CSC421 Intro to Artificial Intelligence

UNIT 02:
Solving Problems by Searching

Search problems

- Blind (no information about problem other than it's definition)
- Informed (heuristic) search (next lecture)
- Examples of search problems:
  - Board games
  - Scheduling
  - Theorem proving
  - Robot Navigation
  - Combat NPC in game
- The workhorse of old classic AI
- Works well for “toy words”

Sidenote I

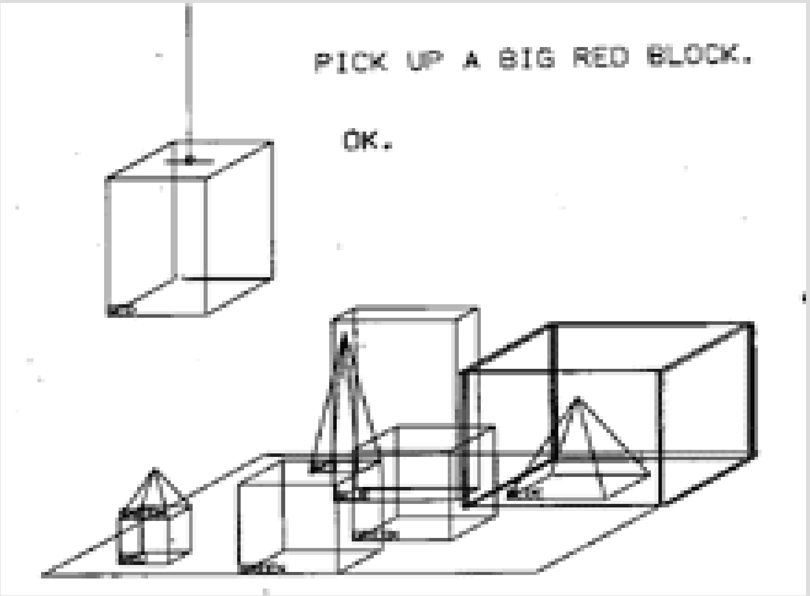
Search works really well in “Microworlds” or “toy worlds”

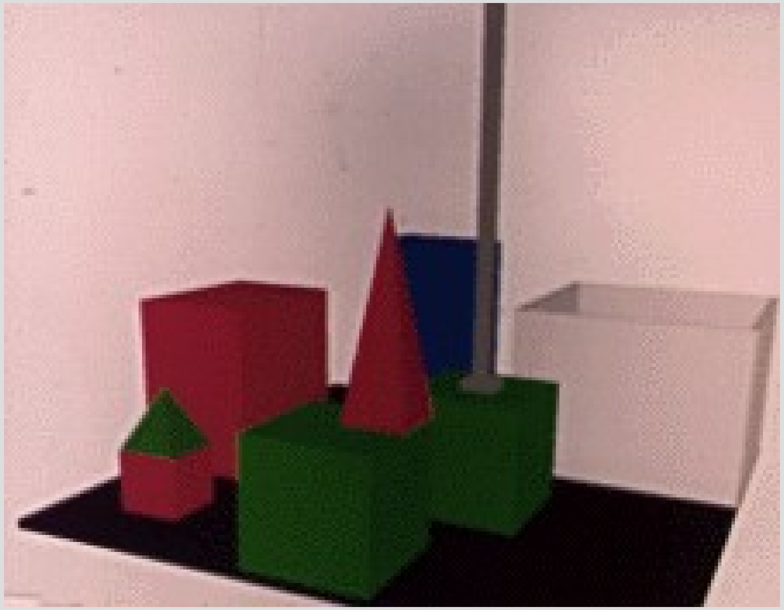
SAINT (James Stagle – 1963) Closed-form calculus integration problems

ANALOGY (Tom Evans-1968) Geometry analogy problems that appear in IQ test

Blocks world (vision, constraint-propagation, learning, natural language understanding)

Sidenote II





Sidenote III

Person: PICK UP A BIG RED BLOCK.
Computer: OK. (does it)
Person: GRASP THE PYRAMID.
Computer: I DON'T UNDERSTAND WHICH PYRAMID YOU MEAN.
Person: FIND A BLOCK WHICH IS TALLER THAN THE ONE YOU ARE HOLDING AND PUT IT INTO THE BOX.
Computer: BY "IT", I ASSUME YOU MEAN THE BLOCK WHICH IS TALLER THAN THE ONE I AM HOLDING.
Computer: OK. (does it)
Person: WHAT DOES THE BOX CONTAIN?
Computer: THE BLUE PYRAMID AND THE BLUE BLOCK.
Person: WHAT IS THE PYRAMID SUPPORTED BY?
Computer: THE BOX.
Person: HOW MANY BLOCKS ARE NOT IN THE BOX?
Computer: FOUR OF THEM.

Searching is limited by

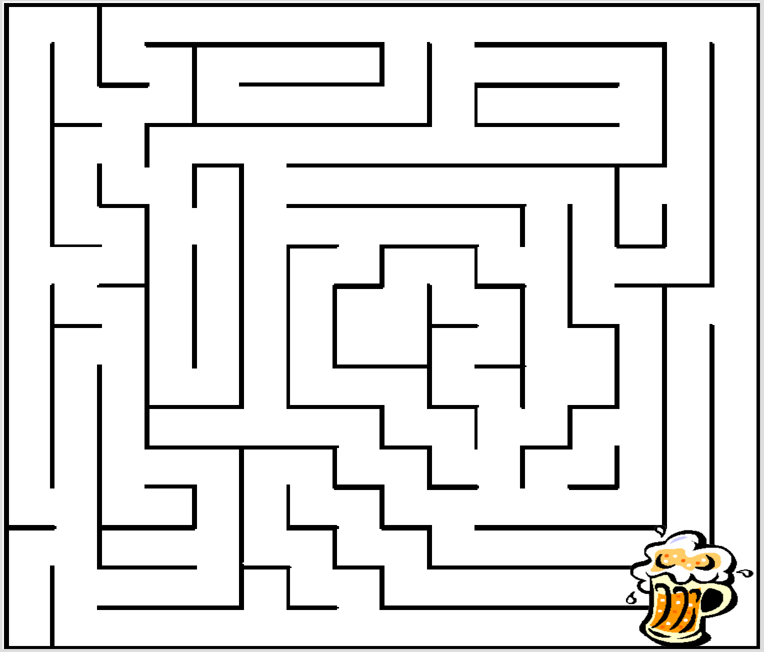
- Precise formulation of problem
- Typically
  - Static
  - Deterministic
  - Offline
- No learning
- Hard to deal with uncertainty
- Easier to implement and understand
- Therefore cover the corresponding material relatively quickly

