ECSE 321 - Tutorial 7

Path Finding

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Finding our way...

- **Pathfinding** is a class of **algorithms** which can find the route between two points.
- Algorithms exist for solving different complexities of problems:
  - Are we in a 2D or 3D space?
  - Are there obstacles?
  - Are there moving obstacles?
  - How much time do we have to make a decision?
  - Will the end point change

Bomberman

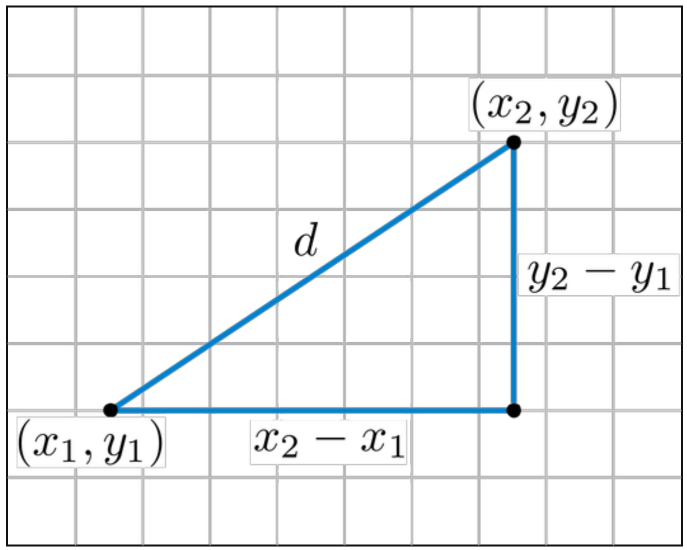
Our particular problem

- We have a 2D grid.
- There are obstacles on the grid.
    - **These obstacles can appear/dissapear!**
- We'd like our game to run smoothly, so there shouldn't be any discernible "thinking" phase.
- Enemies need to use 2 algorithms:

1. Determining if Bomberman is within a certain distance.
2. Finding the path to Bomberman / their next move position

Euclidean Distance

This is a formula for determining the distance between two points. You can think of this as if you drew a straight line between two points and measured it with a ruler.



Euclidean Distance Cont'd.

Given the points (x1, y1) and (x2, y2), the distance is calculated by:

```
double distance = Math.sqrt(
    Math.pow(x1 - x2, 2) + Math.pow(y1 - y2, 2));
```

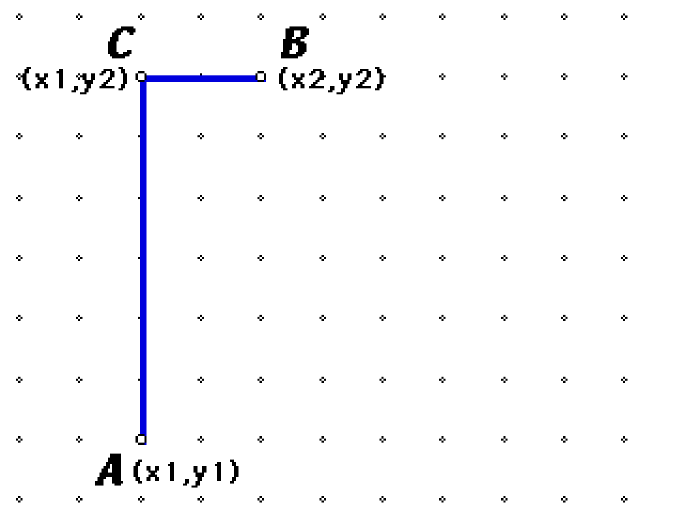
This can now help us answer questions such as Is Bomberman within the distance *d* from an enemy.

As the distance is initially a *double*, it is common to round it to work with it as an integer. Then we can check if distance <= 3. If we left it as a double, we have to worry about accuracy.

Taxicab Distance

This is a different *metric* for determining the distance between two points. Since we are working on a 2D grid, we can think of distance like we would in a regular city.

