

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

7	2	4
5		6
8	3	1

Start State

	1	2
3	4	5
6	7	8

Goal State

states?

actions?

goal test?

path cost?

Example: The 8-puzzle

7	2	4
5		6
8	3	1

Start State

	1	2
3	4	5
6	7	8

Goal State

states? locations of tiles

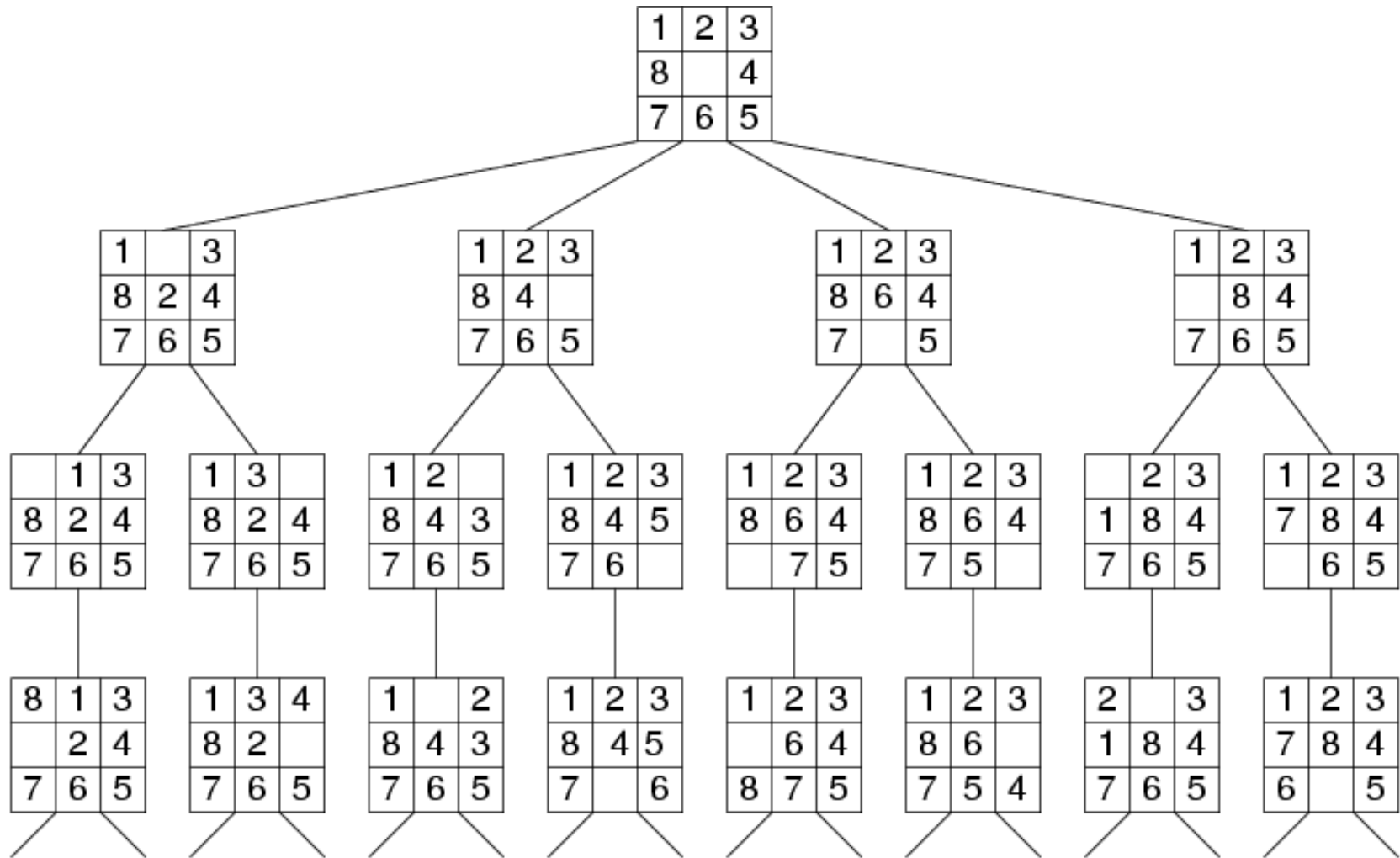
actions? move blank left, right, up, down

goal test? = goal state (given)

