search for a particular wall to avoid duplicates. Additionally, the adjacency  
 lists for each cell are created. This is done through the cell.addNeighbors(cell c) method.  
 \*/  
 for (int listIndex = 0; listIndex < cells.size(); listIndex++) {  
 // get the current cell from list  
 cell workingCell = cells.get(listIndex);  
  
 // get working cell's position on the grid  
 int cellX = workingCell.getX();  
 int cellY = workingCell.getY();  
  
 // add walls and neighbors to working cell  
 // add top wall and neighbor  
 if (cellY == 1) {  
 wall workingTop = new wall(workingCell, null);  
 walls.add(workingTop);  
 workingCell.setTopWall(workingTop);  
 workingCell.setTopNeighbor(null);  
 } else {  
 wall workingTop = new wall(workingCell, cells.get(listIndex - xSize));  
 if (walls.contains(workingTop)) {  
 workingCell.setTopWall(walls.get(walls.indexOf(workingTop)));  
 } else {  
 workingCell.setTopWall(workingTop);  
 walls.add(workingTop);  
 }  
 workingCell.setTopNeighbor(cells.get(listIndex - xSize));  
 }  
 // add right wall and neighbor  
 if (cellX == xSize) {  
 wall workingRight = new wall(workingCell, null);  
 walls.add(workingRight);  
 workingCell.setRightWall(workingRight);  
 workingCell.setRightNeighbor(null);  
 } else {  
 wall workingRight = new wall(workingCell, cells.get(listIndex + 1));  
 if (walls.contains(workingRight)) {  
 workingCell.setRightWall(walls.get(walls.indexOf(workingRight)));  
 } else {  
 workingCell.setRightWall(workingRight);  
 walls.add(workingRight);  
 }  
 workingCell.setRightNeighbor(cells.get(listIndex + 1));  
 }  
 // add bottom wall and neighbor  
 if (cellY == ySize) {  
 wall workingBottom = new wall(workingCell, null);  
 walls.add(workingBottom);  
 workingCell.setBottomWall(workingBottom);  
 workingCell.setBottomNeighbor(null);  
 } else {  
 wall workingBottom = new wall(workingCell, cells.get(listIndex + xSize));  
 if (walls.contains(workingBottom)) {  
 workingCell.setBottomWall(walls.get(walls.indexOf(workingBottom)));  
 } else {  
 workingCell.setBottomWall(workingBottom);  
 walls.add(workingBottom);  
 }  
 workingCell.setBottomNeighbor(cells.get(listIndex + xSize));  
 }  
 // add left wall and neighbor  
 if (cellX ==1) {  
 wall workingLeft = new wall(workingCell, null);  
 walls.add(workingLeft);  
 workingCell.setLeftWall(workingLeft);  
 workingCell.setLeftNeighbor(null);  
 } else {  
 wall workingLeft = new wall(workingCell, cells.get(listIndex - 1));  
 if (walls.contains(workingLeft)) {  
 workingCell.setLeftWall(walls.get(walls.indexOf(workingLeft)));  
 } else {  
 workingCell.setLeftWall(workingLeft);  
 walls.add(workingLeft);  
 }  
 workingCell.setLeftNeighbor(cells.get(listIndex - 1));  
 }  
 }  
 }  
 // Internal Classes  
 public class cell {  
 // Attributes  
 private int[] position;  
 private int visitCount = 0;  
 private wall topWall = null;  
 private wall leftWall = null;  
 private wall rightWall = null;  
 private wall bottomWall = null;  
 private final cell[] neighbors = new cell[4];  
 // Methods  
 cell(int[] coordinates) {  
 // sets the coordinates based on the input array. Once set, this cannot be changed from outside the object  
 // scope.  
 this.setPosition(coordinates);  
 }  
 private void setPosition(int[] orderedPair) {  
 // this method is used solely in the constructor method as the position of individual cells should not  
 // change after creation  
 this.position = orderedPair;  
 }  
 protected int getX() {  
 // returns only the X coordinate of the cell  
 return this.position[0];  
 }  
 protected int getY() {  
 // returns only the Y coordinate of the cell  
 return this.position[1];  
