COMP9414: Artificial Intelligence

Uninformed Search

Wayne Wobcke

Room J17-433
wobcke@cse.unsw.edu.au
Based on slides by Maurice Pagnucco

 ©UNSW, 2011

Uninformed (Blind) Search

- Many problems are amenable to attack by search methods
- We shall analyse a number of different search strategies
- We begin by examining search methods that have no problem-specific knowledge to use as guidance
- Theme:

  "In [search] space, no one can hear you scream."

  [Aliens]
- References:
  - Ivan Bratko, Prolog Programming for Artificial Intelligence, Addison-Wesley, 2001. (Chapter 11)
  - Stuart J. Russell and Peter Norvig, Artificial Intelligence: A Modern Approach, Third Edition, Pearson Education, 2010. (Chapter 3)

 ©UNSW, 2011

Overview

- Breadth-First Search
- Uniform Cost Search
- Depth-First Search
- Depth-Limited Search
- Iterative Deepening Search
- Bidirectional Search
- Conclusion

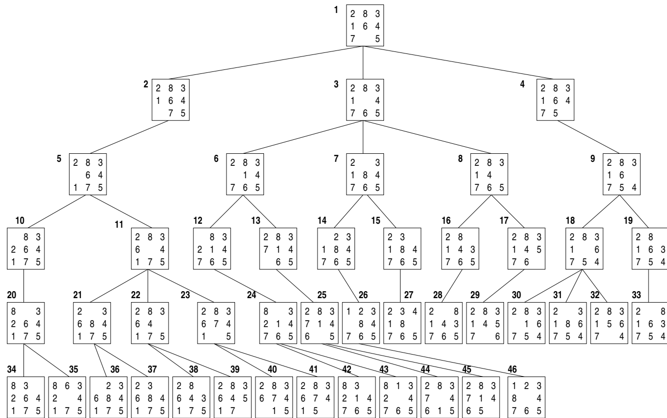
 ©UNSW, 2011

Breadth-First Search

- **Idea:** Expand root node, then expand all children of root, then expand their children, . . .
- All nodes at depth d are expanded before nodes at $d+1$
- Can be implemented by using a queue to store frontier nodes
- Breadth-first search finds shallowest goal state
- Stop when node with goal state is generated
- Include check that generated state has not already been explored

 ©UNSW, 2011

Breadth-First Search



Breadth-First Search

```
% Figure 11.10   An implementation of breadth-first search.

% solve(Start, Solution):
%    Solution is a path (in reverse order) from Start to a goal

solve(Start, Solution)  :-
  breadthfirst([[Start]], Solution).

% breadthfirst([Path1, Path2, ...], Solution):
%   Solution is an extension to a goal of one of paths

breadthfirst([[Node|Path]|_], [Node|Path])  :-
  goal(Node).

breadthfirst([Path|Paths], Solution)  :-
  extend(Path, NewPaths),
  conc(Paths, NewPaths, Paths1),
  breadthfirst(Paths1, Solution).

extend([Node|Path], NewPaths)  :-
  bagof([NewNode, Node|Path],
        (s(Node, NewNode), not member(NewNode, [Node|Path])),
        NewPaths),
  !.

extend(Path, []).            % bagof failed: Node has no successor
```

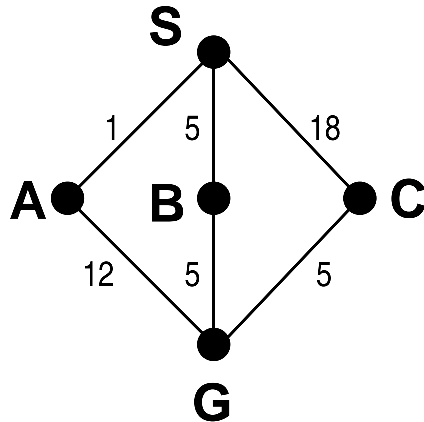

Breadth-First Search — Analysis

- Complete
- Optimal — provided path cost is nondecreasing function of the depth of the node
- Maximum number of nodes generated: $b + b^2 + b^3 + \ldots + b^d$ (where b = forward branching factor; d = path length to solution)
- Time and space requirements are the same $O(b^d)$

