COMP250: Artificial Intelligence

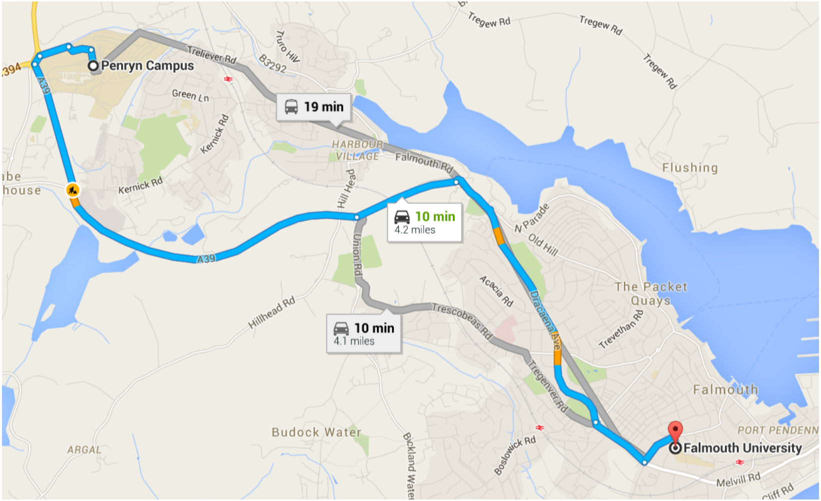
9: Navigation

Pathfinding

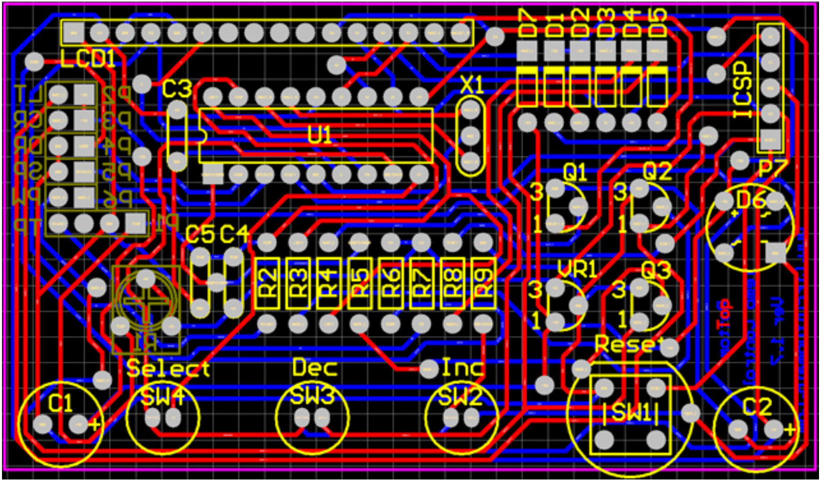
The problem

- We have a **graph**
  - **Nodes** (points)
  - **Edges** (lines between points, each with a **length**)
- E.g. a road map
  - Nodes = addresses
  - Edges = roads
- E.g. a tile-based 2D game
  - Nodes = grid squares
  - Edges = connections between adjacent squares
- Given two nodes A and B, find the **shortest path** from A to B
  - "Shortest" in terms of edge lengths — could be distance, time, fuel cost, ...

Applications of pathfinding



Applications of pathfinding



Applications of pathfinding

Many applications in game AI

- Non-player character AI
- Mouse-based movement (e.g. strategy games)
- Maze navigation
- Puzzle solving

Pathfinding example

- `https://github.com/falmouth-games-academy/comp250-workshop-9`
- Open it in PyCharm

Graph traversal

- **Depth-first** or **breadth-first**
- Recall: can be implemented with a **stack** or a **queue** respectively
- For graphs (as opposed to trees), need to remember which nodes have been **visited** to avoid getting stuck in a loop
- Inefficient — generally has to explore the **entire map**
- Finds a path, but probably not the **shortest**
- Third type of traversal: **best-first**
  - "Best" according to some heuristic evaluation
  - Often implemented with a **priority queue**

Greedy search

- Always try to move **closer** to the goal
- Visit the node whose **distance to the goal** is **minimal**
- Doesn´t handle **dead ends** well
- Not guaranteed to find the **shortest** path

Dijkstra's algorithm

- Let $g(x)$ be the distance of the path found from the start to x
- Choose a node that minimises $g(x)$
- Needs to handle cases where a shorter path to a node is discovered later in the search
- **Is** guaranteed to find the shortest path
- ... but is not the most efficient algorithm for doing so

A^* search

- Let $h(x)$ be an estimate of the distance from x to the goal (as in greedy search)
- Let $g(x)$ be the distance of the path found from the start to x (as in Dijkstra's algorithm)
- Choose a node that minimises $g(x) + h(x)$

Properties of A* search

- A* is **guaranteed** to find the shortest path if the distance estimate $h(x)$ is **admissible**
- Essentially, **admissible** means it must be an **underestimate**
  - E.g. straight line Euclidean distance is clearly an underestimate for actual travel distance
- The more accurate $h(x)$ is, the more efficient the search
  - E.g. $h(x) = 0$ is admissible (and gives Dijkstra's algorithm), but not very helpful
- $h(x)$ is a **heuristic**
  - In AI, a heuristic is an estimate based on human intuition
  - Heuristics are often used to prioritise search, i.e. explore the most promising options first

Tweaking A*

- Can change how $g(x)$ is calculated
  - Increased movement cost for rough terrain, water, lava...
  - Penalty for changing direction
- Different $h(x)$ can lead to different paths (if there are multiple “shortest” paths)