 }  
 protected void setTopWall(wall inputWall) {  
 // method to place the top wall into its appropriate place  
 this.topWall = inputWall;  
 }  
 protected wall getTopWall() {  
 // returns the top wall object  
 return this.topWall;  
 }  
 protected void setLeftWall(wall inputWall) {  
 // method to place the left wall into its appropriate place  
 this.leftWall = inputWall;  
 }  
 protected wall getLeftWall() {  
 // returns the left wall object  
 return this.leftWall;  
 }  
 protected void setRightWall(wall inputWall) {  
 // method to place the right wall into its appropriate place  
 this.rightWall = inputWall;  
 }  
 protected wall getRightWall() {  
 // returns the right wall------- object  
 return this.rightWall;  
 }  
 protected void setBottomWall(wall inputWall) {  
 // method to place the bottom wall into its appropriate place  
 this.bottomWall = inputWall;  
 }  
 protected wall getBottomWall() {  
 // returns the bottom wall object  
 return this.bottomWall;  
 }  
 protected void visit() {  
 // increases the visit count by 1 every time the method is called  
 this.visitCount++;  
 }  
 protected int getVisitCount() {  
 // returns the visit count when called  
 return this.visitCount;  
 }  
 protected void setTopNeighbor(cell c) {  
 // this method takes a cell as input and adds as the top neighbor  
 this.neighbors[0] = c;  
 }  
 protected void setRightNeighbor(cell c) {  
 // this method takes a cell as input and adds as the right neighbor  
 this.neighbors[1] = c;  
 }  
 protected void setBottomNeighbor(cell c) {  
 // this method takes a cell as input and adds as the bottom neighbor  
 this.neighbors[2] = c;  
 }  
 protected void setLeftNeighbor(cell c) {  
 // this method takes a cell as input and adds as the left neighbor  
 this.neighbors[3] = c;  
 }  
 protected cell[] getNeighbors() {  
 // returns the array list of neighboring cells  
 // The array is of format:  
 // 0 = top  
 // 1 = right  
 // 2 = bottom  
 // 3 = left  
 return this.neighbors;  
 }  
 @Override  
 public boolean equals(Object obj) {  
 if (!(obj instanceof cell)) {  
 return false;  
 } else {  
 cell compareCell = (cell) obj;  
 return (this.getX() == compareCell.getX() && this.getY() == compareCell.getY());  
 }  
 }  
 }  
 public class wall {  
 // Attributes  
 private final cell cellOne;  
 private final cell cellTwo;  
 private boolean passage = false;  
 // Methods  
 wall(cell cellOne, cell cellTwo) {  
 // constructor method assigns each cell to an end of an edge. These two cells exist on each side of the  
 // "wall" and are divided by this object  
 this.cellOne = cellOne;  
 this.cellTwo = cellTwo;  
 }  
 public cell getCellOne() {  
 // returns the first cell in the edge (or wall, such as it is)  
 return this.cellOne;  
 }  
 public cell getCellTwo() {  
 // returns the second cell in the edge (or wall)  
 return this.cellTwo;  
 }  
 public void setPassage(boolean tf) {  
 // sets the passage parameter in the wall, if the wall is meant to be "knocked down" use this to specify  
 this.passage = tf;  
 }  
 public boolean isPassage() {  
 // returns the value that determines whether this edge is a passage or not. The default is 'false' which  
 // indicates this wall is non-passable.  
 return this.passage;  
 }  
 @Override  
 public boolean equals(Object obj) {  
 if (!(obj instanceof wall)) {  
 return false;  
 } else {  
 return ((this.getCellOne().equals(((wall)obj).getCellOne()) || this.getCellOne().equals(((wall)obj).getCellTwo())) &&  
 (this.getCellTwo().equals(((wall)obj).getCellOne()) || this.getCellTwo().equals(((wall)obj).getCellTwo())));  
 }  
 }  
 }  
}

