Lecture 2: Uninformed search

Artificial Intelligence
CS-GY-6613-I

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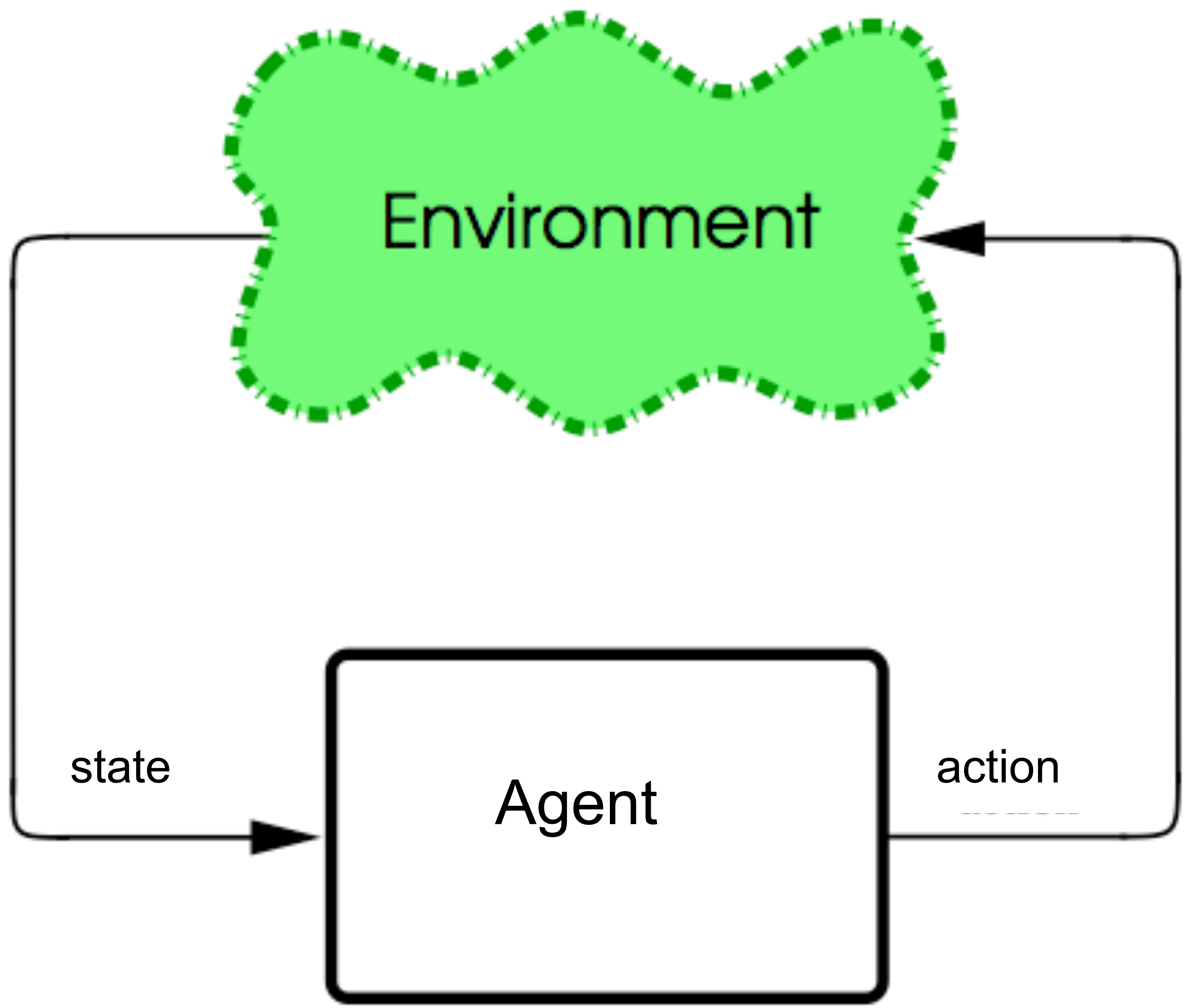
On the menu

- Problem solving as search
- Uninformed search algorithms
- Assignments

An agent



Problem-solving as search

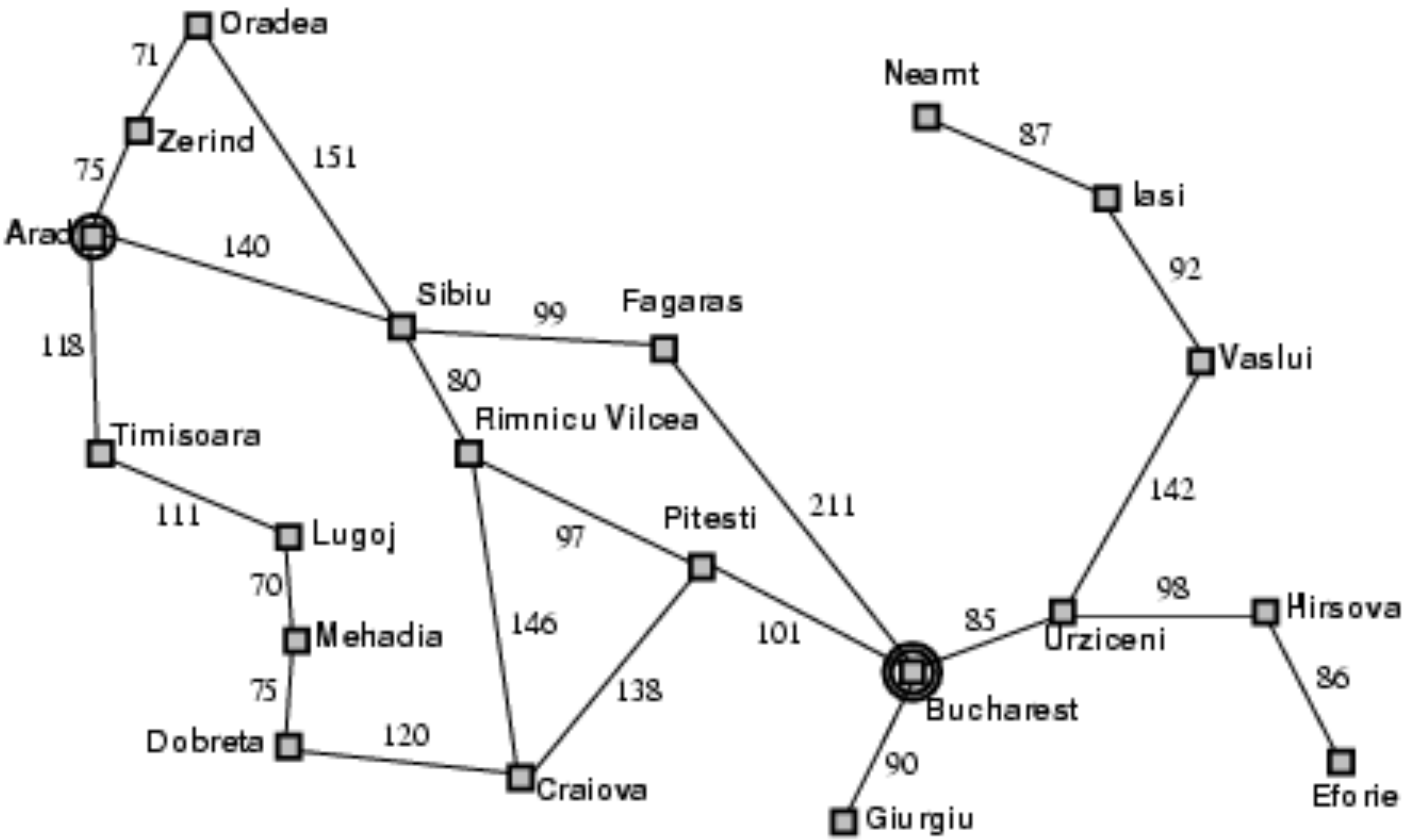
- An agent is in a *state*
- It wants to get to a *goal state*
- It needs to find the sequence of actions that gets it there
  - (cheapest, fastest, safest…)

Problem-solving agent

```
function SIMPLE-PROBLEM-SOLVING-AGENT(percept) returns an action
    static: seq, an action sequence, initially empty
            state, some description of the current world state
            goal, a goal, initially null
            problem, a problem formulation

    state ← UPDATE-STATE(state, percept)
    if seq is empty then do
        goal ← FORMULATE-GOAL(state)
        problem ← FORMULATE-PROBLEM(state, goal)
        seq ← SEARCH(problem)
    action ← FIRST(seq)
    seq ← REST(seq)
    return action
```

From Arad to Bucharest



Problem types

- Deterministic, fully observable: single-state problem
  - Agent knows exactly which state it will be in; solution is a sequence
- Non-observable: sensorless problem
  - Agent may have no idea where it is; solution is a sequence
- Nondeterministic and/or partially observable: contingency problem
  - percepts provide new information about current state
- Unknown state space: exploration problem

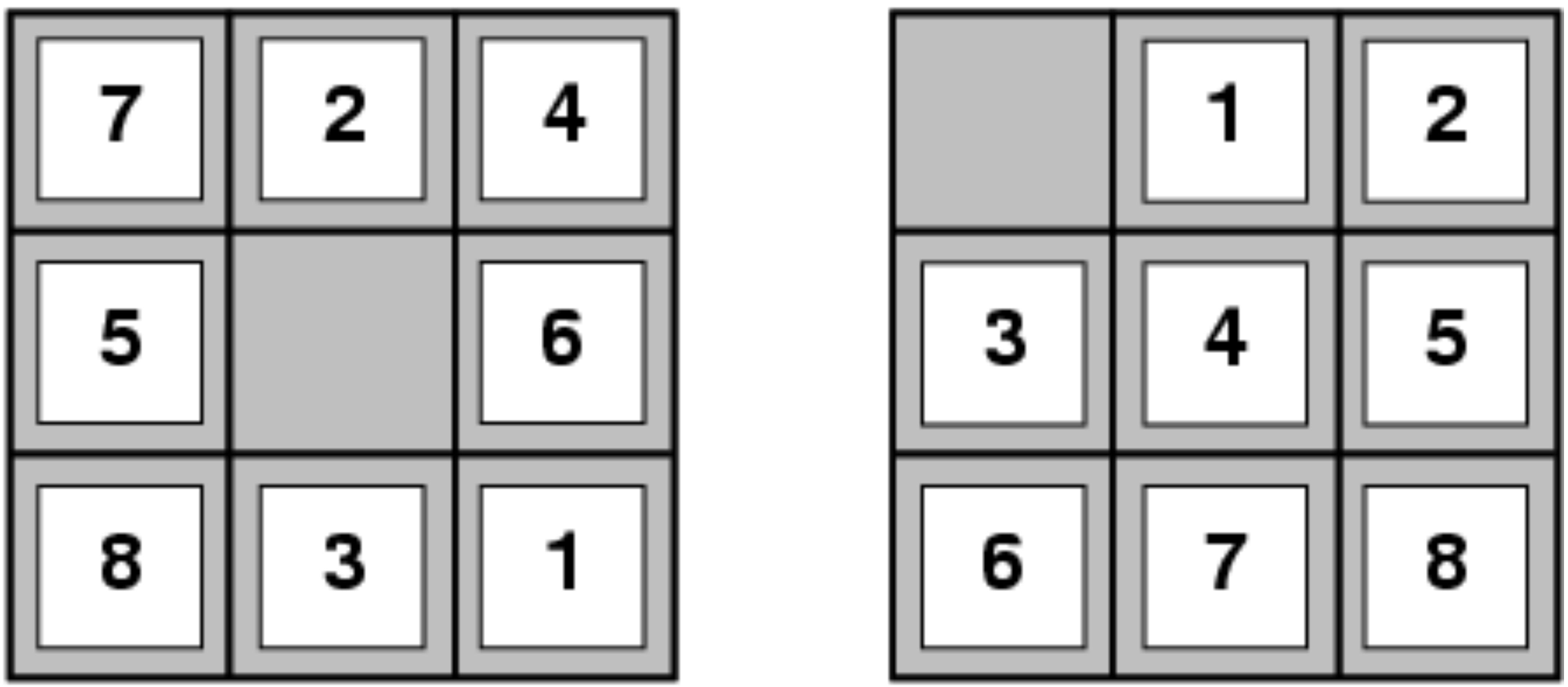
What problem type is…

- Driving to Bucharest?
- Flying to Bucharest?
- Playing Pac-Man?
- Playing StarCraft?
- Playing Poker?
- Living a good life?