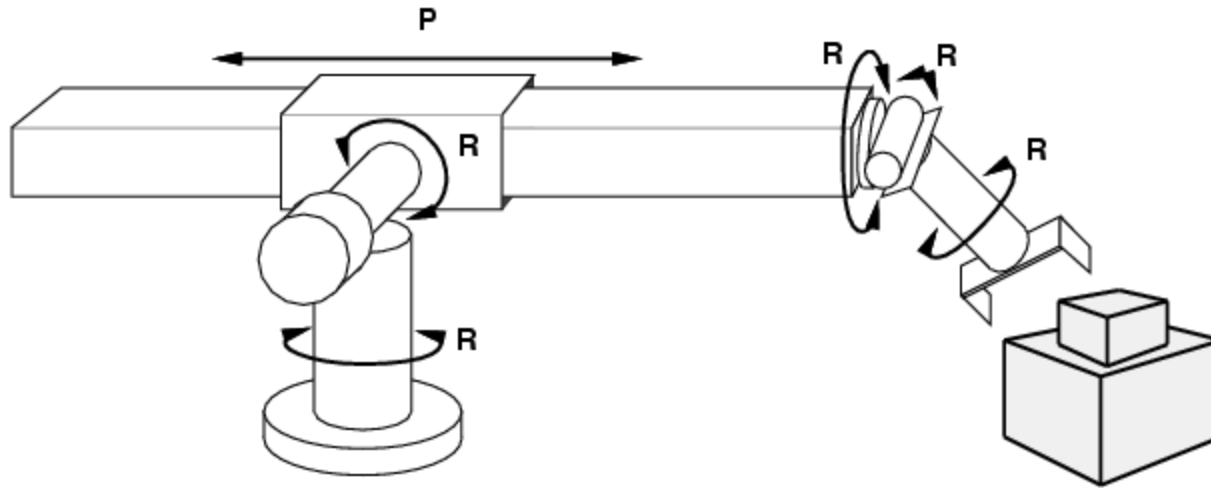
path cost? 1 per move

[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

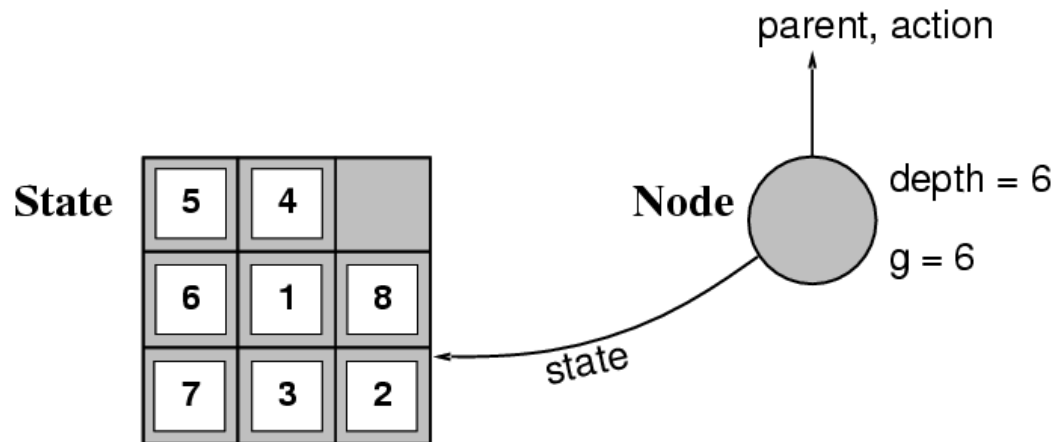
goal test?: complete assembly

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

Frontier = root node

Repeat while Frontier non-empty

Take n from Frontier

For all n' in Expand(n)

if n' is a goal, return it

else add n' to Frontier

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 shallowest 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