### mainController.java

package assignment01;  
  
import javafx.fxml.Initializable;  
import javafx.scene.canvas.Canvas;  
import javafx.scene.canvas.GraphicsContext;  
import javafx.scene.control.Button;  
import javafx.scene.control.MenuItem;  
import javafx.scene.control.TextField;  
import javafx.scene.layout.BorderPane;  
import javafx.scene.paint.Color;  
import javafx.stage.Stage;  
import java.net.URL;  
import java.util.ArrayList;  
import java.util.LinkedList;  
import java.util.Random;  
import java.util.ResourceBundle;  
  
public class mainController implements Initializable {  
 // GUI Objects  
 public BorderPane borderPane;  
 public Canvas centerCanvas;  
 public TextField notificationText;  
 public TextField dataTextField;  
 public Button generateMazeButton;  
 public Button clearMazeButton;  
 public Button solveMazeButton;  
 public Button setStartFinishButton;  
 public MenuItem generateMazeMenuButton;  
 public MenuItem clearMazeMenuButton;  
 public MenuItem solveMazeMenuButton;  
 public MenuItem setStartFinishMenuButton;  
 public MenuItem aboutMenuButton;  
 public GraphicsContext canvasGc;  
 // private attributes  
 private int pixelSize;  
 private gridGraph graph;  
 private ArrayList<gridGraph.cell> mazePath = new ArrayList<>();  
 private LinkedList<gridGraph.cell> solutionPath = new LinkedList<>();  
 private gridGraph.cell startCell;  
 private gridGraph.cell goalCell;  
 private String dataString = "No maze present.";  
  