Uniform Cost Search

- Also known as Lowest-Cost-First search
- Shallowest goal state may not be the least-cost solution
- **Idea:** Expand lowest cost (measured by path cost $g(n)$) node on the frontier
- Order nodes in the frontier in increasing order of path cost
- Breadth-first search $\approx$ uniform cost search where $g(n) = depth(n)$ (except breadth-first search stops when goal state generated)
- Include check that generated state has not already been explored
- Include test to ensure frontier contains only one node for any state – for path with lowest cost

Uniform Cost Search



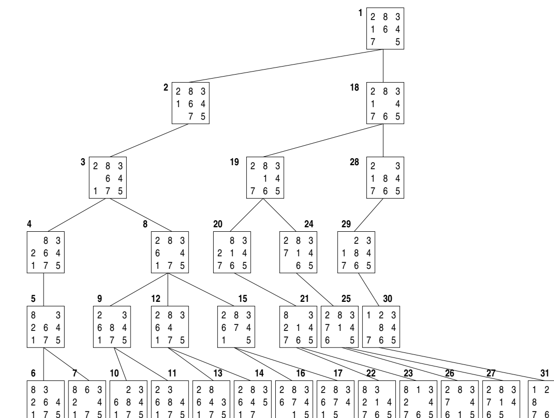
Uniform Cost Search — Analysis

- Complete
- Optimal — provided path cost does not decrease along path (i.e. $g(successor(n)) \geq g(n)$ for all n)
- Reasonable assumption when path cost is cost of applying operators along the path
- Performs like breadth-first search when $g(n) = depth(n)$
- If there are paths with negative cost we would need to perform an exhaustive search

Depth-First Search

- **Idea:** Always expand node at deepest level of tree and when search hits a dead-end return back to expand nodes at a shallower level
- Can be implemented by using a stack to store frontier nodes
- At any point depth-first search stores single path from root to leaf together with any remaining unexpanded siblings of nodes along path
- Stop when node with goal state is expanded
- Include check that generated state has not already been explored along a path – cycle checking

Depth-First Search



Depth-First Search

```
% Figure 11.7   A depth-first search program that avoids cycling.
% solve(Node, Solution):
%    Solution is acyclic path (in reverse order) btwn Node and goal

solve(Node, Solution)  :-
  depthfirst([], Node, Solution).

% depthfirst(Path, Node, Solution):
%   extending the path [Node|Path] to a goal gives Solution

depthfirst(Path, Node, [Node|Path])  :-
  goal(Node).

depthfirst(Path, Node, Sol)  :-
  s(Node, Node1),
  not member(Node1, Path),  % Prevent a cycle
  depthfirst([Node|Path], Node1, Sol).
```


Depth-First Search — Analysis

- Storage: $O(bm)$ nodes (where m = maximum depth of search tree)
- Time: $O(b^m)$
- In cases where problem has many solutions depth-first search may outperform breadth-first search because there is a good chance it will happen upon a solution after exploring only a small part of the search space
- However, depth-first search may get stuck following a deep or infinite path even when a solution exists at a relatively shallow level
- Therefore, depth-first search is not complete and not optimal
- Avoid depth-first search for problems with deep or infinite paths

Depth-Limited Search

- **Idea:** impose bound on depth of a path
- In some problems you may know that a solution should be found within a certain cost (e.g. a certain number of moves) and therefore there is no need to search paths beyond this point for a solution

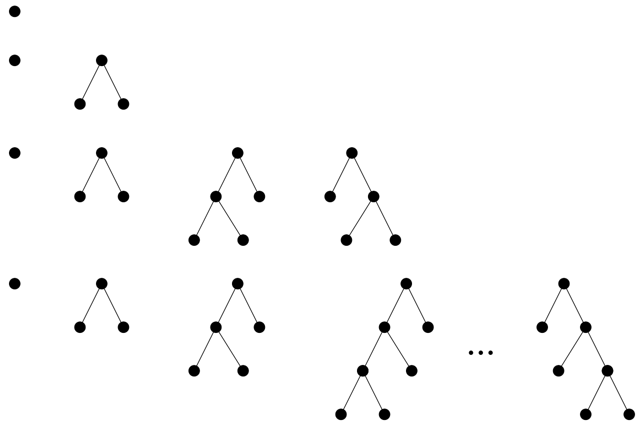
Depth-Limited Search — Analysis

- Complete but not optimal (may not find shortest solution)
- However, if the depth limit chosen is too small a solution may not be found and depth-limited search is incomplete in this case
- Time and space complexity similar to depth-first search (but relative to depth limit rather than maximum depth)

