Search

EECS 348

Intro to Artificial Intelligence

(slides from Oren Etzioni, based on Stuart Russell,
Dan Weld, Henry Kautz, and others)

What is Search?

Search is a class of techniques for systematically finding or constructing solutions to problems.

Example technique: *generate-and-test*.

Example problem: Combination lock.

1. Generate a possible solution.
2. Test the solution.
3. If solution found THEN done ELSE return to step 1.

Search thru a Problem Space / State Space

Input:

- Set of states
- Operators [and costs]
- Start state
- Goal state [test]

Output:

- Path: start $\Rightarrow$ a state satisfying goal test
- [May require shortest path]

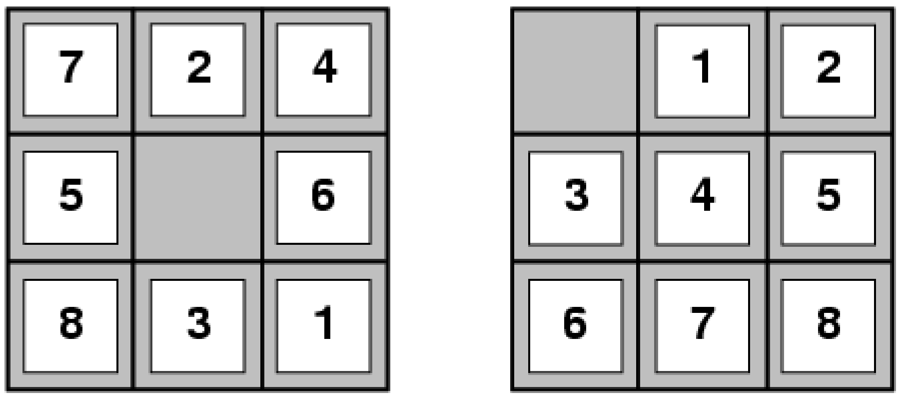
Why is search interesting?

Many (all?) AI problems can be formulated as search problems!

Examples:

- Path planning
- Games
- Natural Language Processing
- Machine learning
- Genetic algorithms

Example: The 8-puzzle



Start State Goal State

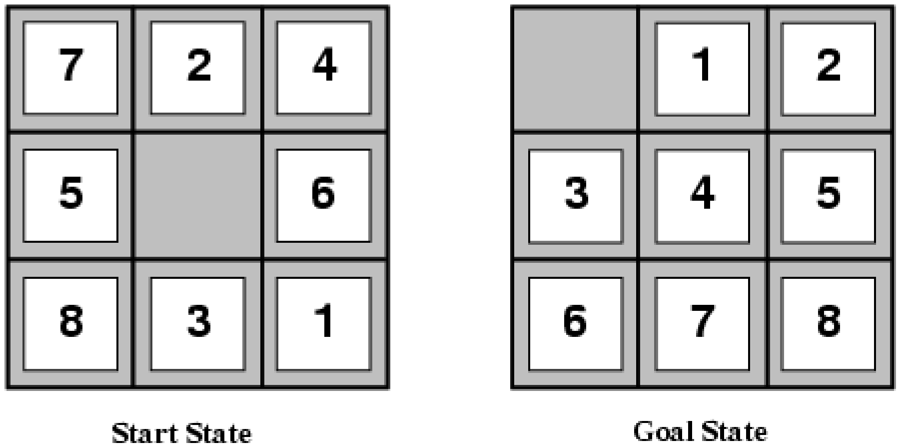
states?

actions?

goal test?

path cost?