 @Override  
 public void initialize(URL location, ResourceBundle resources) {  
 // get the Graphics Context of the center canvas  
 canvasGc = centerCanvas.getGraphicsContext2D();  
 // draw the grid upon startup with default pixel size equal to 20 pixels  
 setPixelSize20();  
 drawOutline(canvasGc);  
 // set initial UI configuration  
 updateDataTextArea(dataString);  
 clearMazeButton.setDisable(true);  
 clearMazeMenuButton.setDisable(true);  
 solveMazeButton.setDisable(true);  
 solveMazeMenuButton.setDisable(true);  
 setStartFinishButton.setDisable(true);  
 setStartFinishMenuButton.setDisable(true);  
 }  
 // Public Event Handling Methods  
 public void generateMaze() {  
 // method used to generate the maze object and display it on the mainCanvas object  
 // method variables  
 int canvasWidth = (int)canvasGc.getCanvas().getWidth();  
 int canvasHeight = (int)canvasGc.getCanvas().getHeight();  
 int gridWidth = canvasWidth/this.pixelSize;  
 int gridHeight = canvasHeight/this.pixelSize;  
 ArrayList<gridGraph.wall> wallList = new ArrayList<>();  
 // Start with a grid full of walls.  
 graph = new gridGraph(gridWidth, gridHeight);  
 // pick a random cell and add it to the maze and add walls to wall list  
 // for this, we want the start to be on the left hand row, so will need to pick a cell w/ xPos == 1  
 Random random = new Random();  
 int startCellXpos = random.nextInt(gridHeight);  
 gridGraph.cell startCell = graph.getCell((startCellXpos \* gridWidth));  
 startCell.visit();  
 mazePath.add(startCell);  
 addWalls(startCell, wallList);  
 // while there are walls left in the list  
 while (!(wallList.isEmpty())) {  
 // pick a random wall from the list  
 Random rand = new Random();  
 int choice = rand.nextInt(wallList.size());  
 gridGraph.wall workingWall = wallList.get(choice);  
 // get cells adjacent to wall  
 gridGraph.cell cellOne = workingWall.getCellOne();  
 gridGraph.cell cellTwo = workingWall.getCellTwo();  
 // if adjacent cell is in the path, add the other to the path and mark wall as passage  
 if (!(mazePath.contains(cellTwo))) {  
 mazePath.add(cellTwo);  
 workingWall.setPassage(true);  
 // add new cell's walls to wall list  
 addWalls(cellTwo, wallList);  
 wallList.remove(workingWall);  
 } else if (!(mazePath.contains(cellOne))) {  
 mazePath.add(cellOne);  
 workingWall.setPassage(true);  
 addWalls(cellOne, wallList);  
 wallList.remove(workingWall);  
 } else {  
 // as both cells are already in the path, remove wall from list  
 wallList.remove(workingWall);  
 }  
 }  
 // draw the actual maze in the GUI and give notification maze has been generated  
 updateNotificationArea("Maze successfully generated with a grid unit size of " + this.pixelSize + " pixels.");  
 dataString = "Size = " + this.pixelSize;  
 updateDataTextArea(dataString);  
 drawMaze(canvasGc, mazePath);  
 drawOutline(canvasGc);  
 // change UI configuration  
 setStartFinishButton.setDisable(false);  
 setStartFinishMenuButton.setDisable(false);  
 clearMazeButton.setDisable(false);  
 clearMazeMenuButton.setDisable(false);  
 generateMazeButton.setDisable(true);  
 generateMazeMenuButton.setDisable(true);  
 }  
 public void clearMaze() {  
 // method used to reset the application to its initial state  
 canvasGc.clearRect(0,0,centerCanvas.getWidth(),centerCanvas.getHeight());  
 mazePath.clear();  
 drawOutline(canvasGc);  
 updateNotificationArea("Maze cleared");  
 dataString = "No maze present.";  
 updateDataTextArea(dataString);  
 // change UI configuration  
 setStartFinishButton.setDisable(true);  
 setStartFinishMenuButton.setDisable(true);  
 clearMazeButton.setDisable(true);  
 clearMazeMenuButton.setDisable(true);  
 solveMazeButton.setDisable(true);  
 solveMazeMenuButton.setDisable(true);  
 generateMazeMenuButton.setDisable(false);  
 generateMazeButton.setDisable(false);  
 generateMazeButton.requestFocus();  
 }  
 public void solveMaze() throws NullPointerException {  
 // clear the canvas  
 try {  
 canvasGc.clearRect(0, 0, centerCanvas.getWidth(), centerCanvas.getHeight());  
 // this method invokes the AI agent that will solve the maze  
 aiAgent solver = new aiAgent(this.startCell, this.goalCell);  
 solver.solveMaze();  
 this.solutionPath = solver.getSolutionPath();  
 updateNotificationArea("The maze has been solved");  
 for (int drawIndex = 0; drawIndex < this.solutionPath.size(); drawIndex++) {  
 gridGraph.cell drawnCell = solutionPath.get(drawIndex);  
 int xPos = drawnCell.getX();  
 int yPos = drawnCell.getY();  
 drawPixel(canvasGc, xPos, yPos, "light blue");  
 }  
 drawPixel(canvasGc, startCell.getX(), startCell.getY(), "green");  
