Problem Solving by Search

COURSE: CS60045

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Search Frameworks

- State space search
  - Uninformed / Blind search
  - Informed / Heuristic search
- Problem reduction search
- Game tree search
- Advances
  - Memory bounded search
  - Multi-objective search
  - Learning how to search

State space search

- Basic Search Problem:
  - Given: [S, s, O, G] where
    - S is the (implicitly specified) set of states
    - s is the start state
    - O is the set of state transition operators
    - G is the set of goal states
  - To find a sequence of state transitions leading from s to a goal state

8-puzzle problem

- State description (S)
  - Location of each of the eight tiles (and the blank)
- Start state (s)
  - The starting configuration (given)
- Operators (O)
  - Four operators, for moving the blank left, right, up or down
- Goals (G)
  - One or more goal configurations (given)

8-queens problem

Placing 8 queens on a chess board, so that none attacks the other

- Formulation – I
  - A state is any arrangement of 0 to 8 queens on board
  - Operators add a queen to any square

8-queens problem

- Formulation – II
  - A state is any arrangement of 0-8 queens with none attacked
  - Operators place a queen in the left-most empty column

8-queens problem

- Formulation – III
  - A state is any arrangement of 8 queens, one in each column
  - Operators move an attacked queen to another square in the same column

Missionaries and cannibals

- Three missionaries and three cannibals are on one side of a river, along with a boat that can hold one or two people. Find a way to get everyone to the other side, without ever leaving a group of missionaries outnumbered by cannibals

Missionaries and cannibals

- State: (#m, #c, 1/0)
  - #m: number of missionaries in the first bank
  - #c: number of cannibals in the first bank
  - The last bit indicates whether the boat is in the first bank.

- Start state: (3, 3, 1)   Goal state: (0, 0, 0)
- Operators:

  Boat carries (1, 0) or (0, 1) or (1, 1)   or (2, 0) or (0, 2)

Outline of a search algorithm

1. Initialize: Set OPEN = {s}
2. Fail: If OPEN = { }, Terminate with failure
3. Select: Select a state, n, from OPEN
4. Terminate: If n $\in$ G, terminate with success
5. Expand: Generate the successors of n using O and insert them in OPEN
6. Loop: Go To Step 2.

Basics of the search algorithm

- OPEN is a queue (FIFO) vs a stack (LIFO)
- Is this algorithm guaranteed to terminate?
- Under what circumstances will it terminate?

Complexity

- b: branching factor   d: depth of the goal
- Breadth-first search:
  - Time: $1 + b + b^2 + b^3 + \ldots + b^d = O(b^d)$
  - Space: $O(b^d)$
- Depth-first search:
  - Time: $O(b^m)$,
    where m: depth of state space tree
  - Space: $O(bm)$

Tradeoff between space and time

- Iterative deepening
  - Perform DFS repeatedly using increasing depth bounds
  - Works in $O(b^d)$ time and $O(bd)$ space

- Bi-directional search
  - Possible only if the operators are reversible
  - Works in $O(b^{d/2})$ time and $O(b^{d/2})$ space

Saving the explicit space

1. Initialize: Set OPEN = {s}, CLOSED = { }
2. Fail: If OPEN = { },

   Terminate with failure

3. Select: Select a state, n, from OPEN and

   save n in CLOSED

4. Terminate: If $n \in G$, terminate with success
5. Expand: Generate the successors of n using O.

   For each successor, m, insert m in OPEN only if $m \notin$ [OPEN $\cup$ CLOSED]

6. Loop: Go To Step 2.

Search and Optimization

- Given: [S, s, O, G]
- To find:
  - A minimum cost sequence of transitions to a goal state
  - A sequence of transitions to the minimum cost goal
  - A minimum cost sequence of transitions to a min cost goal

Uniform Cost Search

This algorithm assumes that all operators have a cost:

1. Initialize: Set OPEN = {s},
   CLOSED = { } Set C(s) = 0

2. Fail: If OPEN = { }, Terminate & fail

3. Select: Select the minimum cost state, n,
   from OPEN and save n in CLOSED

4. Terminate: If n $\in$ G, terminate with success

Uniform Cost Search

5. Expand:

Generate the successors of n using O.