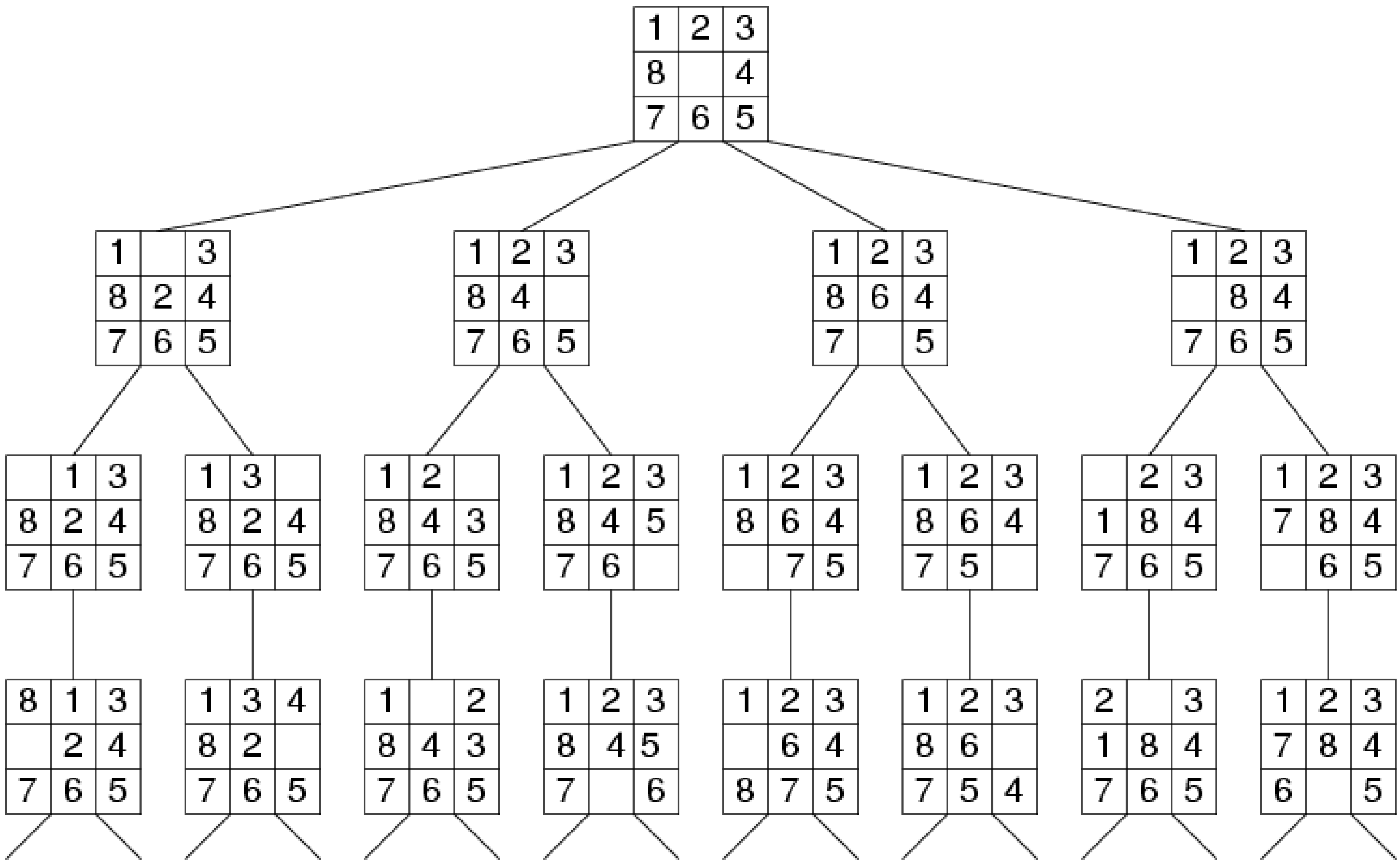
Example: The 8-puzzle



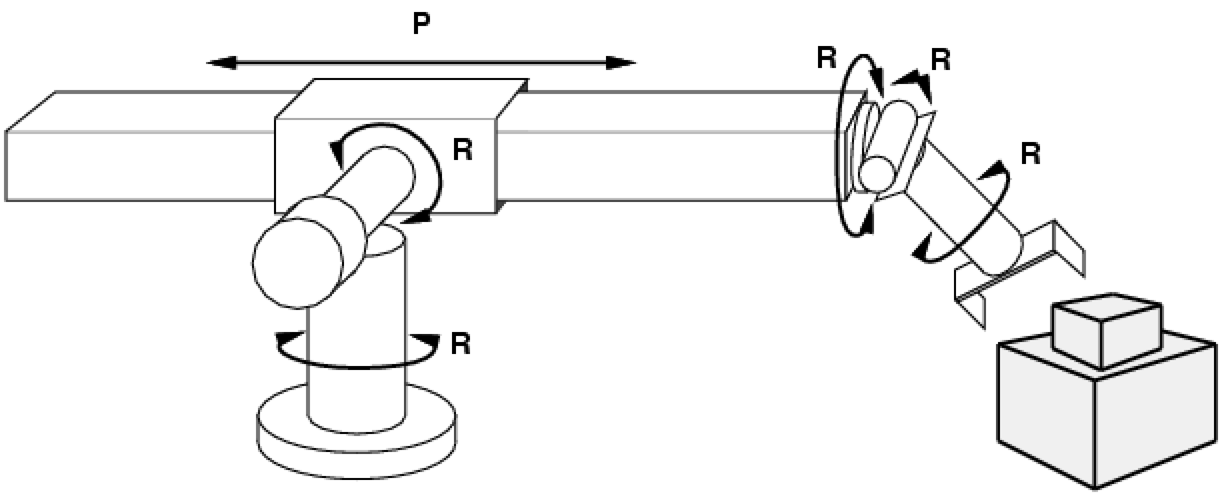
<u>states?</u> locations of tiles
<u>actions?</u> move blank left, right, up, down
<u>goal test?</u> = goal state (given)
<u>path cost?</u> 1 per move

[Note: optimal solution of *n*-Puzzle family is NP-hard]