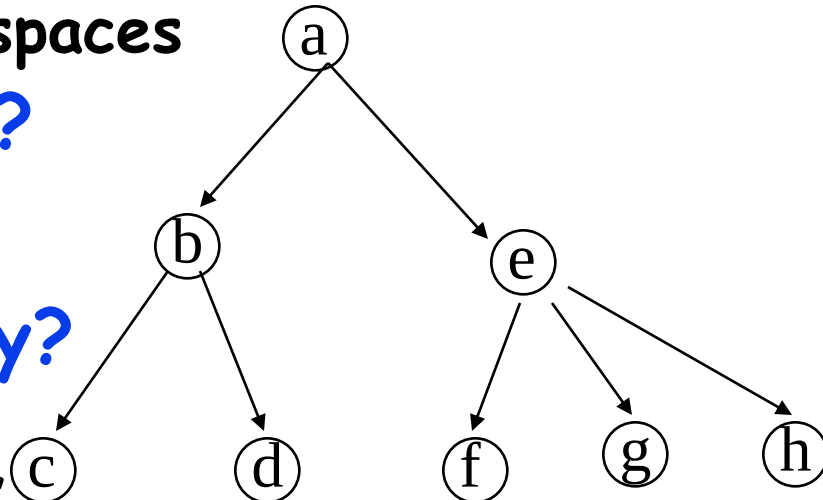
- **Time Complexity?**

$O(b^m)$

- **Space Complexity?**

$O(mb)$

(with "backtracking"
can be $O(m)$)