Formulation: the main challenge

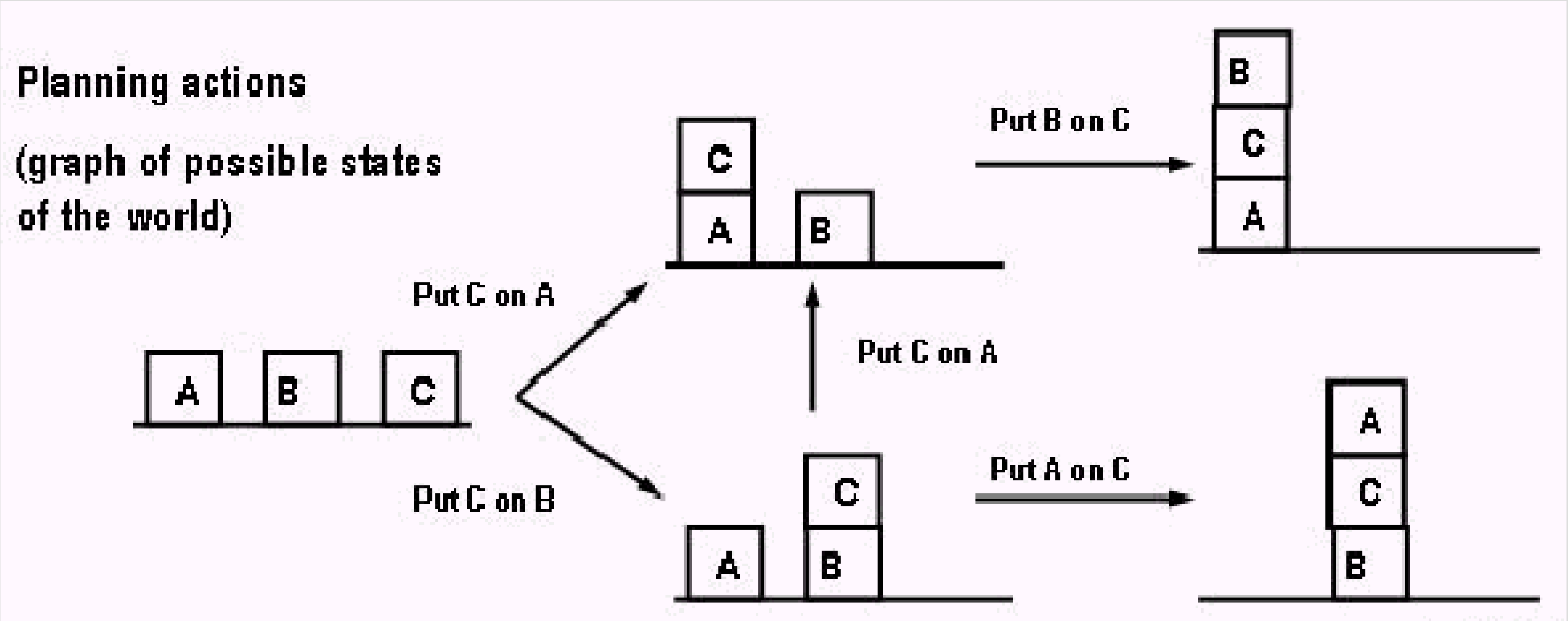
Formulate-goal
- Discover the scroll of infinite AI wisdom