 drawPixel(canvasGc, goalCell.getX(), goalCell.getY(), "red");  
 // redraw the grid above the path plots  
 drawMaze(canvasGc, mazePath);  
 drawOutline(canvasGc);  
 // change UI configuration  
 solveMazeButton.setDisable(true);  
 solveMazeMenuButton.setDisable(true);  
 clearMazeButton.setDisable(false);  
 clearMazeMenuButton.setDisable(false);  
 } catch (NullPointerException ex) {  
 updateNotificationArea("An error occurred. Clear the maze and start over.");  
 clearMazeButton.setDisable(false);  
 clearMazeMenuButton.setDisable(false);  
 solveMazeButton.setDisable(true);  
 solveMazeMenuButton.setDisable(true);  
 }  
 }  
 public void setStartFinishCells() {  
 // this method sets the start and goal cells from the gridGraph object that are then used to solve the maze.  
 Random startChoice = new Random();  
 Random endChoice = new Random();  
 this.startCell = mazePath.get(startChoice.nextInt(mazePath.size()));  
 this.goalCell = mazePath.get(endChoice.nextInt(mazePath.size()));  
 drawPixel(canvasGc, startCell.getX(), startCell.getY(), "green");  
 drawPixel(canvasGc, goalCell.getX(), goalCell.getY(), "red");  
 String formerString = dataString;  
 dataString = "Start: (" + startCell.getX() + ", " + startCell.getY() +  
 "), End: (" + goalCell.getX() + ", " + goalCell.getY() + "), "  
 + formerString;  
 updateDataTextArea(dataString);  
 // change UI configuration  
 setStartFinishButton.setDisable(true);  
 setStartFinishMenuButton.setDisable(true);  
 solveMazeButton.setDisable(false);  
 solveMazeMenuButton.setDisable(false);  
 }  
 public void showAbout() throws Exception {  
 // this method calls the about window and displays the result  
 aboutController about = new aboutController();  
 about.showWindow();  
 }  
 public void closeProgram() {  
 // this method ensure the program closes appropriately  
 Stage activeStage = (Stage) this.borderPane.getScene().getWindow();  
 activeStage.close();  
 }  
 public void setPixelSize5() {  
 // used as part of the radio menu selector to set the appropriate pixel size  
 this.pixelSize = 5;  
 clearMaze();  
 //drawGrid(canvasGc);  
 }  
 public void setPixelSize10() {  
 // used as part of the radio menu selector to set the appropriate pixel size  
 this.pixelSize = 10;  
 clearMaze();  
 //drawGrid(canvasGc);  
 }  
 public void setPixelSize20() {  
 // used as part of the radio menu selector to set the appropriate pixel size  
 this.pixelSize = 20;  
 clearMaze();  
 //drawGrid(canvasGc);  
 }  
 // Private Methods  
 private void updateNotificationArea(String notification) {  
 // this method takes a string as input and displays it in the notification text field  
 notificationText.setText(notification);  
 }  
 private void updateDataTextArea(String data) {  
 // method takes a string as input and displays it in the data text field  
 dataTextField.setText(data);  
 }  
 private void addWalls(gridGraph.cell inputCell, ArrayList<gridGraph.wall> inputList) {  
 // this method takes a cell and a list and adds all walls that are not already on the list  
 if (!(inputCell.getTopWall().getCellTwo() == null)) {  
 gridGraph.wall workingWall = inputCell.getTopWall();  
 if (!(inputList.contains(workingWall))) {  
 inputList.add(workingWall);  
 } else {  
 // do nothing  
 }  
 }  
 if (!(inputCell.getRightWall().getCellTwo() == null)) {  
 gridGraph.wall workingWall = inputCell.getRightWall();  
 if (!(inputList.contains(workingWall))) {  
 inputList.add(workingWall);  
 } else {  
 // do nothing  
 }  
 }  
 if (!(inputCell.getBottomWall().getCellTwo() == null)) {  
 gridGraph.wall workingWall = inputCell.getBottomWall();  
 if (!(inputList.contains(workingWall))) {  
 inputList.add(workingWall);  
 } else {  
 // do nothing  
 }  
 }  
 if (!(inputCell.getLeftWall().getCellTwo() == null)) {  
 gridGraph.wall workingWall = inputCell.getLeftWall();  
 if (!(inputList.contains(workingWall))) {  
 inputList.add(workingWall);  
 } else {  
 // do nothing  
 }  
 }  
 }  
 private void drawMaze(GraphicsContext contextInput, ArrayList<gridGraph.cell> inputMaze) {  
 // draws a grid with cell size in pixels, size of pixel can be changed with the parameters given below  
 ArrayList<gridGraph.wall> drawnWalls = new ArrayList<>();  
 // iterate over each cell in mazePath array  
 for (int cellIndex = 0; cellIndex < inputMaze.size(); cellIndex++) {  
 // get the particular cell from the mazePath array  
 gridGraph.cell workingCell = inputMaze.get(cellIndex);  
 // iterate over each wall in the cell  
 // top wall  
 if (workingCell.getTopWall().getCellTwo() != null && !(workingCell.getTopWall().isPassage())) {  