Search Tree Example: Fragment of 8-Puzzle Problem Space



Example: robotic assembly



states?: real-valued coordinates of robot joint angles parts of the object to be assembled

actions?: continuous motions of robot joints

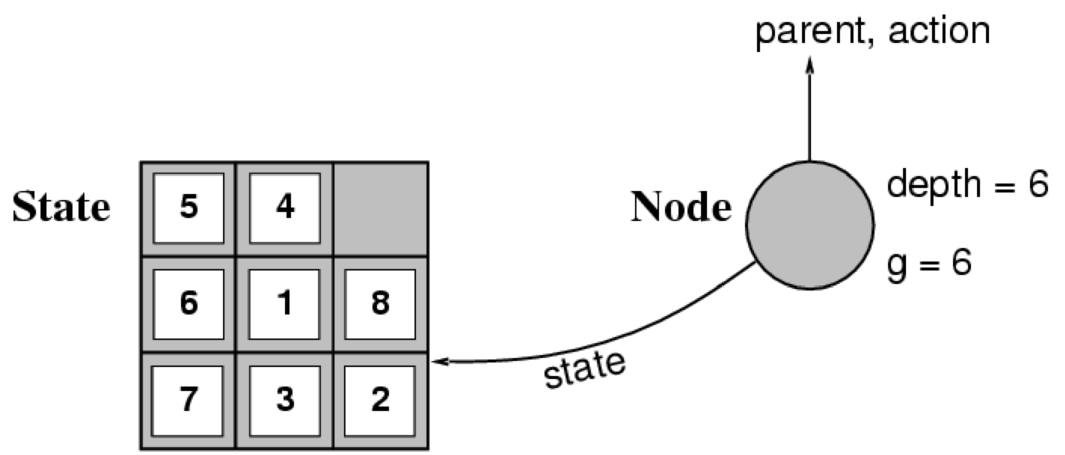
goal test?: complete assembly

path cost?: time to execute

Implementation: states vs. nodes

A state is a (representation of) a physical configuration

A node is a data structure constituting part of a search tree includes state, parent node, action, path cost *g(x)*, depth



The `Expand` function creates new nodes, filling in the various fields and using the `SuccessorFn` of the problem to create the corresponding states.

Tree Search

Fringe = root node
Repeat while Fringe non-empty
  Take *n* from Fringe
  If *n* is a goal
        break (we're done)
  Else
        Add Expand(*n*) to Fringe

If *n* is a goal, return path to *n*
Otherwise return failure

Search strategies

A search strategy is defined by picking the order of node expansion

Strategies are evaluated along the following dimensions:

- completeness: does it always find a solution if one exists?
- time complexity: number of nodes generated
- space complexity: maximum number of nodes in memory
- optimality: does it always find a least-cost solution?
- systematicity: does it visit each state at most once?

Time and space complexity are measured in terms of

- *b:* maximum branching factor of the search tree
- *d:* depth of the least-cost solution
- *m*: maximum depth of the state space (may be ∞)

Uninformed search strategies

Uninformed search strategies use only the information available in the problem definition

Breadth-first search

Depth-first search

Depth-limited search

Iterative deepening search

Depth First Search

Maintain stack of nodes to visit

Evaluation

- Complete?

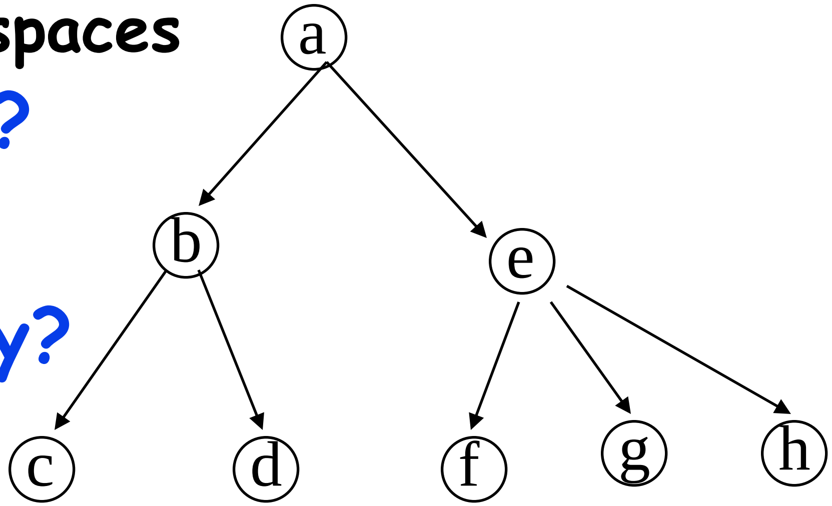
  Not for infinite spaces

- Time Complexity?

  O(b^m)

- Space Complexity?

  O(m)
  (though vanilla alg.
  in book has no backtracking, so O(mb))



Breadth First Search

Maintain queue of nodes to visit

Evaluation

- Complete?