Formulate-problem
- States: Grid locations
- Actions: NW, N, NE, W, E, SW, S, SE

Formulate-solution
- Sequence of grid locations



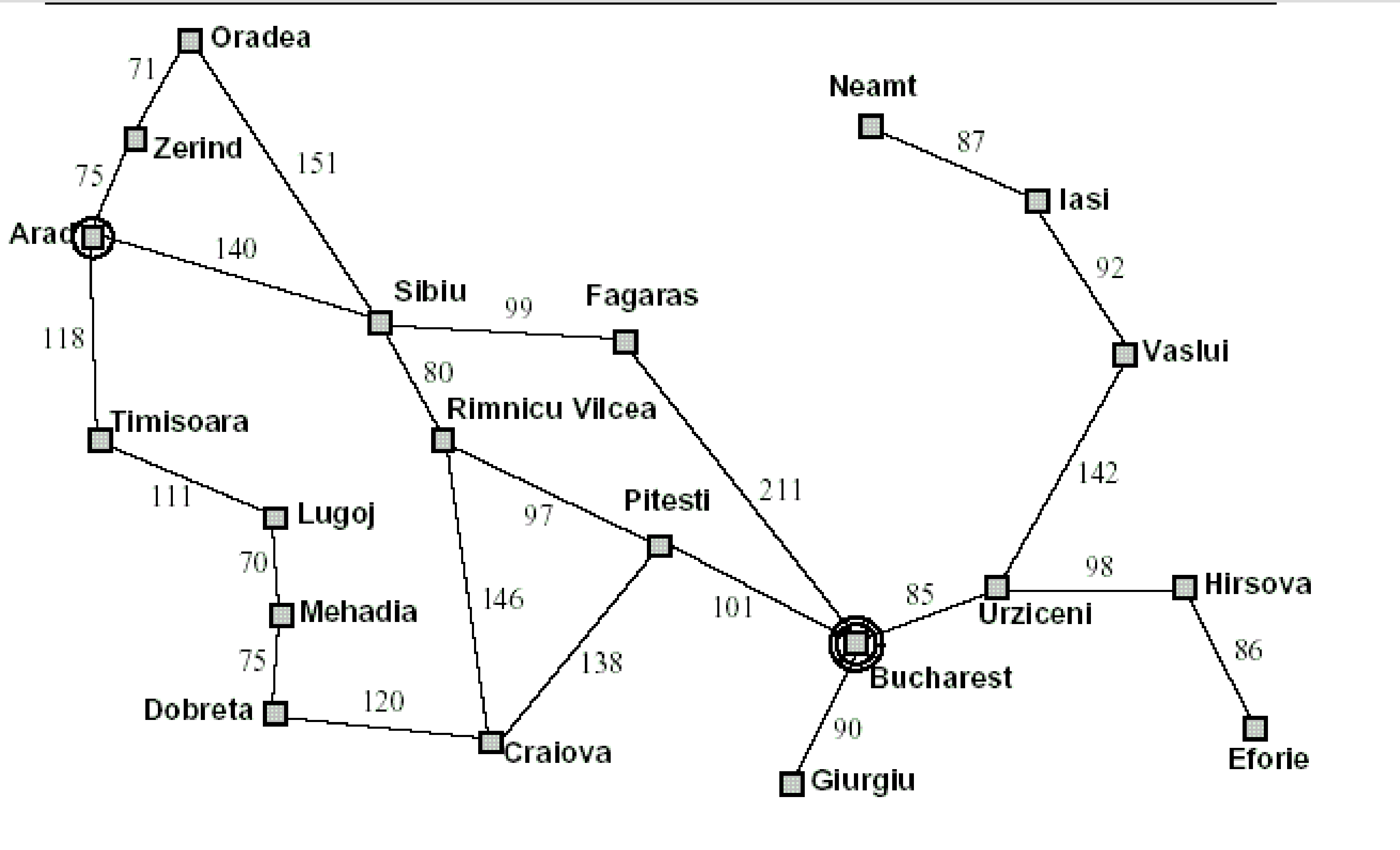
Graphs are your friend



A **path** through such a graph (from a start node to a goal node) is a "plan of action" to achieve some desired goal state from some known starting state.

Turn AI problems into graphs and you are almost done

Map example


Oradea
71
Zerind
75
Arad
151
140
118
Sibiu
99
Fagaras
80
Rimnicu Vilcea
Timisoara
111
Lugoj
70
Mehadia
75
Dobreta
120
Craiova
146
97
Pitesti
138
101
211
Neamt
87
Iasi
92
Vaslui
142
Urziceni
85
98
Hirsova
86
Eforie
Bucharest
90
Giurgiu

Single state-space formulation

A problem is defined by four items:

Initial state e.g., "at Arad"

Actions and successor function *S:* = set of **action-state** tuples

e.g., *S(Arad)* = {*(goZerind, Zerind), (goTimisoara, Timisoara), (goSilbiu, Silbiu)*}

Goal test, can be

explicit, e.g., x = "at Bucharest"

implicit, e.g., *Checkmate(x)*

Path cost (additive)

e.g., sum of distances, or number of actions executed, etc.

$c(x,a,y)$ is the step cost, assumed to be ≥ 0

A solution is a sequence of actions leading from the initial state to a goal state

State Spaces

Real world is absurdly complex - state space must be abstract

For for problem solving :

(Abstract) state = set of real states

(Abstract) action = complex combination of real actions e.g., “go from Arad to Zerind" represents a complex set of possible routes, de-tours, rest stops, etc. For guaranteed realizability, any real state in Arad must get to some real state in Zerind

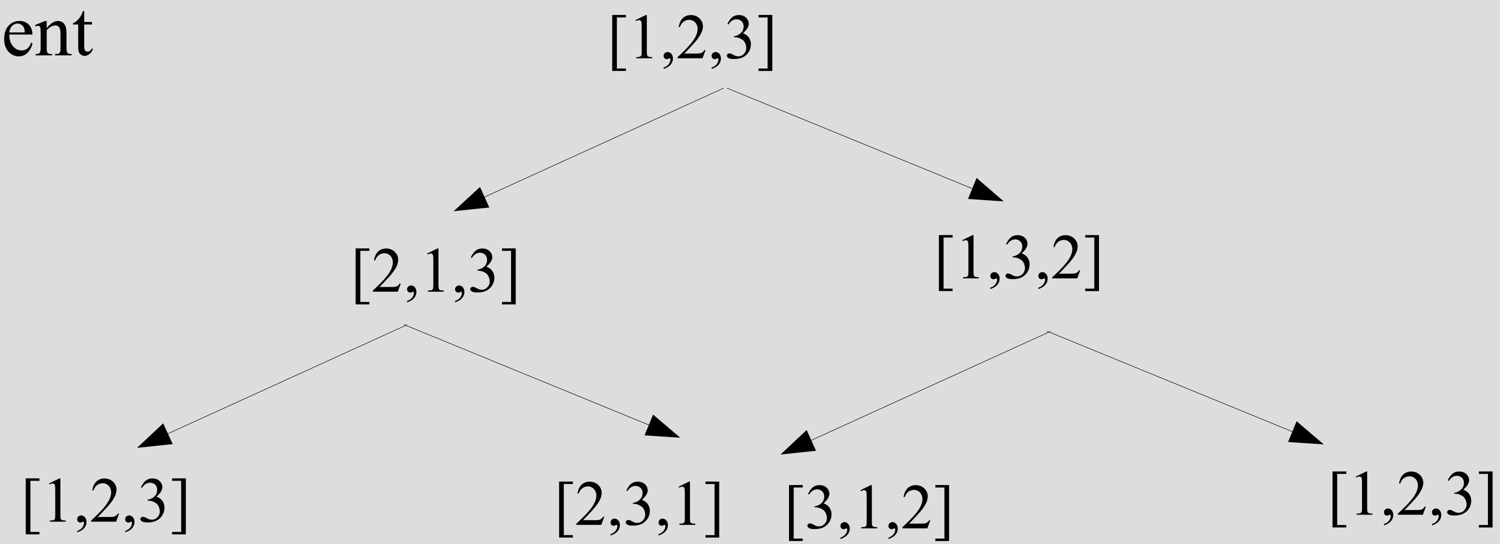
(Abstract) solution = set of real paths that are solutions in the real world Each abstract action should be “easier" than the original problem!

