Chapter 5.4
Artificial Intelligence: Pathfinding

Introduction

- Almost every game requires pathfinding
- Agents must be able to find their way around the game world
- Pathfinding is not a trivial problem
- The fastest and most efficient pathfinding techniques tend to consume a great deal of resources

Representing the Search Space

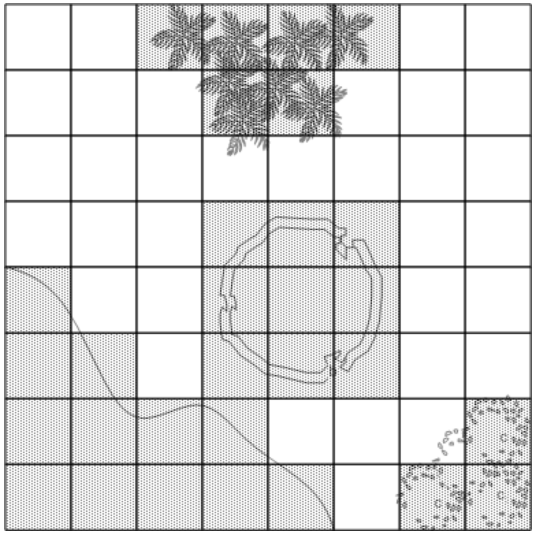
- Agents need to know where they can move
- Search space should represent either
  - Clear routes that can be traversed
  - Or the entire walkable surface
- Search space typically doesn't represent:
  - Small obstacles or moving objects
- Most common search space representations:
  - Grids
  - Waypoint graphs
  - Navigation meshes

Grids

- 2D grids – intuitive world representation
  - Works well for many games including some 3D games such as *Warcraft III*
- Each cell is flagged
  - Passable or impassable
- Each object in the world can occupy one or more cells

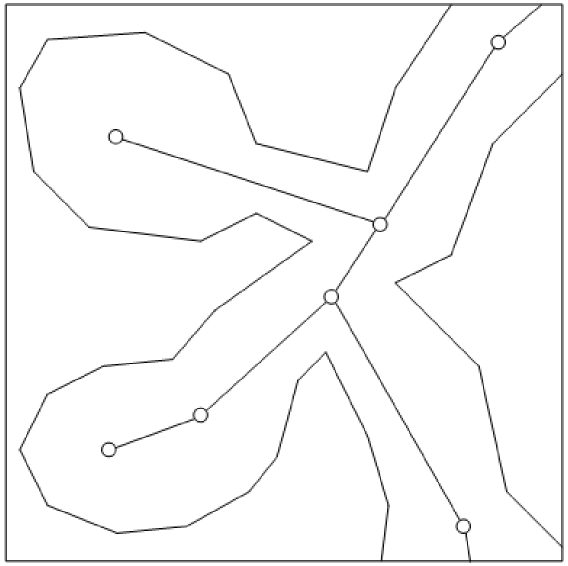
Characteristics of Grids

- Fast look-up
- Easy access to neighboring cells
- **Complete** representation of the level



Waypoint Graph

- A waypoint graph specifies lines/routes that are “safe” for traversing
- Each line (or link) connects exactly two waypoints