If a taxicab needs to drive up 3 blocks and then right 4 blocks to get you to your house, the distance is 7!



Taxicab Distance Cont'd

Given two points (x1, y1) and (x2, y2) the taxicab distance is calculated:

```
int distance = Math.abs(x1 - x2) + Math.abs(y1 - y2);
```

Note: Taxicab distance gives you the distance as an *int*!

Also note that Taxicab distance only really makes sense if your points are integers (eg. no 10.5)

Distance Calculation Recap

- Euclidean distance draws a line between two points and measures it
- Taxicab is based on a city grid, and calculates the number of blocks between two points. **(Only works for integer points)**
- Both are heuristics and thus give therefore answers for distances.
- Neither take obstacles into consideration!
- **DEMO TIME!!!**

Finding the Shortest Path

A*

The A* Algorithm

- The A* algorithm lets you find the shortest distance between two points.
- It uses some kind of distance calculation - we'll be using Euclidean!
- **<u>Our particular scenario:</u>**
  - 2D grid where entities can move in 4 directions.
  - Some cells are obstacles.
- Fast enough that we can recalculate easily so this supports the map changing.

Shortest Distance?

- The definition of **shortest distance** changes on the problem.
- In our case, we mean the **shortest number of moves** to get from one point to another.
  - *We assume that moving in any direction "costs" the same*.
- Some problems are different! Suppose you are making Google Maps - there are actual distances between cities, and we want to find the path for which you have to drive the least!

Important Note

- A* isn't the only path finding algorithm - Dijkstra's algorithm is another famous one!
- Ideally, we want our algorithm to not only give us the shortest distance but the **path that will give us this distance** as well!
  - For our monsters, it's no good knowing the shortest distance to get to Bomberman if we don't know how to move!

Some Background: The Queue

- A *Queue* is a standard data structure which works like a line at a bank. You put items into it (**enqueue**) and can remove the item which has been in the queue for the longest (**dequeue**).
  - People enqueue in the bank line and the person who was here first gets served first.

Some Background: The Priority Queue

- A *Priority Queue* is a special type of Queue which is **sorted** based on some **ordering**.
  - Instead of dequeue removing the first element, it removes the one with the *highest priority.*
- Java provides the PriorityQueue<T> class.
  - Note that either the objects you put in the priority queue should be **Comparable** or you should provide a **Comparator**
  - This has an **add** method (enqueue) and **add** method (dequeue).
  - The queue is **automatically sorted** for you.

Some A* Terms

- A* works by exploring potential shortest paths one square at a time.
- We maintain a priority queue of **candidates**, which are squares which have not yet been explored but are adjacent to a square which has been.
    - Here we order them based on how **good** the candidate is according to a **heuristic** (huh?!)
- We also maintain a set of **closed points**, which are squares that have already been seen and that we don't need to look at again.

The Basic Idea

- Initially only the starting point is in the queue of candidates.
- At each round, we dequeue "best" candidate.
  - If the candidate is already in the closed list, ignore it.
  - If the best candidate is the end point, we've found the shortest path!
  - If not, we process the point and add it to the closed list.
- If our priority queue is empty and we never reached the end point, then there is no possible path!

"Best"?

Points are evaluated based on the sum of a "past" score and a "future" score.

- The **past** score is the length of the path from the starting point to this point.
- The **future** score is a guess at the length of the point to the finish.
  - We have to guess since we don't know what obstacles we may see! We use a distance function here to guess!
- The **best** therefore has the lowest **score**:

```
score = pastDistance + futureDistance;
```

What does a Point have?

- For our purposes, a Point object will have the following properties:
  - *int x, y* representing their coordinates on the grid.
  - *Point parent* a link to the point that was used tor each this point (or null if it's the starting point)
  - *int pastScore* (should be parent.pastScore + 1)
  - **Note:** futureScore can just be calculated so we don't need to store it!
- Once we've extracted the end point as the best candidate, we can build the path by repeatedly getting the parent's coordinates!