Appliance Factory Example

Three work cells 1,2,3 – arrange cells to form assembly line

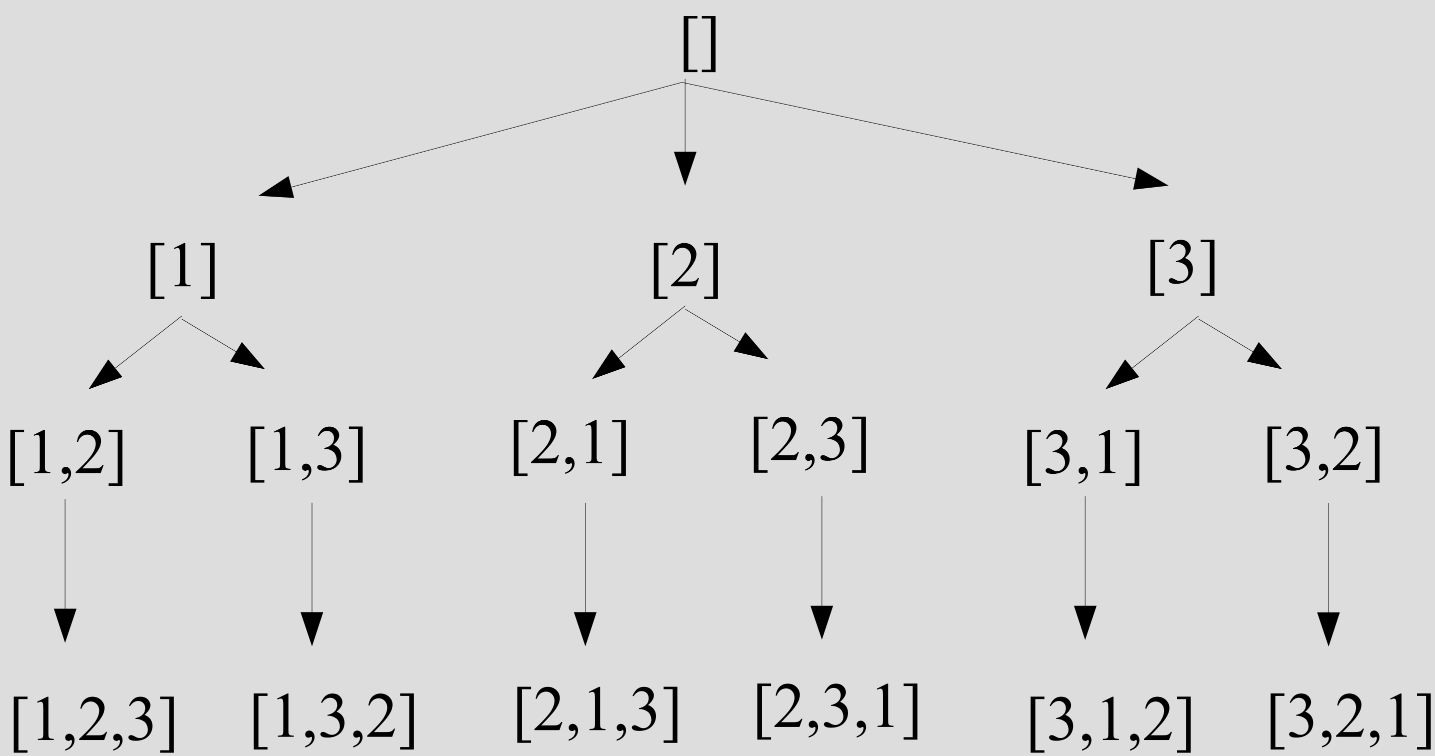
Each work cell capable of performing different assembly operations with dependencies