Iterative Deepening Search

- It can be very difficult to decide upon a depth limit for search
- The maximum path cost between any two nodes is known as the diameter of the state space
- This would be a good candidate for a depth limit but it may be difficult to determine in advance
- **Idea:** try all possible depth limits in turn
- Combines benefits of depth-first and breadth-first search

Iterative Deepening Search



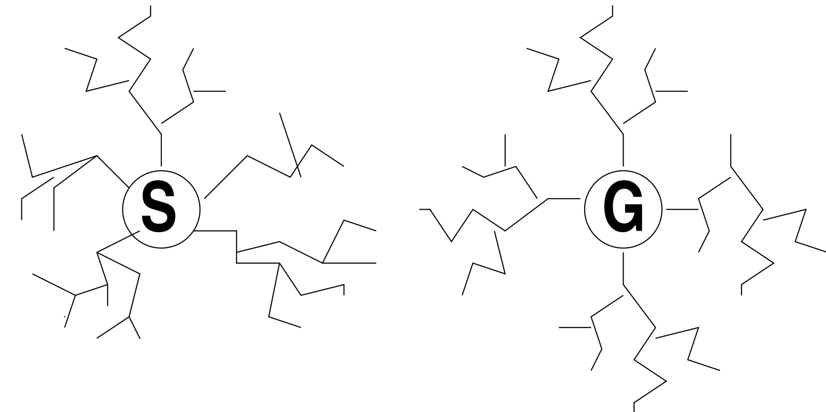
Iterative Deepening Search — Analysis

- Optimal; Complete; Space — $O(bd)$
- Some states are expanded multiple times. Isn't this wasteful?
- Number of expansions to depth $d = 1 + b + b^2 + b^3 + \ldots + b^d$
- Therefore, for iterative deepening, total expansions $= (d+1)1 + (d)b + (d-1)b^2 + \ldots + 3b^{d-2} + 2b^{d-1} + b^d$
- The higher the branching factor, the lower the overhead (even for $b = 2$, search takes about twice as long)
- Hence time complexity still $O(b^d)$
- May consider doubling depth limit at each iteration — overhead $O(d\log d)$
- In general, iterative deepening is the preferred search strategy for a large search space where depth of solution is not known

Bidirectional Search

- **Idea:** search forward from initial state and backward from goal state at the same time until the two meet
- To search backwards we need to generate predecessors of nodes (this is not always possible or easy)
- If operators are reversible successor sets and predecessor sets are identical
- If there are many goal states we can try a multi-state search (how would you do this in chess, say?)
- Need to check whether a node occurs in both searches — may not be easy
- Which is the best search strategy for each half?

Bidirectional Search



Bidirectional Search — Analysis

- If solution exists at depth d then bidirectional search requires time $O(2b^{\frac{d}{2}}) = O(b^{\frac{d}{2}})$ (assuming constant time checking of intersection)
- To check for intersection must have all states from one of the searches in memory, therefore space complexity is $O(b^{\frac{d}{2}})$

Summary — Blind Search

Criterion	Breadth First	Uniform Cost	Depth-First	Depth-Limited	Iterative Deepening	Bidirectional
Time	b^d	b^d	b^m	b^l	b^d	$b^{\frac{d}{2}}$
Space	b^d	b^d	bm	bl	bd	$b^{\frac{d}{2}}$
Optimal	Yes	Yes	No	No	Yes	Yes
Complete	Yes	Yes	No	Yes, if $l \geq d$	Yes	Yes

b — branching factor
d — depth of shallowest solution
m — maximum depth of tree
l — depth limit

Conclusion

- We have surveyed a variety of uninformed search strategies
- All can be implemented within the framework of the general search procedure
- There are other considerations we can make like trying to save time by not expanding a node which has already been seen on some other path
- There are a number of techniques available and often use is made of a hash table to store all nodes generated