 if (!(drawnWalls.contains(workingCell.getTopWall()))) {  
 // draw the top wall line  
 drawGridLine(contextInput, workingCell, "top");  
 // add wall to drawn wall list  
 drawnWalls.add(workingCell.getTopWall());  
 }  
 }  
 // right wall  
 if (workingCell.getRightWall().getCellTwo() != null && !(workingCell.getRightWall().isPassage())) {  
 if (!(drawnWalls.contains(workingCell.getRightWall()))) {  
 drawGridLine(contextInput, workingCell, "right");  
 drawnWalls.add(workingCell.getRightWall());  
 }  
 }  
 // bottom wall  
 if (workingCell.getBottomWall().getCellTwo() != null && !(workingCell.getBottomWall().isPassage())) {  
 if (!(drawnWalls.contains(workingCell.getBottomWall()))) {  
 drawGridLine(contextInput, workingCell, "bottom");  
 drawnWalls.add(workingCell.getBottomWall());  
 }  
 }  
 // left wall  
 if (workingCell.getLeftWall().getCellTwo() != null && !(workingCell.getLeftWall().isPassage())) {  
 if (!(drawnWalls.contains(workingCell.getLeftWall()))) {  
 drawGridLine(contextInput, workingCell, "left");  
 drawnWalls.add(workingCell.getLeftWall());  
 }  
 }  
 }  
 }  
 private void drawGridLine(GraphicsContext inputContext, gridGraph.cell inputCell, String direction) {  
 // method draws a line according to the location of the wall given an input cell and direction string  
 // set drawing parameters  
 int pixelSize = this.pixelSize;  
 int gridXpos = inputCell.getX()-1;  
 int gridYpos = inputCell.getY()-1;  
 inputContext.setLineWidth(1.0);  
 inputContext.setStroke(Color.*BLACK*);  
 // define the relative coordinates of each corner  
 int topLeftXpos = gridXpos \* pixelSize;  
 int topLeftYpos = gridYpos \* pixelSize;  
 int topRightXpos = topLeftXpos + pixelSize;  
 int topRightYpos = topLeftYpos;  
 int bottomLeftXpos = topLeftXpos;  
 int bottomLeftYpos = topLeftYpos + pixelSize;  
 int bottomRightXpos = topRightXpos;  
 int bottomRightYpos = bottomLeftYpos;  
 // draw the actual lines on the canvas given the appropriate direction  
 if (direction.equalsIgnoreCase("top")) {  
 inputContext.strokeLine(topLeftXpos, topLeftYpos, topRightXpos, topRightYpos);  
 }  
 if (direction.equalsIgnoreCase("right")) {  
 inputContext.strokeLine(topRightXpos, topRightYpos, bottomRightXpos, bottomRightYpos);  
 }  
 if (direction.equalsIgnoreCase("bottom")) {  
 inputContext.strokeLine(bottomRightXpos, bottomRightYpos, bottomLeftXpos, bottomLeftYpos);  
 }  
 if (direction.equalsIgnoreCase("left")) {  
 inputContext.strokeLine(bottomLeftXpos, bottomLeftYpos, topLeftXpos, topLeftYpos);  
 }  
 }  
 private void drawOutline(GraphicsContext context) {  
 // method draws an outline around the entire canvas  
 // Set the stroke color  
 context.setLineWidth(3.0);  
 context.setStroke(Color.*BLACK*);  
 // draw lines around entire canvas  
 context.strokeLine(0, 0, context.getCanvas().getWidth(), 0);  
 context.strokeLine(0,0,0, context.getCanvas().getHeight());  
 context.strokeLine(context.getCanvas().getWidth(), 0, context.getCanvas().getWidth(),  
 context.getCanvas().getHeight());  
 context.strokeLine(0, context.getCanvas().getHeight(), context.getCanvas().getWidth(),  
 context.getCanvas().getHeight());  
 }  
 private void drawPixel(GraphicsContext contextInput, int x, int y, String color) {  
 // creates a pixel that is then drawn onto the particular canvas. Pixel size and color can be defined below.  
 // Set the color of the pixel  
 if (color.equalsIgnoreCase("blue")){  
 contextInput.setFill(Color.*BLUE*);  
 } else if (color.equalsIgnoreCase("red")) {  
 contextInput.setFill(Color.*RED*);  
 } else if (color.equalsIgnoreCase("green")) {  
 contextInput.setFill(Color.*GREEN*);  
 } else if (color.equalsIgnoreCase("light blue")) {  
 contextInput.setFill(Color.*LIGHTBLUE*);  
 } else {  
 contextInput.setFill(Color.*BLACK*);  
 }  
 // Define the Size of the pixel  
 int pixelHeight = this.pixelSize;  
 int pixelWidth = this.pixelSize;  
 // Define the maximum dimensions of the intended canvas  
 double verticalSize = contextInput.getCanvas().getHeight();  
 double horizontalSize = contextInput.getCanvas().getWidth();  
 // Determine location of top right hand corner of pixel from input (X,Y)  
 int canvasXcoord = (x-1) \* pixelWidth;  
 int canvasYcoord = (y-1) \* pixelHeight;  
 // Display error if computed coordinate goes beyond the canvas dimensions  
 if ((canvasXcoord > horizontalSize) || (canvasYcoord > verticalSize)) {  
 System.*out*.println("The computed coordinate is beyond the canvas.");  
 }  
 // Write the actual "pixel" to the canvas  
 contextInput.fillRect(canvasXcoord,canvasYcoord,pixelWidth,pixelHeight);  
 }  
}