Problem components

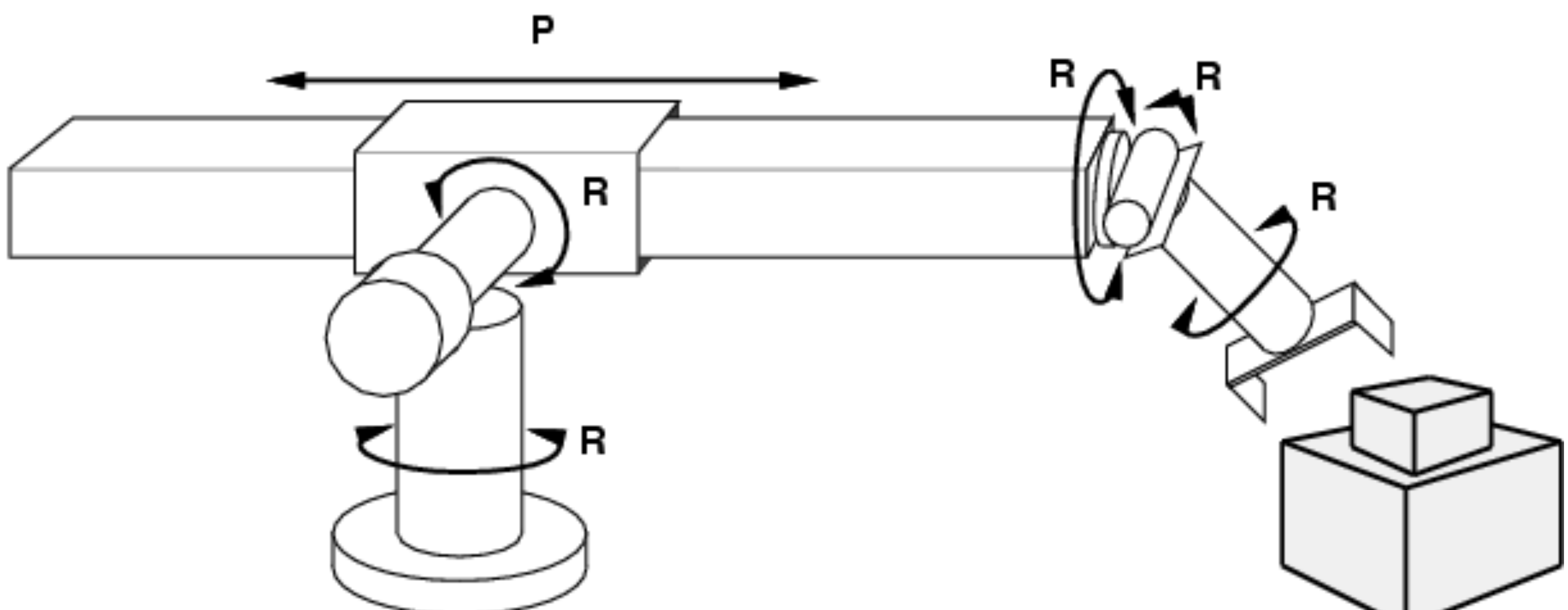
- Initial state
- Actions and successor function
  S(state, action) -> state’
- Goal test (are we there yet?)
- Path cost
- A solution is a sequence of actions leading from the initial state to a goal state

Problem components?



Start State Goal State

Problem components?



Problem components?

Problem components?

Problem components?

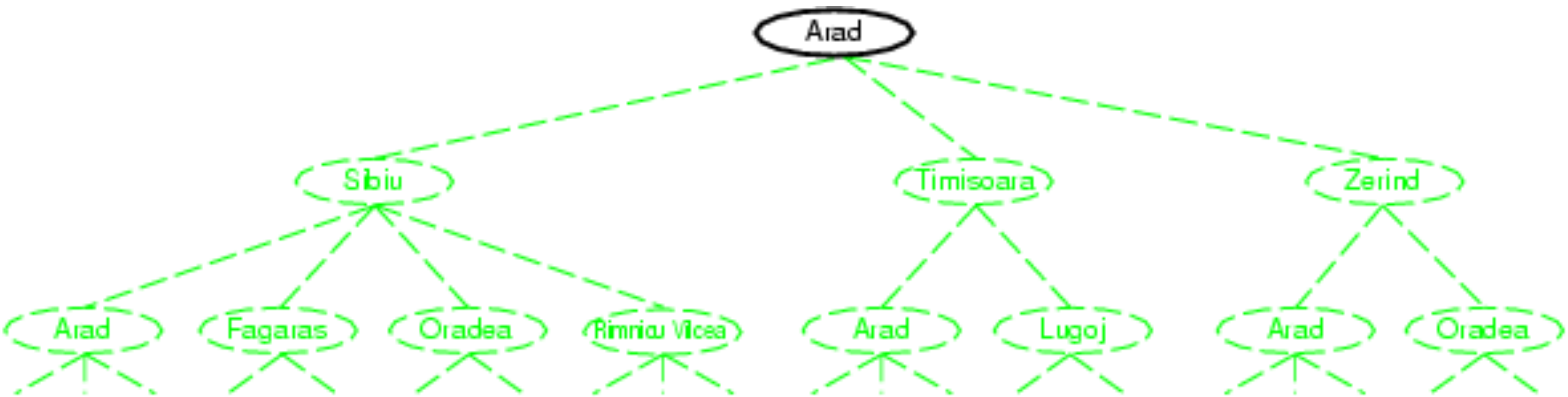
Problem components?

Tree search

- offline, simulated exploration of state space by generating successors of already-explored states (a.k.a.~expanding 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



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Zerind
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Fagaras
Oradea
Rimnicu Vilcea
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Lugoj
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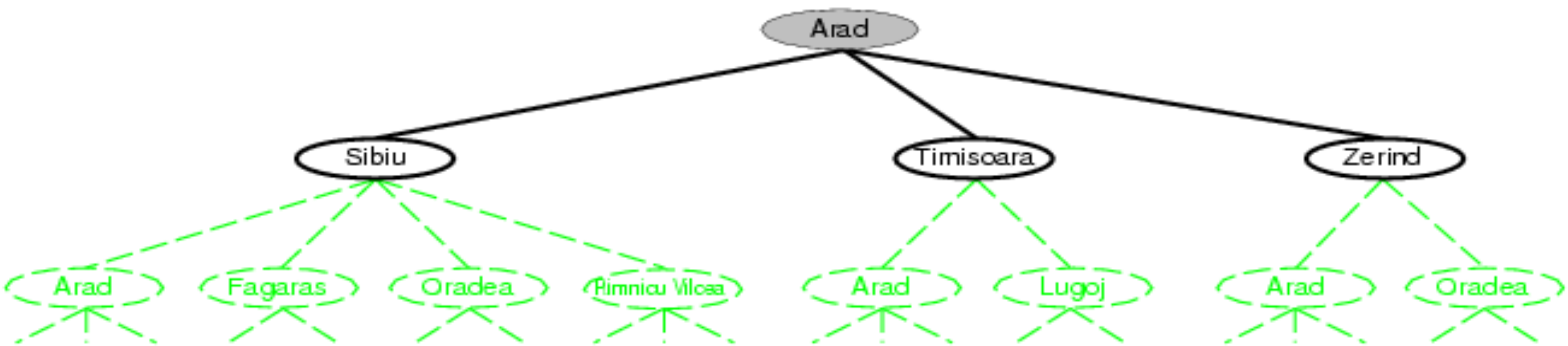
Oradea

Tree search



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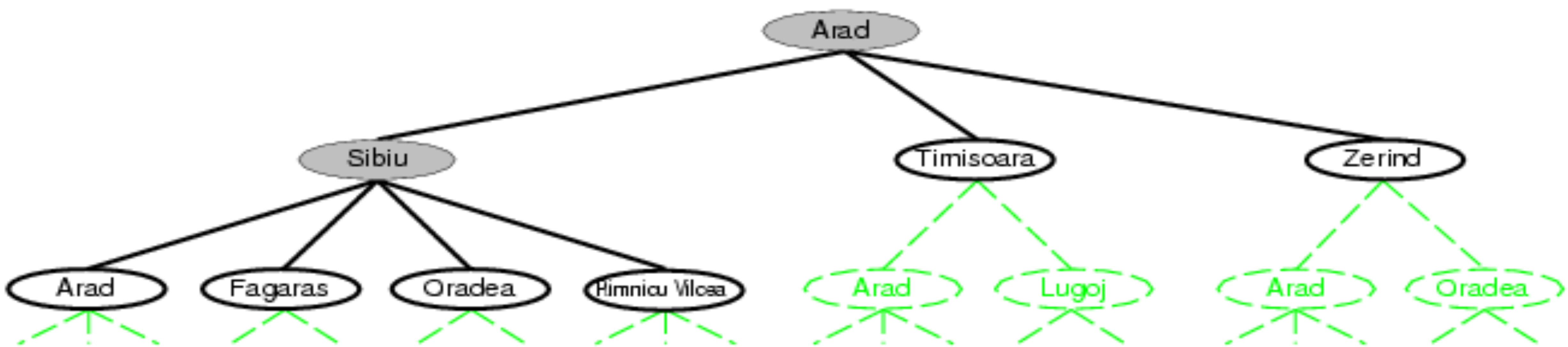