For each successor, m:

If m $\notin$ [OPEN $\cup$ CLOSED]

Set C(m) = C(n) + C(n,m)

and insert m in OPEN

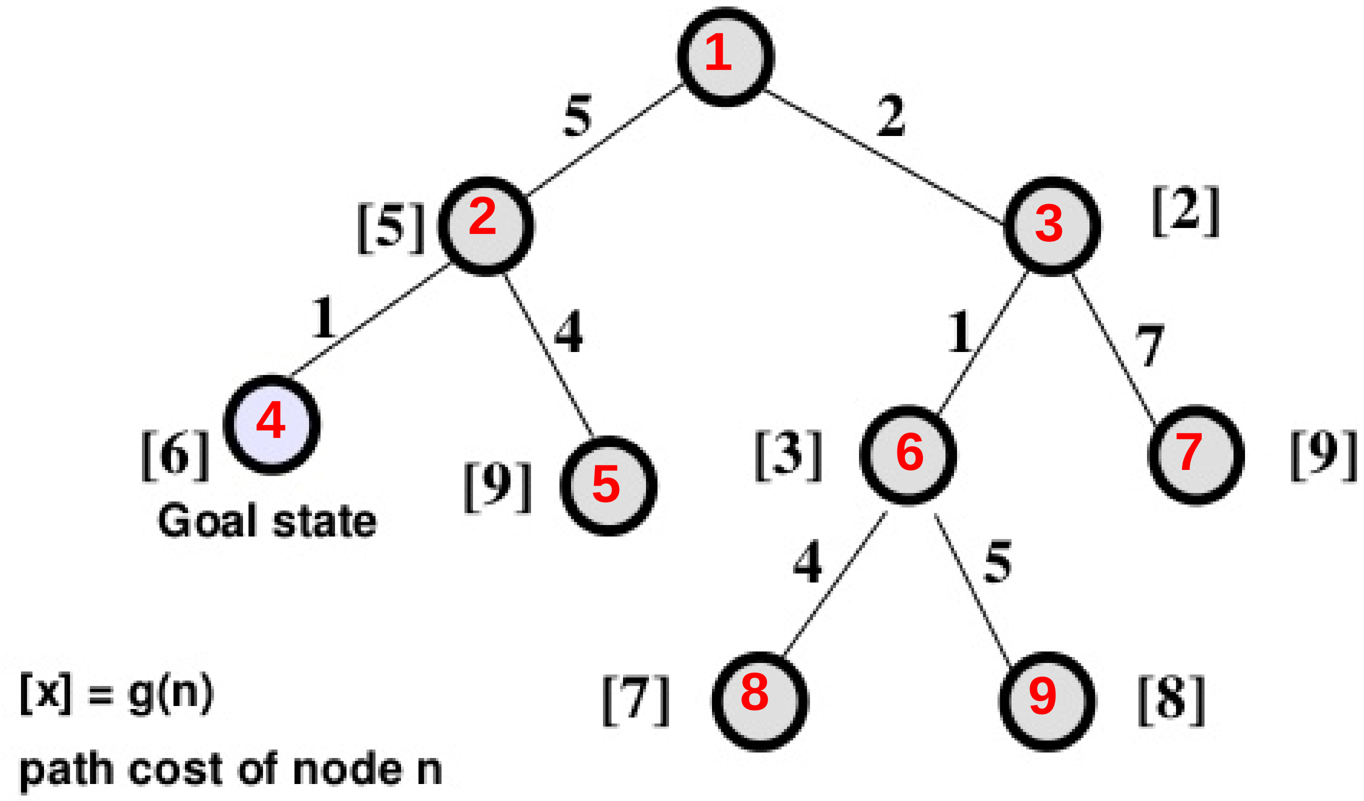
If m $\in$ [OPEN $\cup$ CLOSED]

Set C(m) = min {C(m), C(n) + C(n,m)}

If C(m) has decreased and

m $\in$ CLOSED, move it to OPEN

Sequence of selection of nodes from OPEN:
1 → 3 → 6 → 2 → 4



Searching with costs

- If all operator costs are positive, then the algorithm finds the minimum cost sequence of transitions to a goal.
    - No state comes back to OPEN from CLOSED
- If operators have unit cost, then this is same as BFS
- What happens if negative operator costs are allowed?

Branch-and-bound

1. Initialize: Set OPEN = {s}, CLOSED = { }.
   Set $C(s) = 0$, $C^* = \infty$
2. Terminate: If OPEN = { }, then return C^*
3. Select: Select a state, n, from OPEN and save in CLOSED
4. Terminate: If $n \in G$ and $C(n) < C^*$, then
   Set $C^* = C(n)$ and Go To Step 2.

Branch-and-bound

5. Expand:

   If $C(n) < C^*$ generate the successors of n

   For each successor, m:

   If $m \notin [OPEN \cup CLOSED]$

   Set $C(m) = C(n) + C(n,m)$ and insert m in OPEN

   If $m \in [OPEN \cup CLOSED]$

   Set $C(m) = \min \{C(m), C(n) + C(n,m)\}$

   If C(m) has decreased and $m \in CLOSED$, move it to OPEN

6. Loop: Go To Step 2.