EECS 391
Intro to AI

Problem Solving by Search

L3: Thu, Sep 7, 2017

Outline

- Problem solving agents
- Defining problem spaces
- Search algorithms
  - types
  - implementation
  - characterizing
- Uniformed search strategies
  - breath-first search
  - depth-first search
  - iterative deepening
  - bi-directional search

Problem solving by search: problem space and goal

- problem solving by search:
  - **define a problem space** in which we can find the solution

- **goal** of search:
  - find the **state** representing the (or a) **solution**

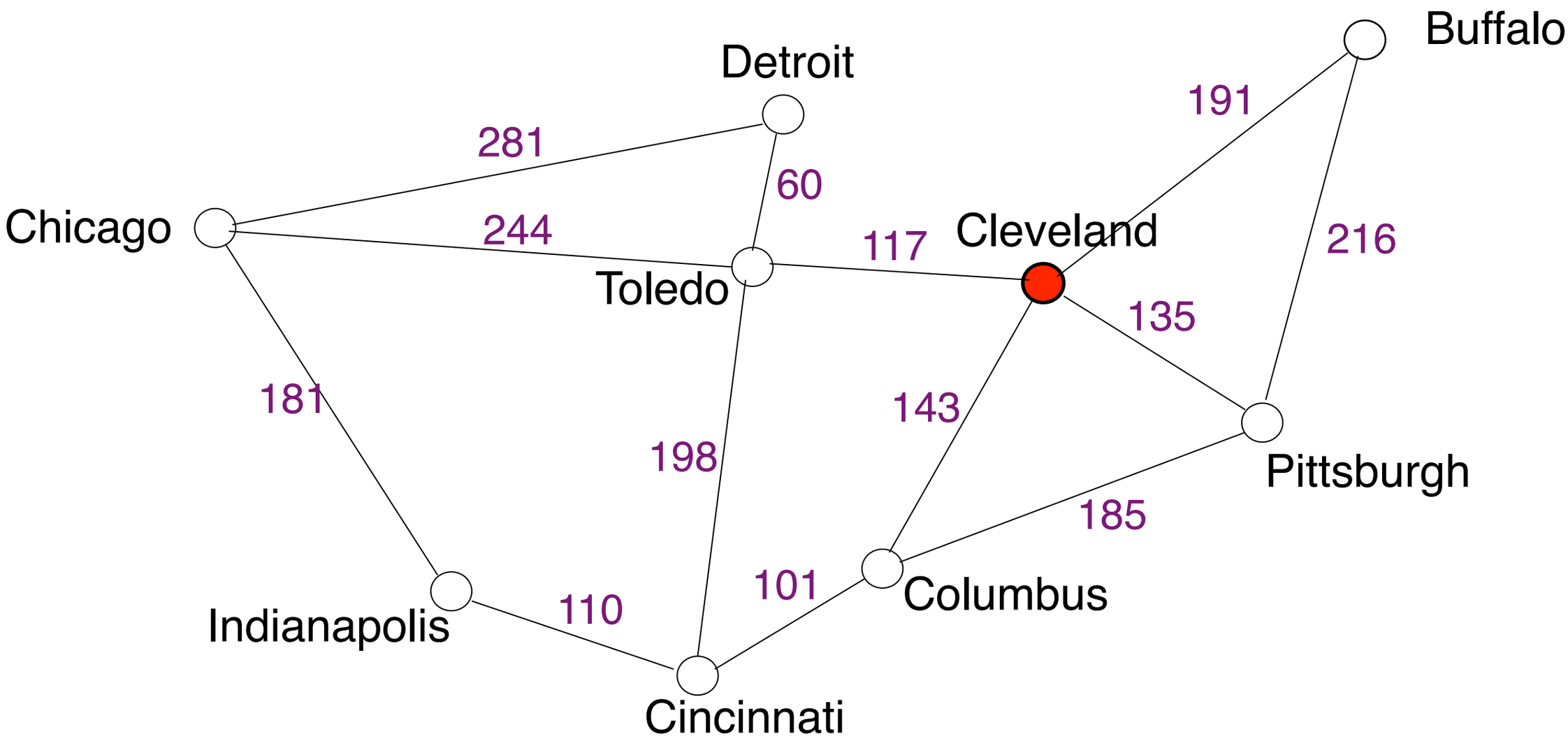
- **uniformed** search:
  - only given the problem definition
  - ***no a priori knowledge*** of where to look for the solution

How do we define the problem space?

- Problem: *How do we get to Cincinnati?*
  - by plane?
  - by car?
  - by bike?

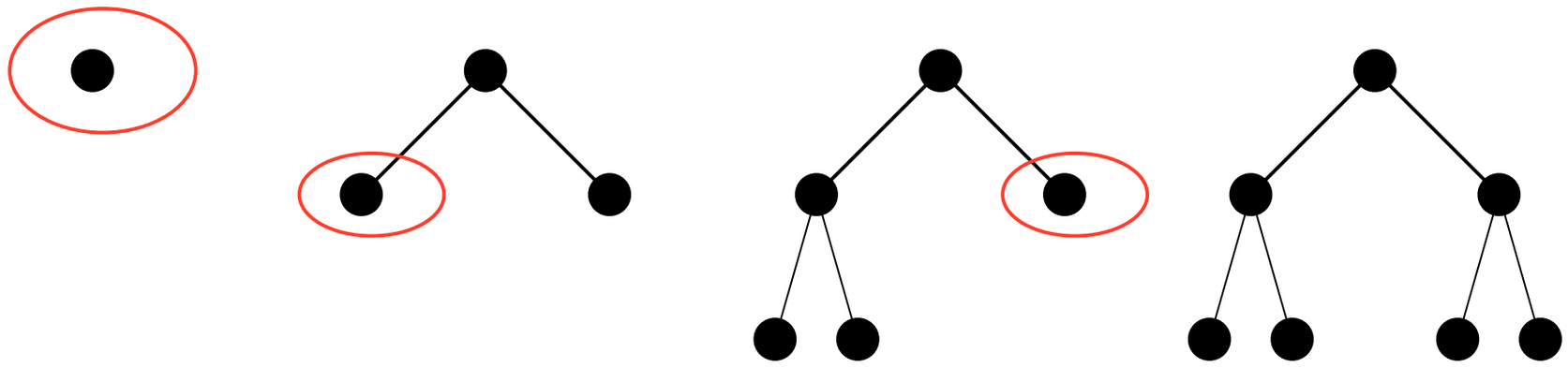
- Need to define:
  1. **initial state**
  2. available **actions**
  3. **goal test**
  4. action **cost** (which we'll address next lecture)

Representing the problem space with a graph



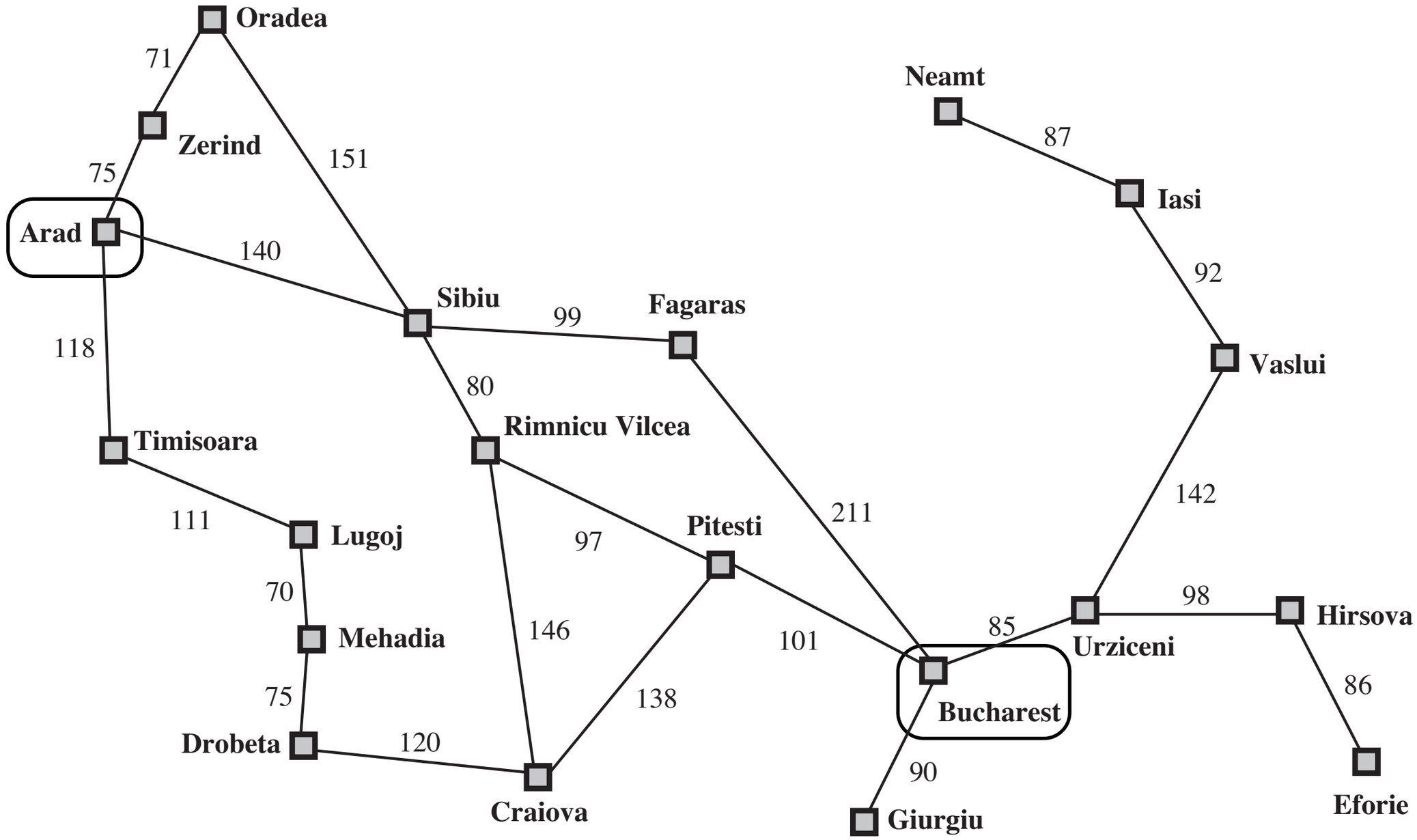
Breadth-first search

function BREADTH-FIRST-SEARCH (*problem*) **returns** a solution or failure
  return GENERAL-SEARCH (*problem*, ENQUEUE-AT-END)



- Type type of search is determined by how the *fringe* is expanded
- breadth-first search is implemented using a first-in first-out (FIFO) *queue*
  - all new nodes go at end of queue
  - shallow nodes are expanded before deeper nodes

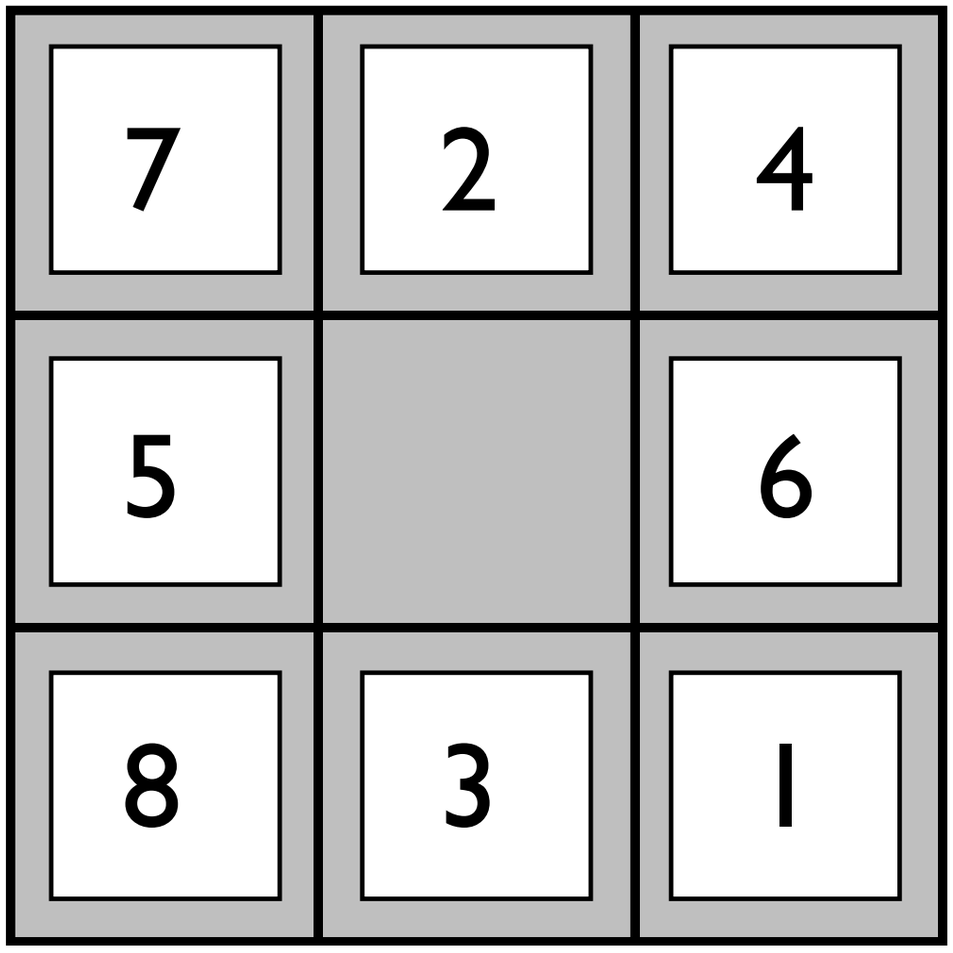
BFS on Romanian road map example



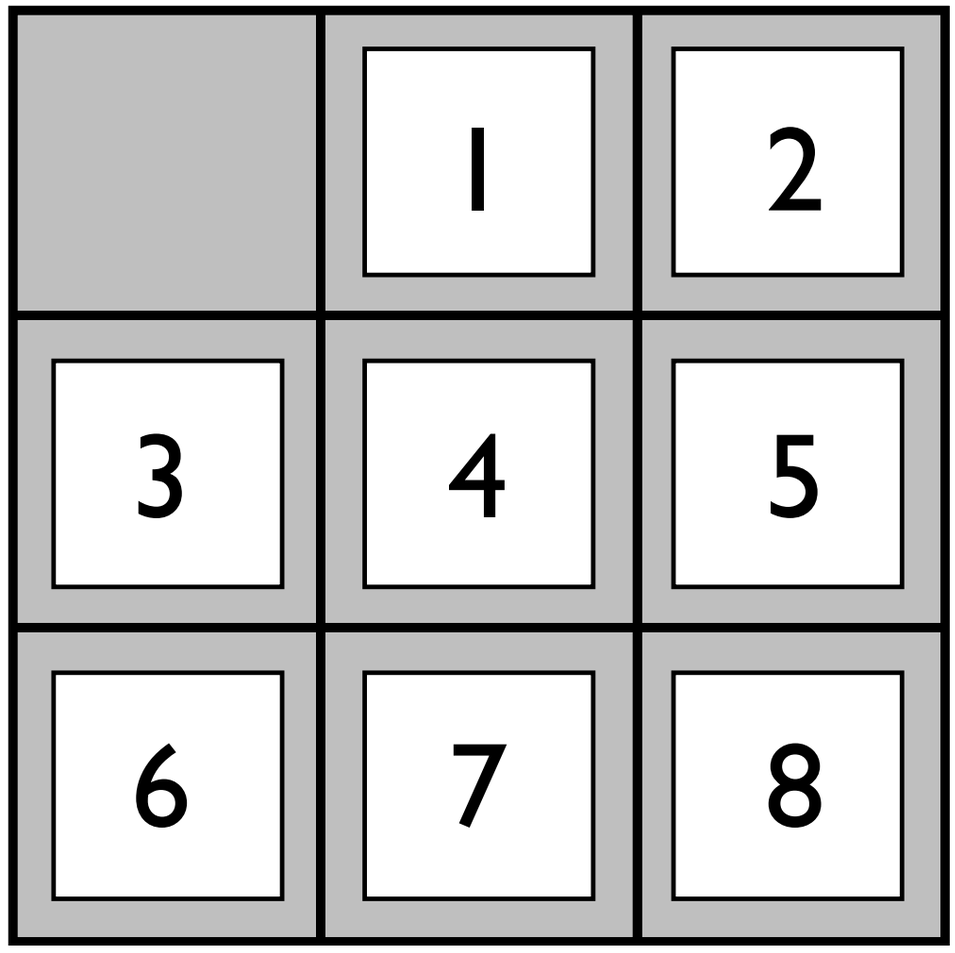
In absence of knowledge, node expansion order is arbitrary, i.e. alphabetical.
(Example on board)

The 8-puzzle (a sliding block puzzle)

start state



goal state



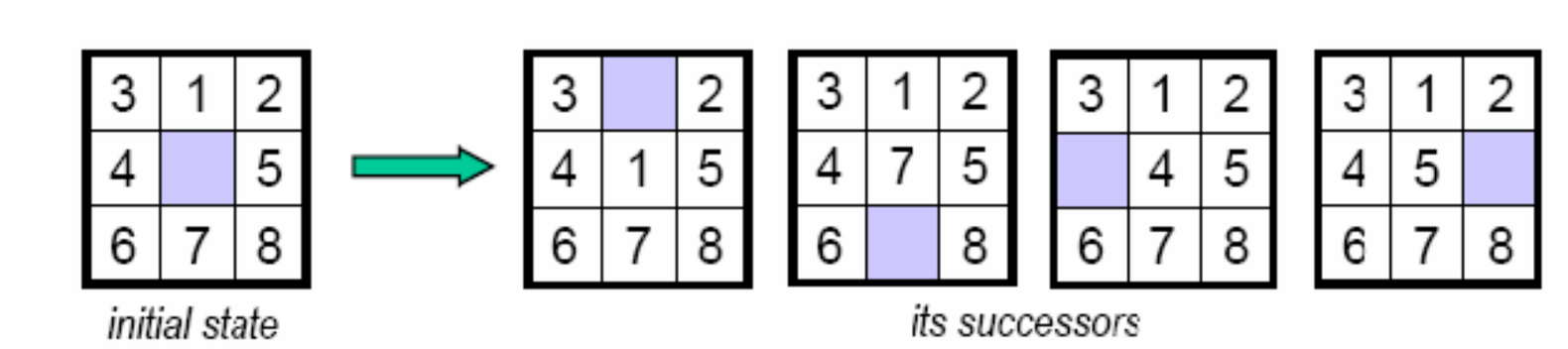
general class is NP-complete

How do we define the problem space?