State Space 1 – all permutations, operators reorder adjacent



Appliance Factory II

State Space 2 – all sequence, operators reorder



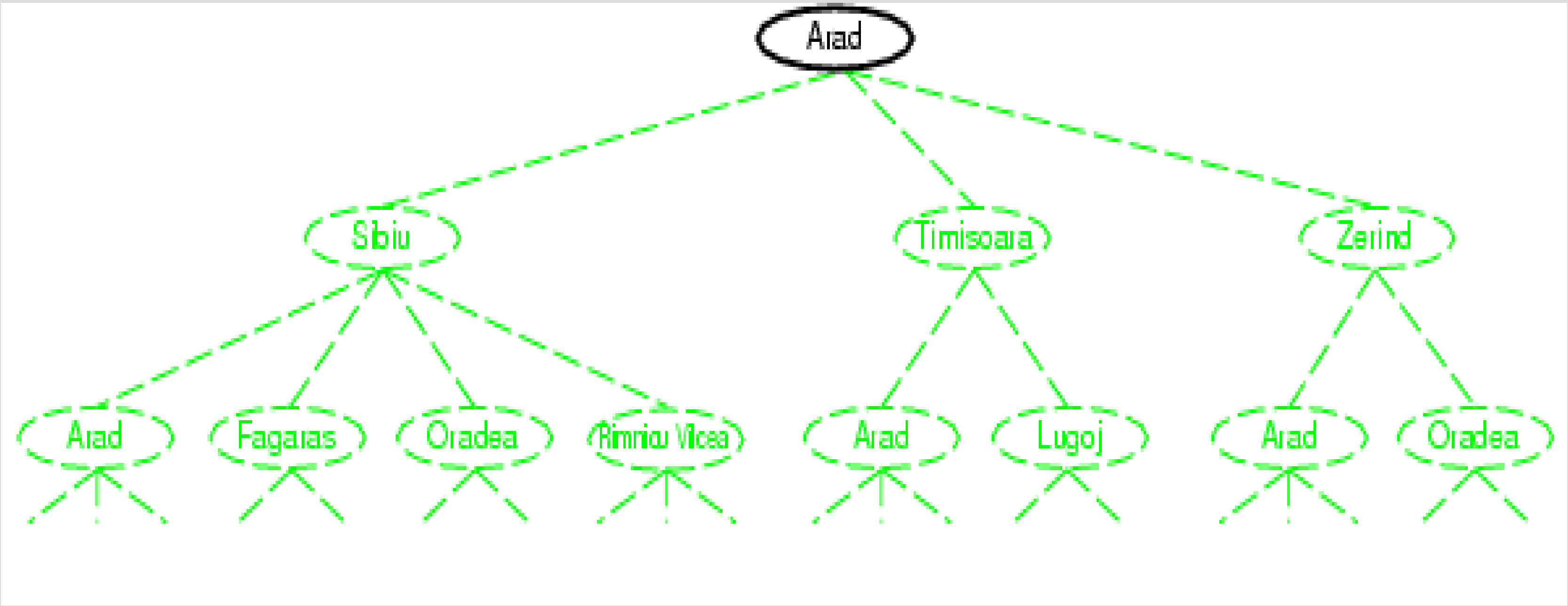
Tree search algorithms

Basic idea:

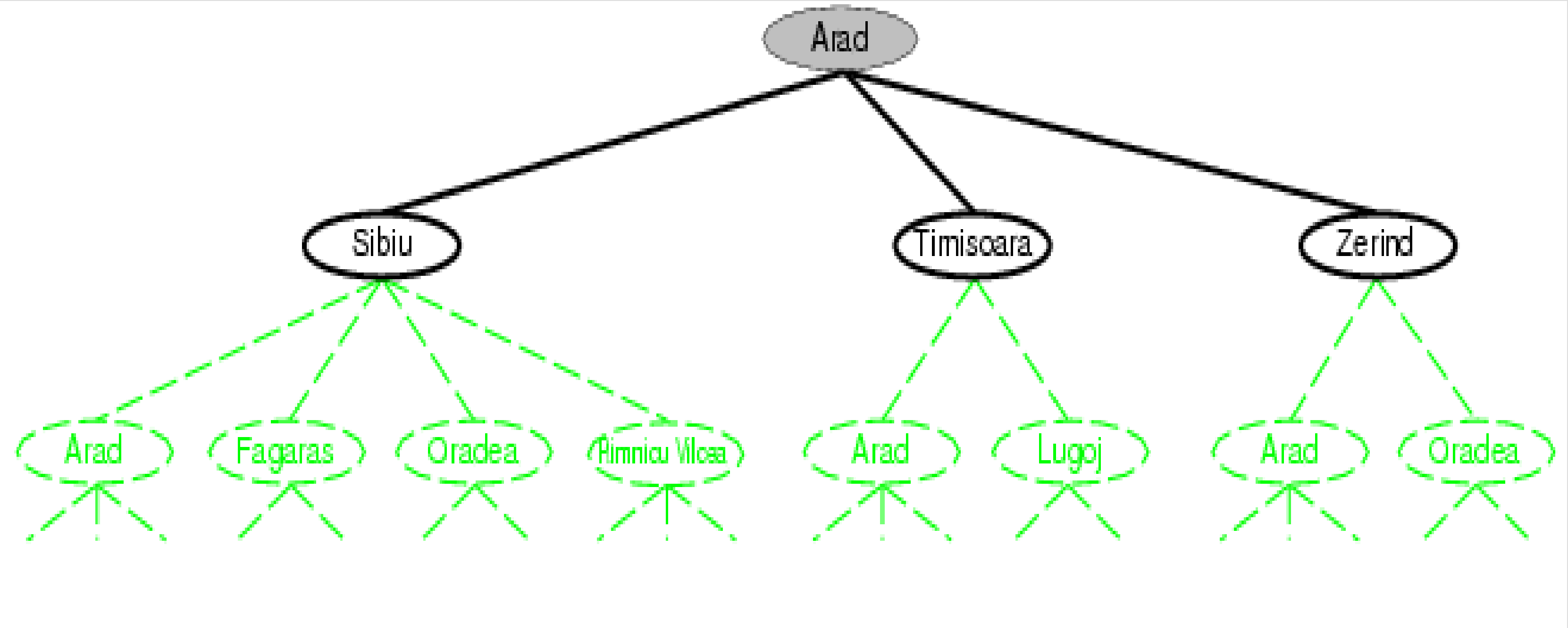
Exploration of state space by generating successors of already explored states

function TREE-SEARCH(*problem*, *strategy*) **returns** a solution, or failure
    initialize the search tree using the initial state of *problem*
    loop do
        if there are no candidates for expansion **then return** failure
        choose a leaf node for expansion according to *strategy*
        if the node contains a goal state **then return** the corresponding solution
        else expand the node and add the resulting nodes to the search tree