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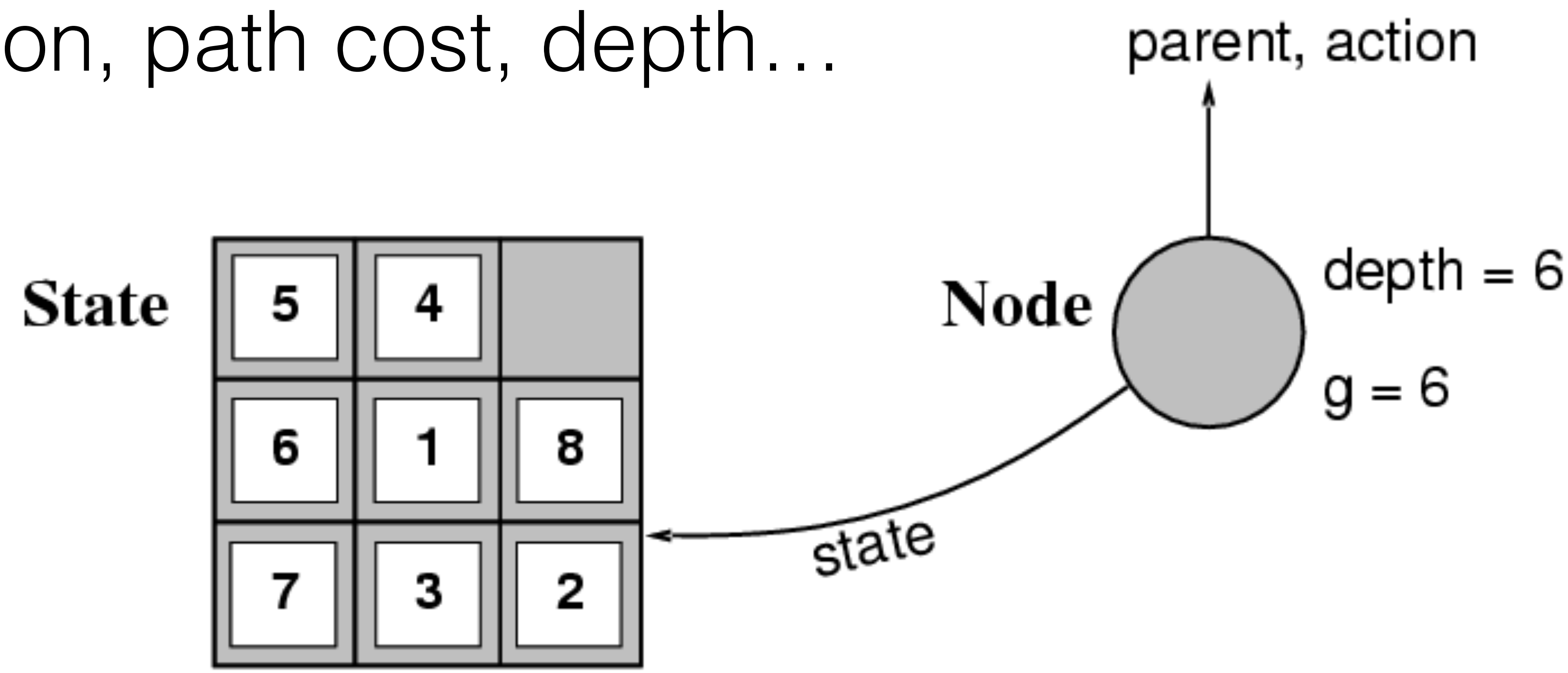
```
function TREE-SEARCH( problem, fringe) returns a solution, or failure
    fringe ← INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
    loop do
        if fringe is empty then return failure
        node ← REMOVE-FRONT(fringe)
        if GOAL-TEST[problem](STATE[node]) then return SOLUTION(node)
        fringe ← INSERTALL(EXPAND(node, problem), fringe)
```

```
function EXPAND( node, problem) returns a set of nodes
    successors ← the empty set
    for each action, result in SUCCESSOR-FN[problem](STATE[node]) do
        s ← a new NODE
        PARENT-NODE[s] ← node;  ACTION[s] ← action;  STATE[s] ← result
        PATH-COST[s] ← PATH-COST[node] + STEP-COST(node, action, s)
        DEPTH[s] ← DEPTH[node] + 1
        add s to successors
    return successors
```

Nodes versus states

- A state is a configuration of an environment/agent
- A node is a data structure constituting part of a search tree, might include state, parent node, action, path cost, depth…

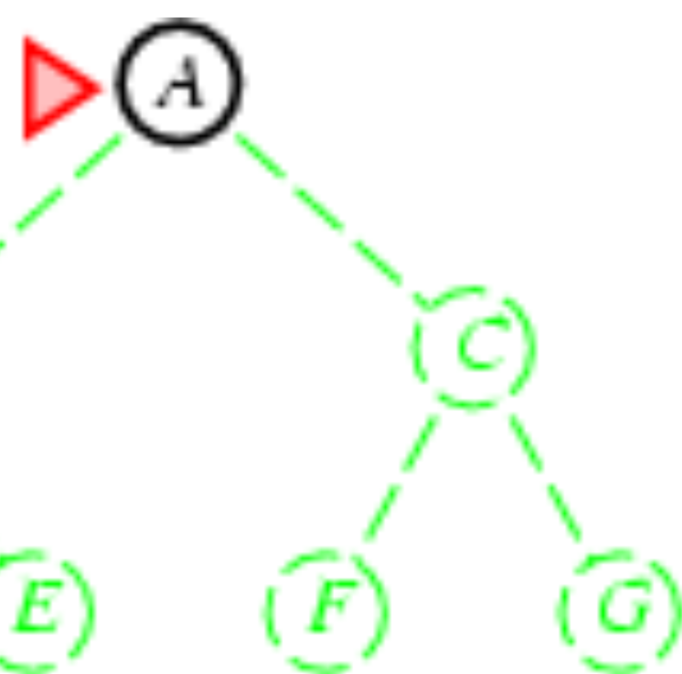


Uninformed search

- Uninformed search strategies use only the information available in the problem definition
- Breadth-first search
- Uniform cost search
- Depth-first search
- Depth-limited search
- Iterative deepening search

Breadth-first search

- Expand shallowest unexpanded node
- Implementation: new nodes added to a FIFO queue



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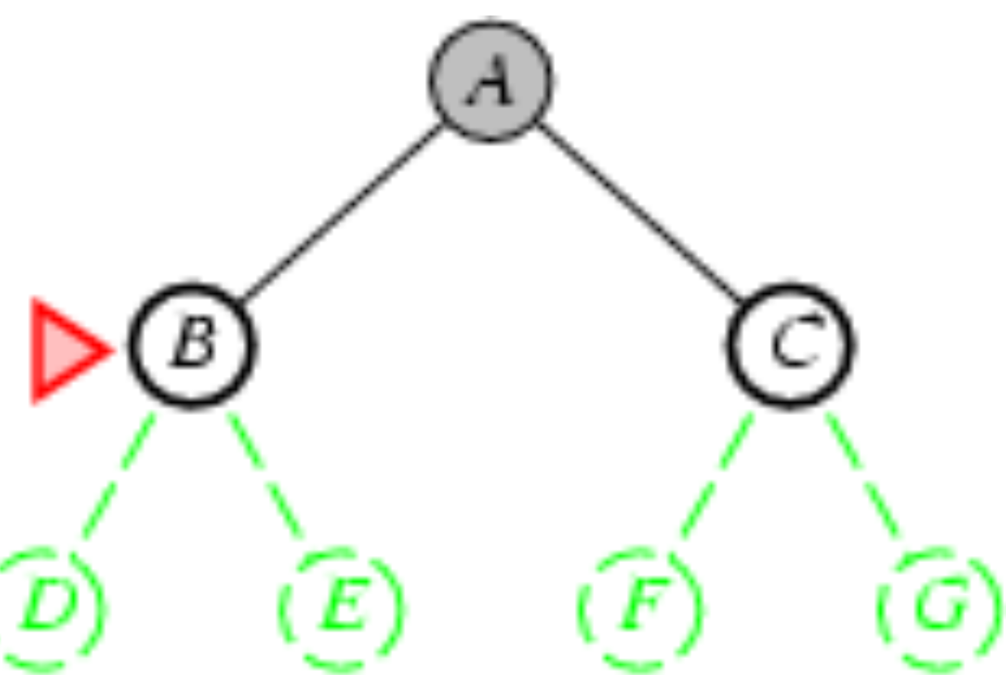

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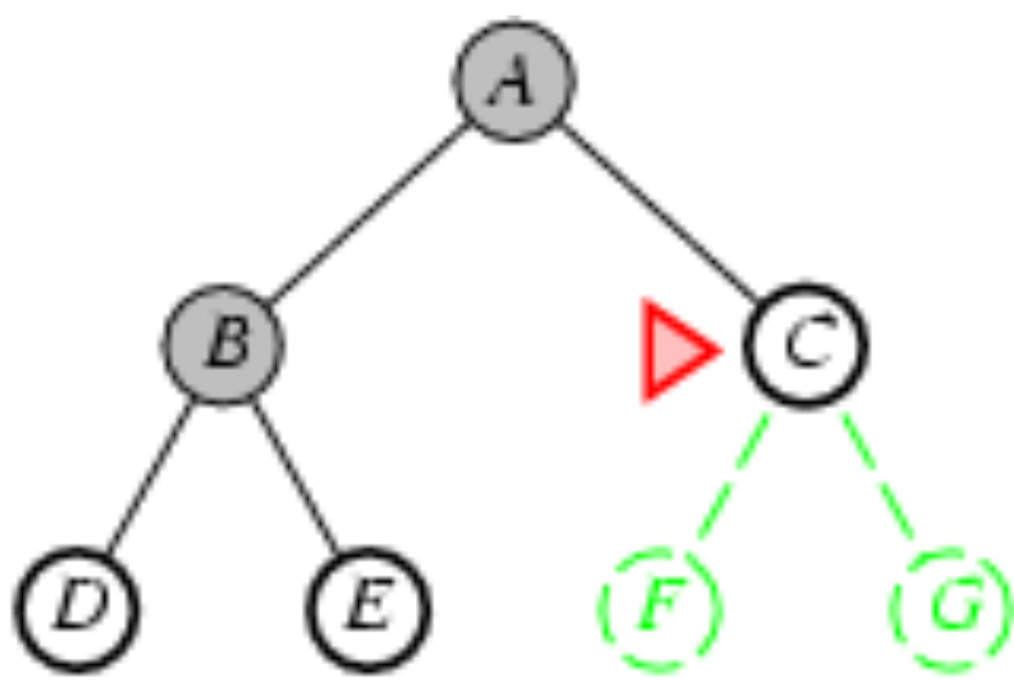