state space, actions, and goal

State-space search

- Each successor defines different moves possible from the current puzzle state



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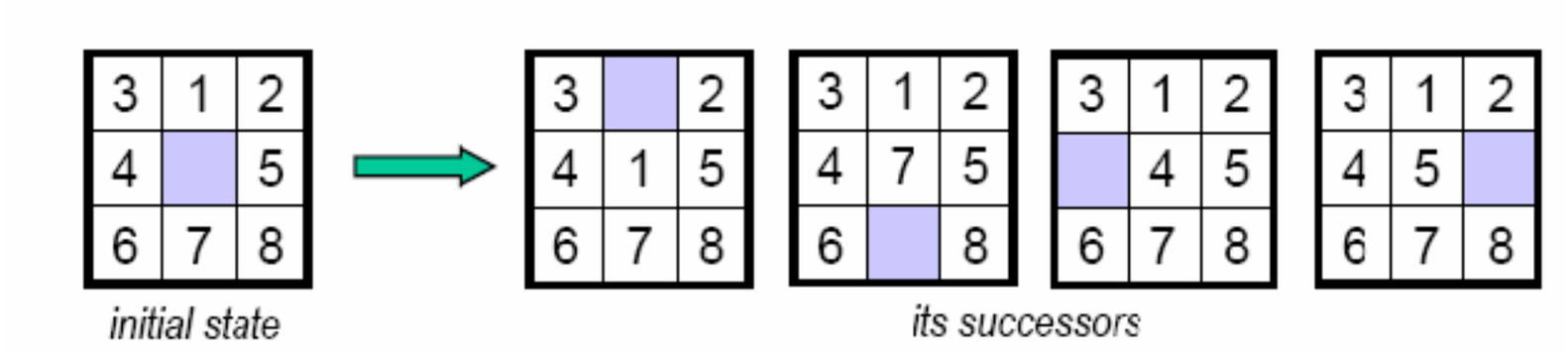
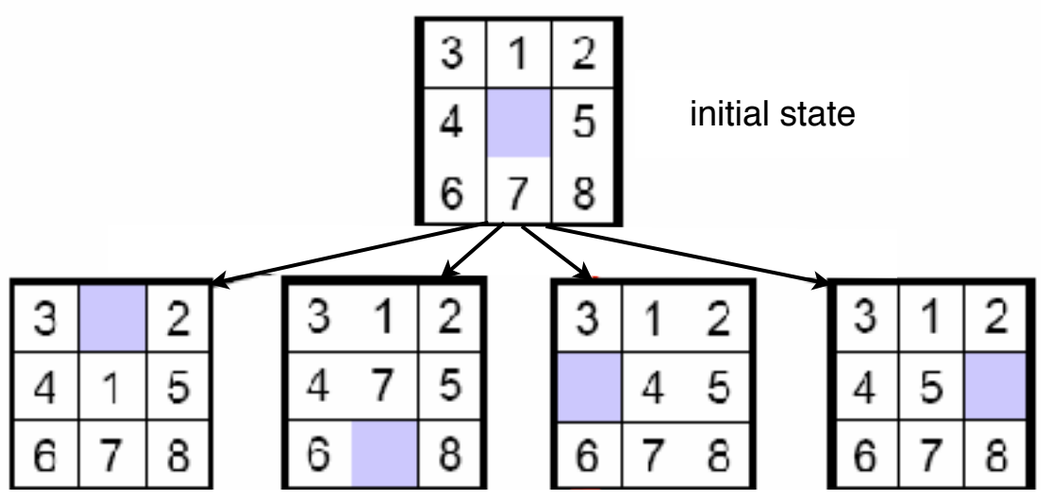
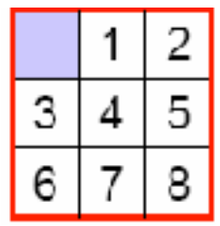


- We can employ different *search strategies* to find the goal state





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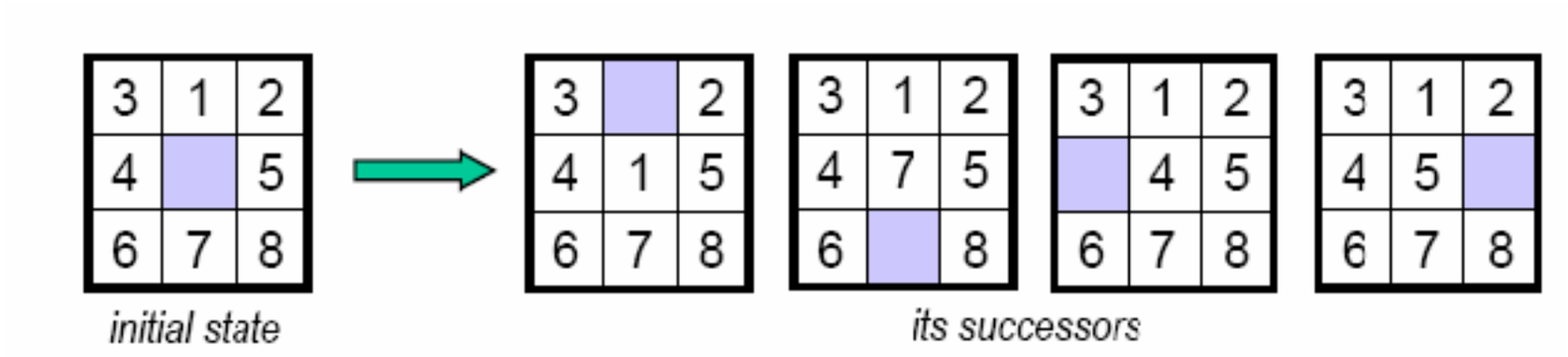

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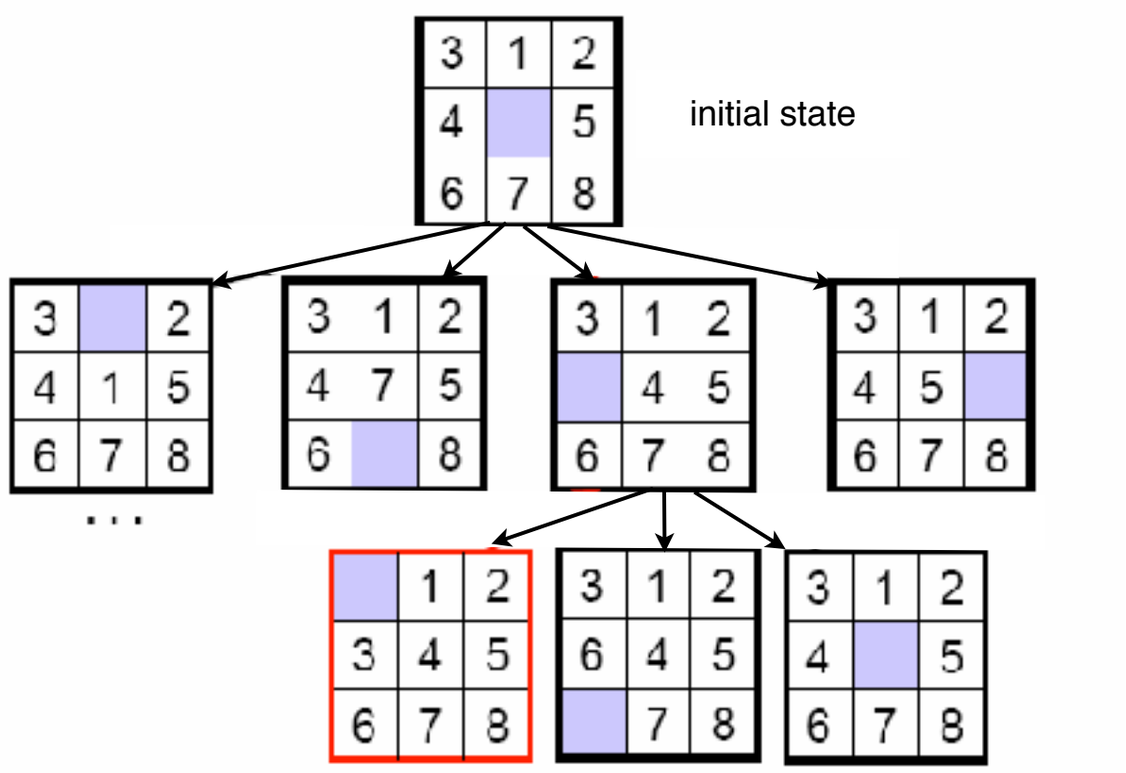
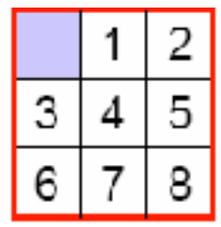
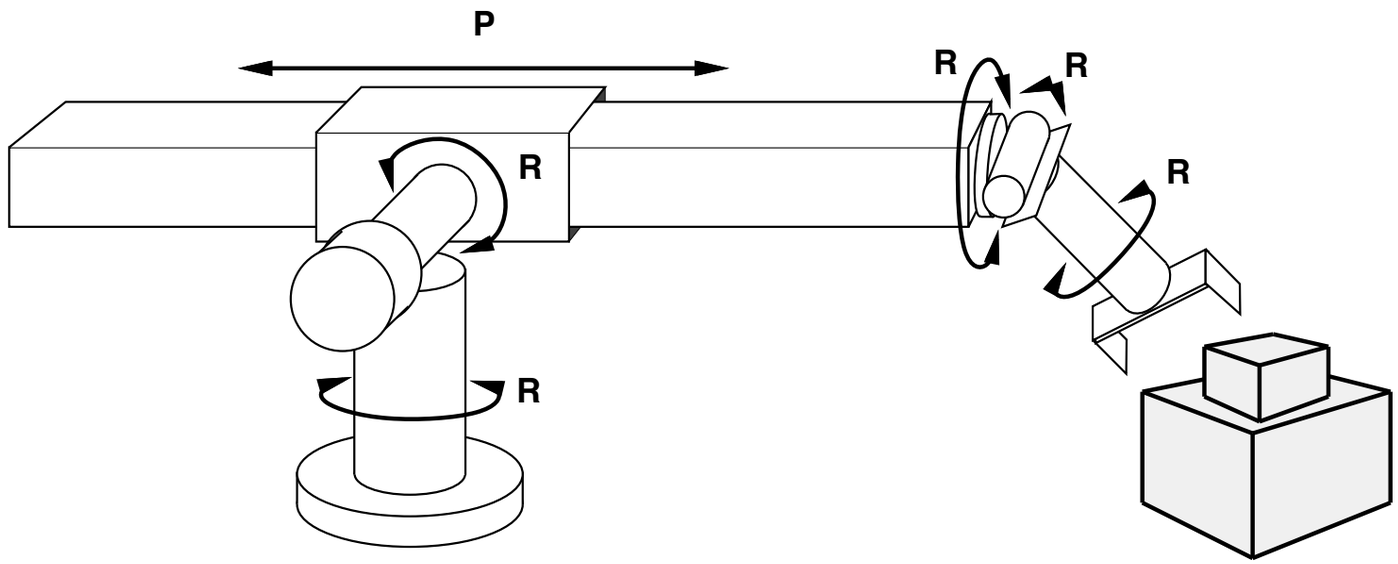




Robotic arm



1. initial state?	Angles and coordinations of joints. Object shape and position
2. available actions?	motion actions of robot arms and manipulators
3. goal?	grasp/place/sort object
4. action cost?	time, accuracy

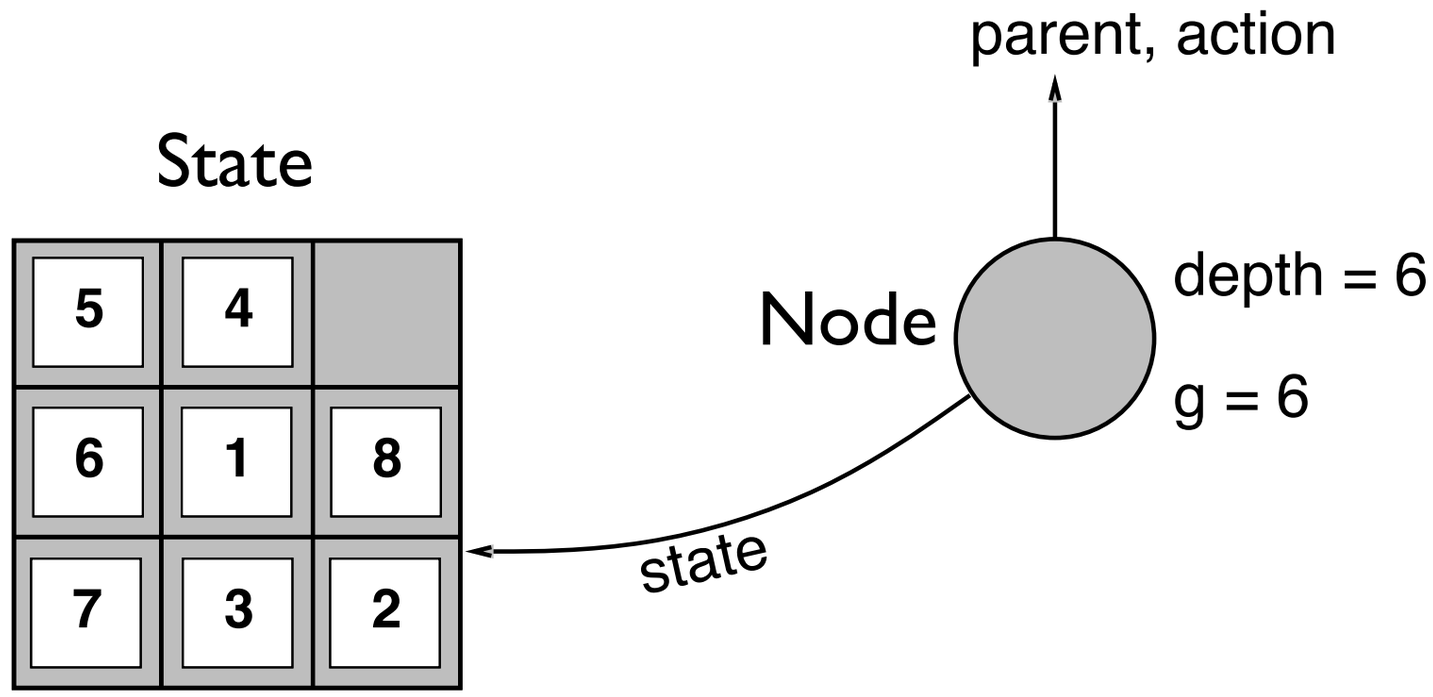
Other types of problems

- puzzles, e.g. Rubik's cube ~ 10^{19} states!
- google maps, GPS navigators
- internet spidering
- decoding
- routing (paths, vehicles, salesman)
- scheduling (meetings, conferences, airlines)
- design (electric grid, VLSI layout)
- protein folding

Implementing search

- state is the representation of the environment (e.g. city, or board position)
- graph nodes are created during search, could be infinite
- need to recognize
  - goal state
  - repeated states

- The **node** data type:
  - state
  - parent node
  - action
  - cost
  - depth



Generic search function outline

function Tree-Search(*problem, strategy*) **returns** solution or failure

initialize tree using initial state of *problem*

loop

if no candidates for expansion **return** failure

choose leaf node for expansion using *strategy*

if node contains goal state **return** solution

else expand node and add resulting nodes to search tree

- How do we specify the *problem*?
- What *strategies* are there? How do we implement them?

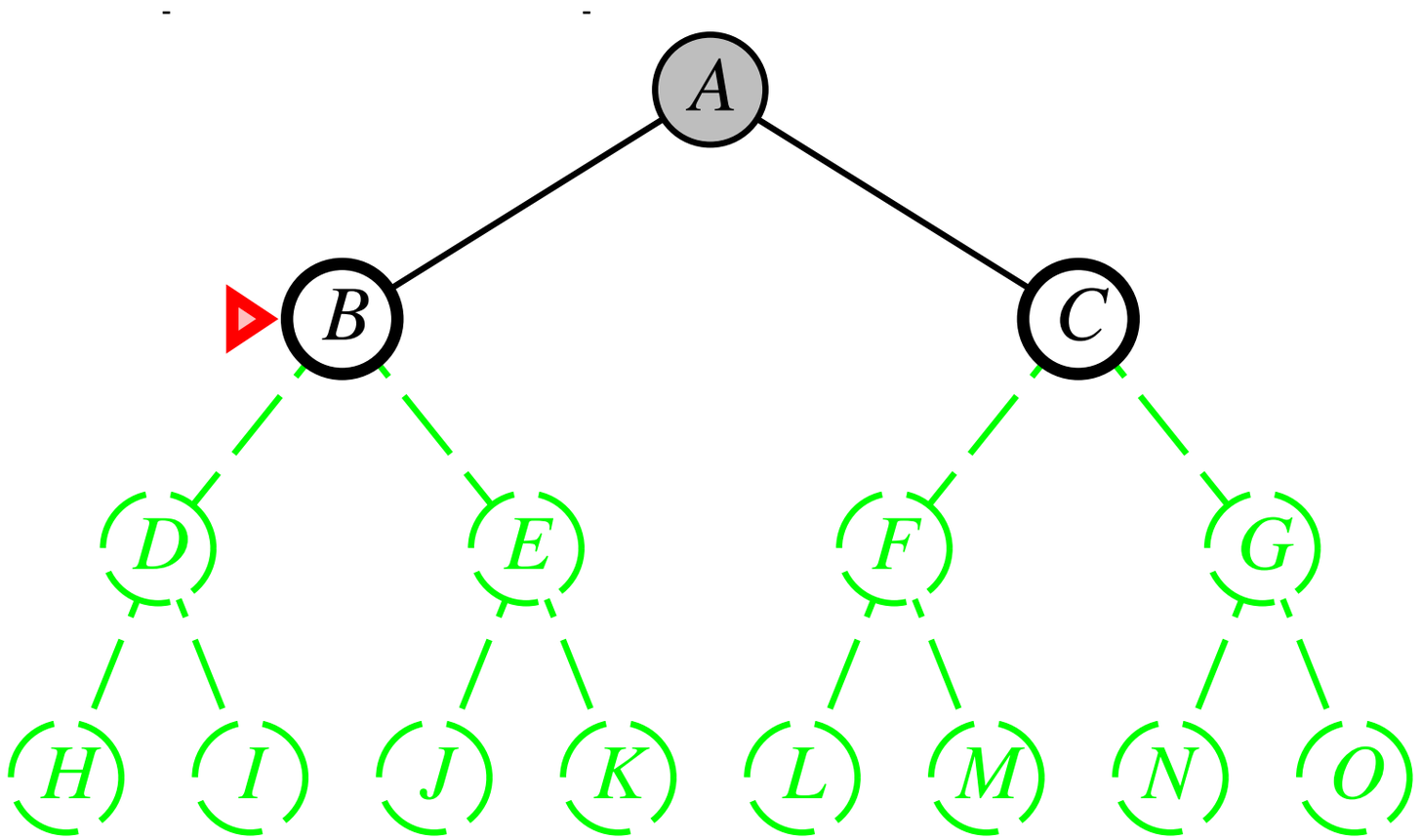
Uninformed search strategies

- Uninformed search strategies can only distinguish goal states from non-goal states, i.e. you can't tell when you're getting closing