Processing a Point

- When we process a best candidate, we want to look at all the **adjacent nodes** and consider them all as potential candidates!
- For processing, we look each the 4 nodes **(neighbors)** next to the candidate. For each neighbor:
    - If you can't walk to the neighbour (eg. it is a wall), ignore it.
    - If the neighbour is in the closed list, ignore it.
    - Create a new Point object representing the neighbour with the candidate as its parent and add it to the candidate queue.

The Candidate Queue

- Remember that the candidate queue is **sorted**. In our case, the **best candidate** has the **lowest score**.
- As we process nodes, we may visit a neighbour which is already in the candidate list but has not been processed yet! It's important to allow for this, as we may have found a better path!
    - **Note:** Some priority queues let you update nodes, so you could use that instead of having a point appear multiple times in the candidate list.
    - To keep this simple, we allow a point multiple times in the candidate list and simply check if it is already closed when processing.

Interactive Demo Time!

http://qiao.github.io/PathFinding.js/visual/

Initializing Pseudocode

```
List<Point> getShortestPath(startX, startY, endX, endY) {
    // Create the queue of candidates.
    PriorityQueue<Point> candidates = new PriorityQueue<Point>(
        new PointComparator(endX, endY));
    // Create a boolean 2D array representing if a given point
    // is in the closed list.
    boolean[][] closed = new boolean[sizeX][sizeY];

    // Add the starting point to the list of candidates.
    candidates.add(new Point(startX, startY, null, 0));

    // ...
}
```

Main Pseudocode

```
// Keep going until there are no candidates left.
while (!candidates.isEmpty()) {
    // Get the best candidate.
    Point candidate = candidates.poll();
    // If the candidate is the end point, we've found the
    // shortest path!
    if (candidate.x == endX && candidate.y == endY)
        return buildPath(candidate);
    // If the candidate is already closed, ignore it.
    if (closed[candidate.x][candidate.y])
        continue;
    // Look at each neighbor of the candidate.
    for (Point neighbor : candidate.getNeighbors()) {
        // If the neighbor is closed or cannot be walked to,
        // it is ignored.
        if (blocked[neighbor.x][neighbor.y] ||
                closed[neighbor.x][neighbor.y])
            continue;
        // Add the candidate.
        candidates.add(neighbor);
    }
    // Close the candidate.
    closed[candidate.x][candidate.y];
}
// No path found!
return null;
```

Comparator Pseudocode

We have to create a comparator specifically tailored to our end point to calculate the distance!

```
public class TestComparator implements Comparator<Point> {

        public TestComparator(int endX, int endY) {
                // Create a comparator based on a given end point.
                this.endX = endX;
                this.endY = endY;
        }

        public int compare(Point p1, Point p2) {
                // Calculate past + future score for both points.
                int score1 = p1.pastScore + distance(p1.x, p1.y, endX, endY);
                int score2 = p2.pastScore + distance(p2.x, p2.y, endX, endY);
                // Point 1 should be before Point 2 if score1 has a lower value.
                return score1 - score2;
        }

        public int distance(x1, y1, x2, y2) {
                // Insert distance function here!
        }
}
```

getNeighbors Pseudocode

```
public class Point {
        // ...
        public List<Point> getNeighbors() {
                List<Point> points = new ArrayList<>();

                // Up direction
                // Check if this point is within the boundaries of the map.
                if (this.y > 0) {
                        // Create the up neighbor with the proper coordinates.
                        // The neighbor will have this point as its parent and
                        // takes the pastScore and adds 1 to represent the move.
                        Point upNeighbor = new Point(
                                this.x, this.y - 1,
                                this, this.pastScore + 1);
                        points.add(upNeighbor);
                }

                // Other directions...

                return points
        }
}
```

Recap

- Distance functions let you determine if a point is within a given range from another point. Different ways of calculating this exist!
  - Euclidean distance draws a line between 2 points and measures it.
  - Taxicab distance pretends we are driving through city blocks to get to the point (can't go through buildings).
- Path finding algorithms such as A* let you find the shortest path between 2 points.