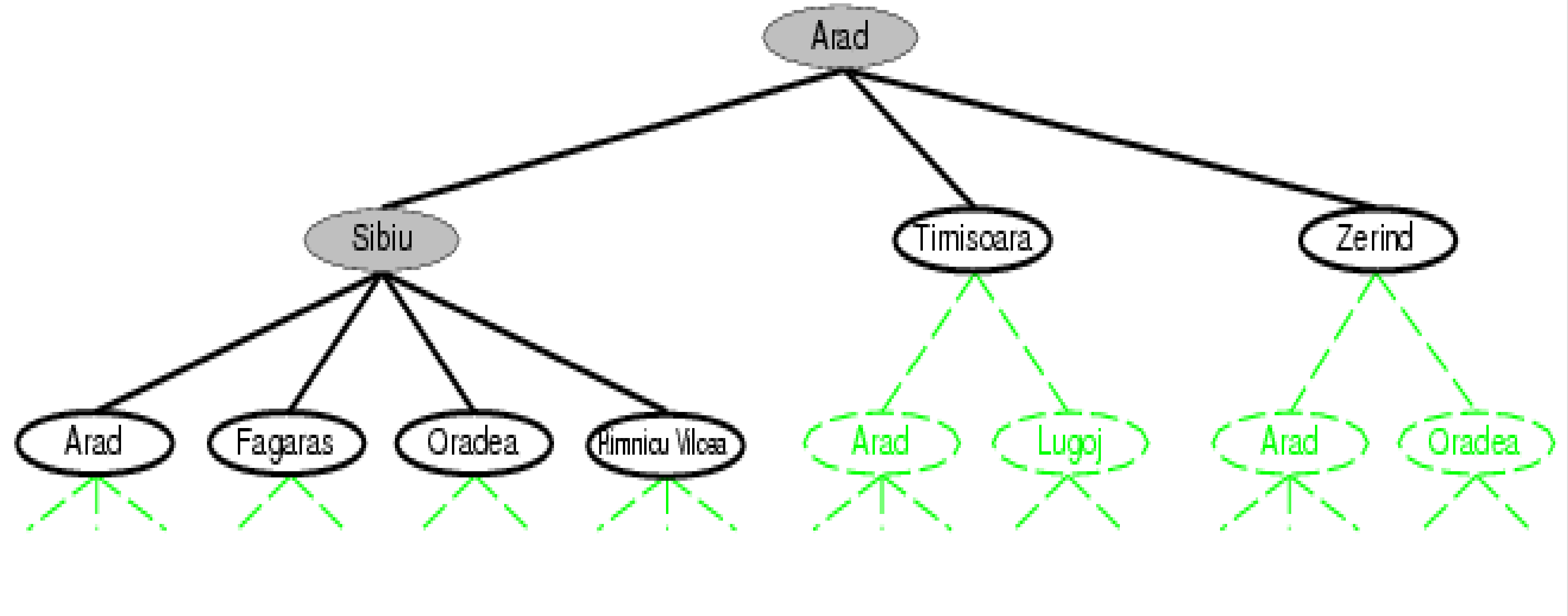
Tree search example



Tree Search example



Tree search example

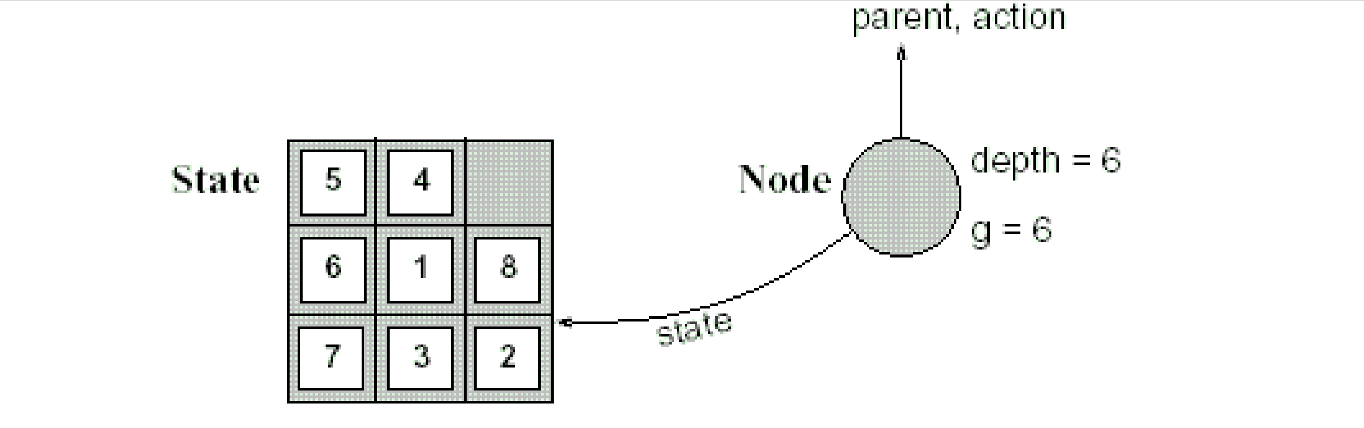


Implementation: States vs Nodes

A state is a representation of a physical configuration

A node is a data structure constituting part of a search tree including (parent, children, depth, cost g(x))

States do not have parents, children or costs



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?

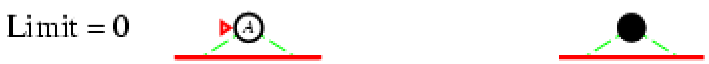
Time and space complexity:

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

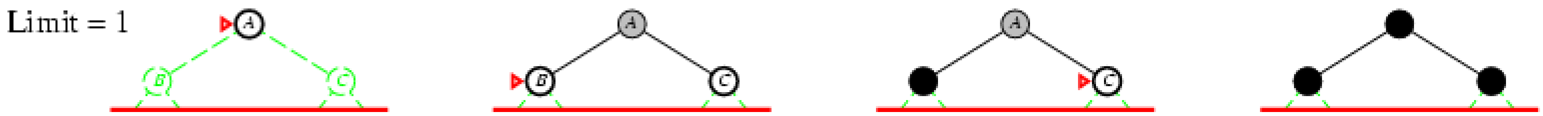
Uninformed Search Strategies

- Breadth-first search
- Uniform-cost search
- Depth-first search
- Depth-limited search
- Iterative-deepening search
- Fringe (collection of nodes that have been generated but not yet expanded)
  - BFS – FIFO
  - UCS – PRIORITY QUEUE
  - DFS – LIFO
  - DLS – DFS with cutoff
  - IDS - Multiple times DLS