- Types of uninformed search strategies:
  - Breadth-first search
  - Depth-first search
  - Depth-limited search
  - Iterative deepening search
  - Bi-directional search

Depth-first search

- expand *deepest* unexpanded node
- when expanding the fringe, the successors are put on the front (LIFO)



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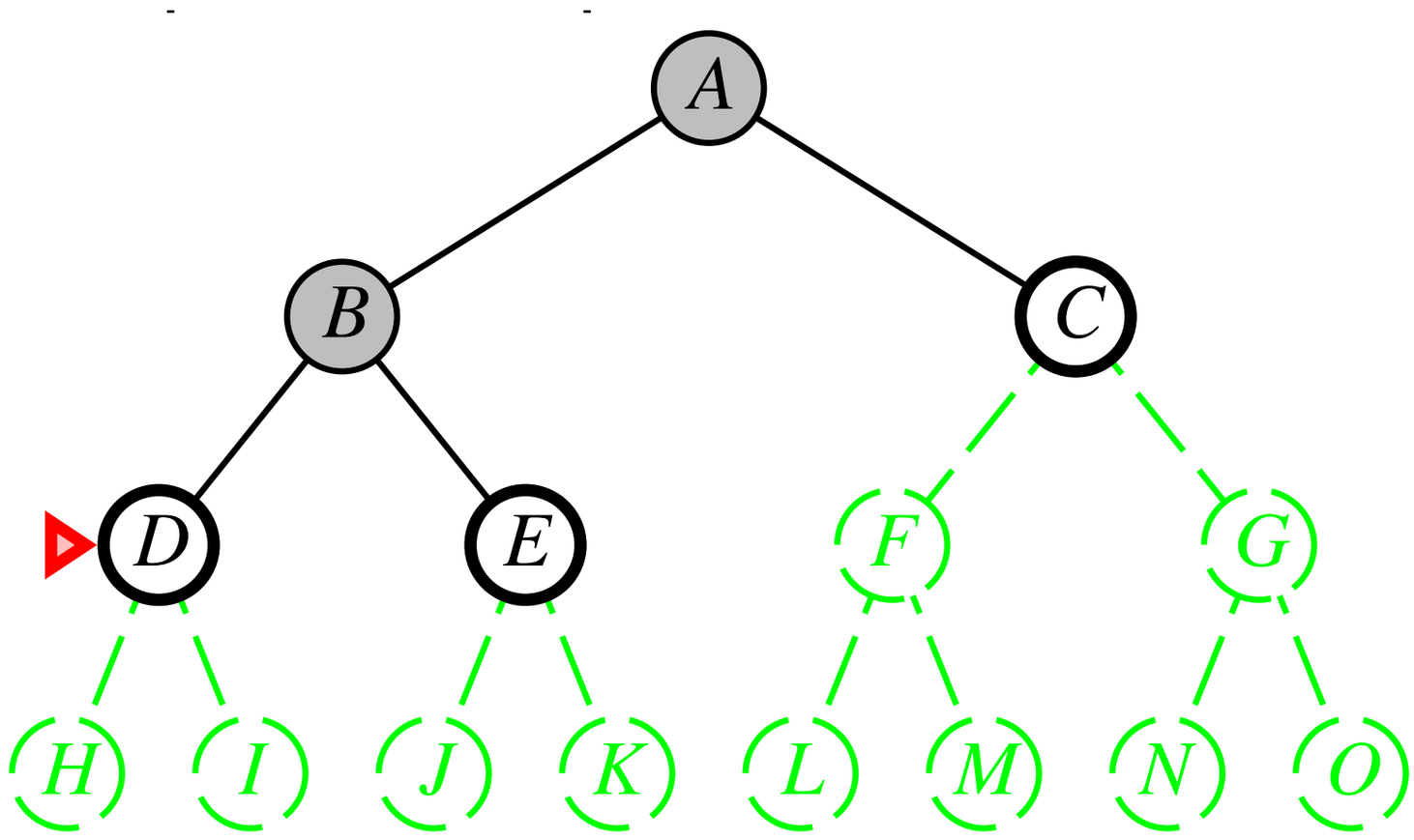

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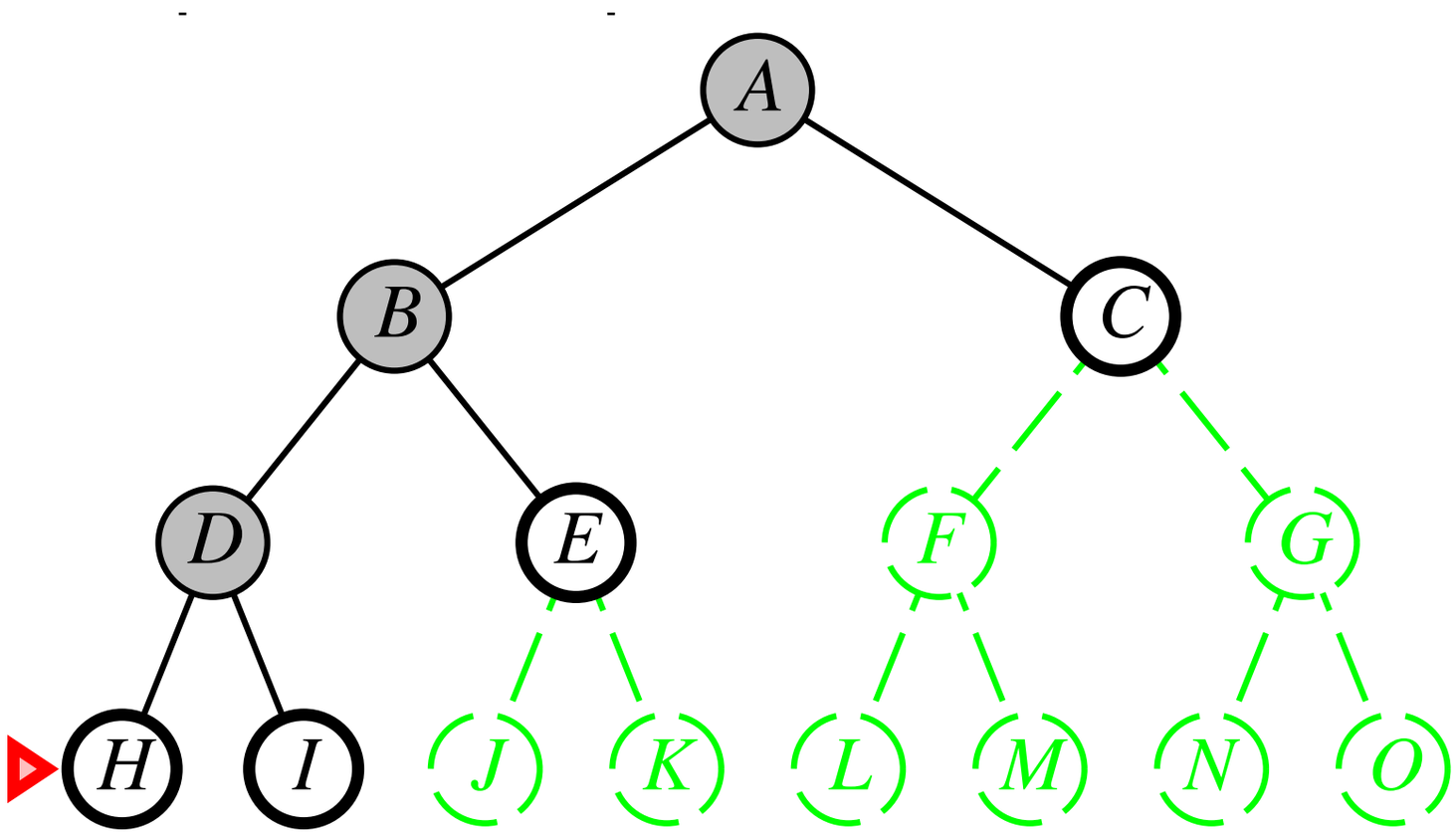

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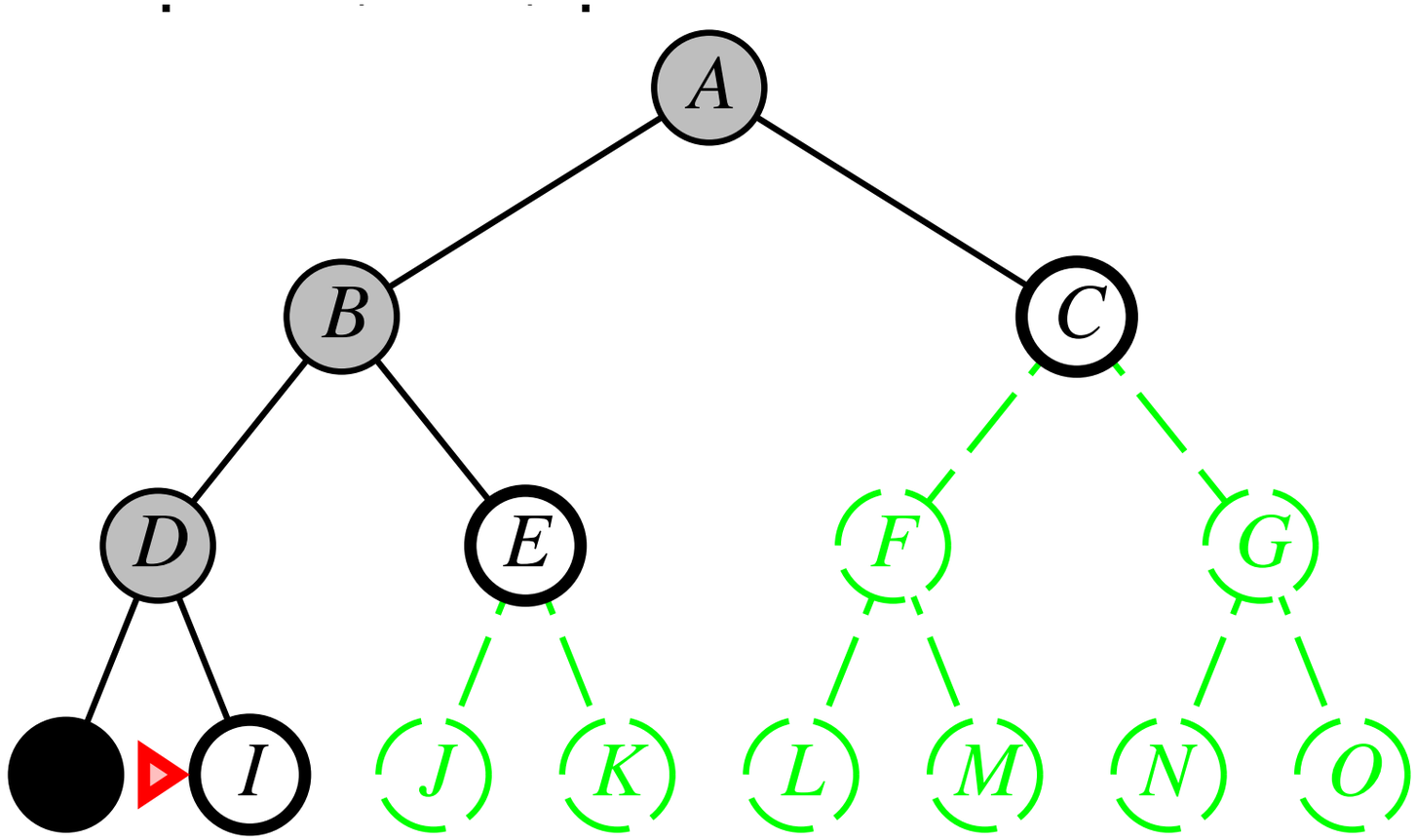

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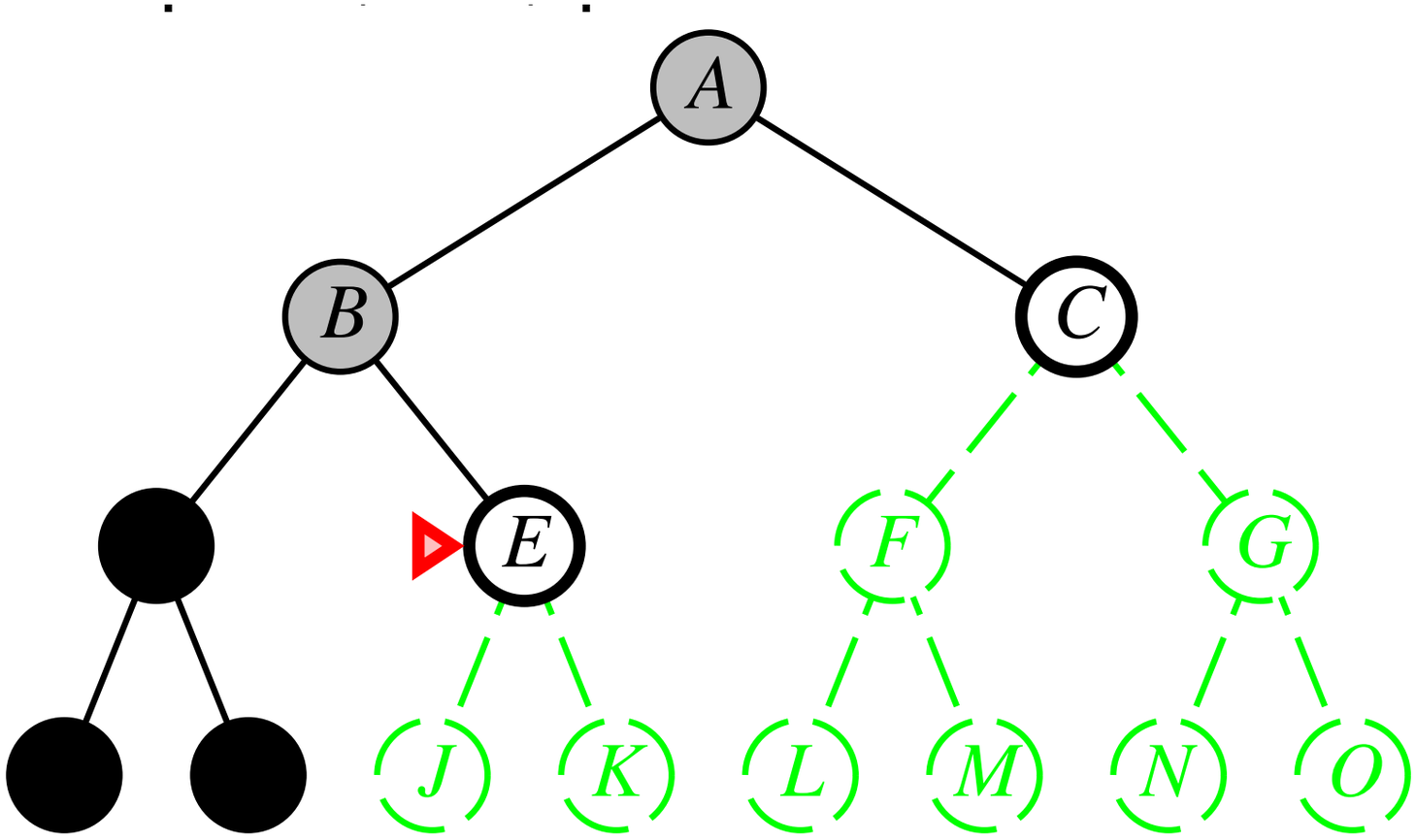

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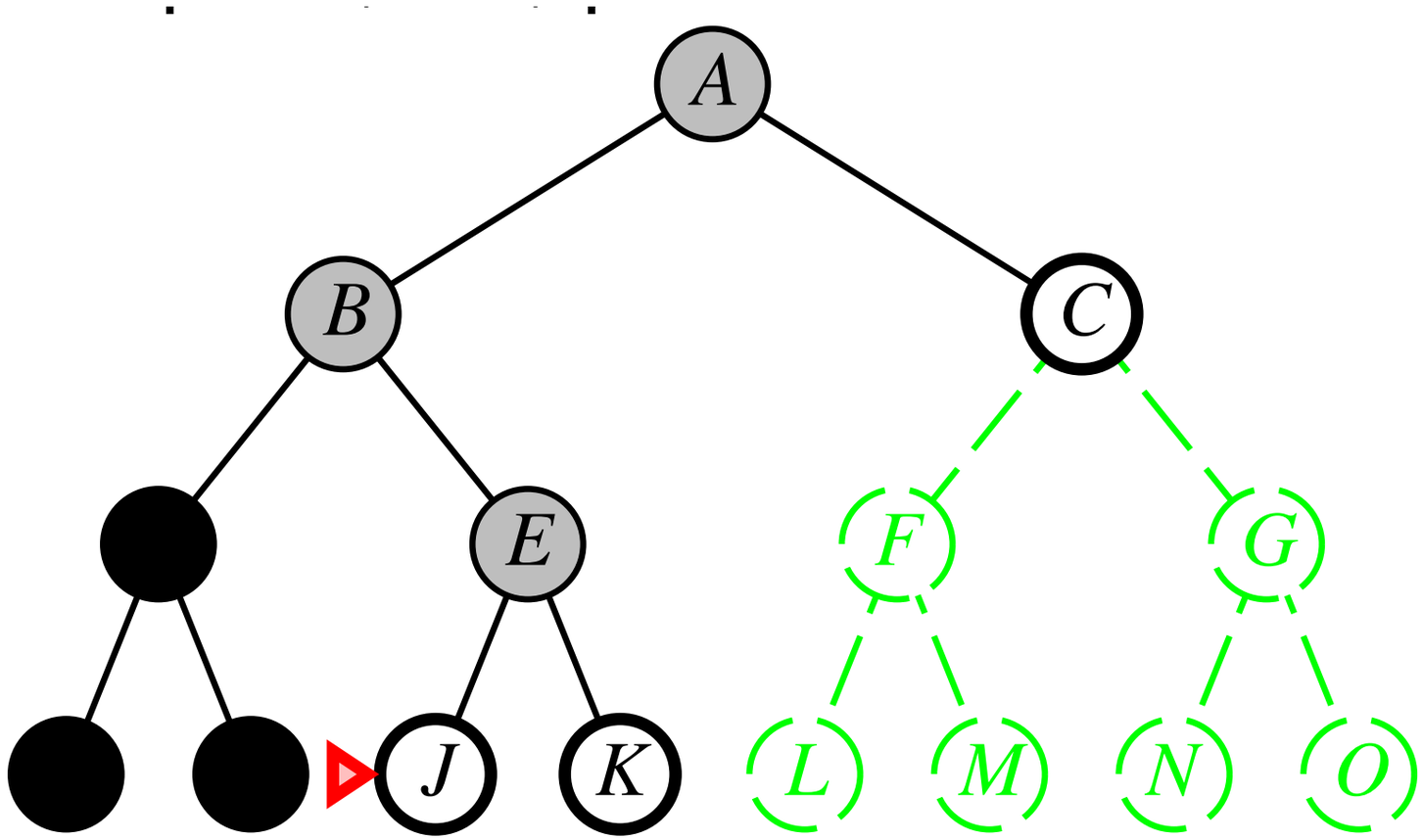