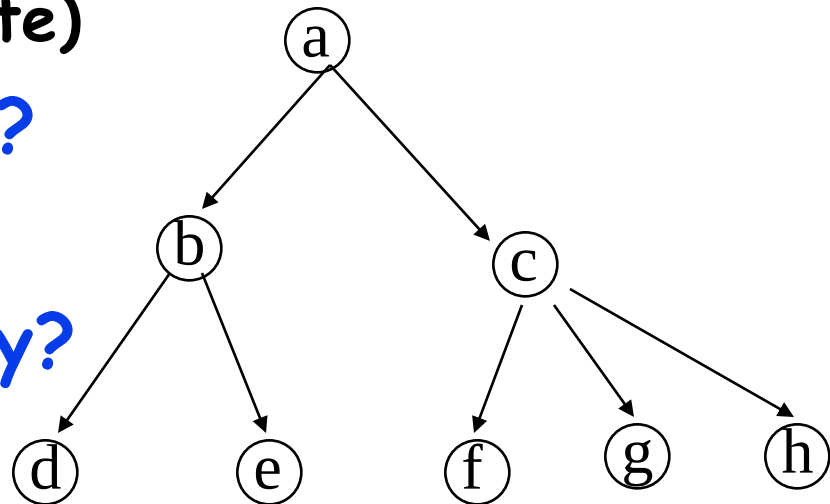


Breadth First Search

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 fail-  
ure  
  inputs: problem, a problem  
  for depth  $\leftarrow$  0 to  $\infty$  do  
    result  $\leftarrow$  DEPTH-LIMITED-SEARCH( problem, depth)  
    if result  $\neq$  cutoff then return result
```

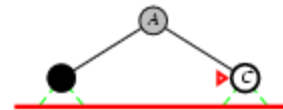
Iterative deepening search / =0

Limit = 0



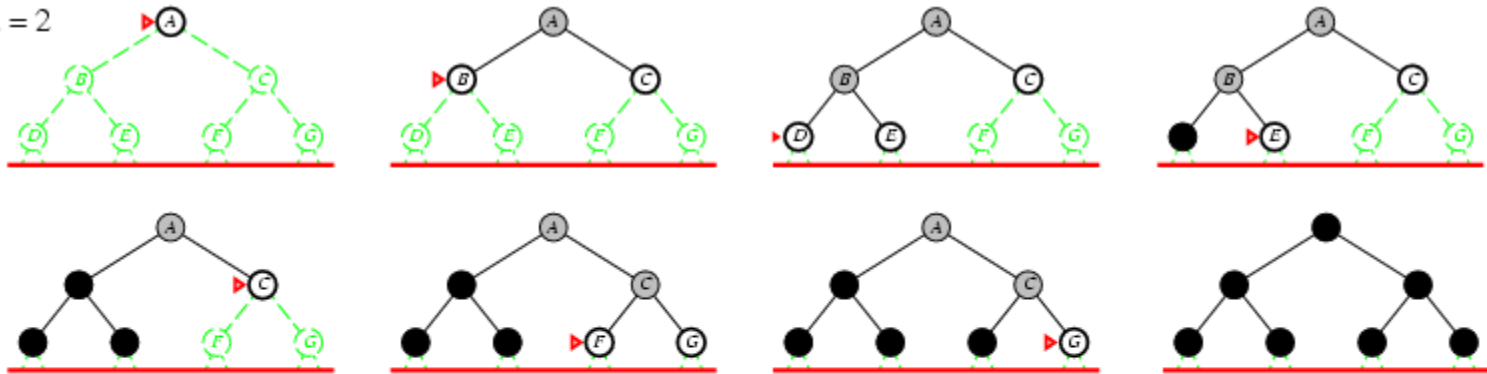
Iterative deepening search / =1