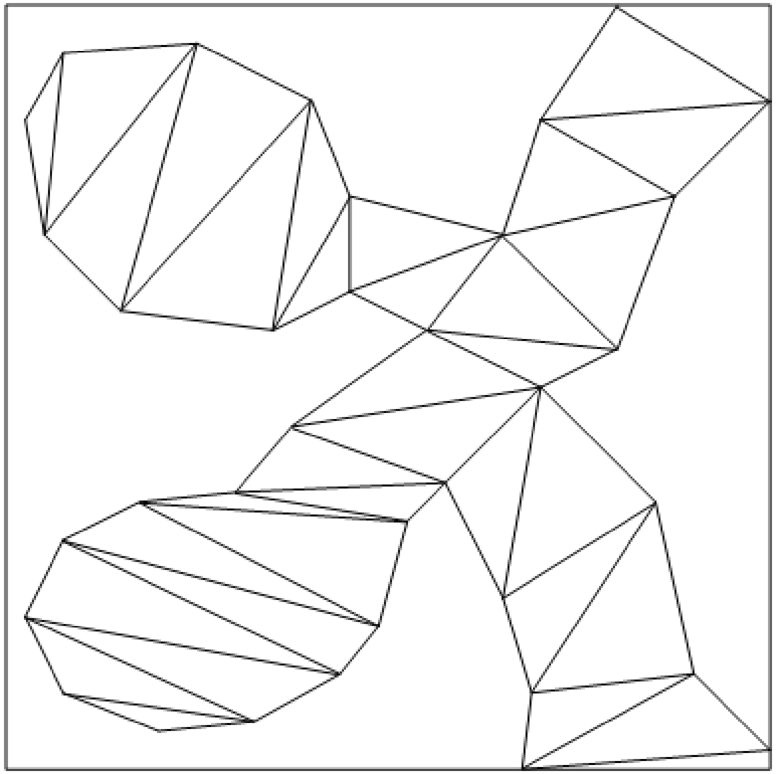
Characteristics of Waypoint Graphs

- Waypoint node can be connected to any number of other waypoint nodes
- Waypoint graph can easily represent arbitrary 3D levels
- Can incorporate auxiliary information
  - Such as ladders and jump pads
- **Incomplete** representation of the level

Navigation Meshes

- Combination of grids and waypoint graphs
- Every node of a navigation mesh represents a convex polygon (or area)
  - As opposed to a single position in a waypoint node
- Advantage of convex polygon
  - Any two points inside can be connected without crossing an edge of the polygon
- Navigation mesh can be thought of as a walkable surface

Navigation Meshes (continued)



Characteristics of Navigation Meshes

- **Complete** representation of the level
- Ties pathfinding and collision detection together
- Can easily be used for 2D and 3D games

Searching for a Path

- A path is a list of cells, points, or nodes that an agent must traverse
- A pathfinding algorithm finds a path
  - From a start position to a goal position
- The following pathfinding algorithms can be used on
  - Grids
  - Waypoint graphs
  - Navigation meshes

Criteria for Evaluating Pathfinding Algorithms

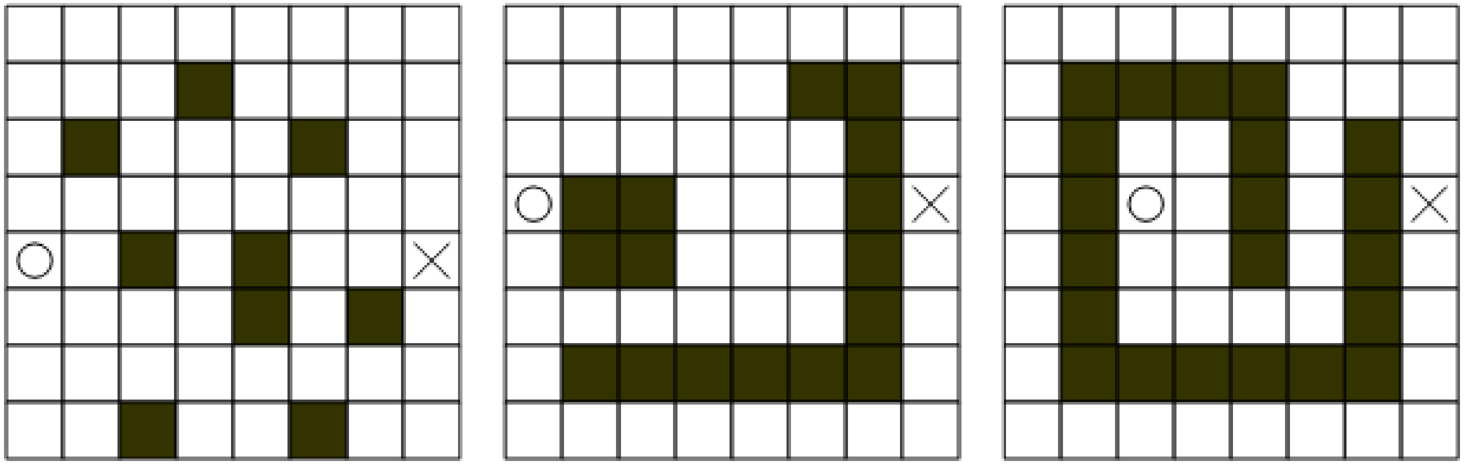
- Quality of final path
- Resource consumption during search
  - CPU and memory
- Whether it is a ***complete*** algorithm
  - A ***complete*** algorithm guarantees to find a path if one exists