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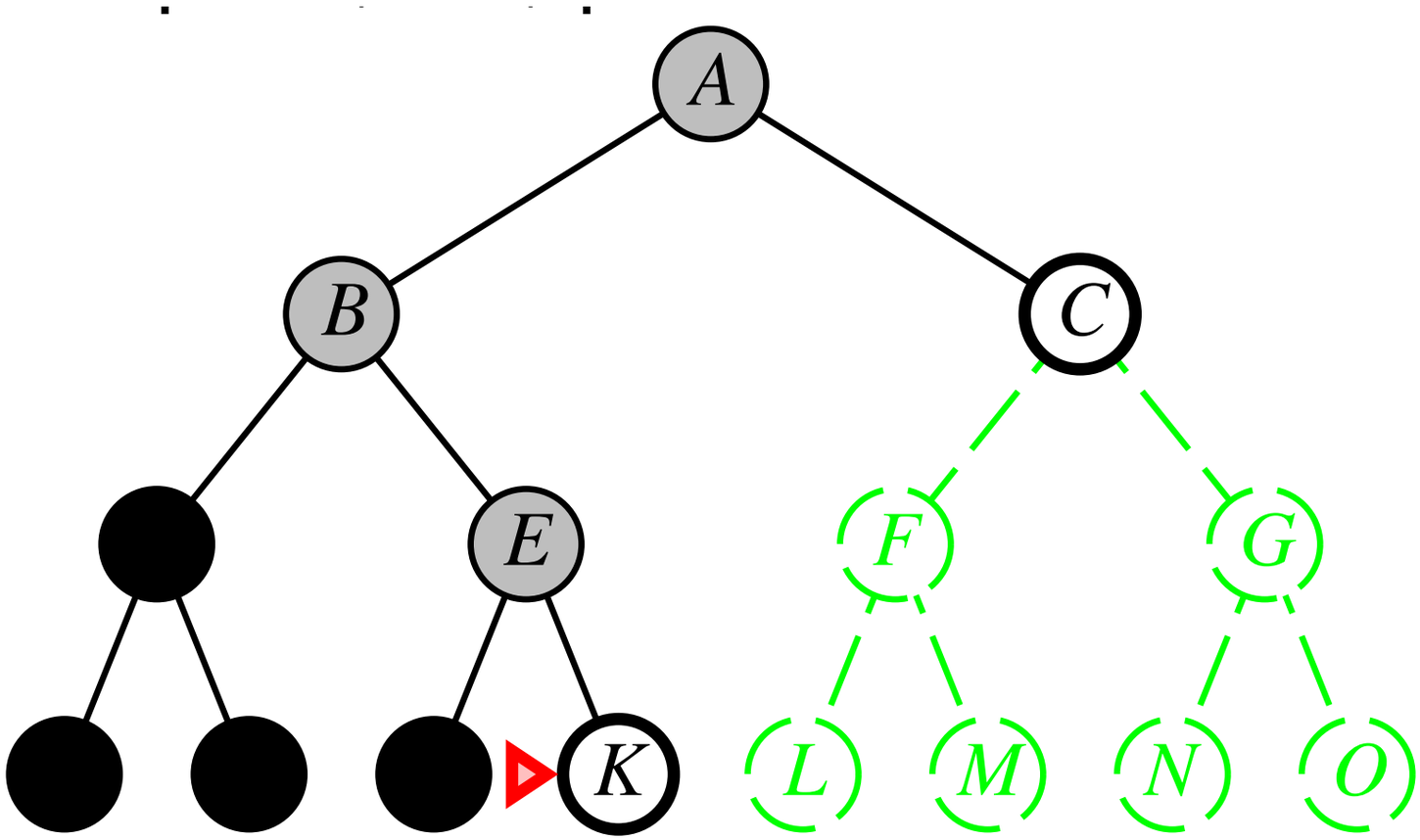

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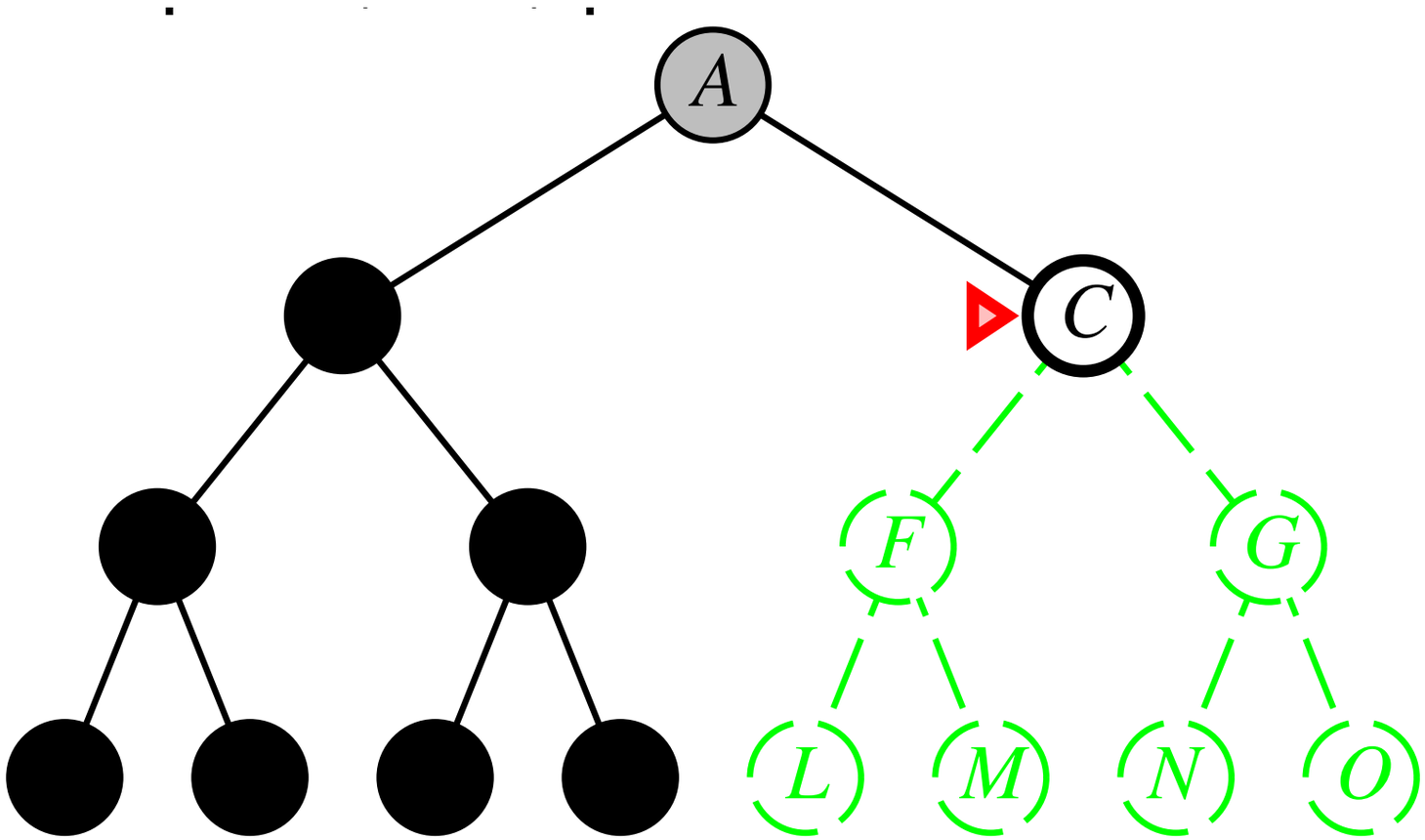
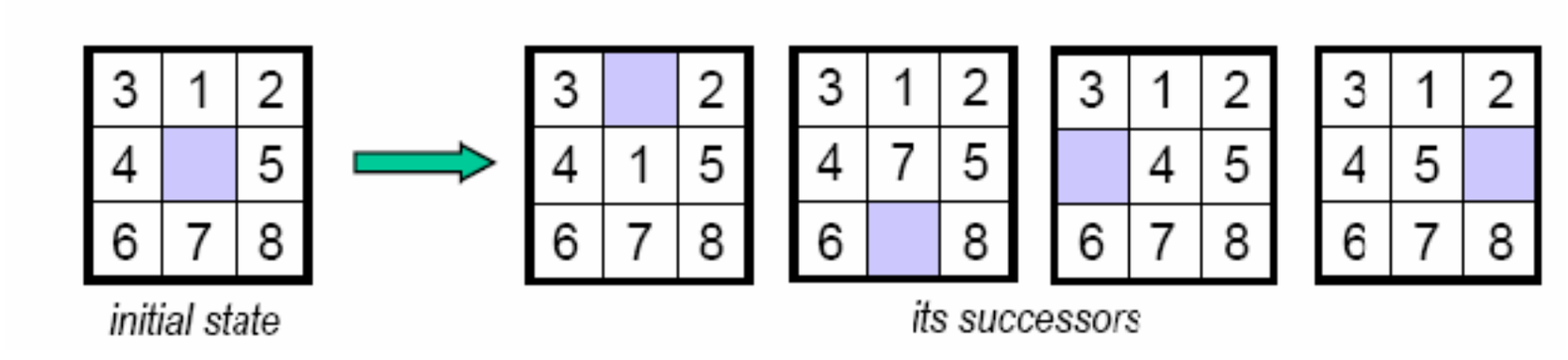
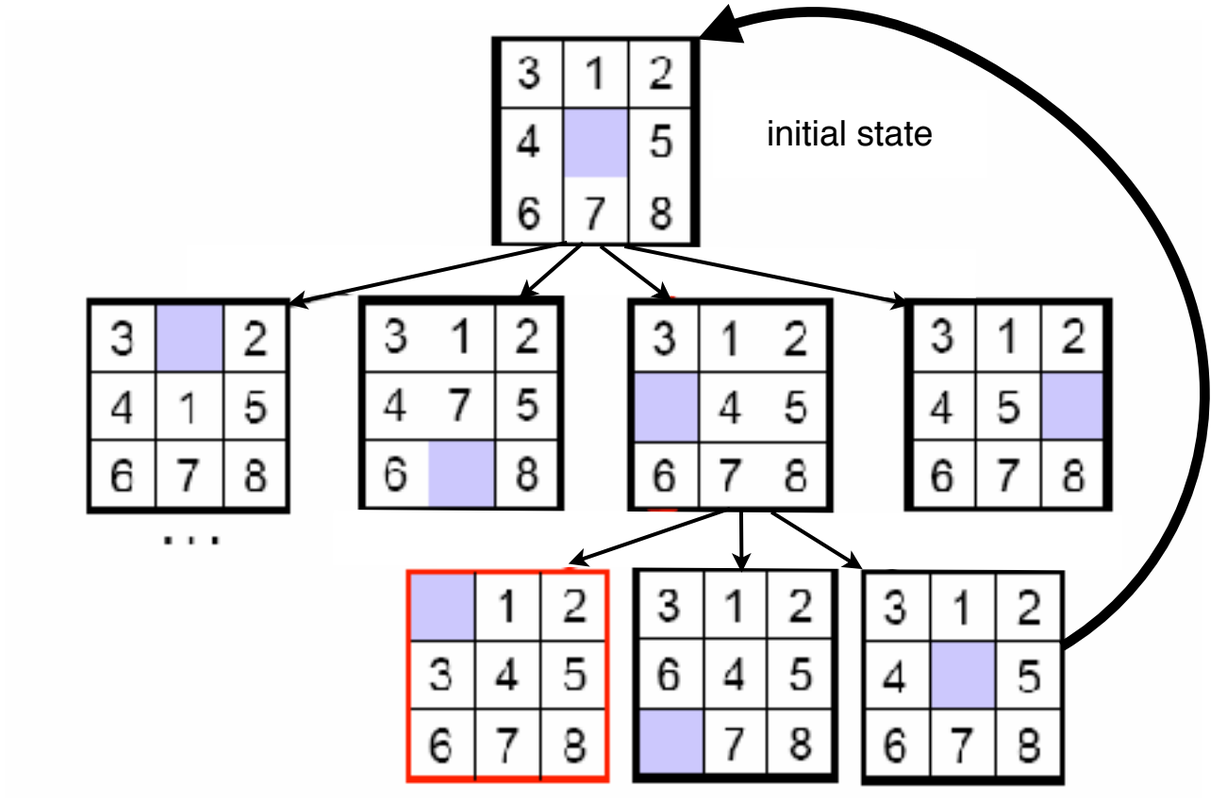


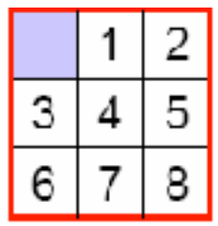
What about loops?

- Each successor defines different moves possible from the current puzzle state



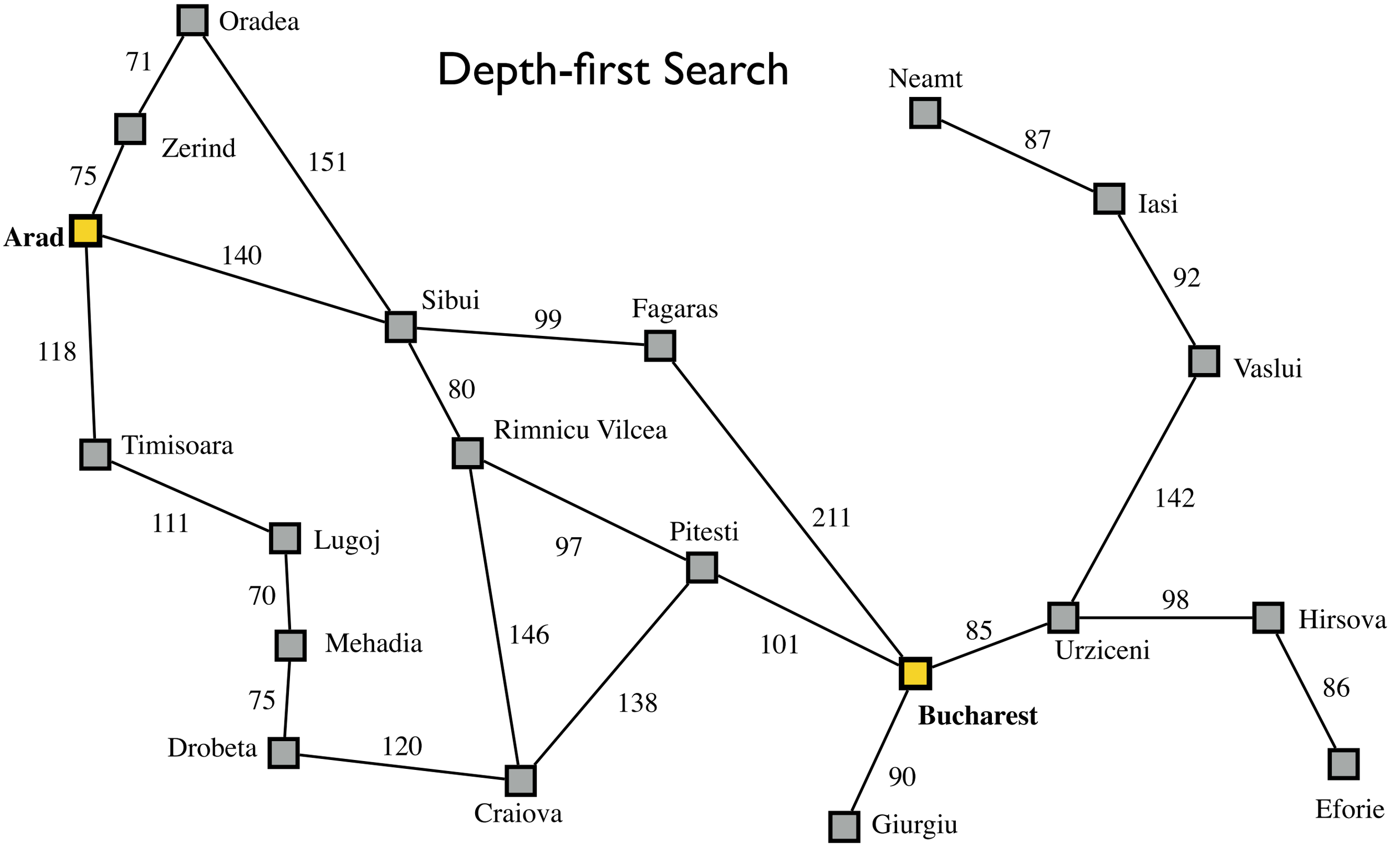
- We can employ different *search strategies* to find the goal state





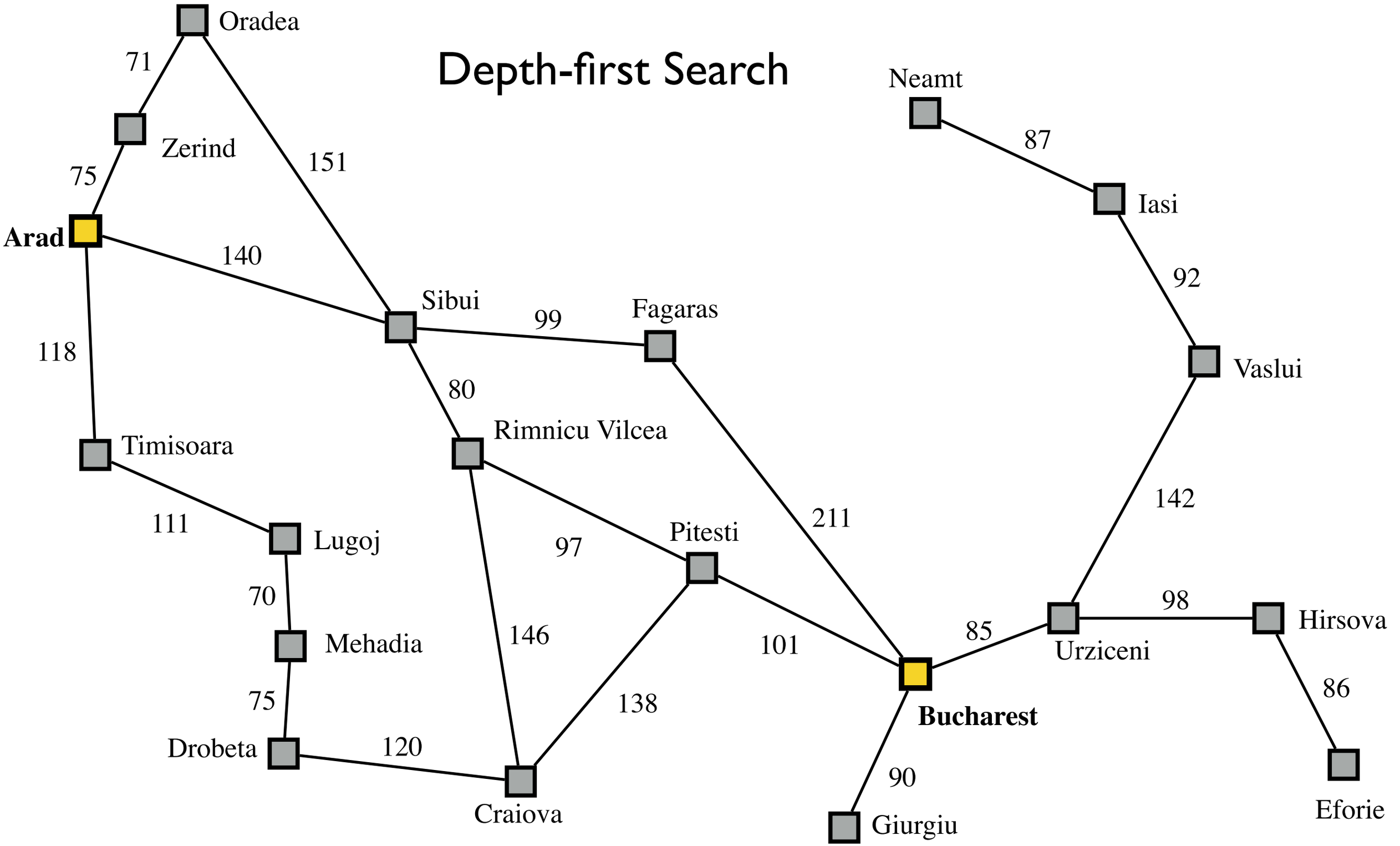
Need to mark nodes that have been visited.