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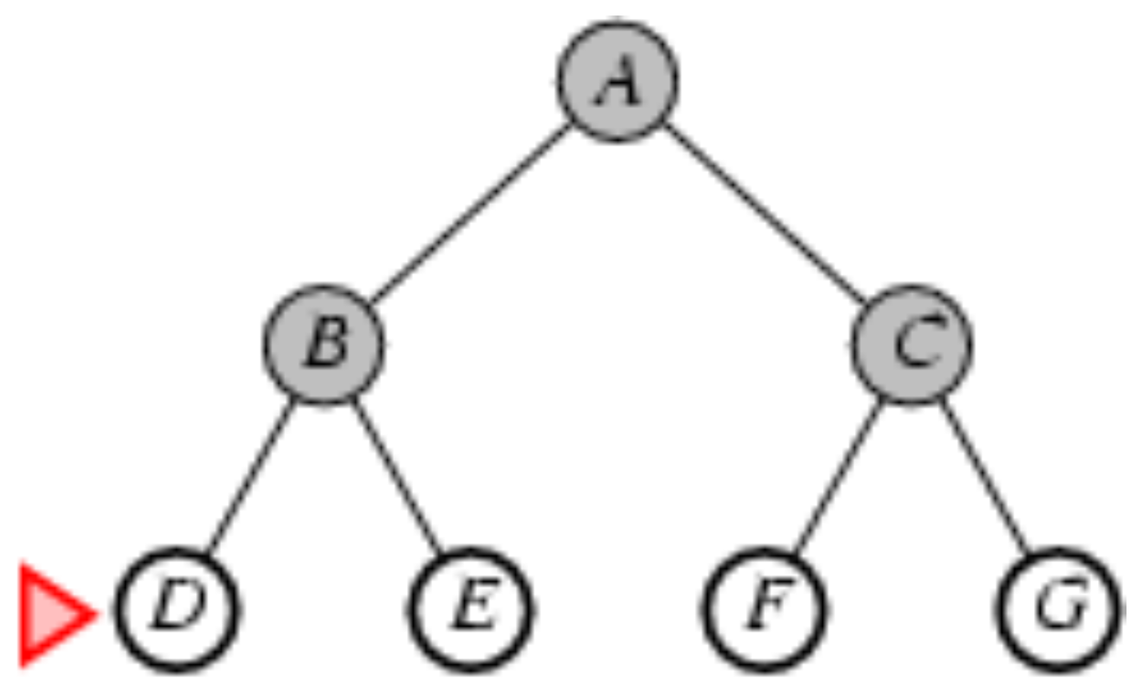
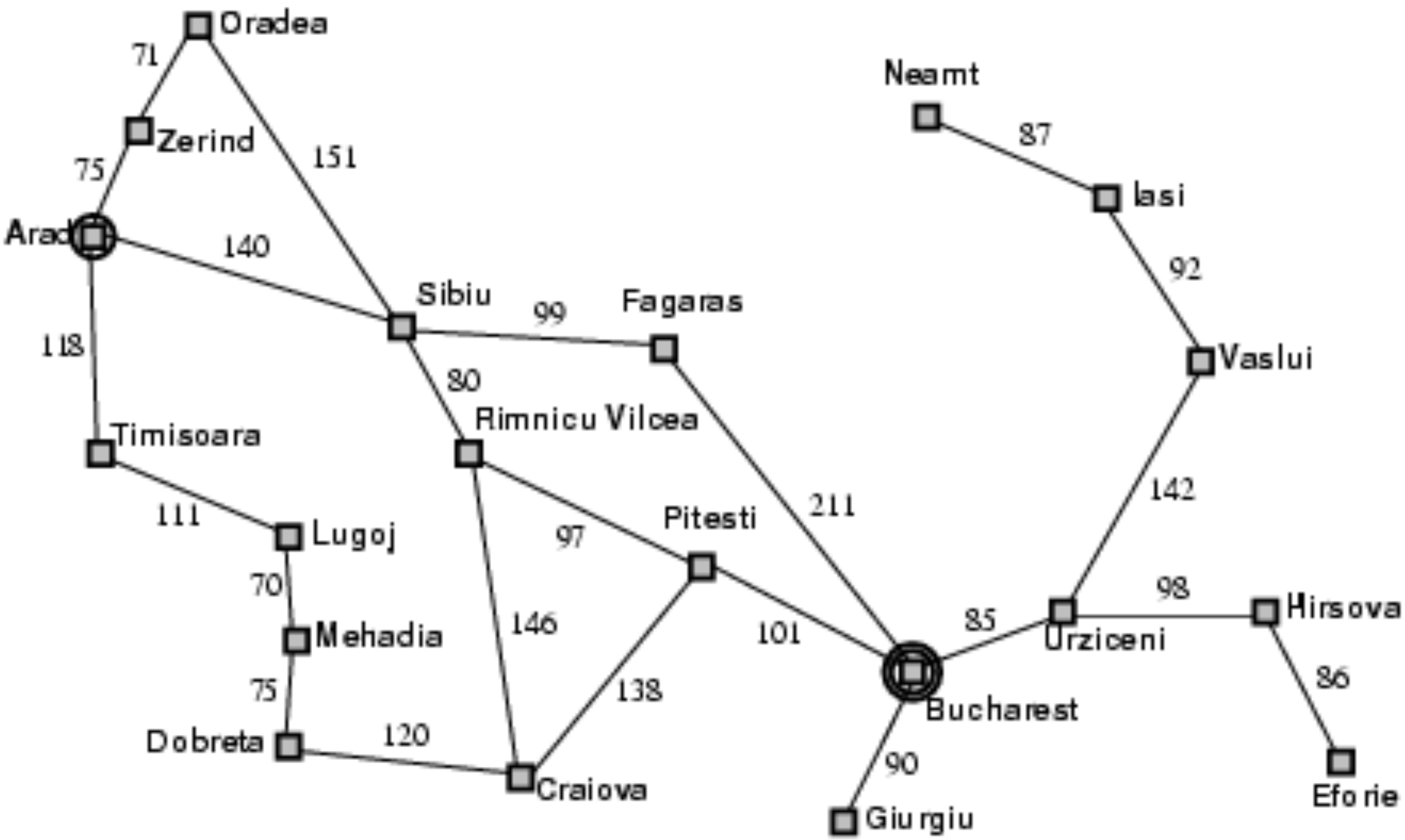


Breadth-first search

- Complete? Yes (if b is finite)
- Time? $1+b+b^2+b^3+\ldots +b^d + b(b^d-1) = O(b^{d+1})$
- Space? $O(b^d+1)$ (keeps every node in memory)
- Optimal? Yes (if cost = 1 per step)

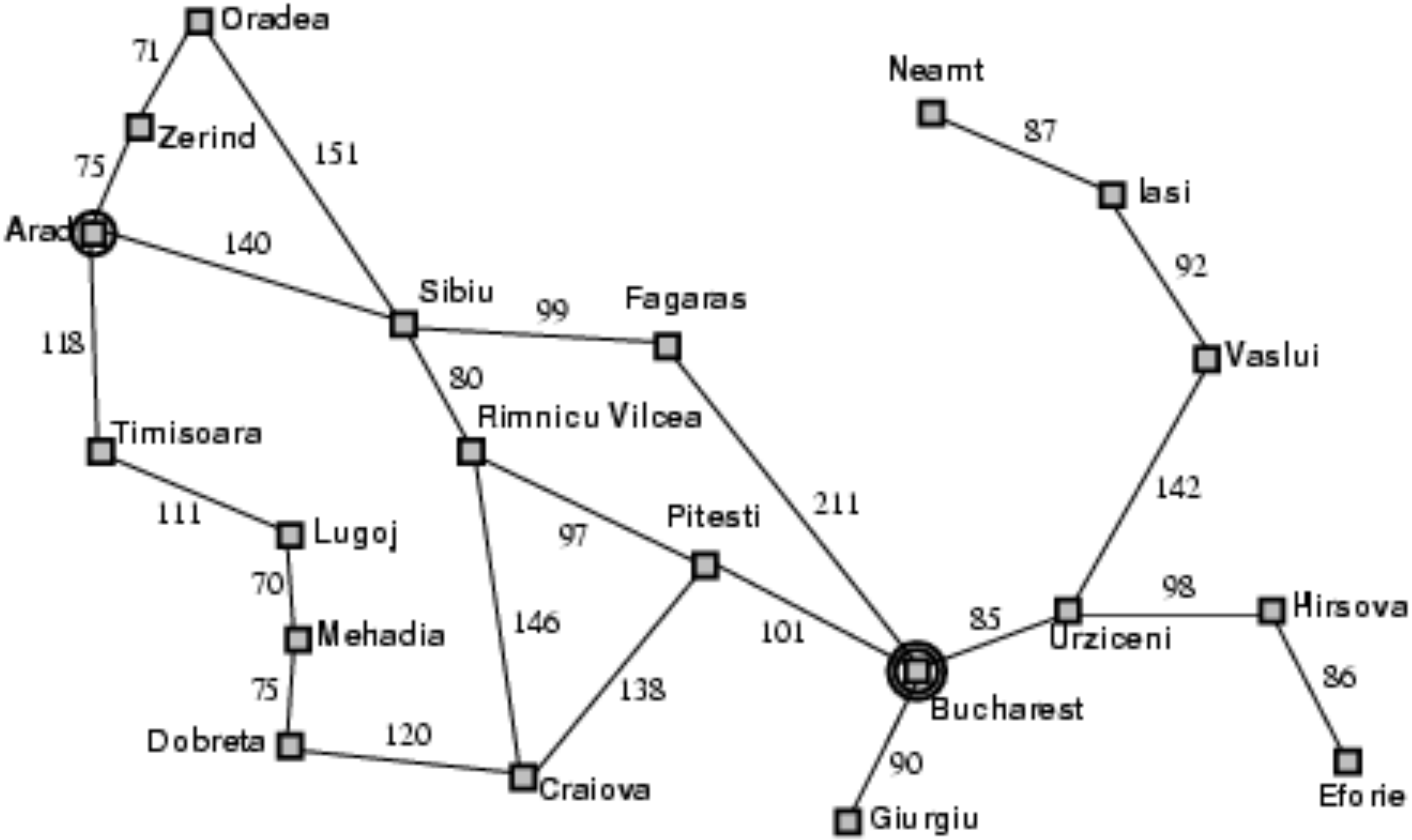
From Arad to Bucharest



Uniform-cost search

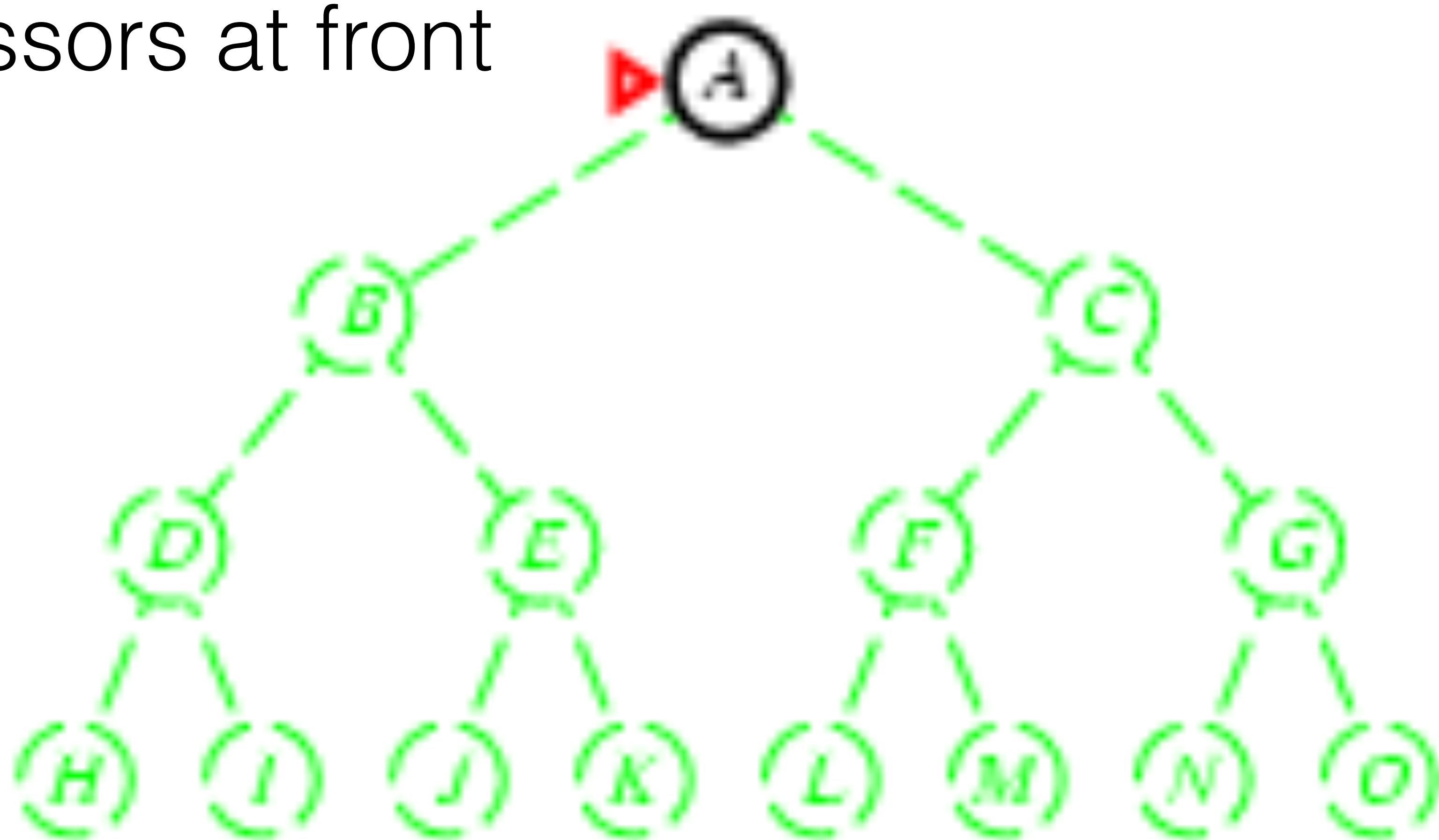
- Expand least-cost unexpanded node
- Equivalent to breadth-first if step costs all equal
- Complete and optimal