Random Trace

- Simple algorithm
  - Agent moves towards goal
  - If goal reached, then done
  - If obstacle
    - Trace around the obstacle clockwise or counter-clockwise (pick randomly) until free path towards goal
  - Repeat procedure until goal reached

Random Trace (continued)

- How will Random Trace do on the following maps?



Random Trace Characteristics

- Not a ***complete*** algorithm
- Found paths are unlikely to be optimal
- Consumes very little memory

Understanding A*

- To understand A*
  - First understand Breadth-First, Best-First, and Dijkstra algorithms
- These algorithms use nodes to represent candidate paths

Understanding A*

```
class PlannerNode
{
public:
    PlannerNode    *m_pParent;
    int             m_cellX, m_cellY;
    ...
};
```

- The m_pParent member is used to chain nodes sequentially together to represent a path

Understanding A*

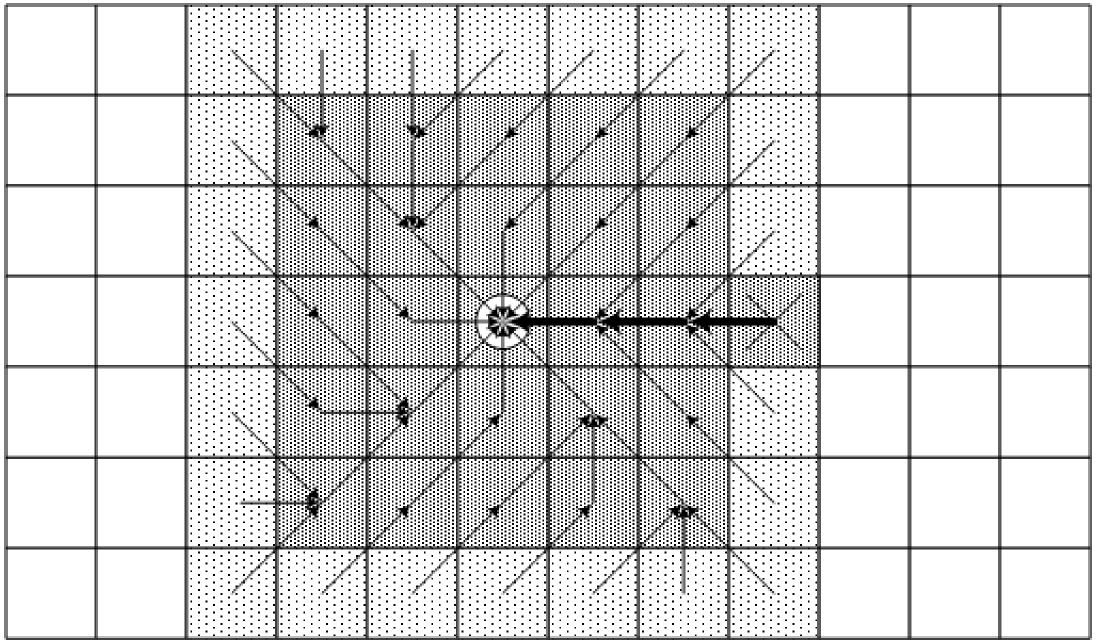
- All of the following algorithms use two lists
  - The ***open*** list
  - The ***closed*** list
- Open list keeps track of promising nodes
- When a node is examined from open list
  - Taken off open list and checked to see whether it has reached the goal
- If it has not reached the goal
  - Used to create additional nodes
  - Then placed on the closed list