Depth-first Search



Ignore the edge costs for now: we're only trying to find the goal.

Depth-first Search



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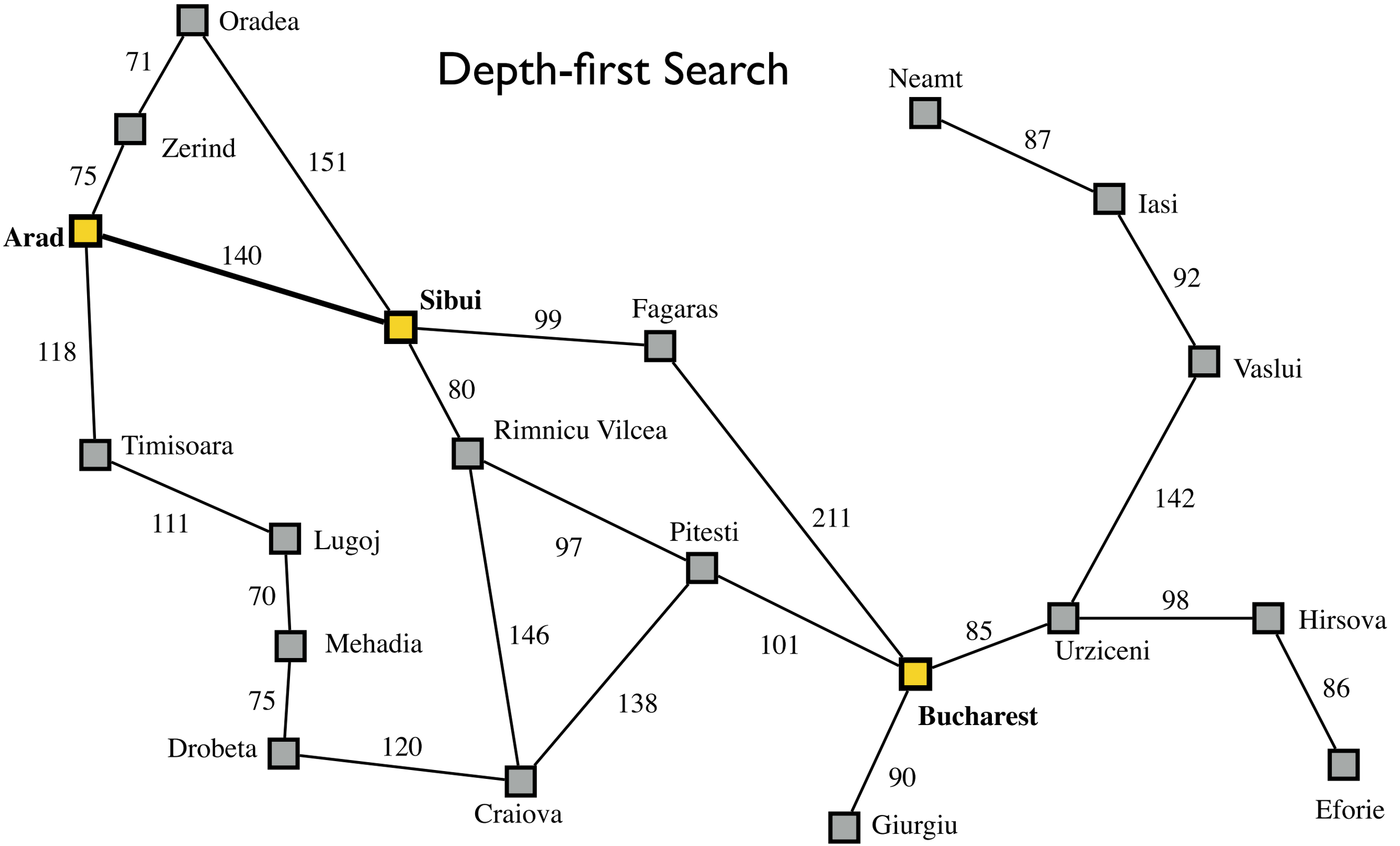

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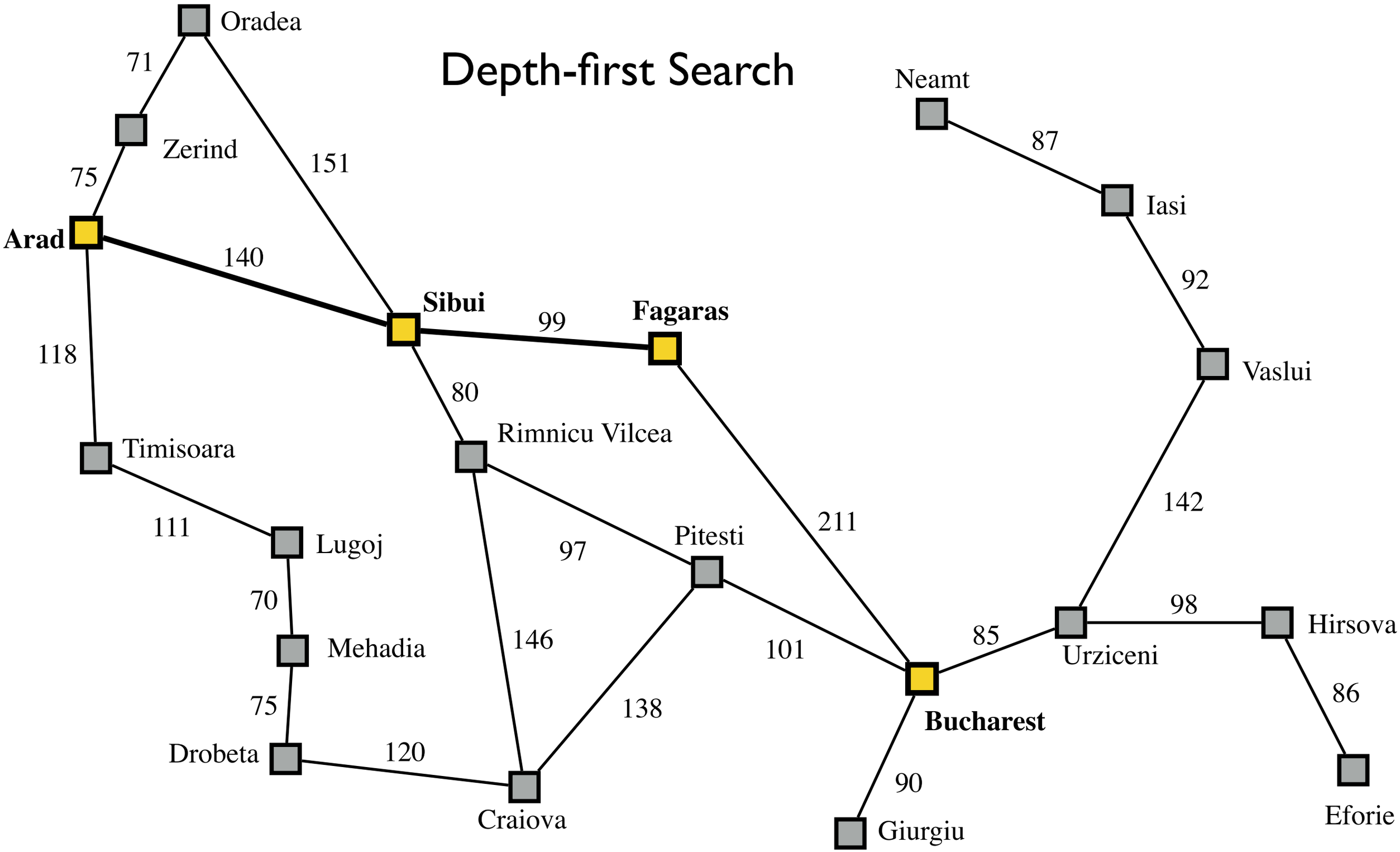

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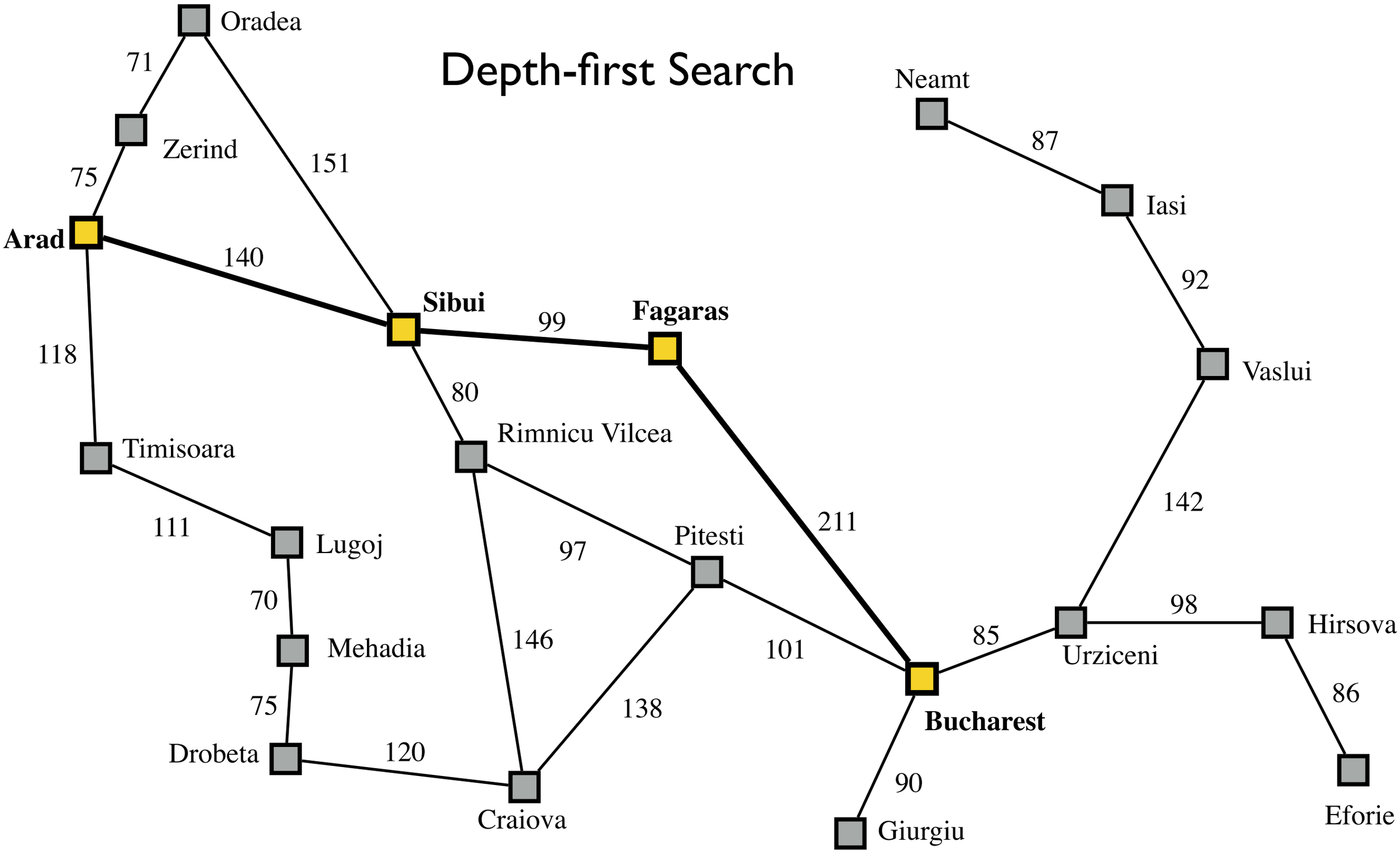

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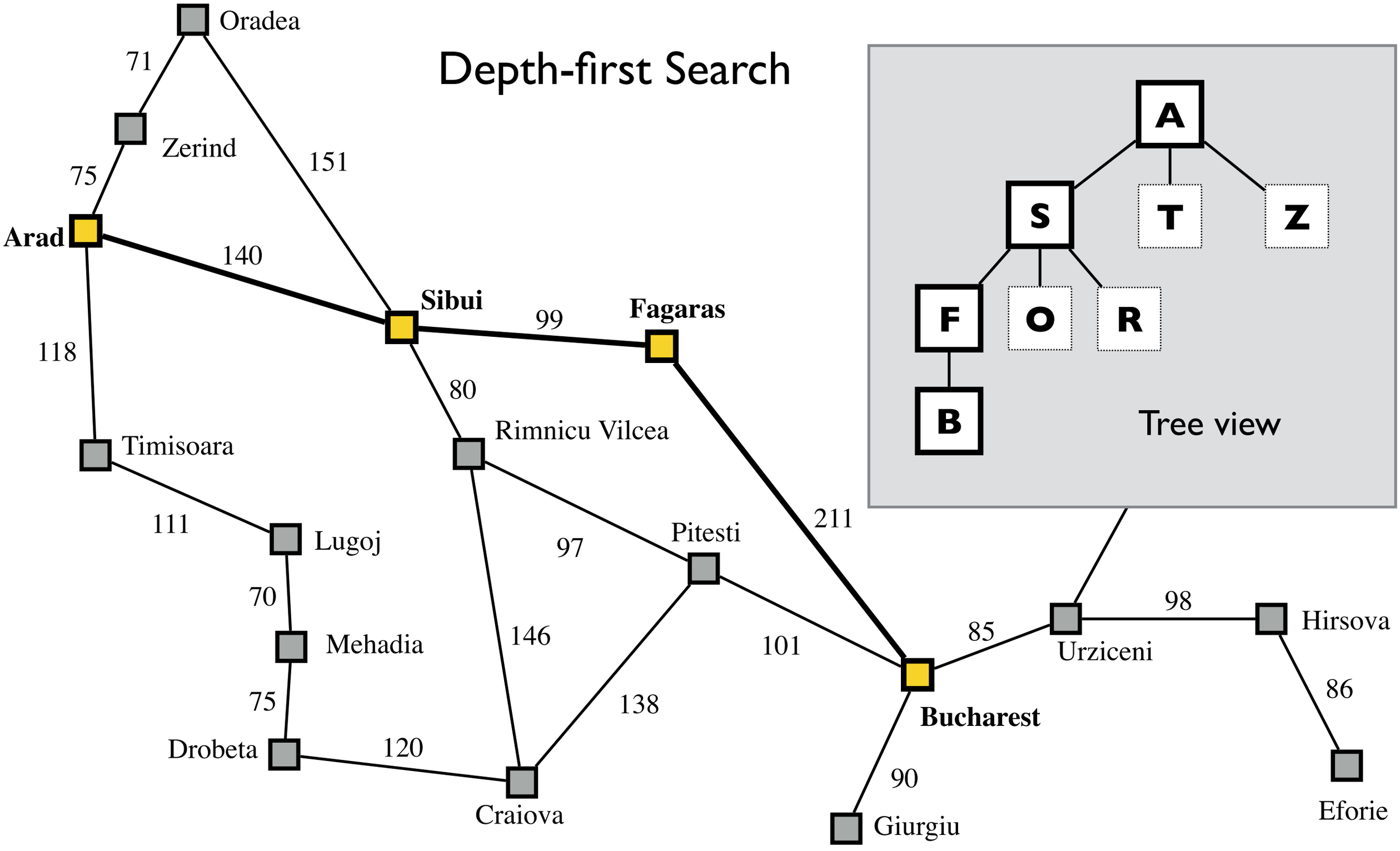

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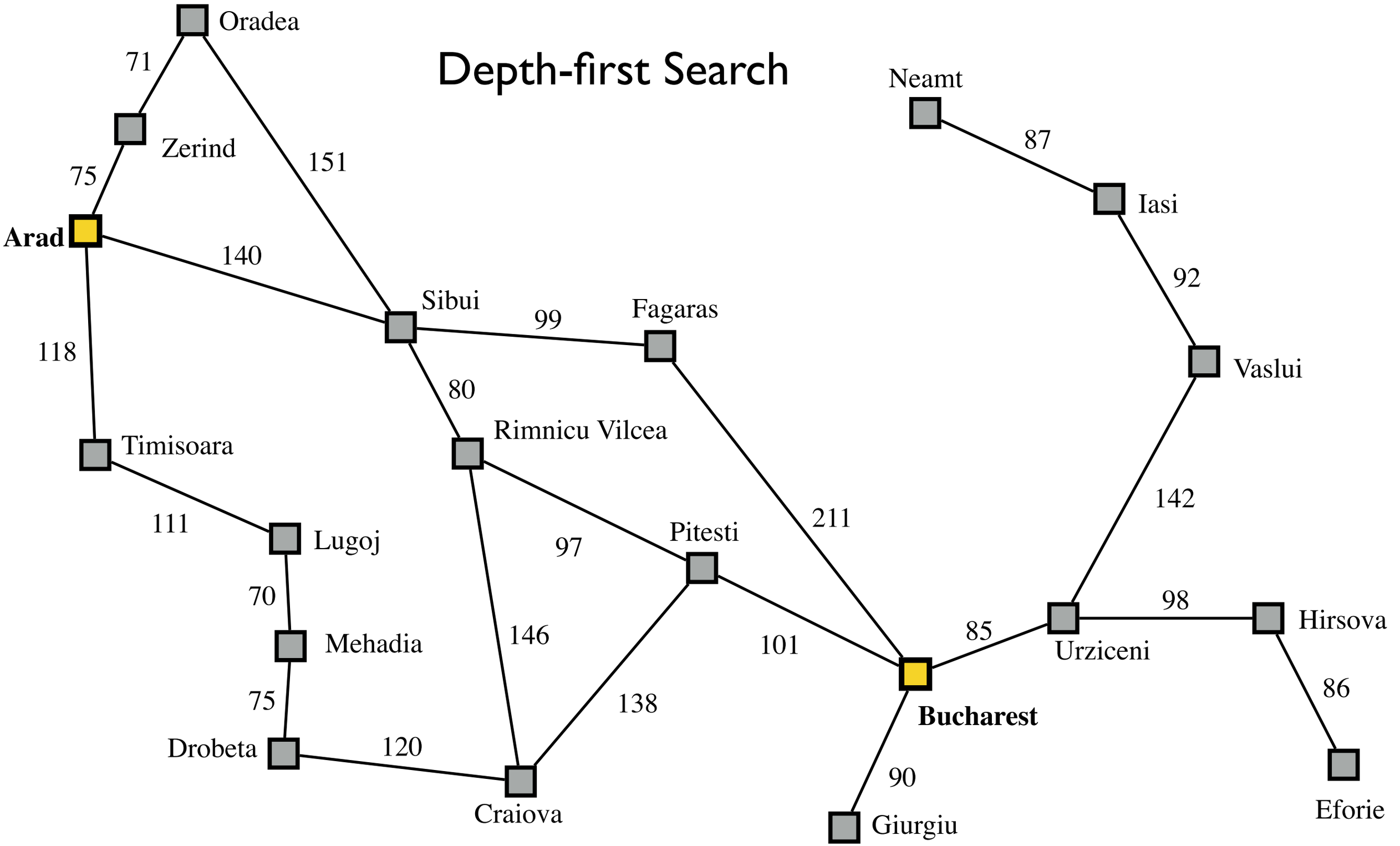

But what if we did reverse-alphabetical expansion?