From Arad to Bucharest



Depth-first search

- Expand deepest unexpanded node
- Implementation: fringe = LIFO queue, i.e., put successors at front



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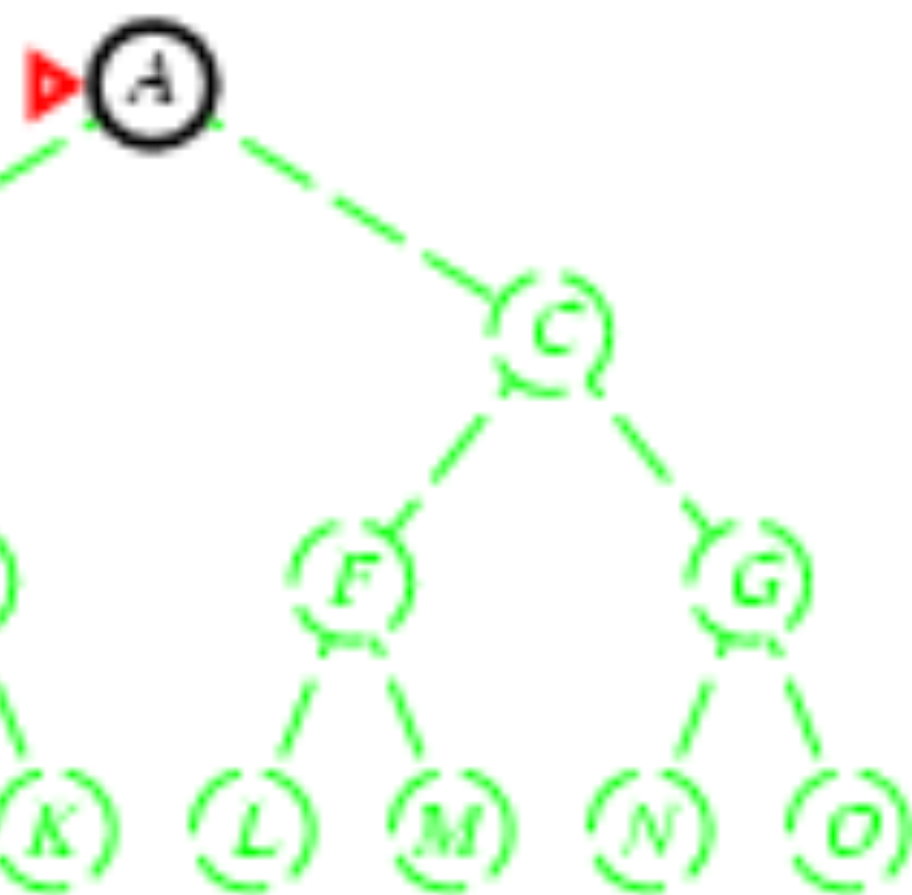