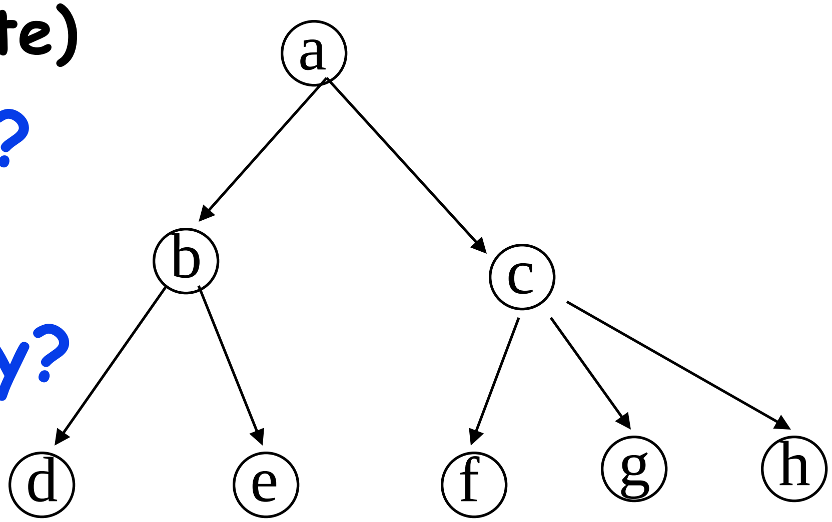
  Yes (assume b finite)

- Time Complexity?

  O(b^d)

- Space Complexity?

  O(b^d)



BFS: Memory Limitation

Suppose:

4-core 2 GHz CPU

8 GB main memory

100 cycles / expansion

10 bytes / node

800,000 expansions / sec

Memory filled in 100 sec … < 2 minutes

Iterative deepening search

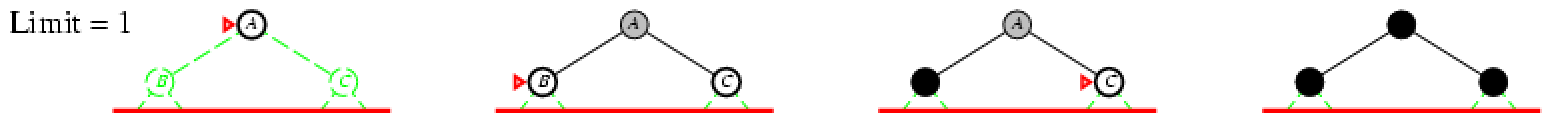
function ITERATIVE-DEEPENING-SEARCH(*problem*) **returns** a solution, or failure
  inputs: *problem*, a problem

  for *depth* ← 0 **to** ∞ **do**
    result ← DEPTH-LIMITED-SEARCH(*problem*, *depth*)
    if *result* ≠ cutoff **then return** *result*