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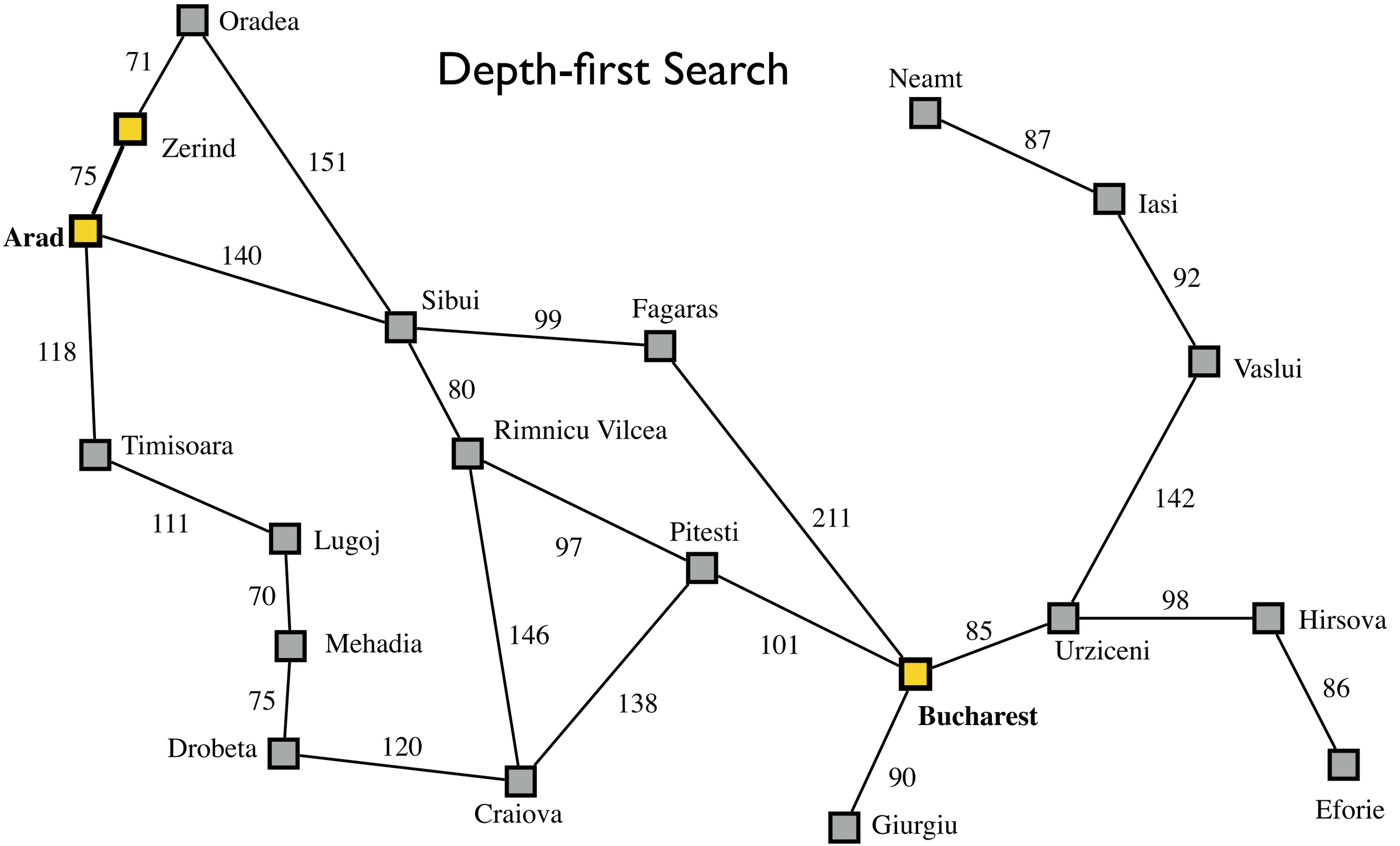

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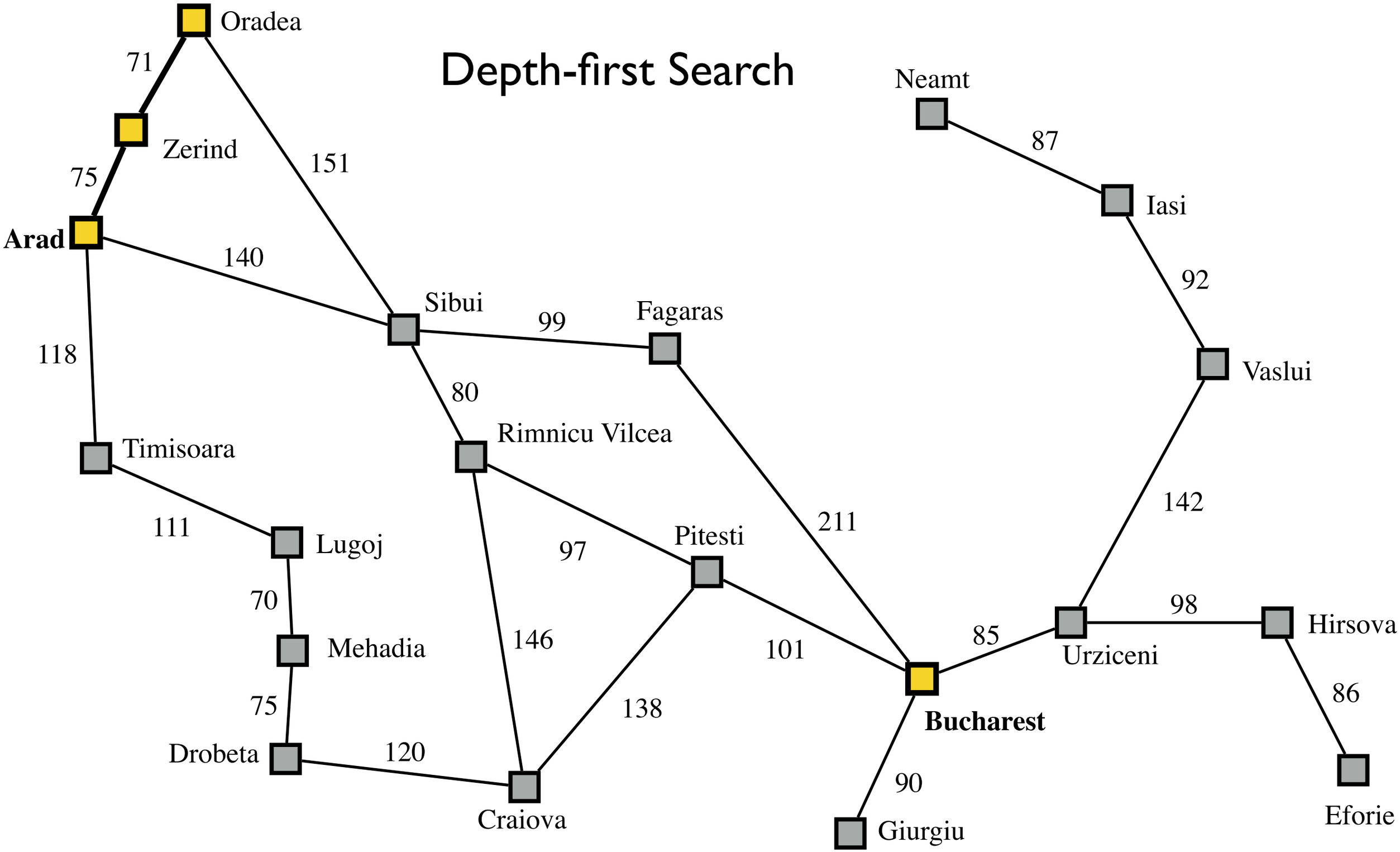

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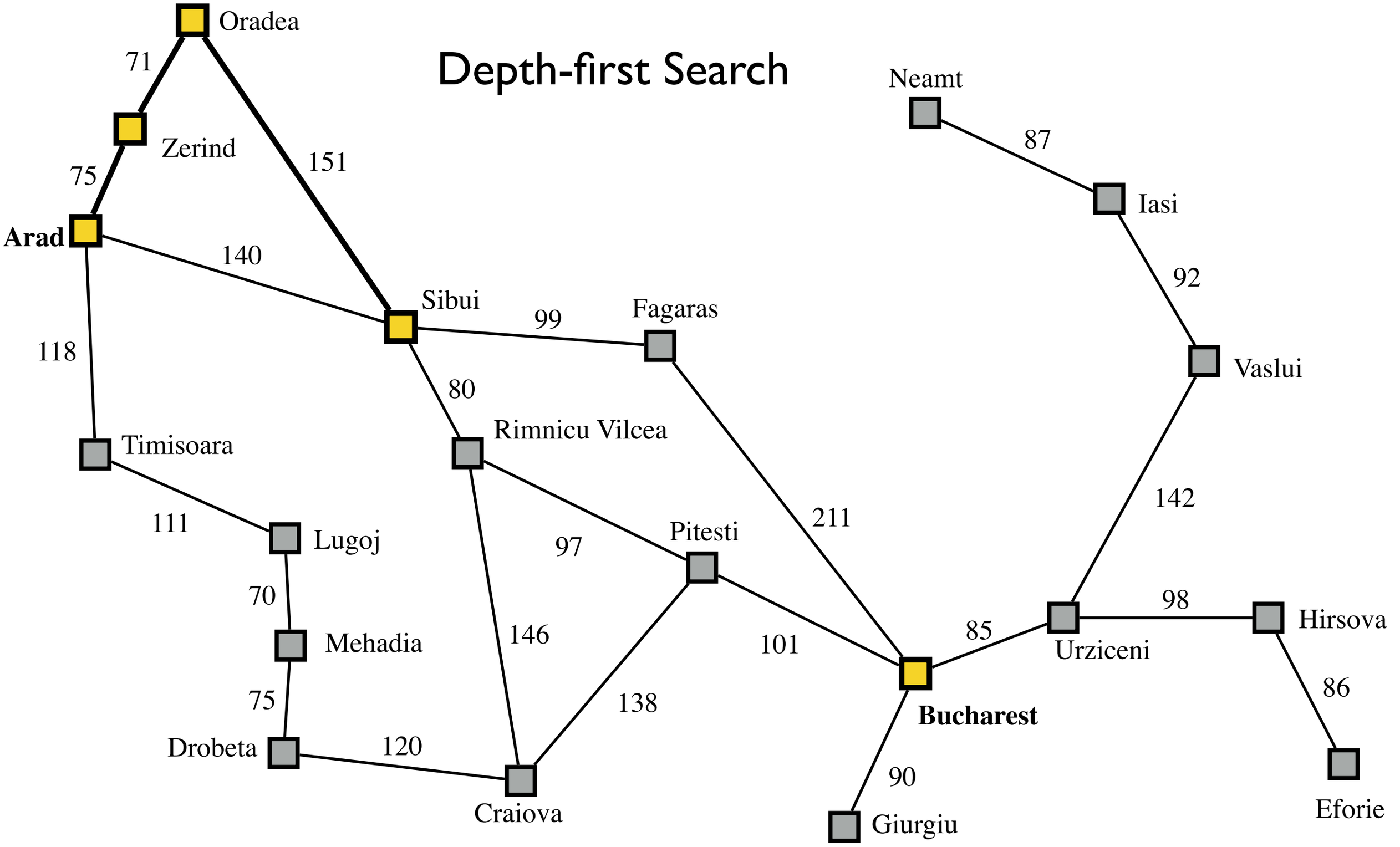

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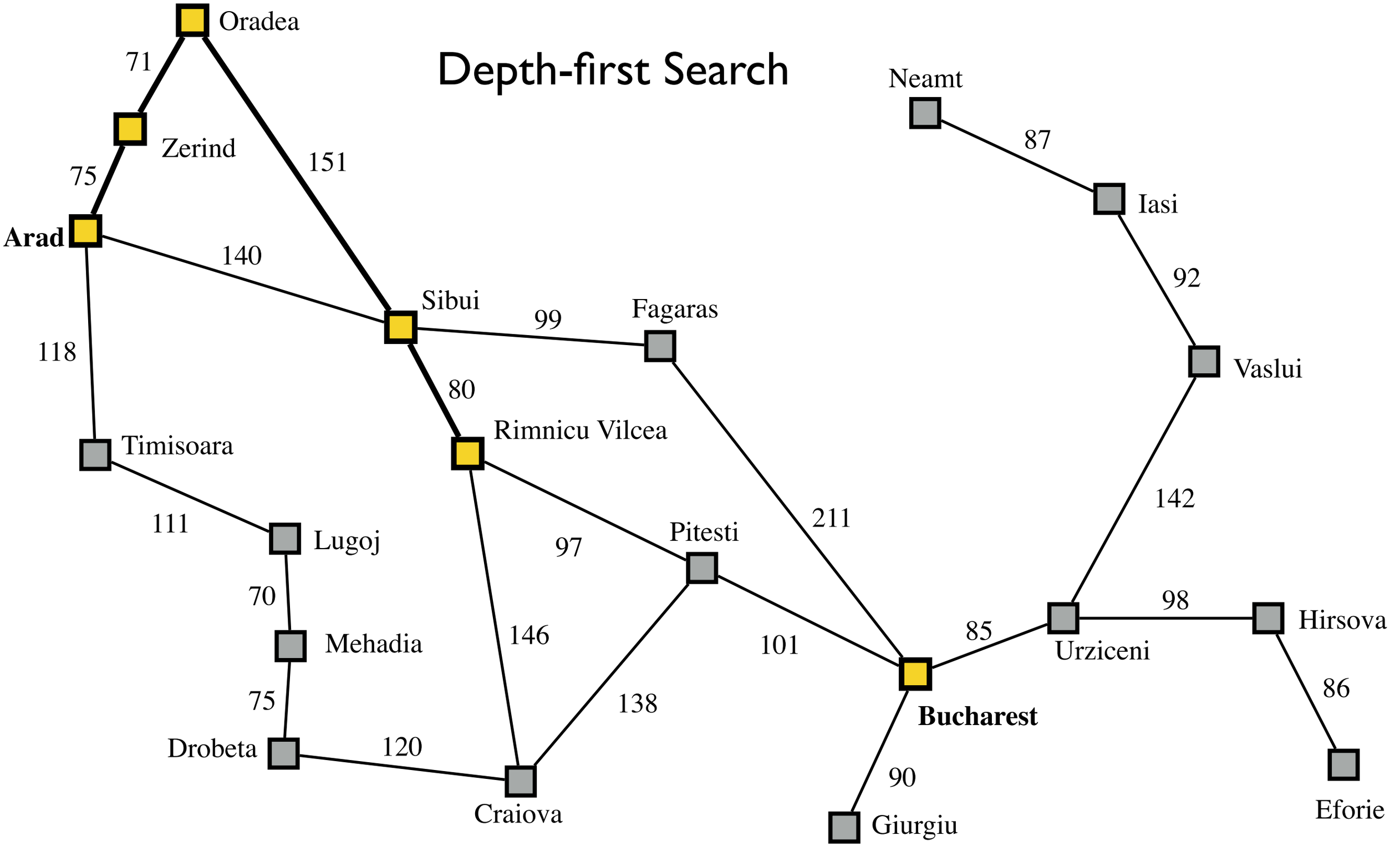