### aboutController.java

package assignment01;  
  
import javafx.fxml.FXMLLoader;  
import javafx.scene.Parent;  
import javafx.scene.Scene;  
import javafx.scene.control.Button;  
import javafx.stage.Stage;  
  
public class aboutController {  
 // Initialize GUI Elements  
 public Button closeAboutButton;  
 public Stage activeStage = new Stage();  
 // Public Methods  
 public void showWindow() throws Exception {  
 Parent root = FXMLLoader.*load*(getClass().getResource("aboutWindow.fxml"));  
 activeStage.setTitle("About");  
 activeStage.setScene(new Scene(root, 350, 250));  
 activeStage.setResizable(false);  
 activeStage.show();  
 }  
 public void closeWindow() {  
 Stage currentStage = (Stage) closeAboutButton.getScene().getWindow();  
 currentStage.close();  
 }  
}

### mainWindow.fxml

<?xml version="1.0" encoding="UTF-8"?>  
  
<?import javafx.geometry.Insets?>  
<?import javafx.scene.canvas.Canvas?>  
<?import javafx.scene.control.Button?>  
<?import javafx.scene.control.Menu?>  
<?import javafx.scene.control.MenuBar?>  
<?import javafx.scene.control.MenuItem?>  
<?import javafx.scene.control.RadioMenuItem?>  
<?import javafx.scene.control.SeparatorMenuItem?>  
<?import javafx.scene.control.TextField?>  
<?import javafx.scene.control.ToggleGroup?>  
<?import javafx.scene.layout.BorderPane?>  
<?import javafx.scene.layout.HBox?>  
<?import javafx.scene.layout.VBox?>  
  