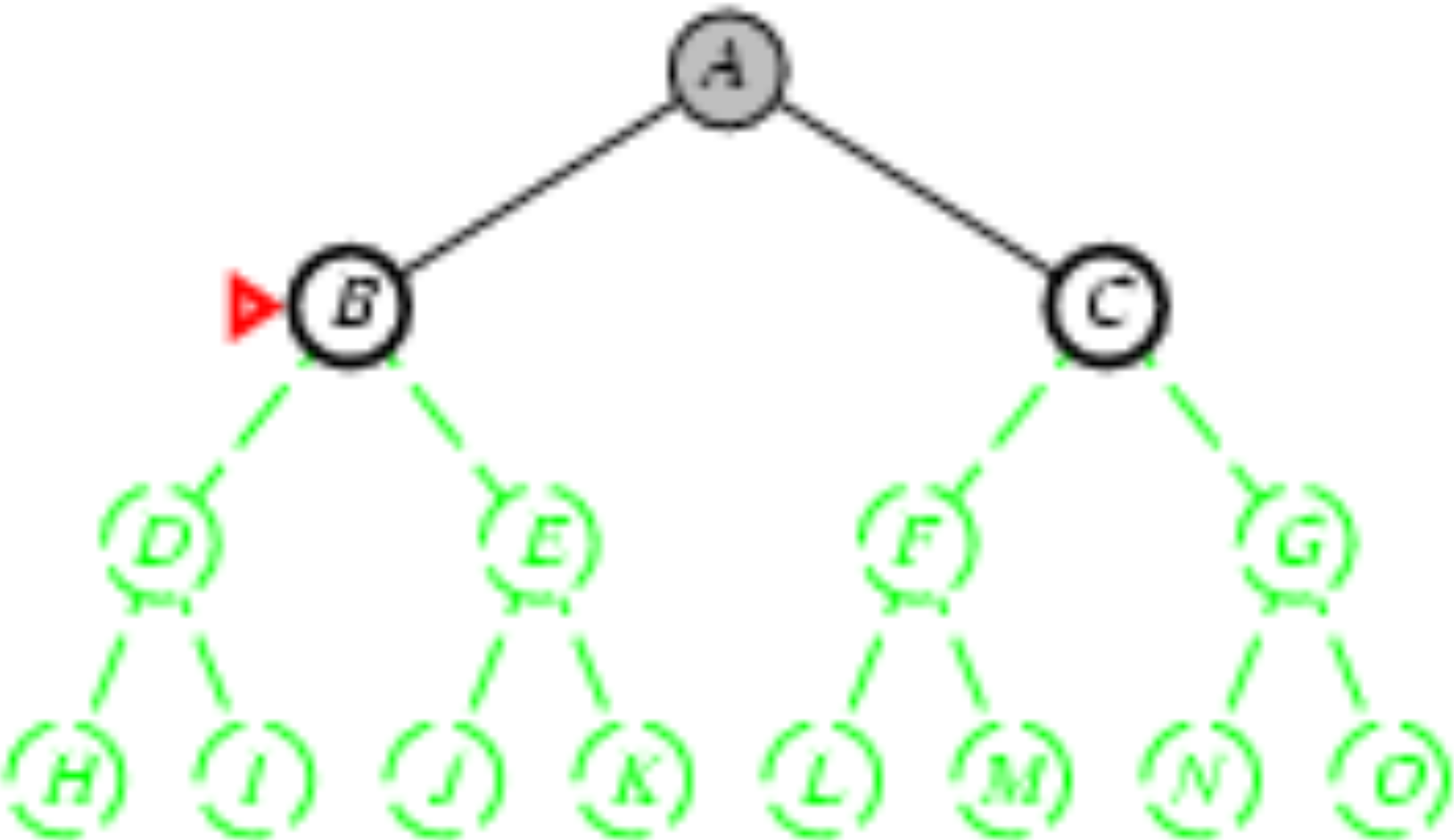
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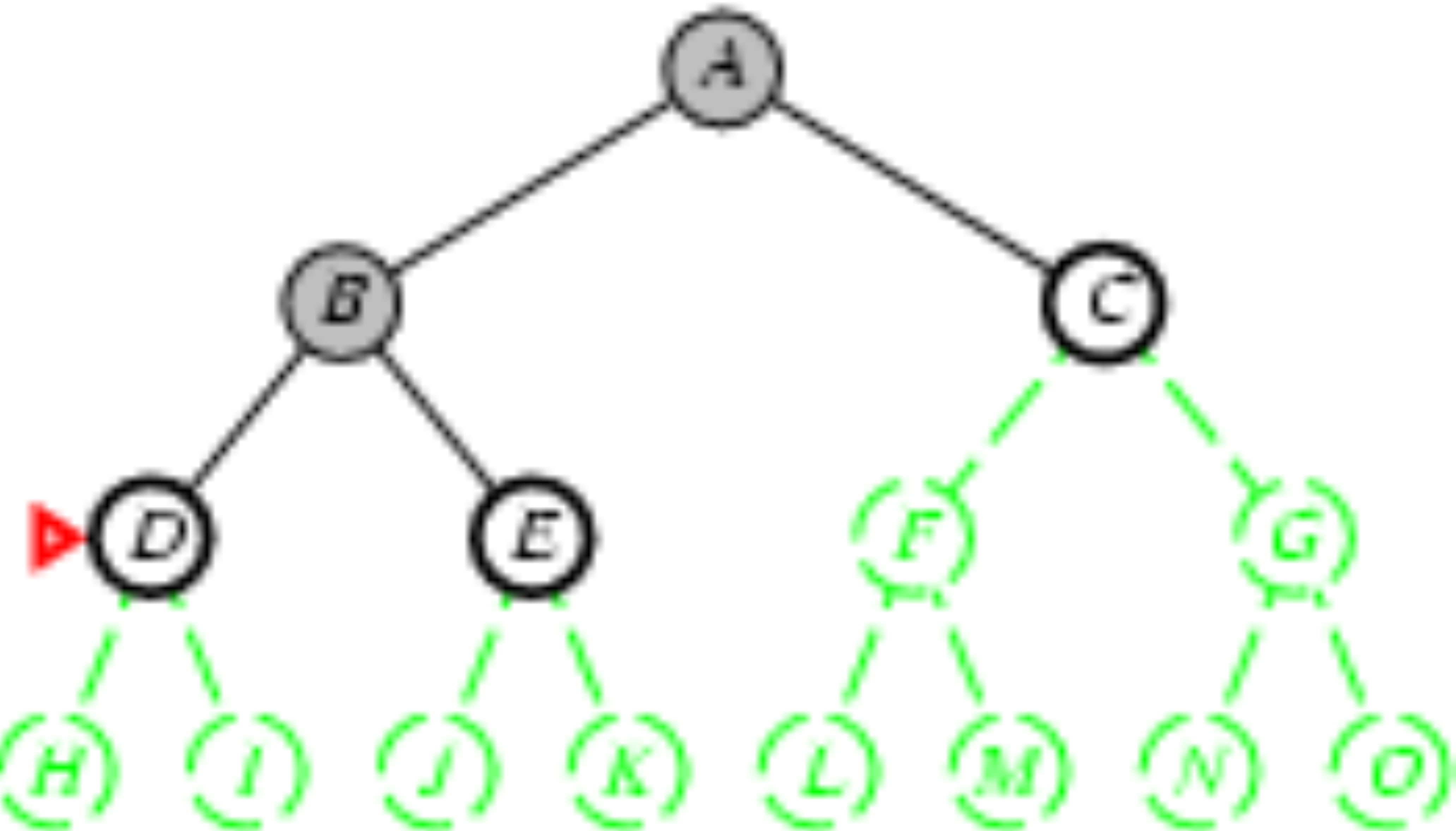
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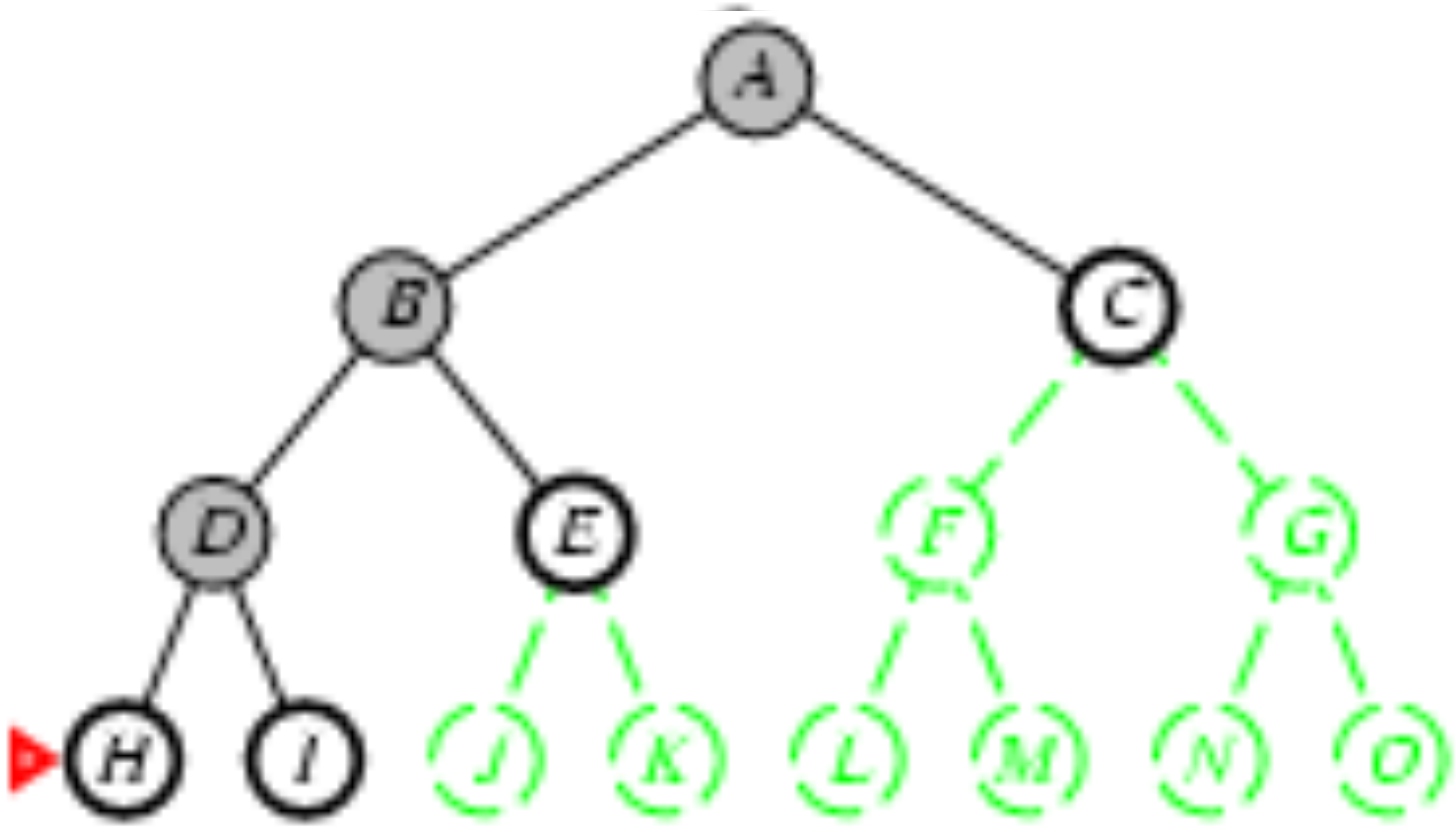
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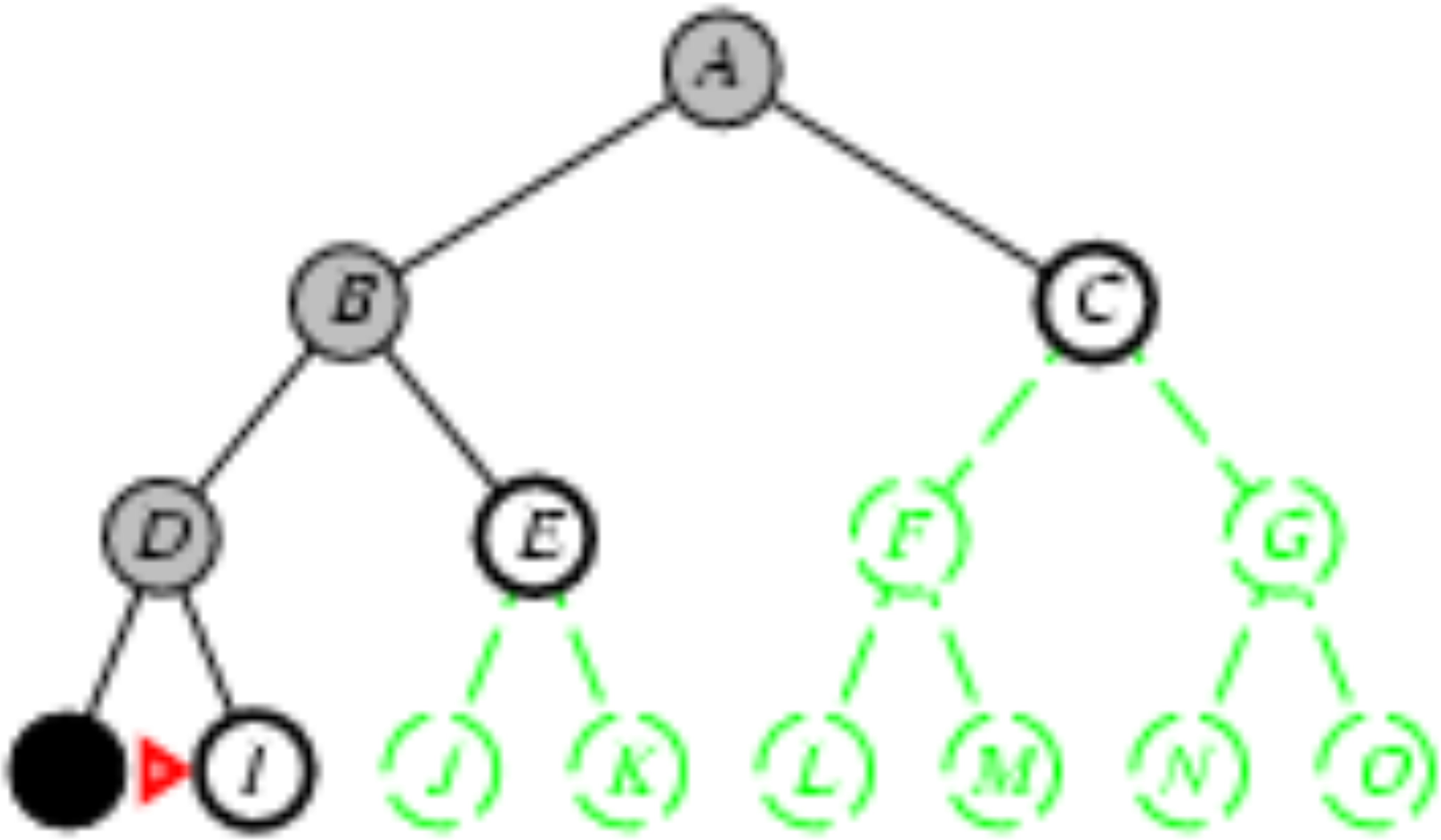
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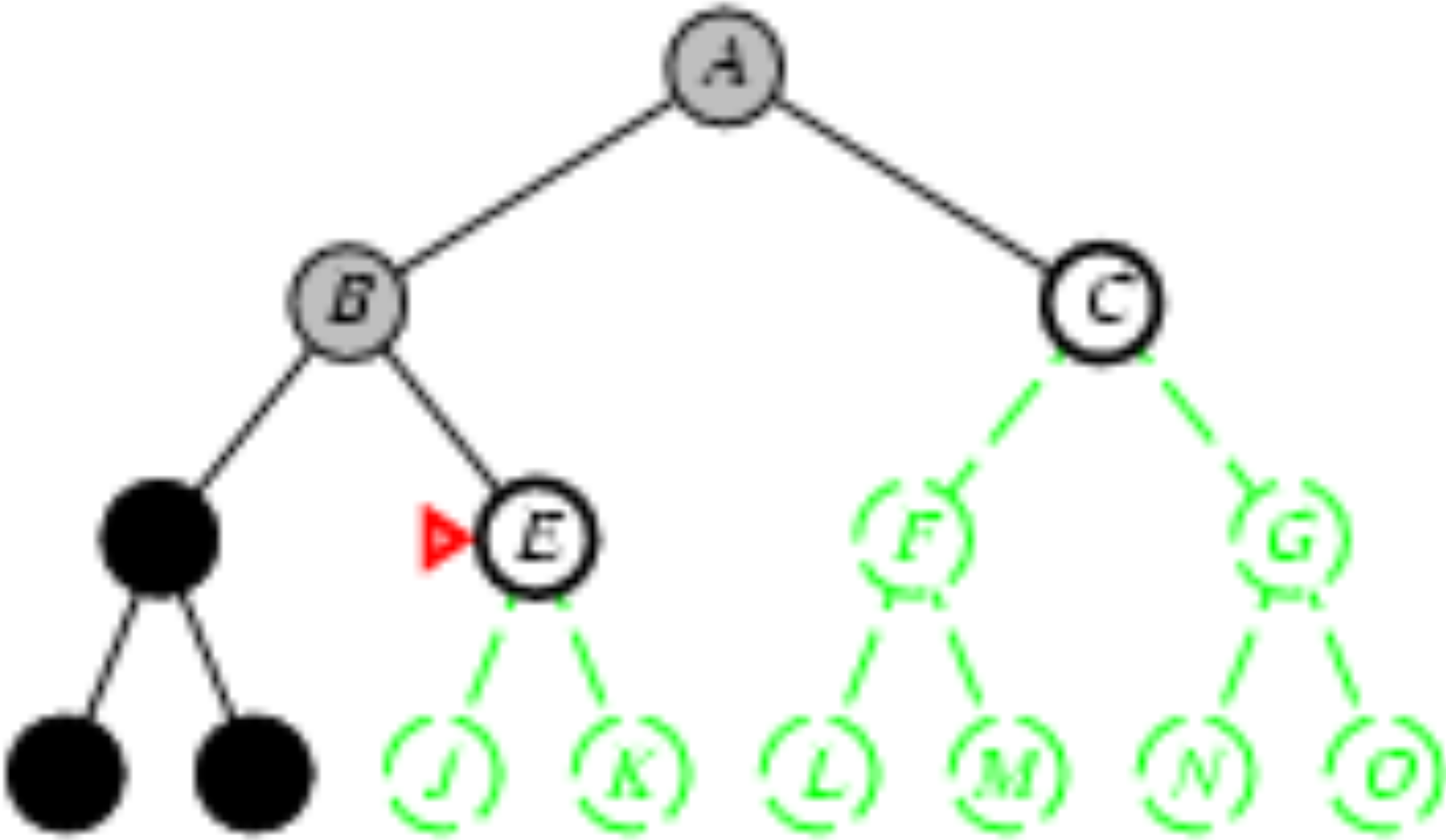
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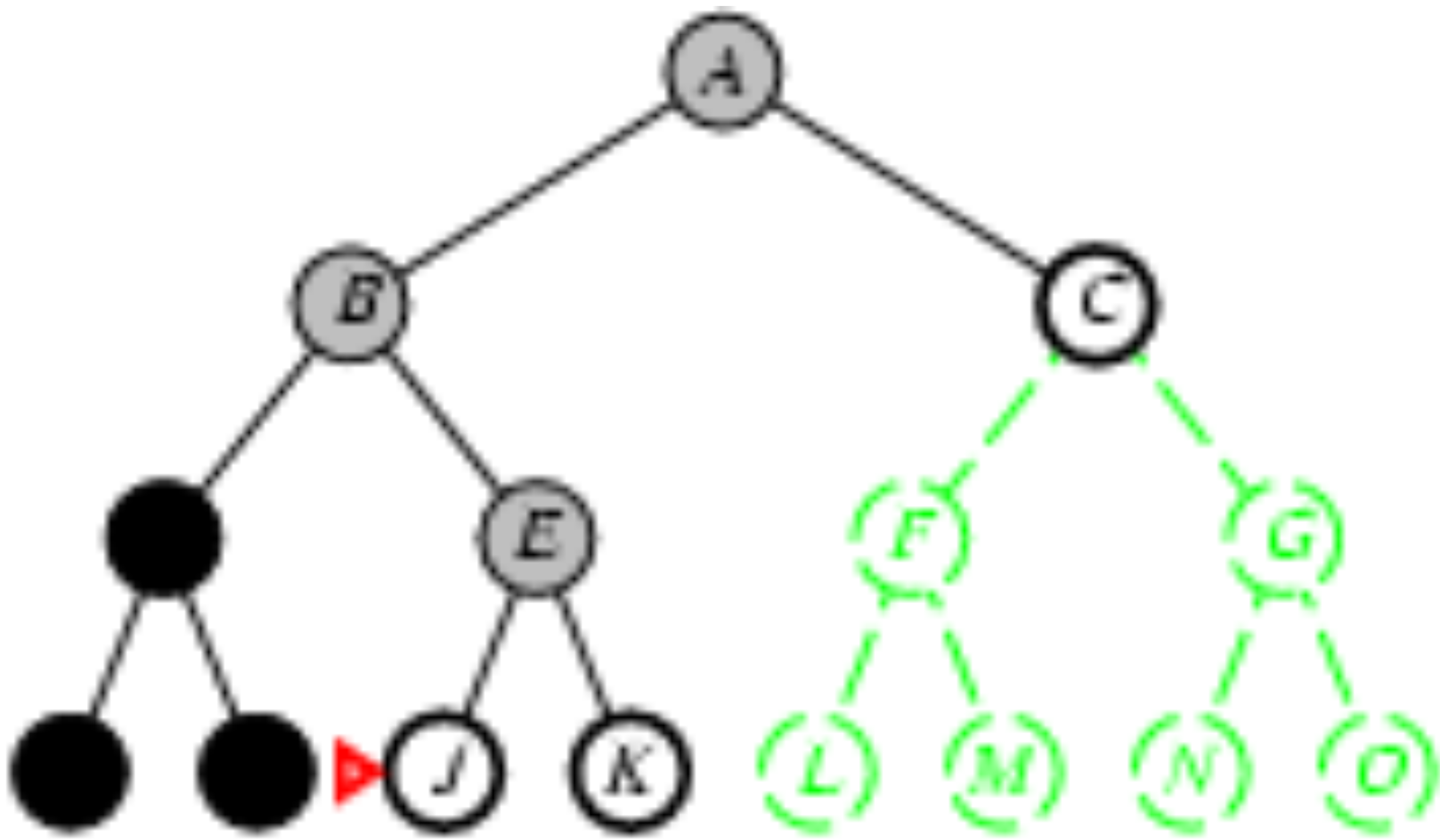