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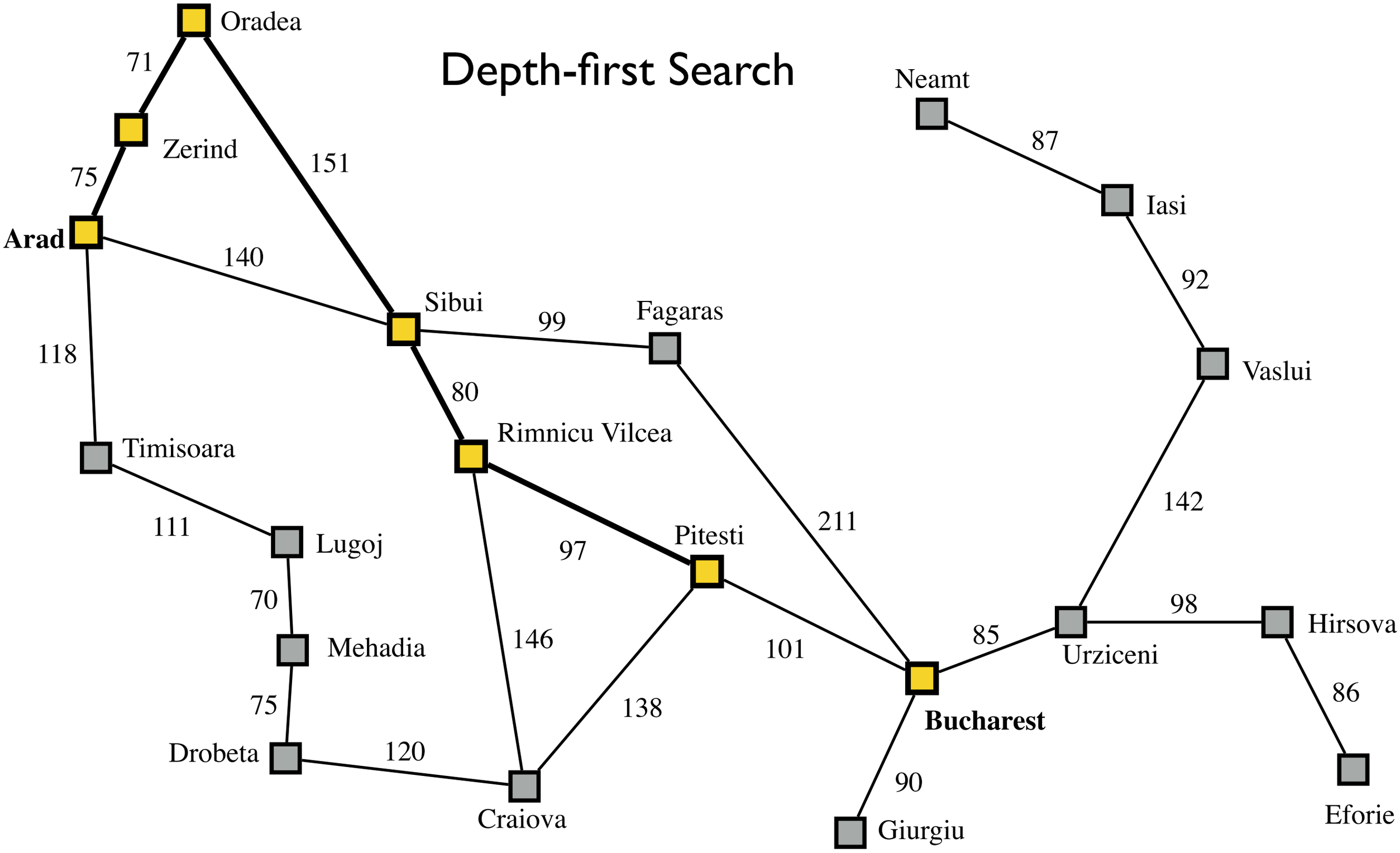

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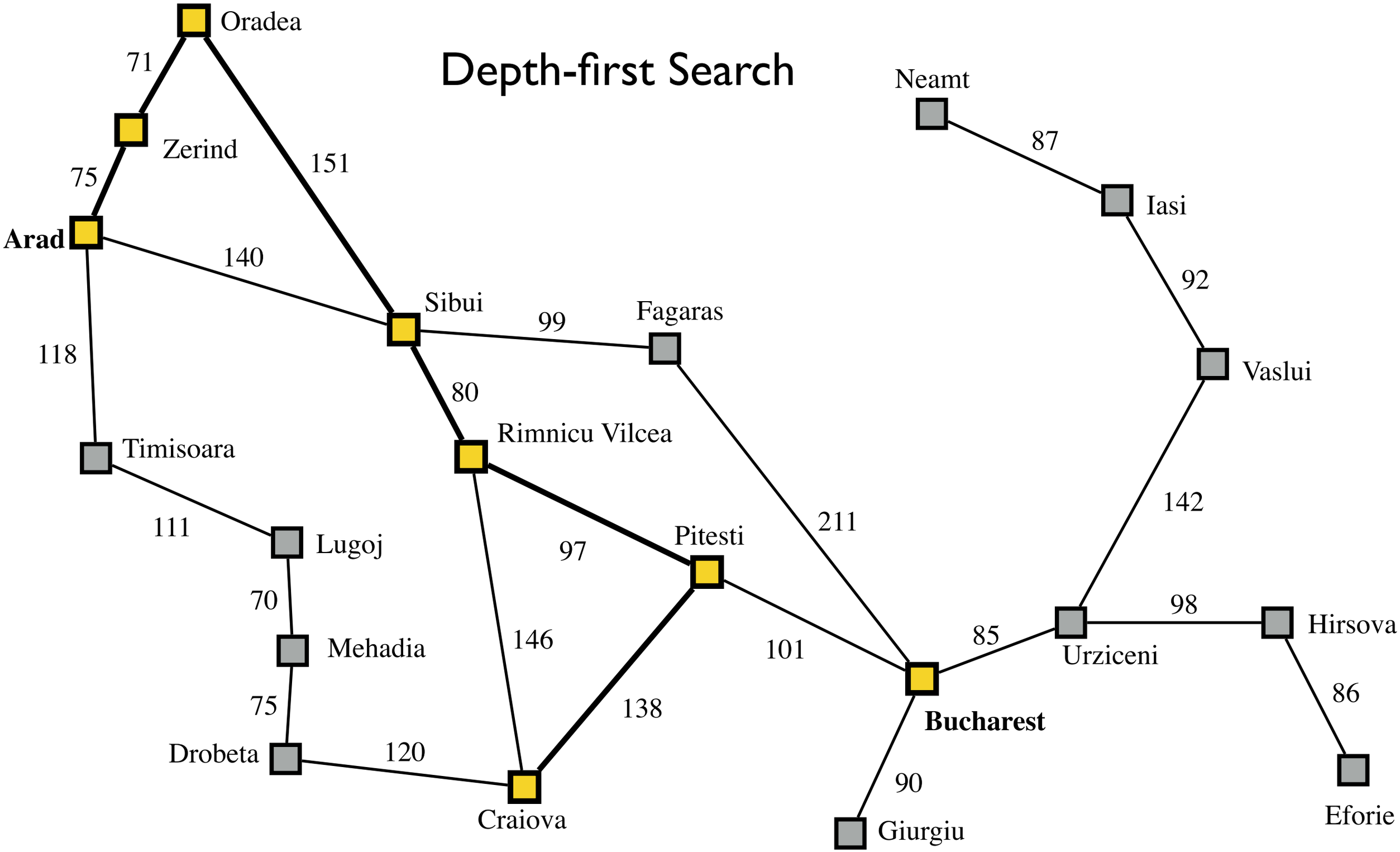

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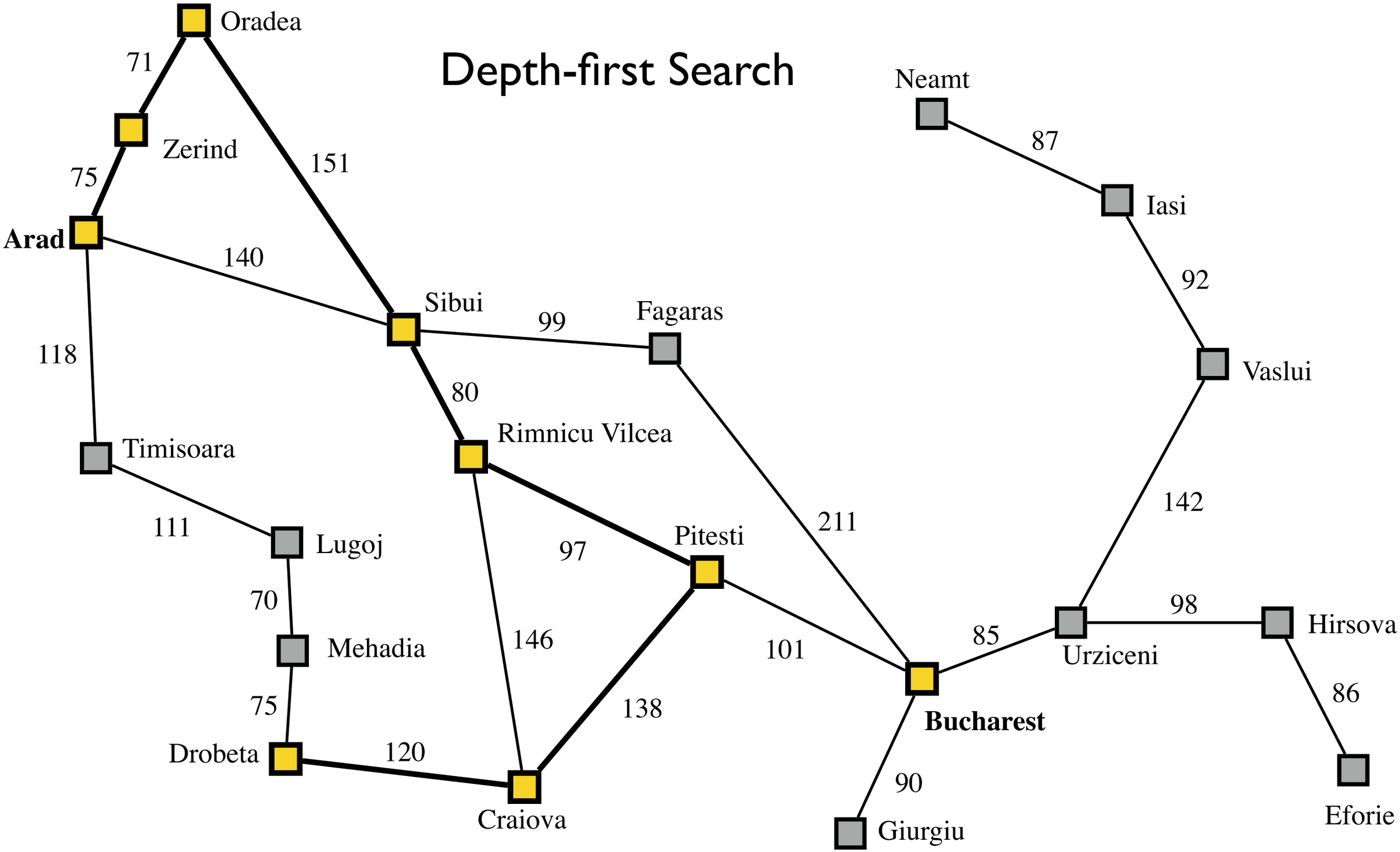

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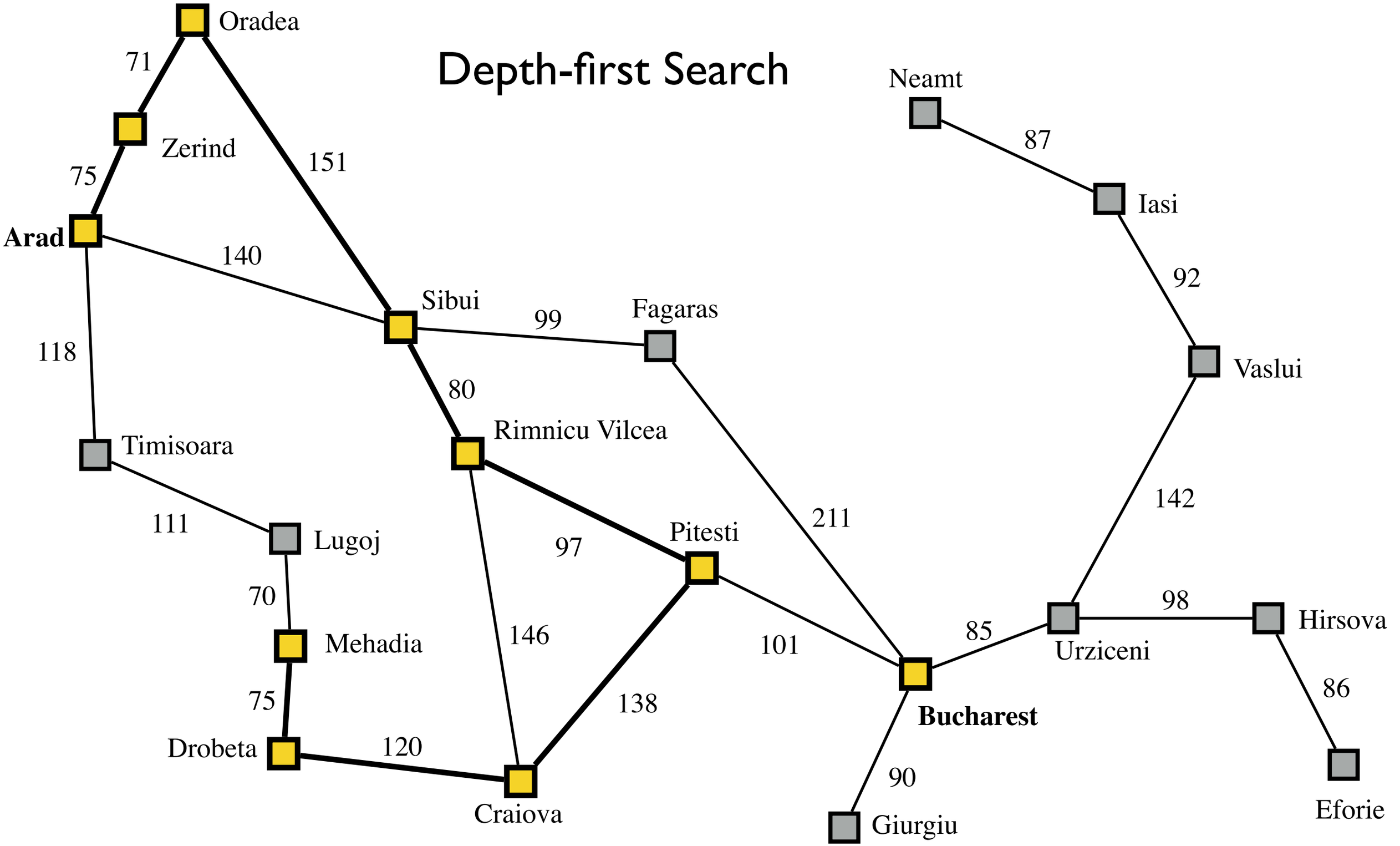

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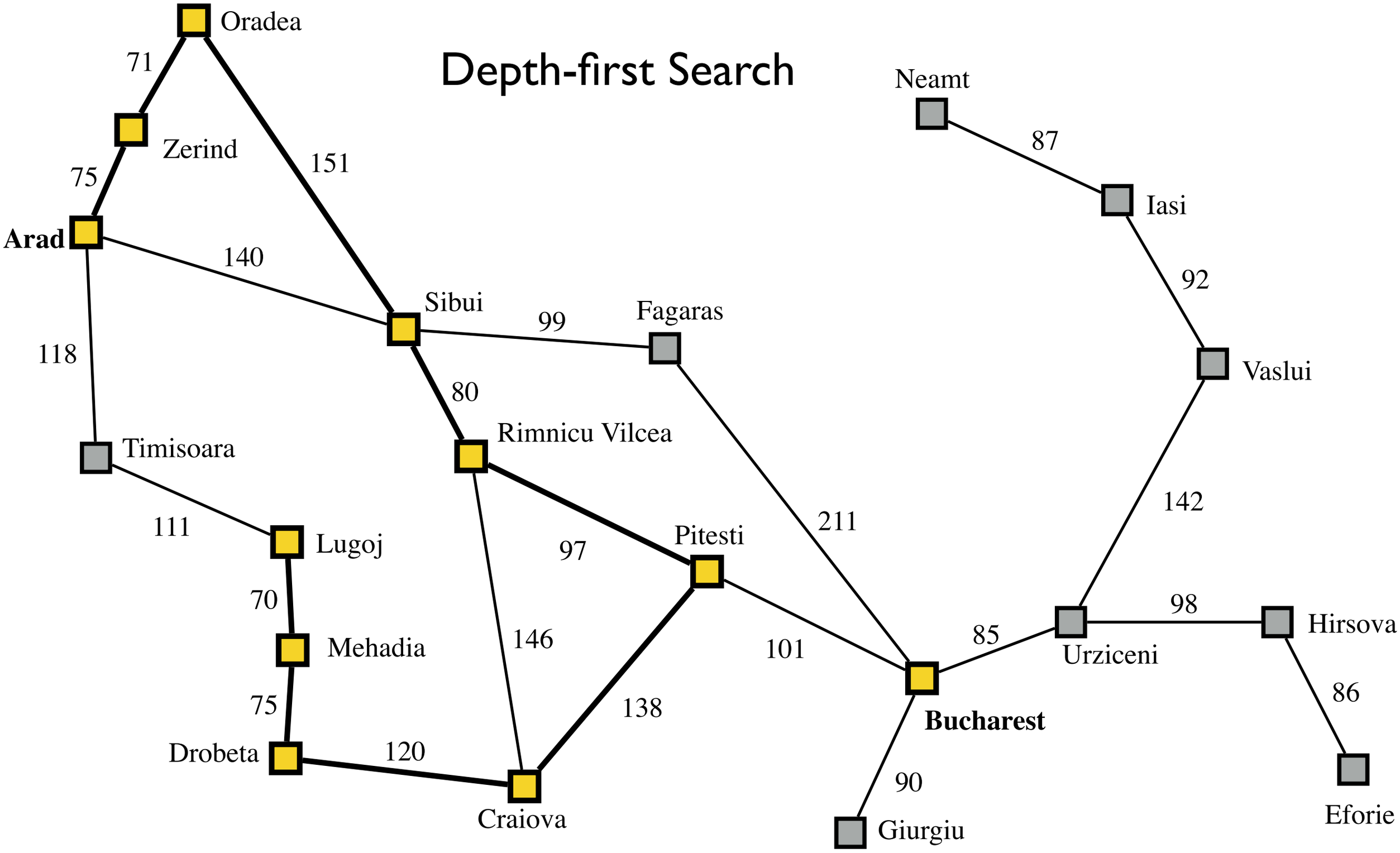

