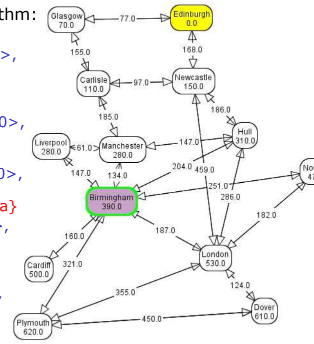
Best First Search

- Now we have a heuristic, we can use it to direct our search towards the goal
- Best first search simply chooses the unvisited node with the best heuristic value to visit next
- It can be implemented in the same algorithm as lowest-cost Breadth First Search
  - This time the priority of each node added to the queue is its heuristic value

Example

- Loops through algorithm:
1. L={<Bi,390>}, V={}
2. L={<Li,280>,<Ma,280>, <Hu,310>,<Ca,500>, <Lo,530>,<Pl,620>}, V={Bi}
3. L={<Ma,280>,<Hu,310>, <Ca,500>,<Lo,530>, <Pl,620>}, V={Bi,Li}
4. L={<Ca,110>,<Hu,310>, <Ca,500>,<Lo,530>, <Pl,620>}, V={Bi,Li,Ma}
5. L={<Gl,70>,<Ne,150>, <Hu,310>,<Ca,500>, <Lo,530>,<Pl,620>}, V={Bi,Li,Ma,Ca}
6. L={<Ed,0>,<Ne,150>, <Hu,310>,<Ca,500>, <Lo,530>,<Pl,620>}, V={Bi,Li,Ma,Ca,Gl}



Best First Search Performance

- Best first works pretty well in this case (as long as Birmingham-Manchester gets tried before Birmingham-Liverpool-Manchester)
- However, it need not. If Hull had a heuristic of 270, it would find Birmingham-Hull-Newcastle-Edinburgh as the best route
  - Overall that has a cost of 558 instead of 551 to go via Manchester
  - In general, the worse the Heuristic is, the worse Best First search is likely to perform
  - The problem is that Best First search doesn't take into account the cost of getting to the node, only the cost to go from there

A* Search

- A* Search is Best First search where the priority value in the queue is $f(x)=g(x)+h(x)$, where
  - $g(x)$ is the cost to get from the start state to x
  - $h(x)$ is the heuristic cost to get from x to the goal
- Can think of it as combining lowest-cost breadth first search ($g(x)$) and Best First search ($h(x)$)
- Definition: A heuristic is admissible if it never overestimates the actual cost to the goal
- Like lowest-cost BFS, A* search with an admissible heuristic is guaranteed to find the shortest path

Which Search to Use

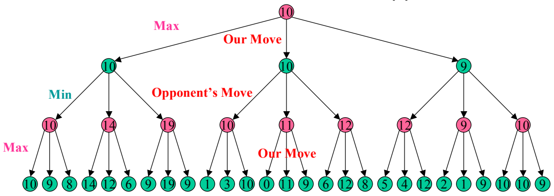
- If you have a good heuristic, obviously you want to use heuristic search
  - But for some domains (as we'll see later) good heuristics are hard to produce
- If not, there are memory and time considerations
  - BFS and the like are guaranteed to find short paths, but use a lot of memory and are slow
  - DFS is much faster, but isn't guaranteed to find a solution
  - Even for heuristic search we sometimes just do the equivalent of DFS on the heuristic value
  - This is known as greedy search

Game Playing

- One common application of search is in games
  - Chess computers (dumb ones) work using a heuristic to evaluate board positions, then search as many moves ahead as they can in the time available and use the heuristic to evaluate the final position
  - Now however, we need to search not only over our moves, but also over the other player's moves
  - Zero-sum games are ones in which what you win is what the other player loses
  - Search in zero-sum games involves choosing the best move for you in your turn, and the worst move for you in your opponent's turn

MINIMAX Search

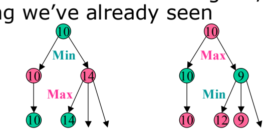
- In MINIMAX search we maximise the heuristic in our turn, then minimise it in our opponent's



- The heuristic is used at the bottom of the tree
- These values propagate up the tree via max and min

Alpha-beta Search

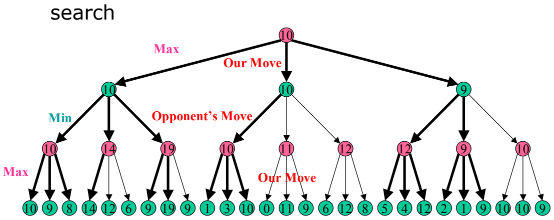
- Alpha-beta search is like minimax, but it uses the fact that we don't need to expand all the tree if we know it will never be as good/bad as something we've already seen



- In the first case, we need not expand leaves after the 14, because it's already more than 10 from the first subtree
- In the second case, we need not expand after the 9 because it's already worse than the first subtree

Example: Alpha-beta Search

- This is the same search tree as for MINIMAX search



- Now we only expand 15 nodes at the third level in the tree, compared with 27 for MINIMAX
- Savings get even bigger the deeper the tree

Algorithm: Alpha-beta Search

Function max-value(s,a,b)
// s = current state, A to play, a = best score for A, b = best score for B
1. If s is a terminal state, return its heuristic value
2. Else for each s' a child of s
3. a = max(a, min-value(s',a,b))
4. if (a >= b) return b
5. Return a

These are recursive: max-value calls min-value, which calls max-value again. This stops when we get to a terminal state (a winning position, or the maximum tree depth)

Function min-value(s,a,b)
1. If s is a terminal state return its heuristic value
2. Else for each s' a child of s
3. b = min(b, max-value(s',a,b))
4. if (b <= a) return a
5. Return b

Algorithm based on the one in Russell and Norvig

Final Words

- Search is the basis for a huge amount of AI
  - Real-world applications include SAT-NAV systems, planning, fault diagnosis (conflict-directed best-first search), robot navigation (probabilistic roadmap search), chess computers, intelligent opponents for computer games, …
- Heuristics are the key to making search efficient
  - Also key in lots of other parts of AI
  - Finding good heuristics is an art in itself
- Many other AI techniques (genetic algorithms, ant colony optimisation, …) are ways to do search without explicitly writing out a search space

What You Need to Know

- All the search algorithms we've covered
  - DFS, BFS, lowest-cost BFS, iterative deepening, best first search, greedy search, A* search, MINIMAX search, alpha-beta search
  - You may have to do examples by hand in the exam
  - You don't need to memorise the algorithms, just remember how they work
  - Using stacks/queues/priority queues
- Heuristics and admissibility