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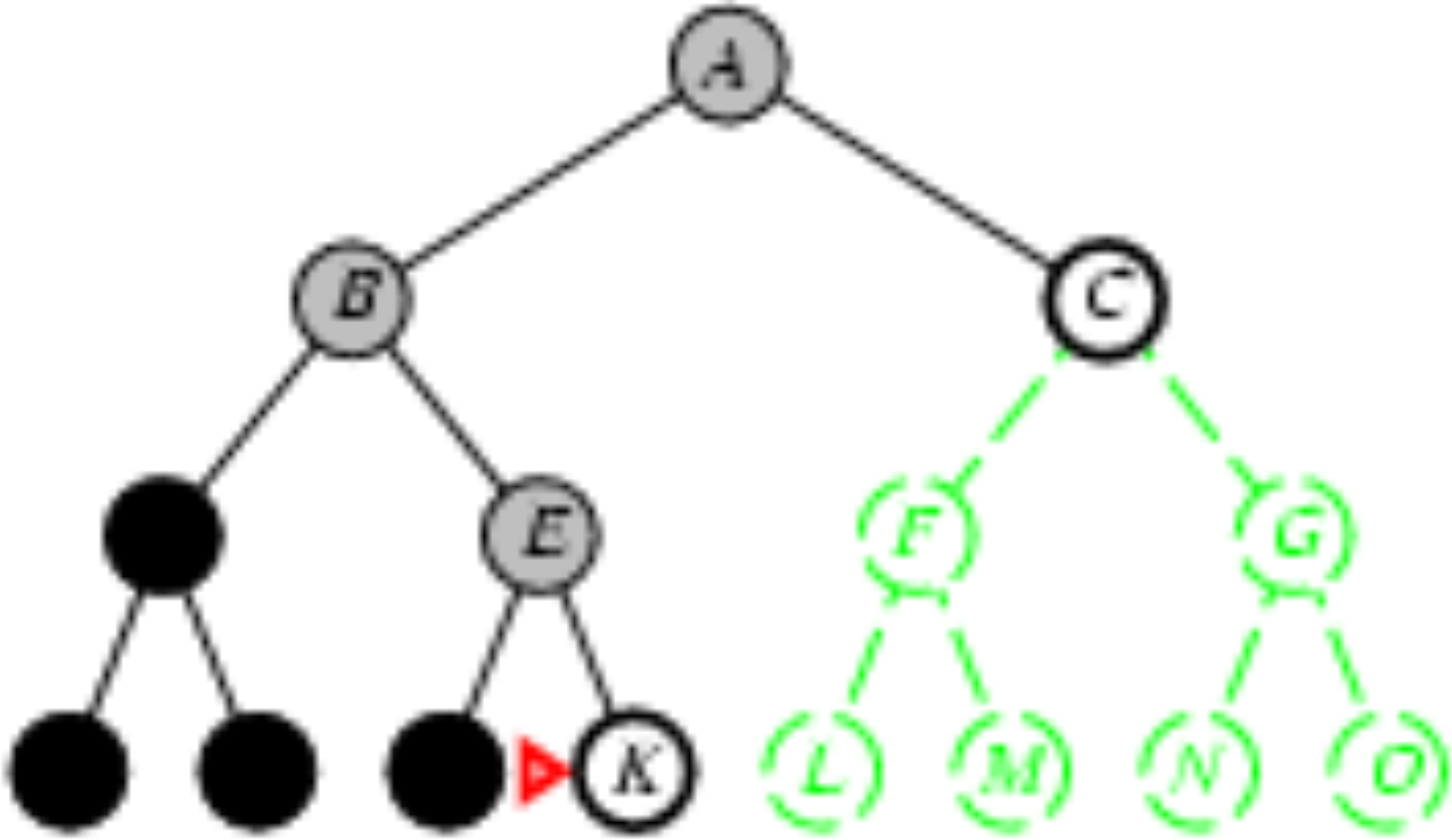
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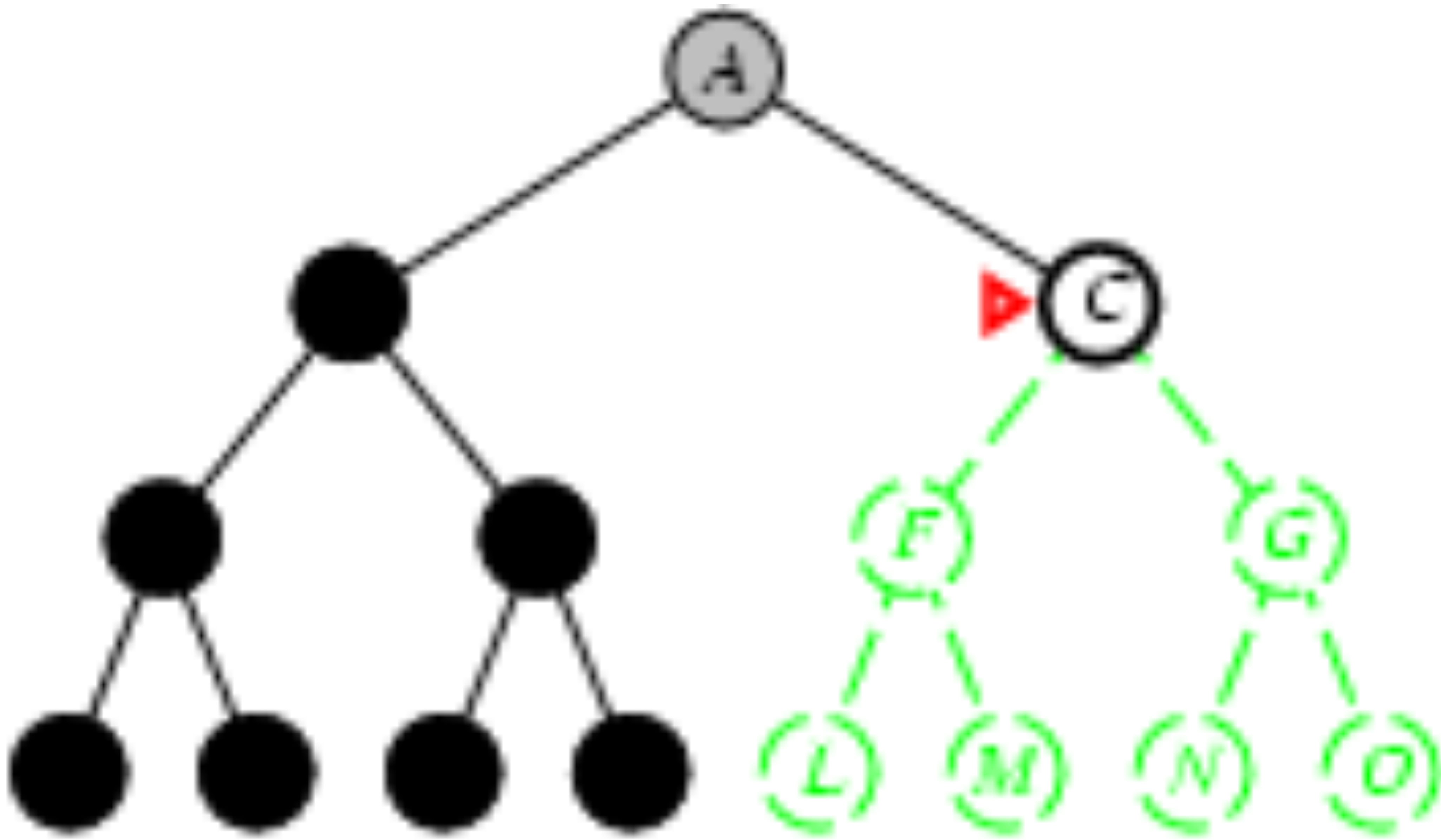
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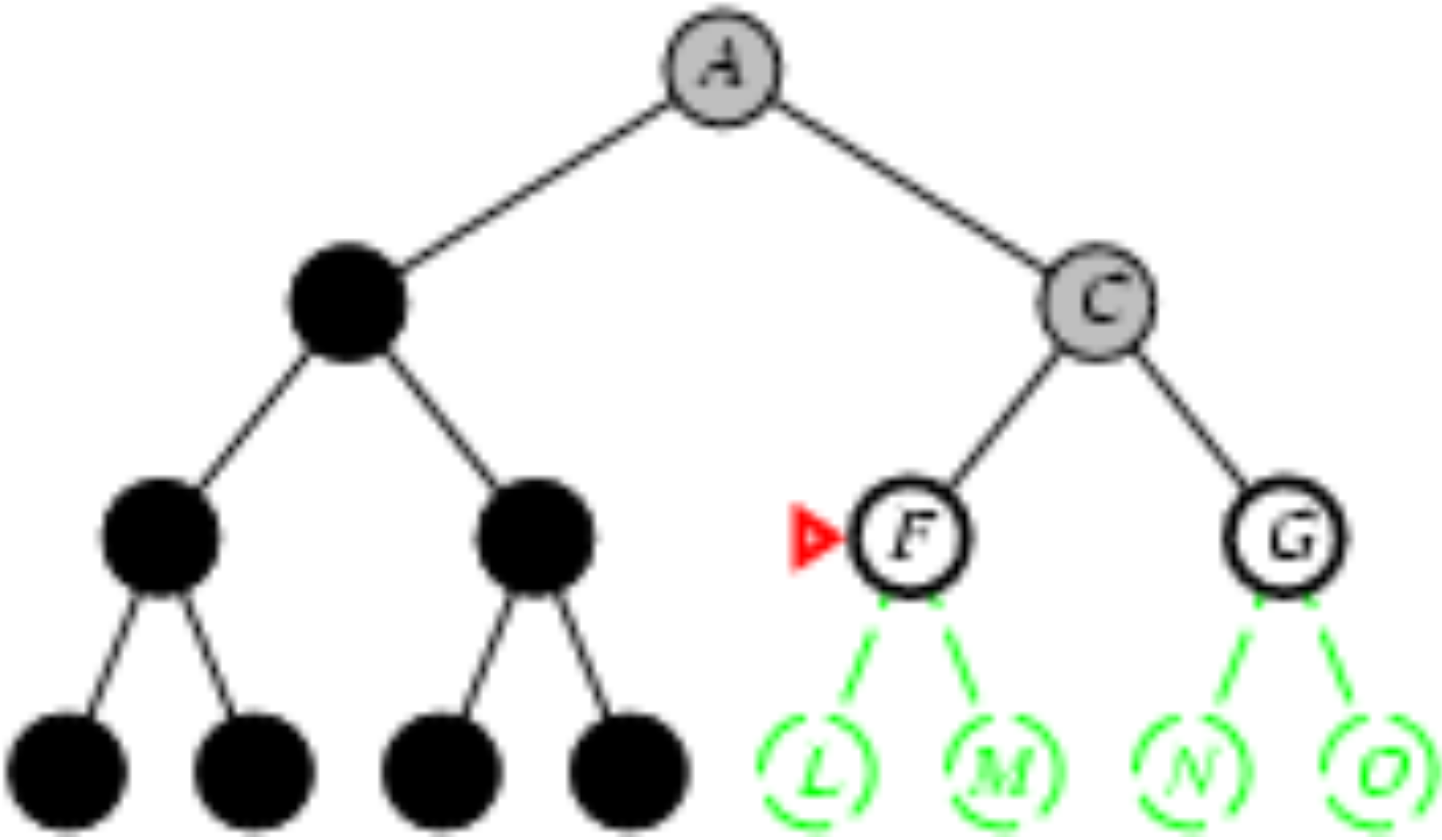
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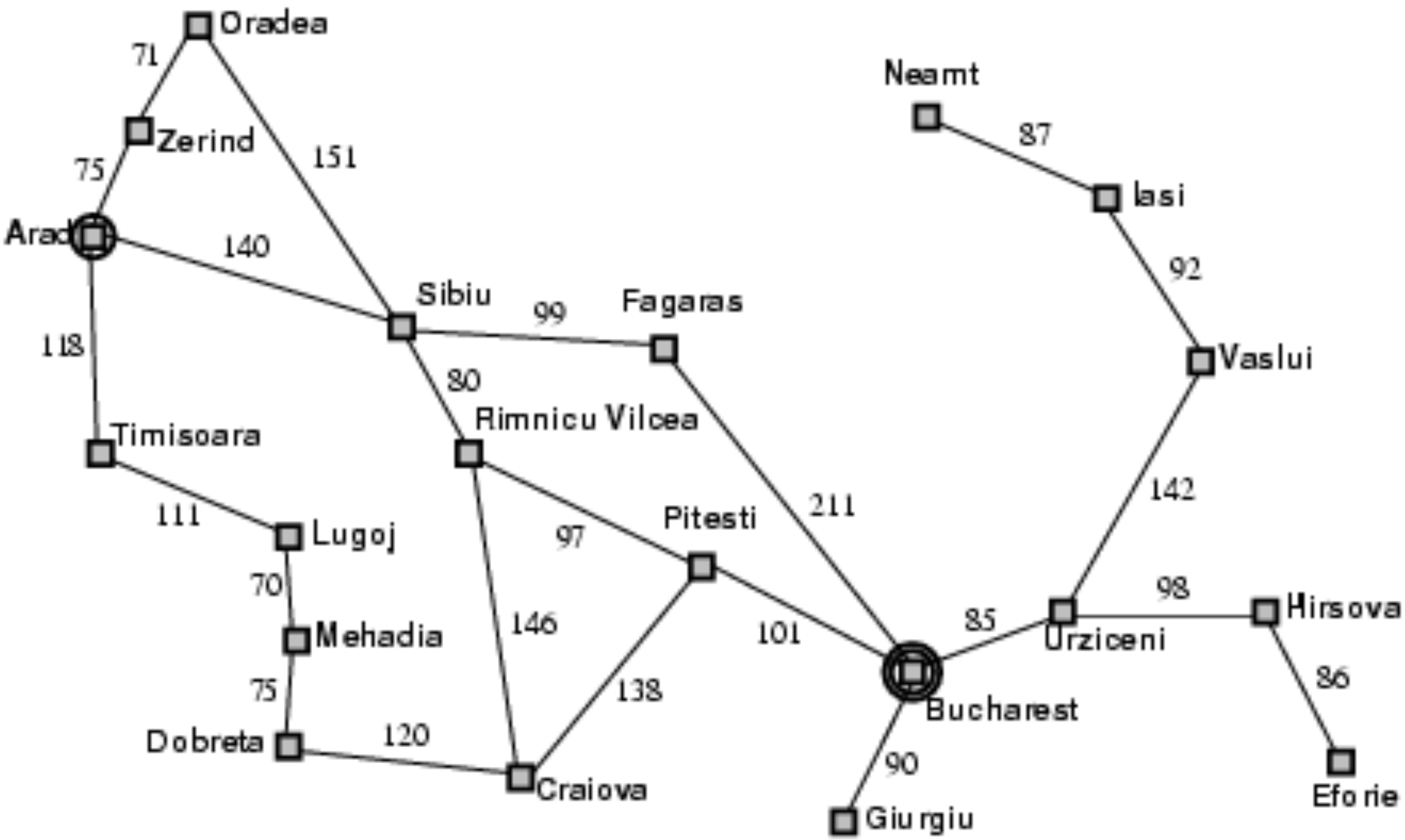
Depth-first search