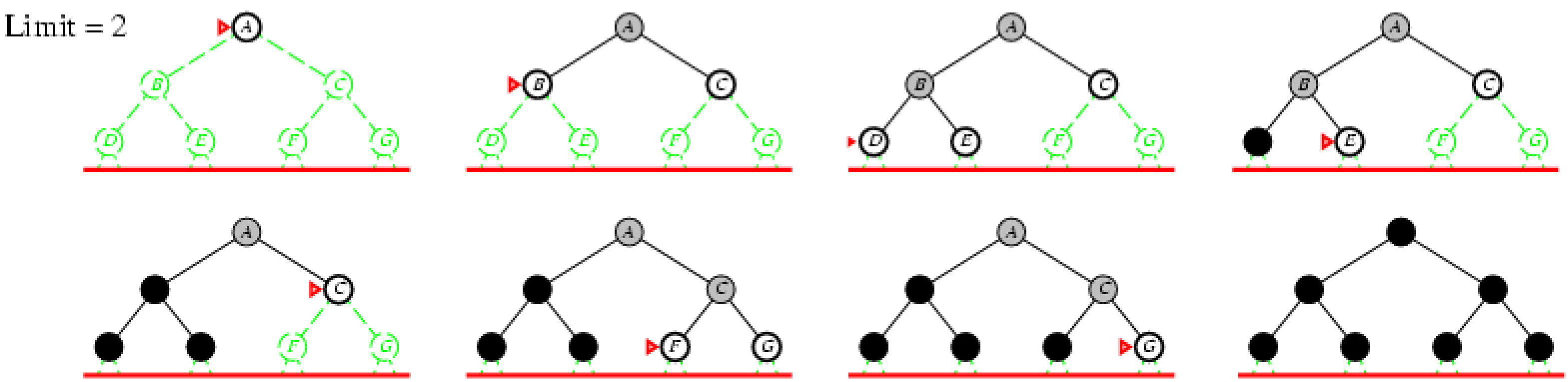
Iterative deepening search / =0

Limit = 0

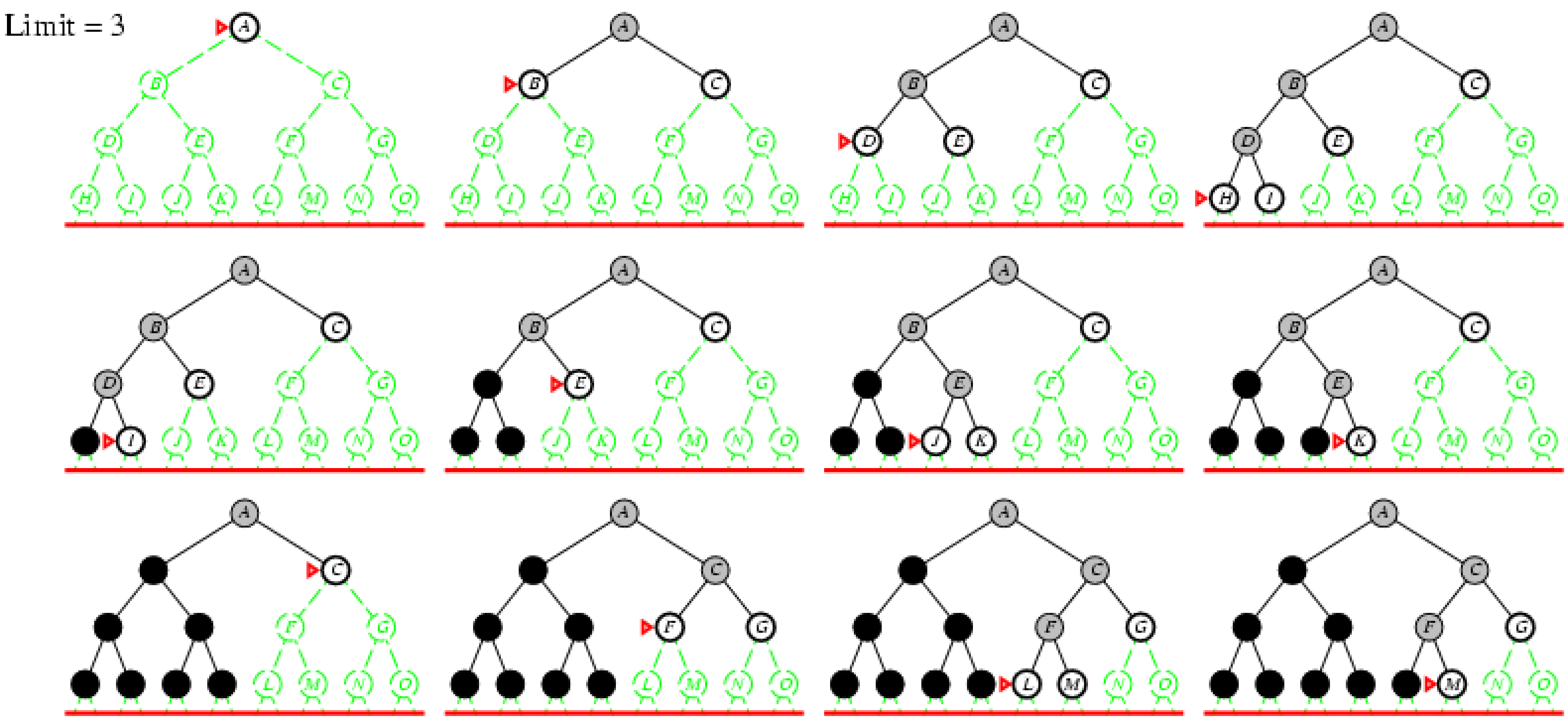
Iterative deepening search *l* =1



Iterative deepening search *l* =2



Iterative deepening search *l* =3



Iterative deepening search

Number of nodes generated in a depth-limited search to depth *d* with branching factor *b*:

$$N_{DLS} = b^0 + b^1 + b^2 + \ldots + b^{d-2} + b^{d-1} + b^d$$

Number of nodes generated in an iterative deepening search to depth *d* with branching factor *b*:

$$N_{IDS} = (d+1)b^0 + d\ b^{\wedge 1} + (d-1)b^{\wedge 2} + \ldots + 3b^{d-2} + 2b^{d-1} + 1b^d$$

For $b = 10$, $d = 5$,

- $N_{DLS} = 1 + 10 + 100 + 1{,}000 + 10{,}000 + 100{,}000 = 111{,}111$
- $N_{IDS} = 6 + 50 + 400 + 3{,}000 + 20{,}000 + 100{,}000 = 123{,}456$

Overhead = (123,456 - 111,111)/111,111 = 11%

Cost of Iterative Deepening

b	ratio ID to DFS
2	3
3	2
5	1.5
10	1.2
25	1.08
100	1.02

iterative deepening search

Complete? Yes

Time?