String pulling

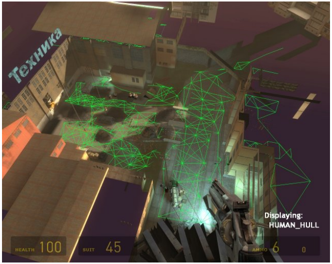
- Paths restricted to edges can look unnatural
- Intuition: visualise the path as a string, then pull both ends to make it taut
- Simple algorithm:
  - Found path is $p[0], p[1], \ldots, p[n]$
  - If the line from $p[i]$ to $p[i+2]$ is unobstructed, remove point $p[i+1]$
  - Repeat until there are no more points that can be removed

Navigation meshes

Pathfinding in videogames

- A* works on any **graph**
- But what if the game world is not a graph? E.g. complex 3D environments

Waypoint navigation

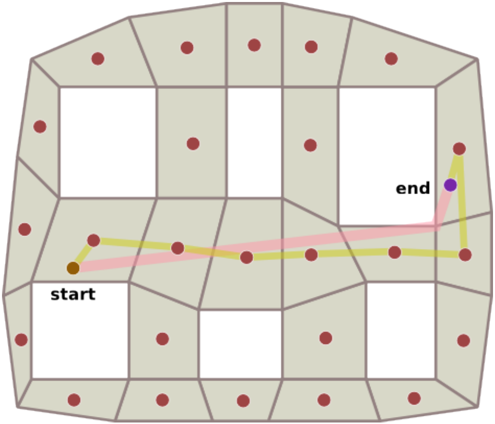


- Manually place graph nodes in the world
- Place them at key points, e.g. in doorways, around obstacles
- Works, but...
  - More work for level designers
  - Requires lots of testing and tweaking to get natural-looking results
  - No good for dynamic environments

Navigation meshes

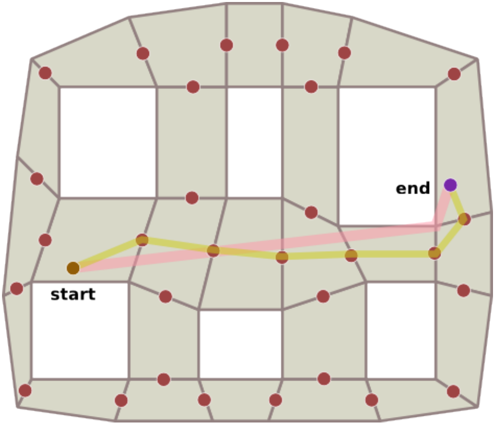
- Automatically generate navigation graph from level geometry
- Basic idea:
  - Filter level geometry to those polygons which are **passable** (i.e. floors, not walls/ceilings/obstacles)
  - Generate graph from polygons

Meshes to graphs



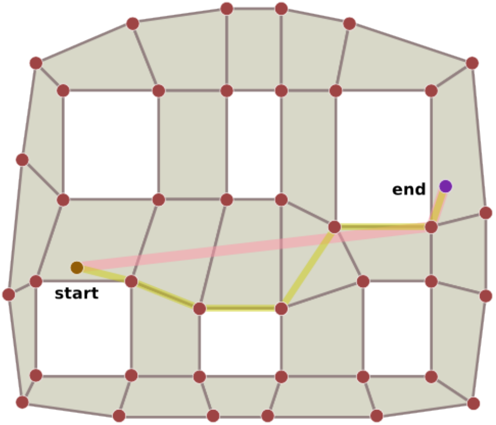
Centres of polygons

Meshes to graphs



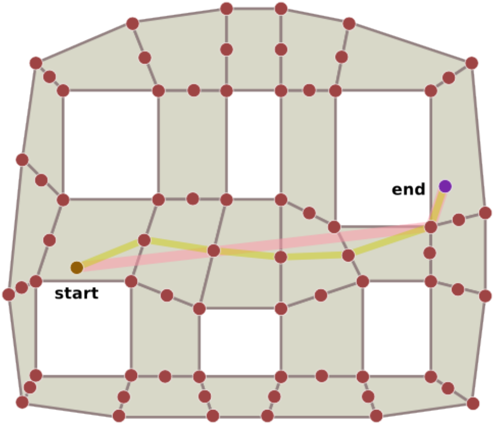
Centres of edges

Meshes to graphs



Vertices of polygons

Meshes to graphs



Hybrid approach: edges and vertices

Following the path

- **Funnelling**: like string pulling but for navigation meshes
  - `http://digestingduck.blogspot.co.uk/2010/03/simple-stupid-funnel-algorithm.html`
  - `http://jceipek.com/Olin-Coding-Tutorials/pathing.html`
- **Steering**: don't have your AI agent follow the path exactly, but instead try to stay close to it
- **Dynamic environments**: may need to re-run pathfinder if environment changes (e.g. movable obstacles, destructible terrain)

The travelling salesman problem

The travelling salesman problem (TSP)

- Classic problem in Computer Science
- We have a **graph**
- From starting node S, find the **shortest possible path** that visits every node **exactly once** and returns to S
- Many real-world applications
  - Transport and logistics
  - Manufacturing
  - Playing Pac-Man
  - Pub crawls (`http://www.math.uwaterloo.ca/tsp/pubs/`)

Solving TSP

- TSP is **NP-complete**
  - If $P \neq NP$, then there is **no** polynomial-time algorithm for solving it
- Entire research field devoted to finding efficient **search algorithms** and **heuristics**

MicroRTS

MicroRTS competition

`https://github.com/falmouth-games-academy/comp250-bot`