- Complete? No: fails in infinite-depth spaces, spaces with loops
  - Modify to avoid repeated states along path
  - complete in finite spaces
- Time? $O(b^m)$: terrible if m is much larger than d
  - but if solutions are dense, may be much faster than breadth-first
- Space? $O(bm)$: linear space!
- Optimal? No

From Arad to Bucharest



Exercise time

- Bring up your laptop, and go here:
- https://qiao.github.io/PathFinding.js/visual/
- Try creating a few mazes that can be solved with breadth first search and see how it works

Depth-limited search

- Depth-first search with depth limit l; nodes at depth l have no successors

```
function DEPTH-LIMITED-SEARCH( problem, limit) returns soln/fail/cutoff
    RECURSIVE-DLS(MAKE-NODE(INITIAL-STATE[problem]), problem, limit)

function RECURSIVE-DLS(node, problem, limit) returns soln/fail/cutoff
    cutoff-occurred? ← false
    if GOAL-TEST[problem](STATE[node]) then return SOLUTION(node)
    else if DEPTH[node] = limit then return cutoff
    else for each successor in EXPAND(node, problem) do
        result ← RECURSIVE-DLS(successor, problem, limit)
        if result = cutoff then cutoff-occurred? ← true
        else if result ≠ failure then return result
    if cutoff-occurred? then return cutoff else return failure
```

Iterative deepening

- Do depth-limited search at increasing depths

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

  for $depth \leftarrow$ 0 **to** ∞ **do**
    $result \leftarrow$ DEPTH-LIMITED-SEARCH(*problem*, *depth*)
    if $result \neq$ cutoff **then return** *result*

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

Bring up your laptop again

- Create a maze that you think will be better solved by depth-first search than breadth-first search
- Take a screenshot of the maze you created (with breadth-first search run on it), and upload this image as exercise 1
- No, it doesn't have to be anything special
- Yes, each one of you has to upload an individual image

First assignment

- Implement a number of search algorithms in Sokoban
- Compare the performance of these algorithms
- Hand in the source code

Important

- Search in state space, not in physical space
- For expanding a node, copy the game state and take actions in it - this is the successor function which returns the next state

TA and office hours

- TA hours held by the TAs (zoom)
  - Tuesday, noon
  - Friday, noon
- Office hours held by Julian (zoom)
  - Tuesday, 1 pm

TA or office hours?

- Go to the TA hours with all implementation questions and questions concerning how algorithms work, reports are written etc
    - If the TAs can’t explain it to you, go to Julian
- Go to Julian (office hours) with administrative questions and everything not listed here
    - Don’t go to Julian with technical problems without going to the TAs first