Overall Structure of the Algorithms

1. Create start point node – push onto open list
2. While open list is not empty
   A. Pop node from open list (call it currentNode)
   B. If currentNode corresponds to goal, break from step 2
   C. Create new nodes (successors nodes) for cells around currentNode and push them onto open list
   D. Put currentNode onto closed list

Breadth-First

- Finds a path from the start to the goal by examining the search space ply-by-ply



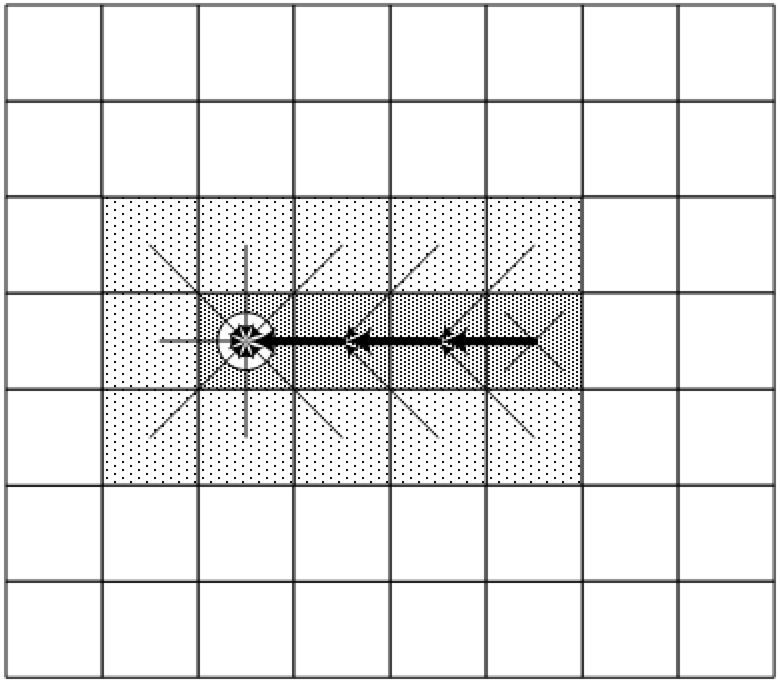
Breadth-First Characteristics

- Exhaustive search
  - Systematic, but not clever
- Consumes substantial amount of CPU and memory
- Guarantees to find paths that have fewest number of nodes in them
  - Not necessarily the shortest distance!
- ***Complete*** algorithm

Best-First

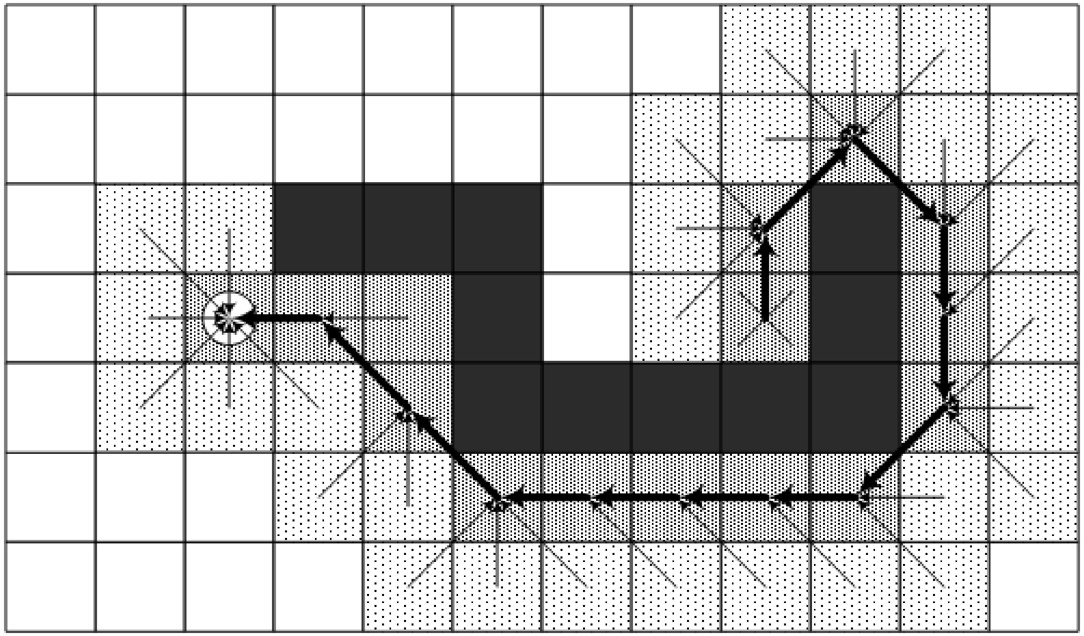
- Uses problem specific knowledge to speed up the search process
- Head straight for the goal
- Computes the distance of every node to the goal
  - Uses the distance (or heuristic cost) as a priority value to determine the next node that should be brought out of the open list