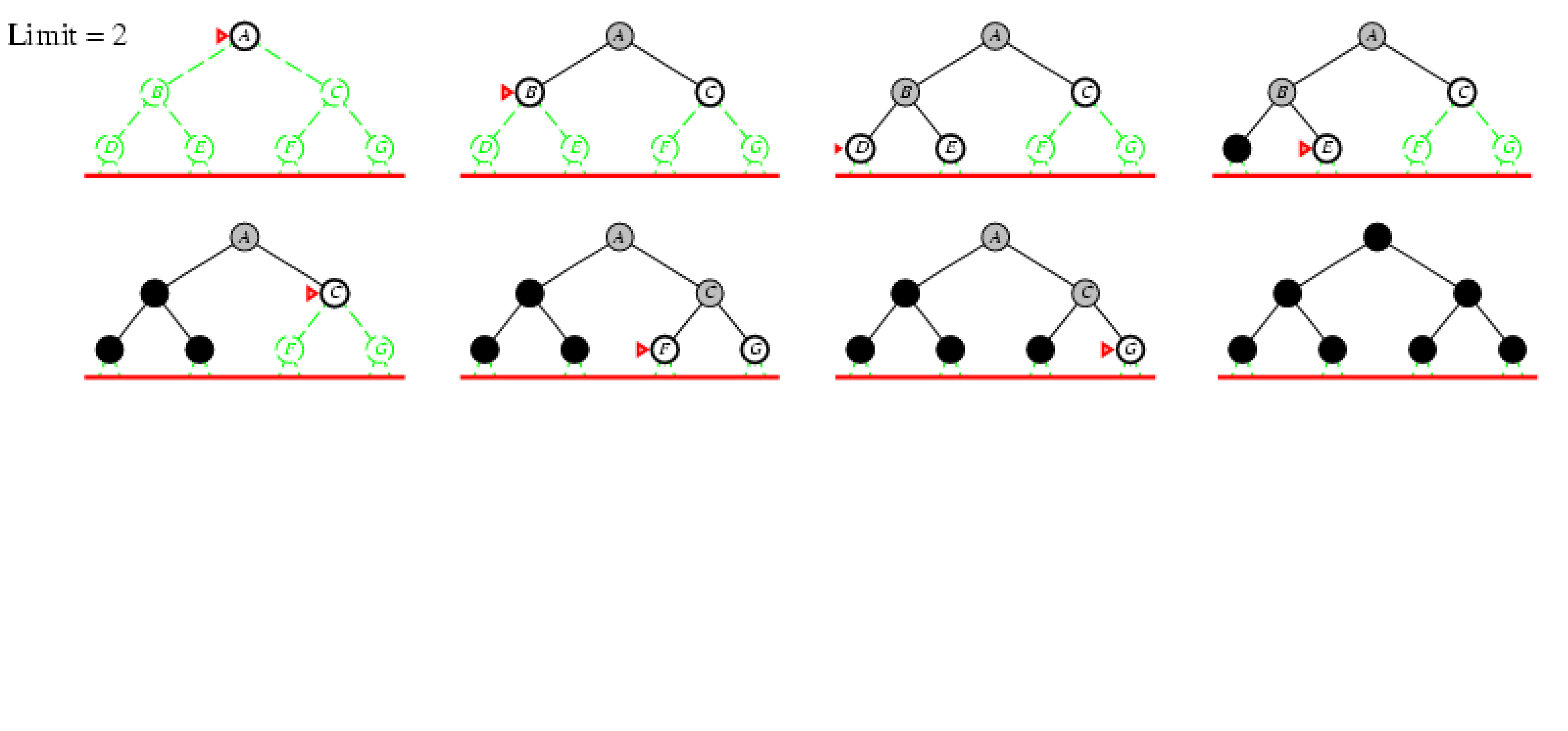
Iterative Deepening



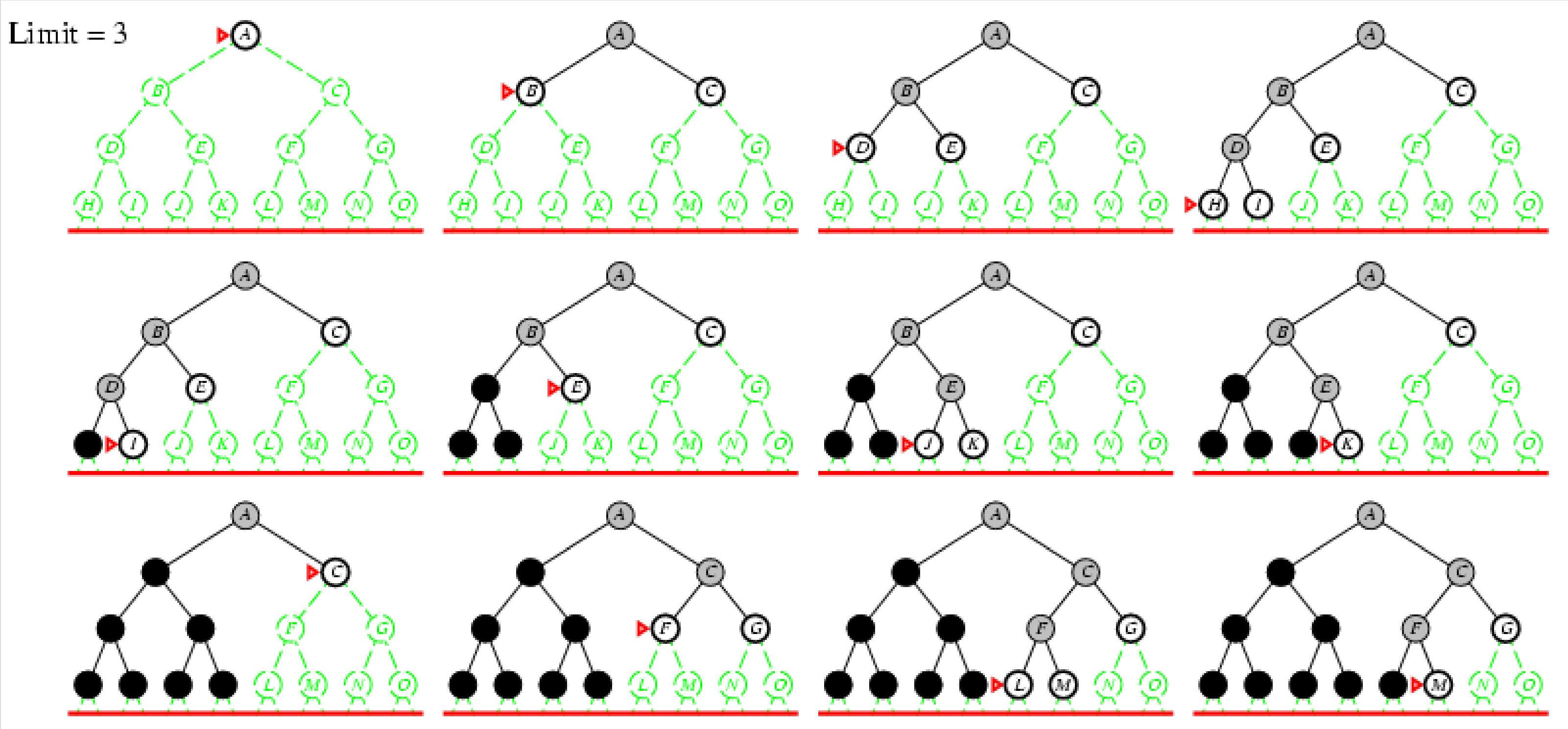
Iterative Deepening



Iterative Deepening



Iterative Deepening

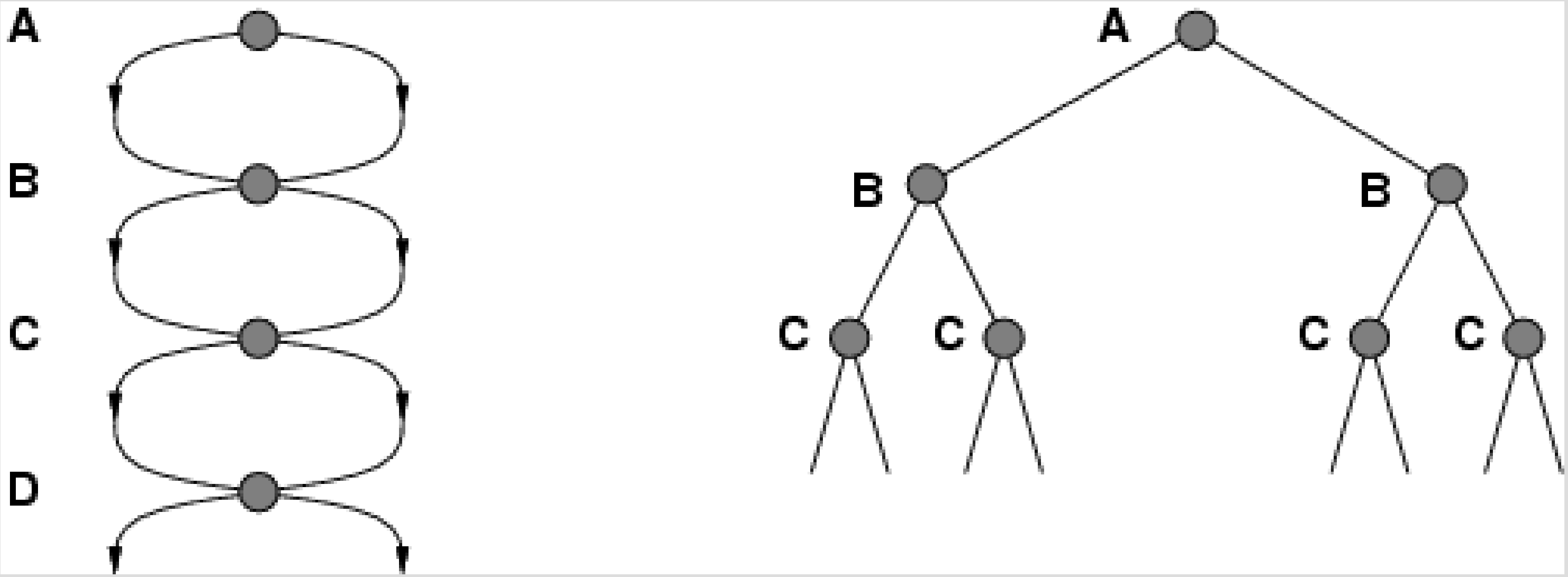


Summary of algorithms

Criterion	Breadth-First	Uniform-Cost	Depth-First	Depth-Limited	Iterative Deepening
Complete?	Yes	Yes	No	No	Yes
Time	$O(b^{d+1})$	$O(b^{\lceil C^*/\epsilon \rceil})$	$O(b^m)$	$O(b^l)$	$O(b^d)$
Space	$O(b^{d+1})$	$O(b^{\lceil C^*/\epsilon \rceil})$	$O(bm)$	$O(bl)$	$O(bd)$
Optimal?	Yes	Yes	No	No	Yes

Repeated states

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



Graph Search

```
function GRAPH-SEARCH( problem, fringe) returns a solution, or failure

   closed ← an empty set
   fringe ← INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
   loop do
       if fringe is empty then return failure
       node ← REMOVE-FRONT(fringe)
       if GOAL-TEST[problem](STATE[node]) then return SOLUTION(node)
       if STATE[node] is not in closed then
           add STATE[node] to closed
           fringe ← INSERTALL(EXPAND(node, problem), fringe)
```