Limit = 1



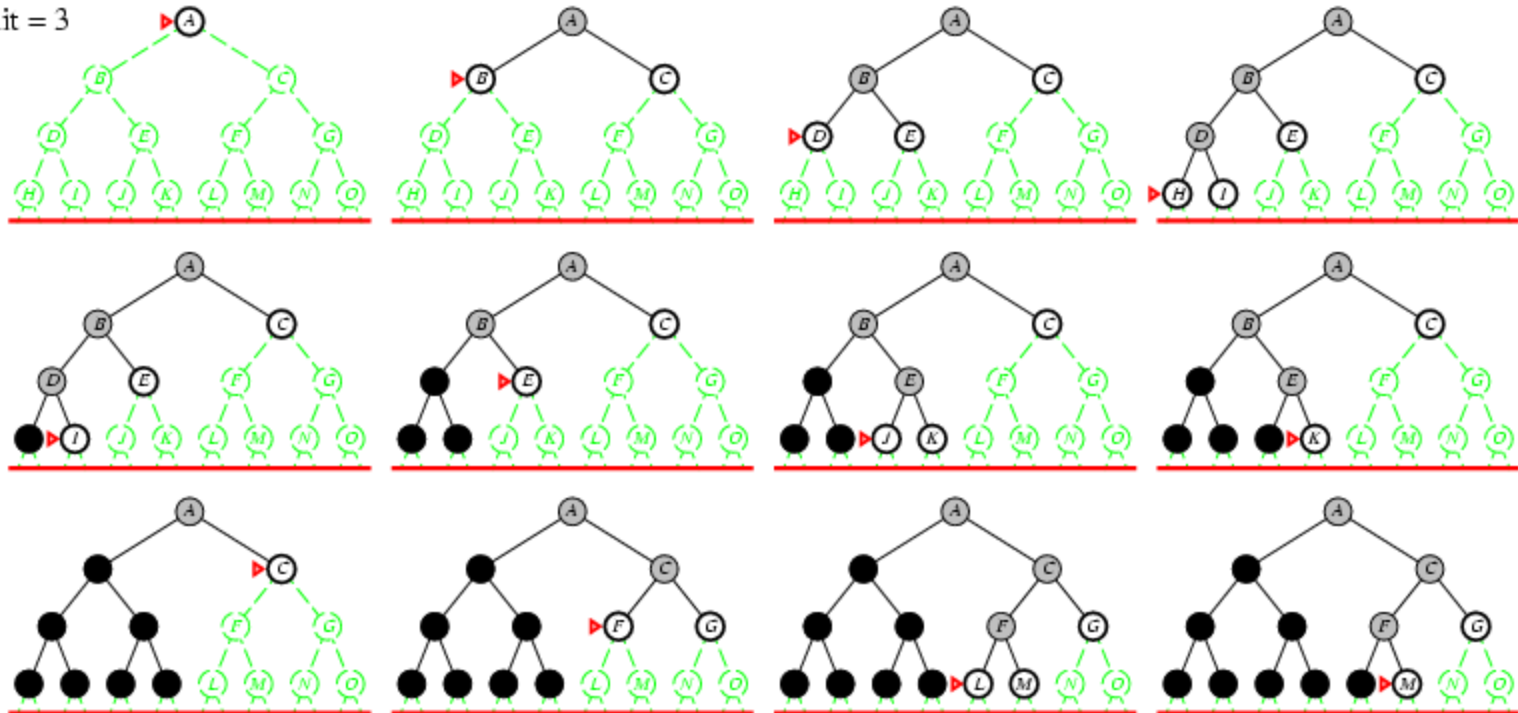
Iterative deepening search / =2

Limit = 2



Iterative deepening search / =3

Limit = 3



Iterative deepening search

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

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

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

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

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