- $(d+1)b^0 + d\,b^1 + (d-1)b^2 + \ldots + b^d = O(b^d)$

Space?

- $O(d)$

Optimal?

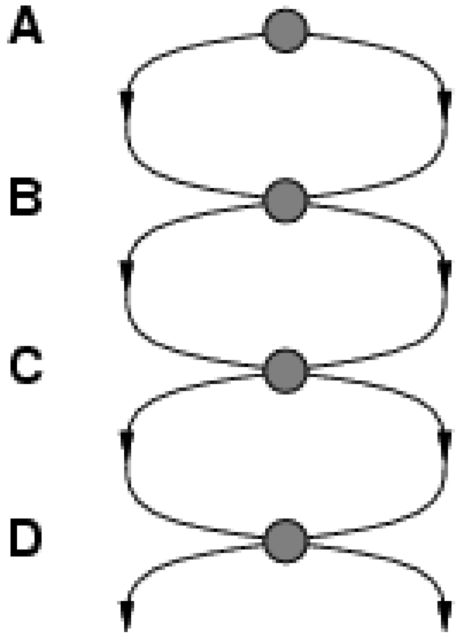
- Yes, if step cost = 1

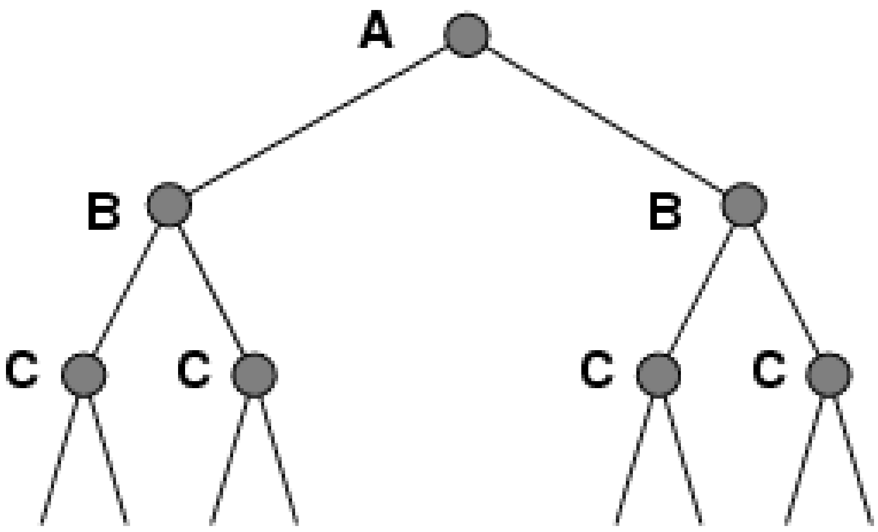
Systematic?

- No, but okay

Repeated states (1 of 3)

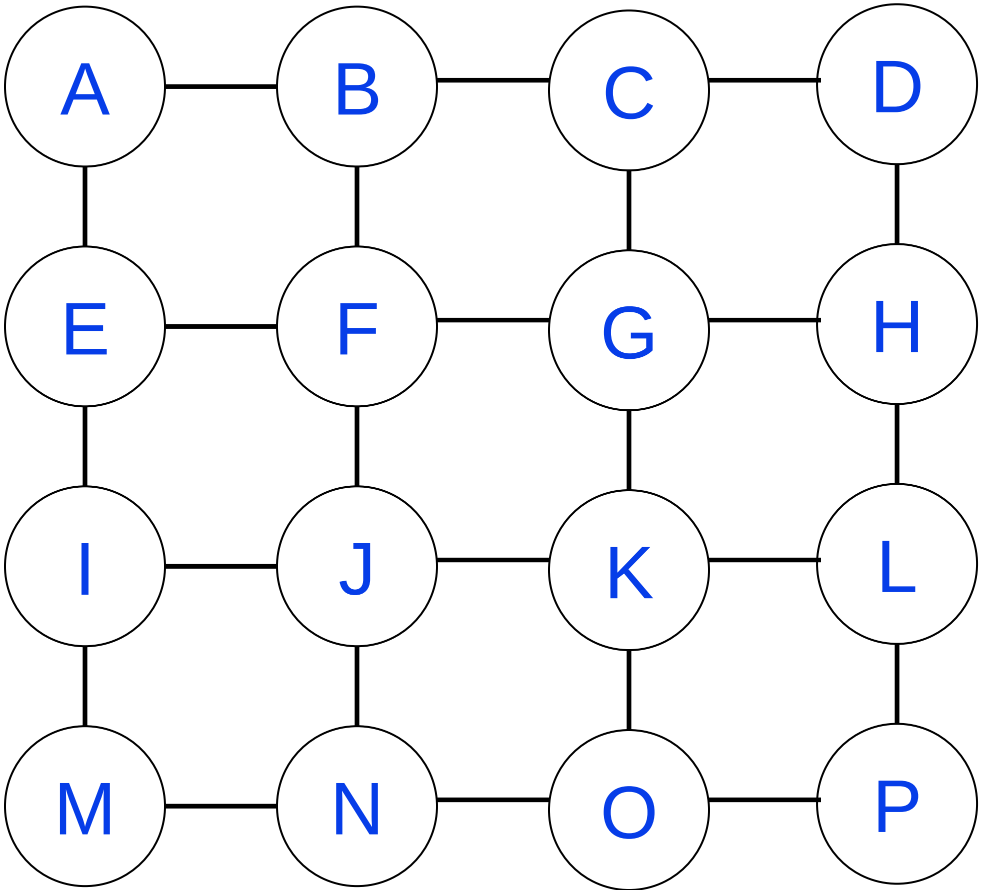
Failure to detect repeated states can turn a linear problem into an exponential one!