<BorderPane fx:id="borderPane" maxHeight="-Infinity" maxWidth="-Infinity" minHeight="-Infinity" minWidth="-Infinity" prefHeight="600.0" prefWidth="600.0" xmlns="http://javafx.com/javafx/15.0.1" xmlns:fx="http://javafx.com/fxml/1" fx:controller="assignment01.mainController">  
 <right>  
 <VBox BorderPane.alignment="CENTER" />  
 </right>  
 <left>  
 <VBox BorderPane.alignment="CENTER" />  
 </left>  
 <top>  
 <MenuBar BorderPane.alignment="CENTER">  
 <menus>  
 <Menu mnemonicParsing="false" text="File">  
 <items>  
 <MenuItem fx:id="closeMenuButton" mnemonicParsing="false" onAction="#closeProgram" text="Close" />  
 </items>  
 </Menu>  
 <Menu mnemonicParsing="false" text="Actions">  
 <items>  
 <MenuItem fx:id="generateMazeMenuButton" mnemonicParsing="false" onAction="#generateMaze" text="Generate Maze" />  
 <MenuItem fx:id="setStartFinishMenuButton" mnemonicParsing="false" onAction="#setStartFinishCells" text="Set Start and Finish" />  
 <MenuItem fx:id="solveMazeMenuButton" mnemonicParsing="false" onAction="#solveMaze" text="Solve Maze" />  
 <MenuItem fx:id="clearMazeMenuButton" mnemonicParsing="false" onAction="#clearMaze" text="Clear Maze" />  
 <SeparatorMenuItem mnemonicParsing="false" />  
 <Menu mnemonicParsing="false" text="Set Pixel Size">  
 <items>  
 <RadioMenuItem fx:id="pixelSize5" mnemonicParsing="false" onAction="#setPixelSize5" text="5">  
 <toggleGroup>  
 <ToggleGroup fx:id="pixelSizeGroup" />  
 </toggleGroup>  
 </RadioMenuItem>  
 <RadioMenuItem fx:id="pixelSize10" mnemonicParsing="false" onAction="#setPixelSize10" text="10" toggleGroup="$pixelSizeGroup" />  
 <RadioMenuItem fx:id="pixelSize20" mnemonicParsing="false" onAction="#setPixelSize20" selected="true" text="20" toggleGroup="$pixelSizeGroup" />  
 </items>  
 </Menu>  
 </items>  
 </Menu>  
 <Menu mnemonicParsing="false" text="Help">  
 <items>  
 <MenuItem fx:id="aboutMenuButton" mnemonicParsing="false" onAction="#showAbout" text="About" />  
 </items>  
 </Menu>  
 </menus>  
 </MenuBar>  
 </top>  
 <center>  
 <Canvas fx:id="centerCanvas" height="500.0" width="500.0" BorderPane.alignment="CENTER" />  
 </center>  
 <bottom>  
 <VBox BorderPane.alignment="CENTER">  
 <children>  
 <HBox alignment="TOP\_CENTER" spacing="5.0">  
 <children>  
 <Button fx:id="generateMazeButton" mnemonicParsing="false" onAction="#generateMaze" text="Generate Maze" />  
 <Button fx:id="setStartFinishButton" mnemonicParsing="false" onAction="#setStartFinishCells" text="Set Start and Finish" />  
 <Button fx:id="solveMazeButton" mnemonicParsing="false" onAction="#solveMaze" text="Solve Maze" />  
 <Button fx:id="clearMazeButton" mnemonicParsing="false" onAction="#clearMaze" text="Clear Maze" />  
 </children>  
 <padding>  
 <Insets bottom="5.0" left="5.0" right="5.0" top="5.0" />  
 </padding>  
 </HBox>  
 <HBox>  
 <children>  
 <TextField fx:id="dataTextField" editable="false" HBox.hgrow="ALWAYS">  
 <HBox.margin>  
 <Insets left="5.0" right="5.0" />  
 </HBox.margin>  
 </TextField>  
 <TextField fx:id="notificationText" alignment="CENTER\_RIGHT" editable="false" text="Must first click &quot;Generate Maze&quot;" HBox.hgrow="ALWAYS">  
 <HBox.margin>  
 <Insets left="5.0" right="5.0" />  
 </HBox.margin></TextField>  
 </children>  
 <VBox.margin>  
 <Insets bottom="5.0" />  
 </VBox.margin>  
 </HBox>  
 </children>  
 </VBox>  
 </bottom>  
</BorderPane>

### aboutWindow.fxml

<?xml version="1.0" encoding="UTF-8"?>  
  
<?import javafx.scene.control.Button?>  
<?import javafx.scene.layout.Pane?>  
<?import javafx.scene.text.Font?>  
<?import javafx.scene.text.Text?>  
  
<Pane fx:id="aboutPane" maxHeight="-Infinity" maxWidth="-Infinity" minHeight="-Infinity" minWidth="-Infinity" prefHeight="250.0" prefWidth="350.0" xmlns="http://javafx.com/javafx/15.0.1" xmlns:fx="http://javafx.com/fxml/1" fx:controller="assignment01.aboutController">  
 <children>  
 <Button fx:id="closeAboutButton" layoutX="148.0" layoutY="209.0" mnemonicParsing="false" onAction="#closeWindow" text="Close" />  
 <Text layoutX="52.0" layoutY="71.0" strokeType="OUTSIDE" strokeWidth="0.0" text="CS 7375 - Assignment 1">  
 <font>  
 <Font size="24.0" />  
 </font>  
 </Text>  
 <Text layoutX="120.0" layoutY="39.0" strokeType="OUTSIDE" strokeWidth="0.0" text="Marion Garrett Sisk" />  
 <Text layoutX="48.0" layoutY="108.0" strokeType="OUTSIDE" strokeWidth="0.0" text="The maze generator uses a &#10;Randomized Prim's Algorithm implementation. &#10;The AI Agent is designed to navigate&#10;the generated maze. It can find a solution,&#10;but may not be the most efficient means." textAlignment="CENTER" />  
 </children>  
</Pane>