- $N_{DLS} = 1 + 10 + 100 + 1,000 + 10,000 + 100,000 = 111,111$

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

$$\text{Overhead} = (123,456 - 111,111)/111,111 = 11\%$$

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?

$$\cdot (d+1)b^0 + d b^1 + (d-1)b^2 + \dots + b^d = O(b^d)$$

Space?

$$\cdot O(bd)$$

Optimal?

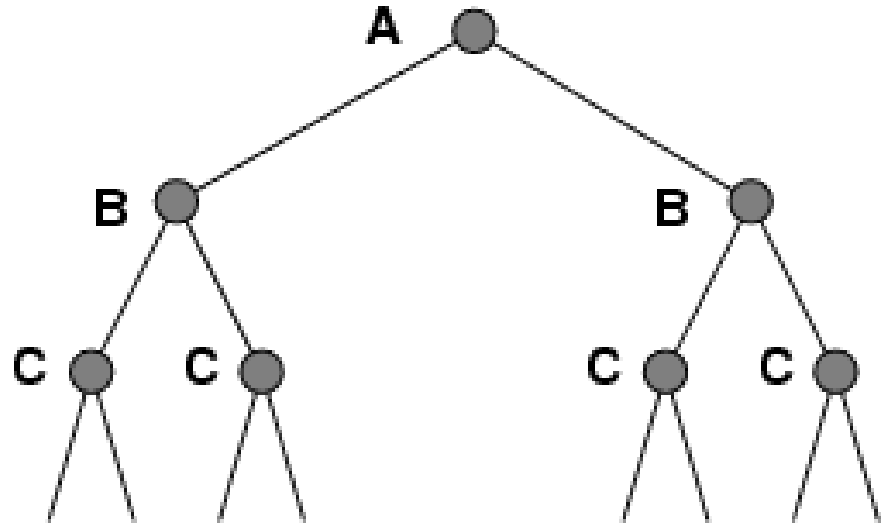
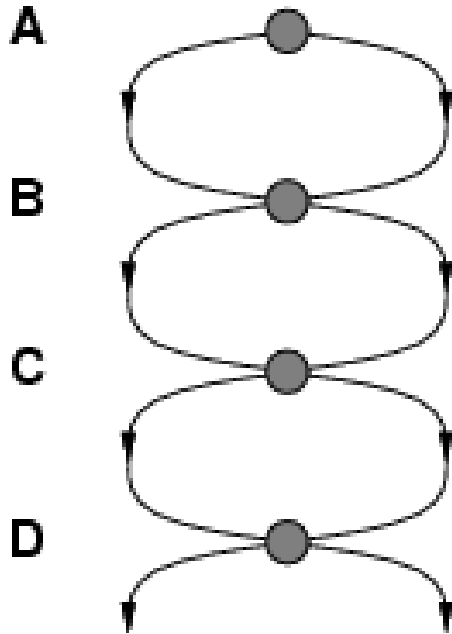
- Yes, if step cost = 1

Systematic?

- No, but okay

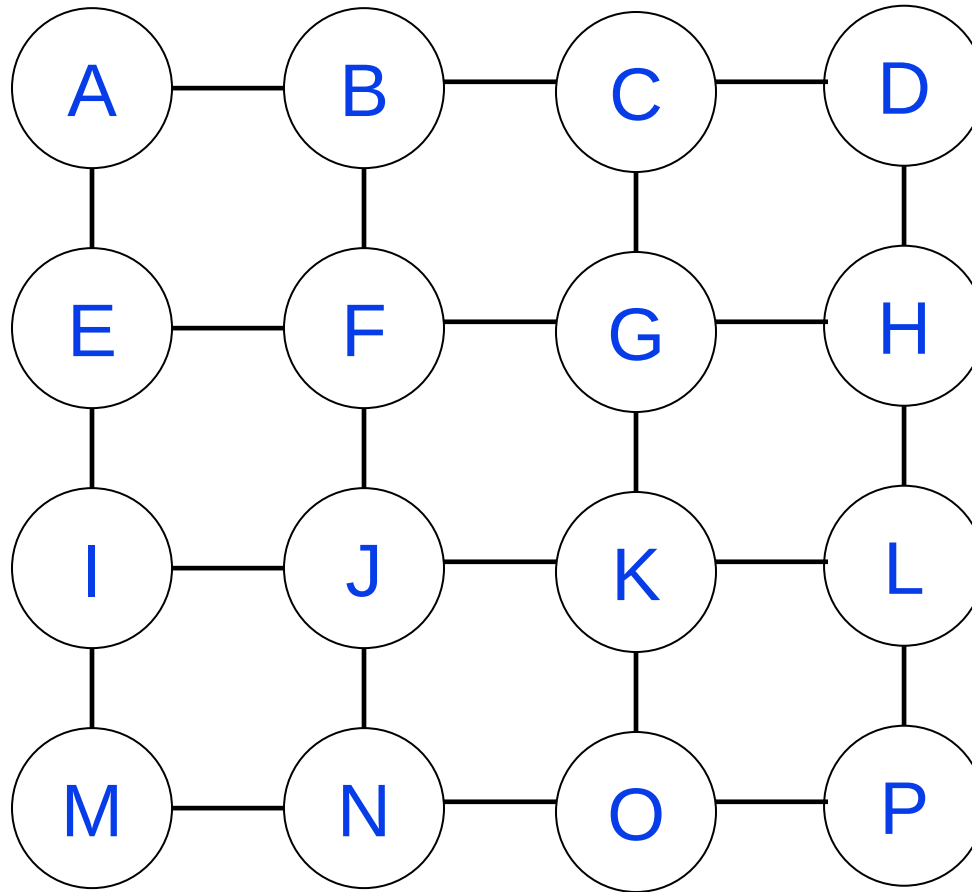