Repeated states (2 of 3)

More realistic case:

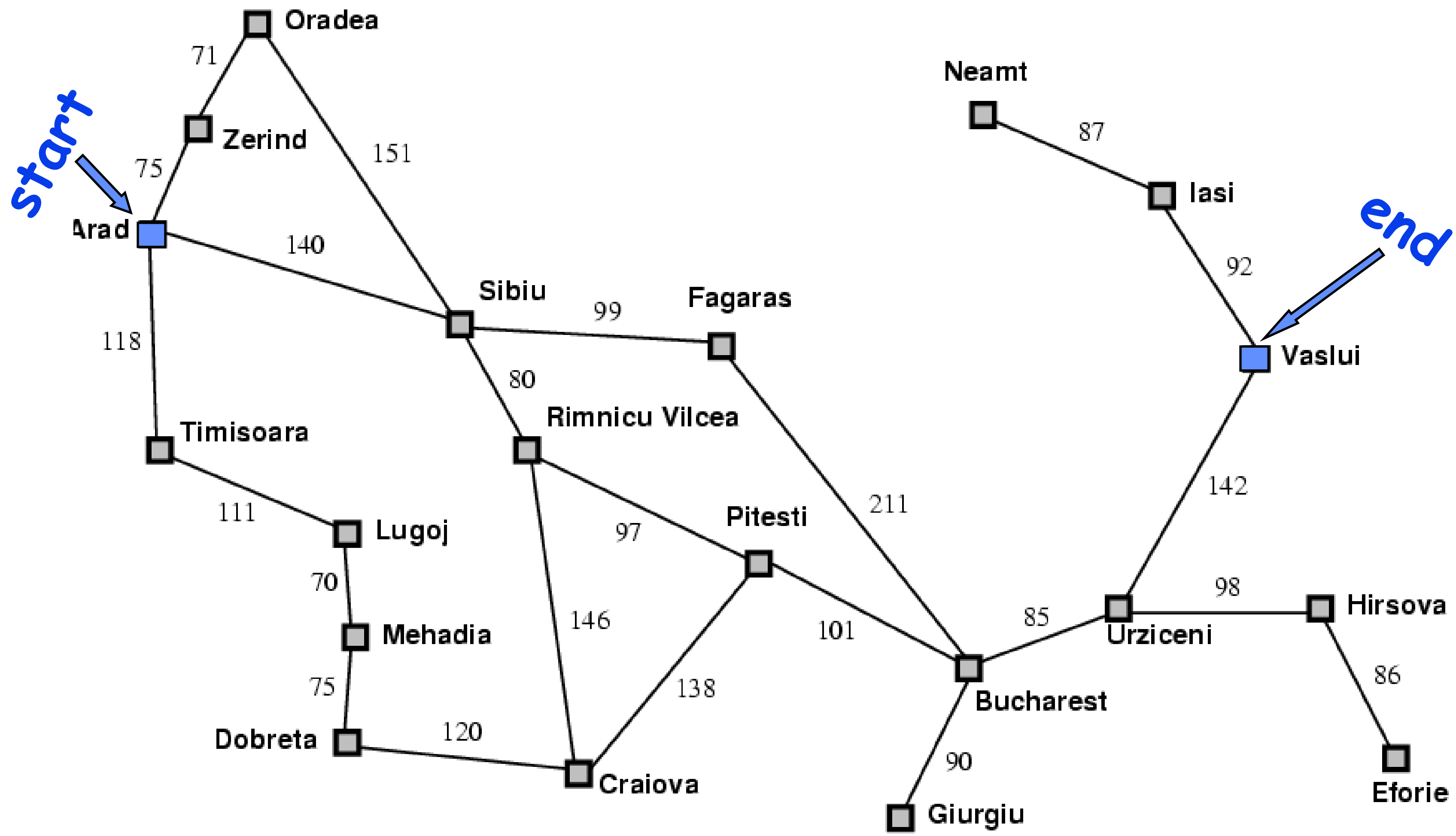


Repeated states (3 of 3)