Best-First (continued)



Best-First (continued)

- Situation where Best-First finds a suboptimal path



Best-First Characteristics

- Heuristic search
- Uses fewer resources than Breadth-First
- Tends to find good paths
  - No guarantee to find most optimal path
- ***Complete*** algorithm

Dijkstra

- Disregards distance to goal
  - Keeps track of the cost of every path
  - No guessing
- Computes accumulated cost paid to reach a node from the start
  - Uses the cost (called the given cost) as a priority value to determine the next node that should be brought out of the open list

Dijkstra Characteristics

- Exhaustive search
- At least as resource intensive as Breadth-First
- Always finds the most optimal path
- ***Complete*** algorithm

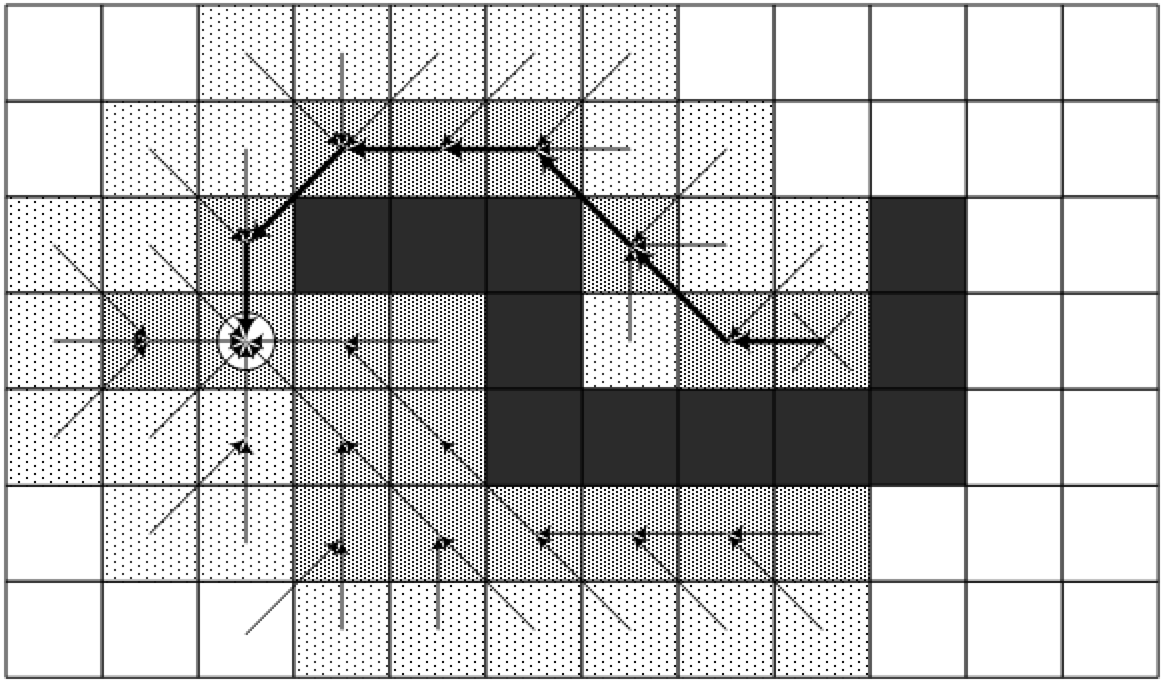
A*

- Uses both heuristic cost and given cost to order the open list