Repeated states (1 of 3)

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



Repeated states (2 of 3)

More realistic case:

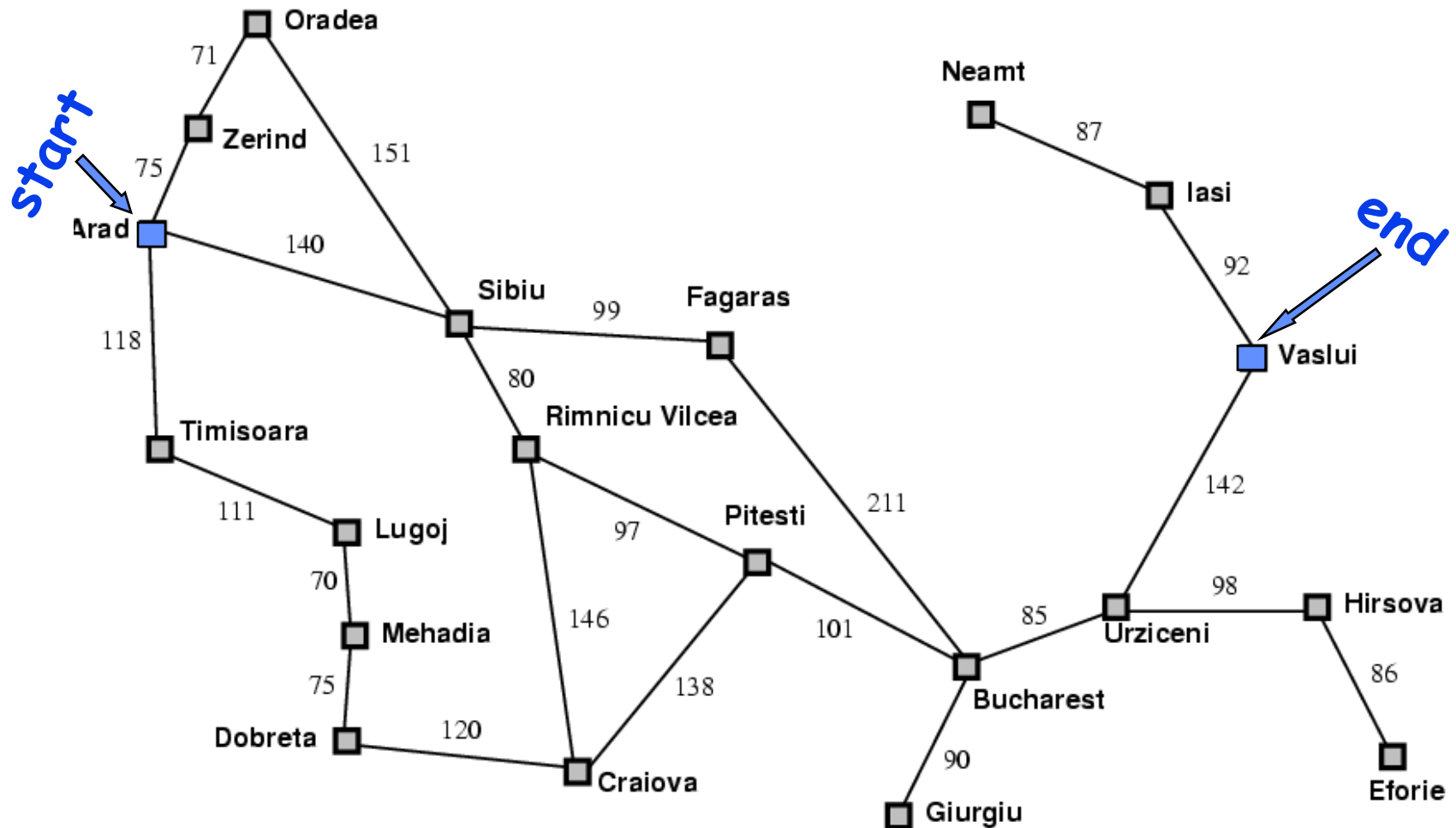


Repeated states (3 of 3)

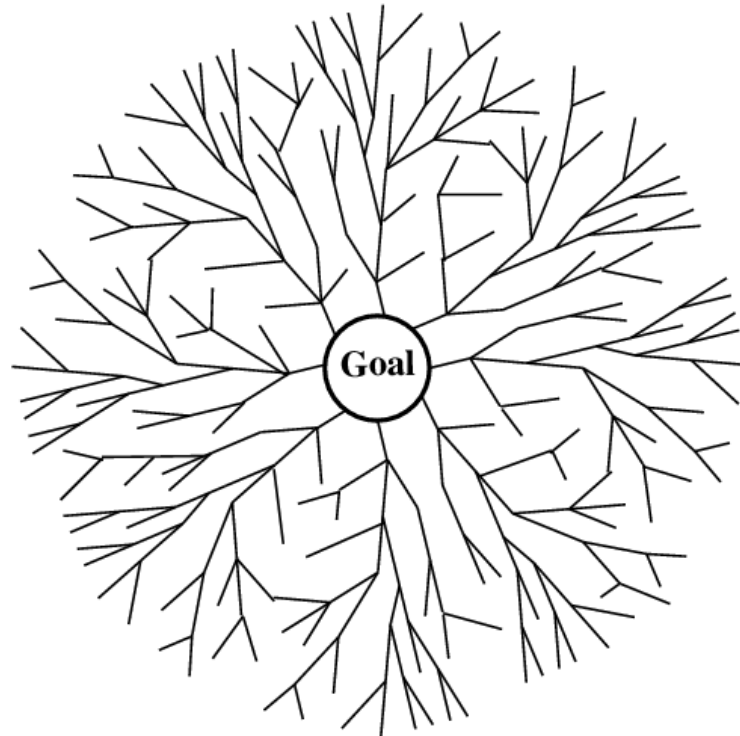
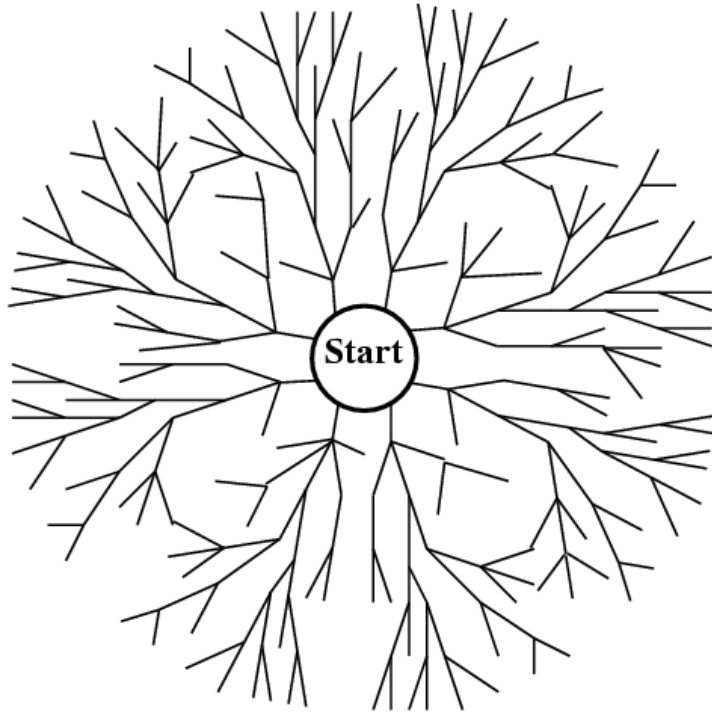
Can save states but...then iterative deepening
with DFS no longer takes $O(d)$ space!

What space is required?

Forwards vs. Backwards



vs. Bidirectional



Recap: Tree Search

Frontier = root node

Repeat while Frontier non-empty

Take n from Frontier

For all n' in Expand(n)

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Summary

Search problems

Search strategies

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

Issue: All these methods are slow (blind)

Solution → add guidance (“heuristic estimate”)
→ “informed search”

Survey!

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

Input:

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

		Q	
Q			
			Q
	Q		

Output