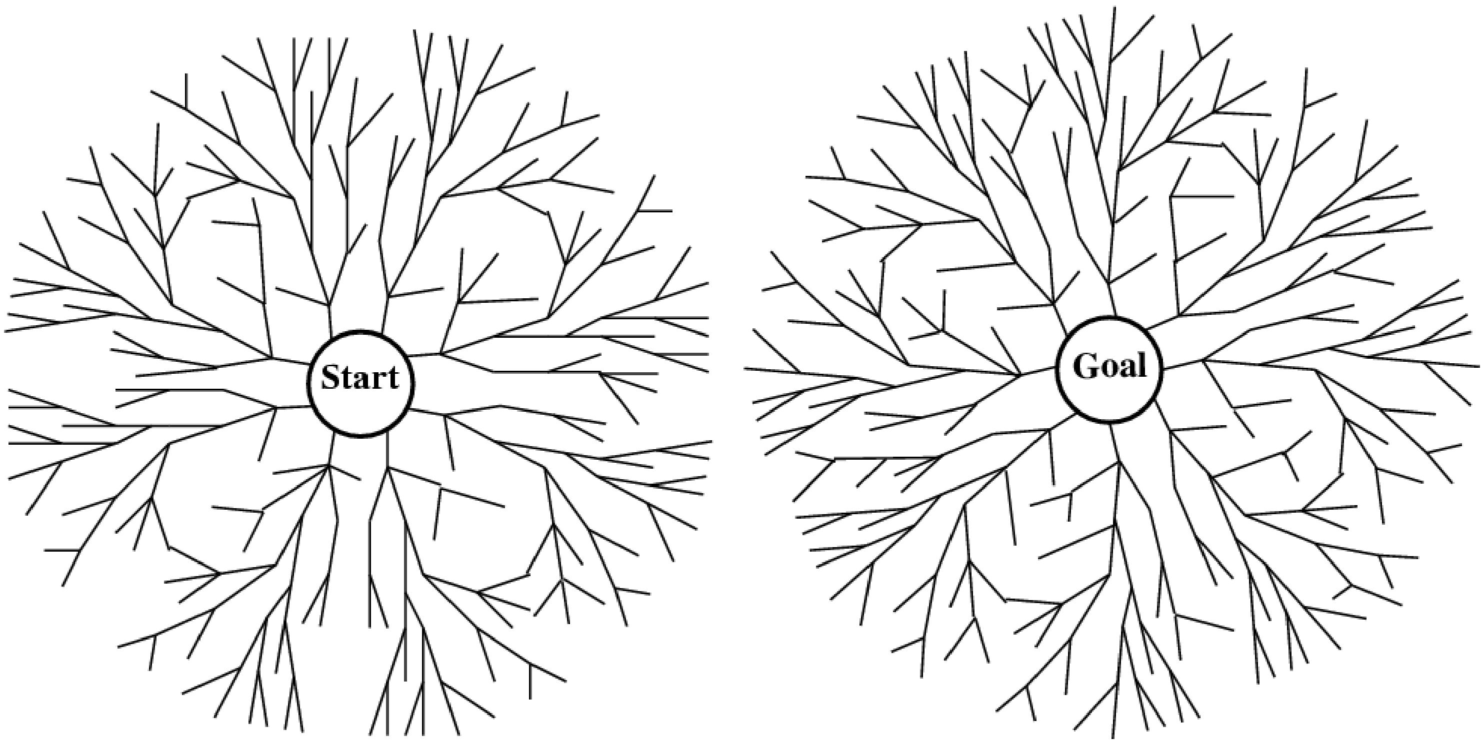
Can save states but…then iterative deepening with DFS no longer takes $O(m)$ space!

What space is required?

Forwards vs. Backwards



vs. Bidirectional



Recap: Tree Search

Fringe = root node

Repeat while fringe non-empty

  Take *n* from Fringe

  If *n* is a goal

      break (we're done)

  Else

      Expand n: add *n*'s successors to Fringe

If n is a goal, return path to n

Otherwise return failure

Summary

Search problems

Search strategies

DFS, BFS, Iterative Deepening w/depth-limited DFS

Issue: All these methods are slow (blind)

Solution → add guidance ("heurstic estimate")

→ "informed search"

Backup

Example: Romania

On holiday in Romania; currently in Arad.
Flight leaves tomorrow from Bucharest

Formulate goal:

- be in Bucharest
-

Formulate problem:

- **states**: various cities
- **actions**: drive between cities
-

Find solution:

- sequence of cities, e.g., Arad, Sibiu, Fagaras, Bucharest

Example: N Queens

		Q	
Q			
			Q
	Q		

Input:

- Set of states

- Operators [and costs]

- Start state

- Goal state (test)

Output