- Final Cost = Given Cost + (Heuristic Cost * Heuristic Weight)

A* (continued)

- Avoids Best-First trap!



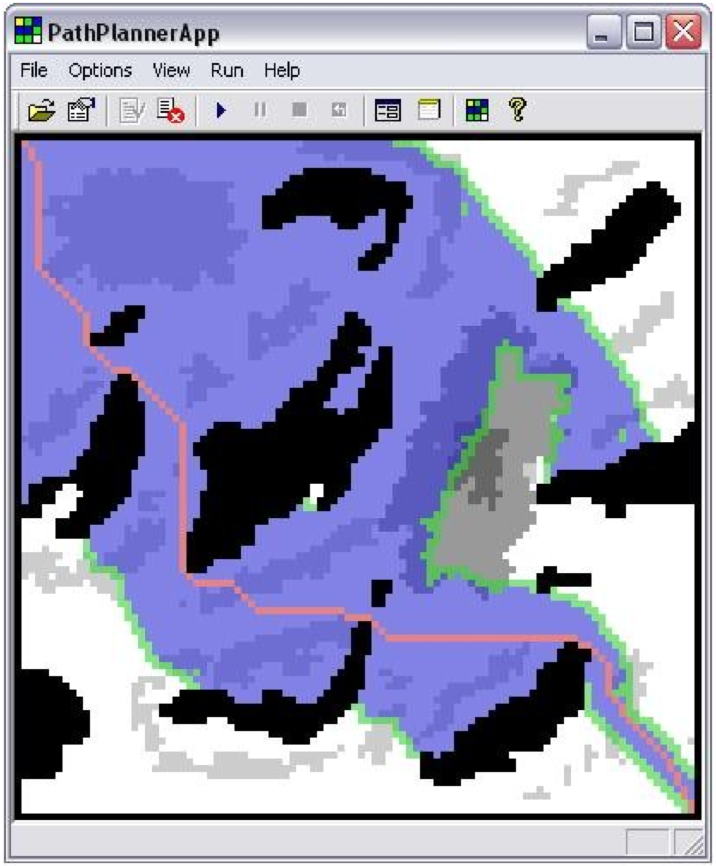
A* Characteristics

- Heuristic search
- On average, uses fewer resources than Dijkstra and Breadth-First
- *Admissible* heuristic guarantees it will find the most optimal path
- ***Complete*** algorithm

Summary

- Two key aspects of pathfinding:
  - Representing the search space
  - Searching for a path

PathPlannerApp Demo



Waypoint Graph Demo

--- Result of Computing ALL paths using A*

	[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
[0]	X	1	2	2	2	1	2	2	2	2	2
[1]	0	X	2	2	2	5	5	5	5	2	2
[2]	0	1	X	3	3	6	6	6	6	3	3
[3]	9	9	9	X	4	9	9	9	9	9	9
[4]	3	3	3	3	X	3	3	3	3	3	3
[5]	1	1	1	6	6	X	6	6	6	6	6
[6]	2	2	2	8	8	5	X	8	8	8	8
[7]	8	8	8	3	3	8	8	X	8	3	3
[8]	6	6	6	7	7	6	6	7	X	7	7
[9]	10	10	10	3	3	10	10	10	10	X	10
[10]	2	2	2	9	9	2	2	2	2	9	X