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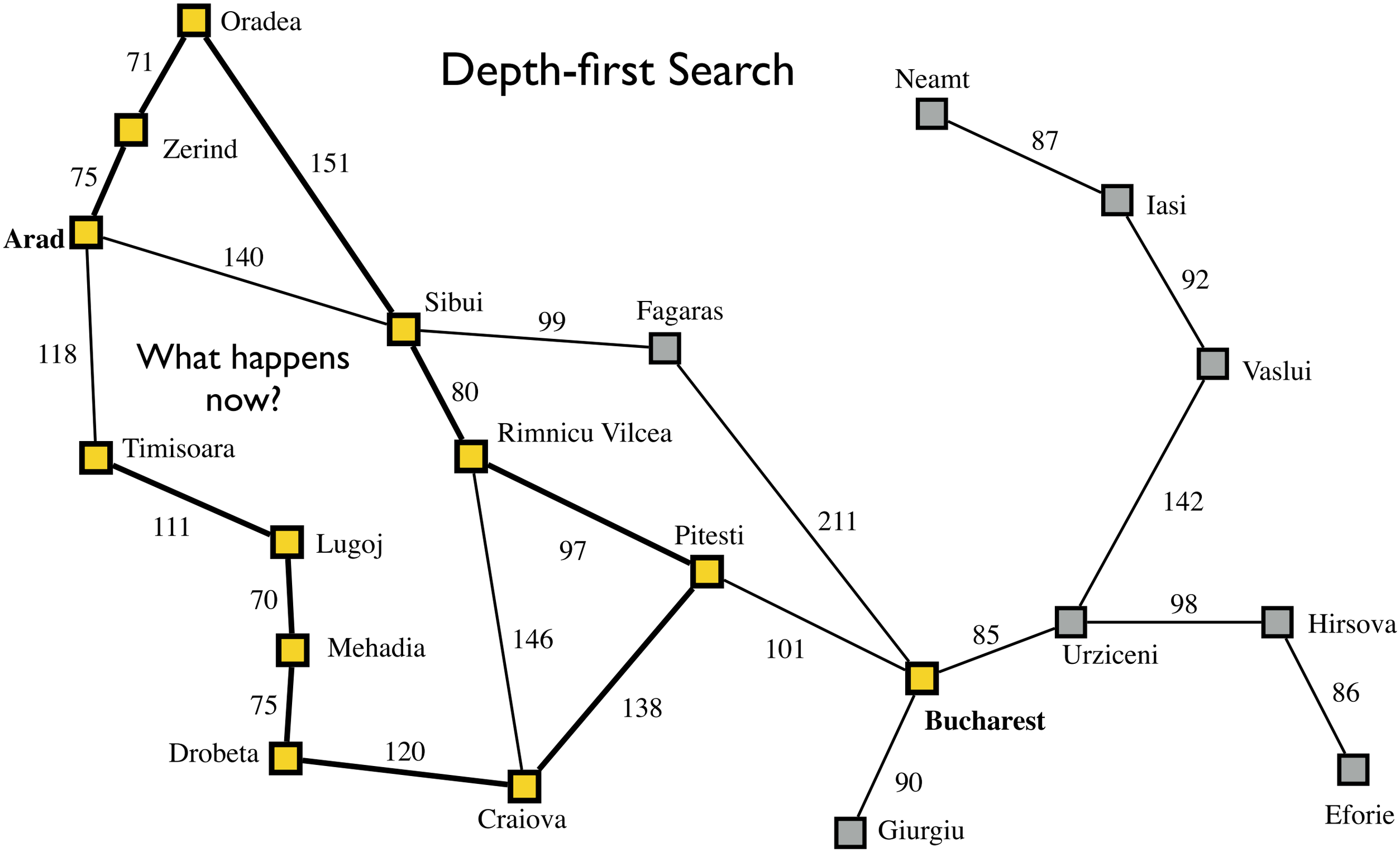

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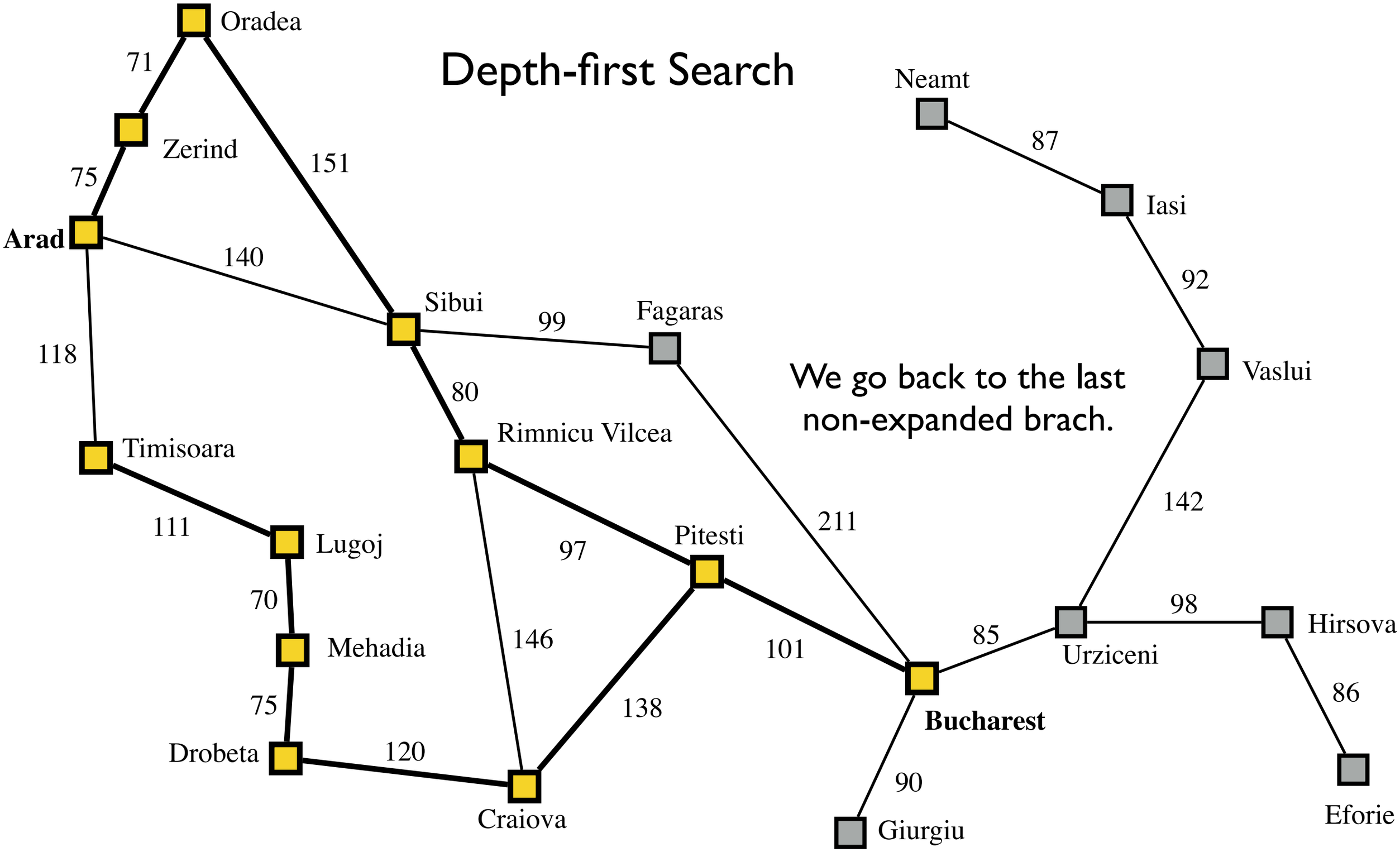
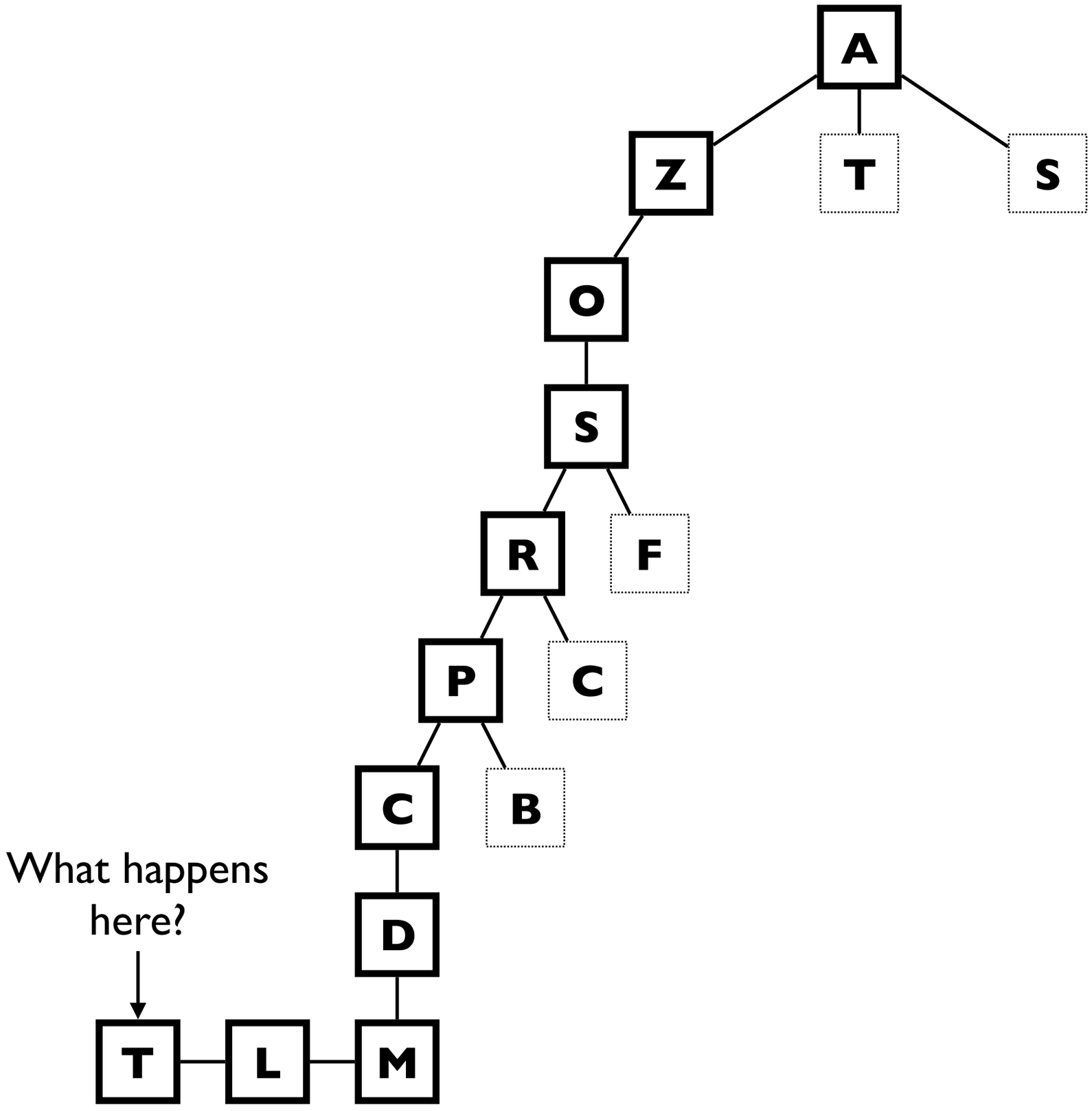
Depth-first Search



We go back to the last non-expanded brach.

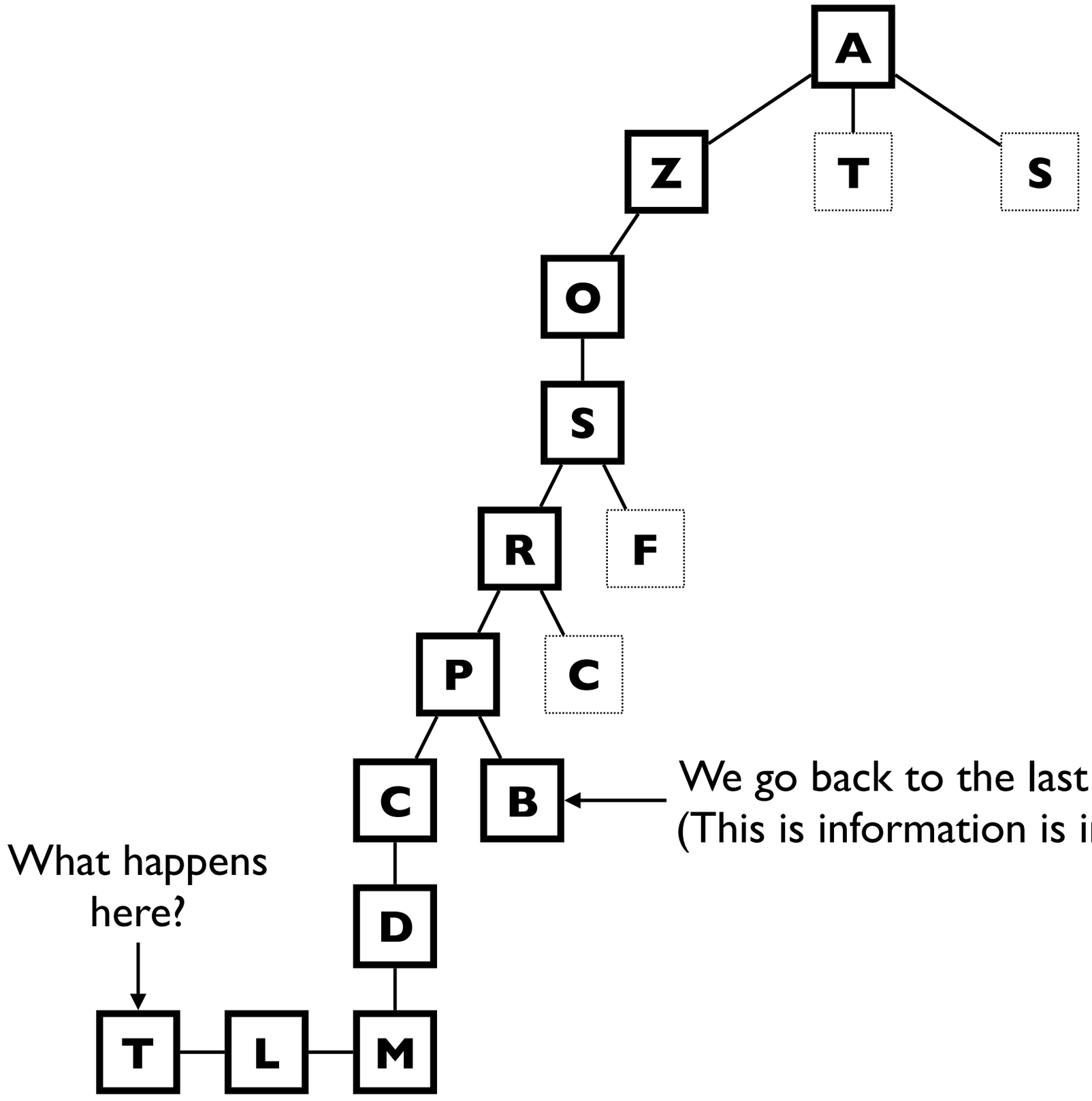
But what if we did reverse-alphabetical expansion?

Tree view of DFS (reverse-alphabetical expansion)



What happens here?

Tree view of DFS (reverse-alphabetical expansion)



We go back to the last non-expanded brach.
(This is information is in the recursion stack)

Generic search function

function Tree-Search(*problem, strategy*) **returns** solution or failure

initialize tree using initial state of *problem*

loop

if no candidates for expansion **return** failure

choose leaf node for expansion using *strategy*

if node contains goal state **return** solution

else expand node and add resulting nodes to search tree

Depth-limited search

- incorporate depth limit in depth-first search
- L = depth limit, ie nodes at depth L are not expanded
- Complete if L >= d
- Still not optimal, because DFS isn't optimal.
- Time is $O(b^L)$
- Space is O(bL)

Recursive implementation of Depth-limited search

```
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 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
```

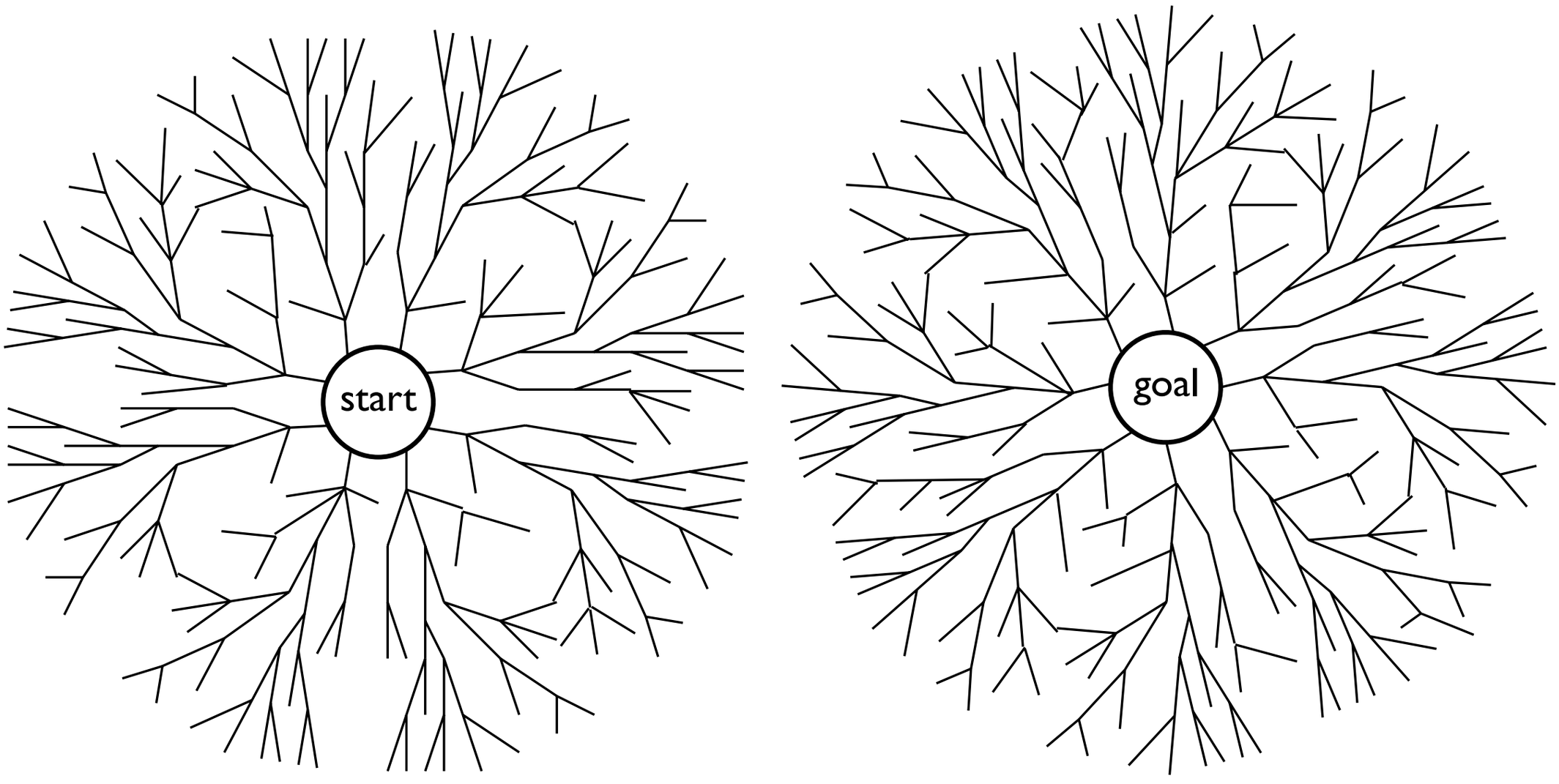
Iterative deepening search

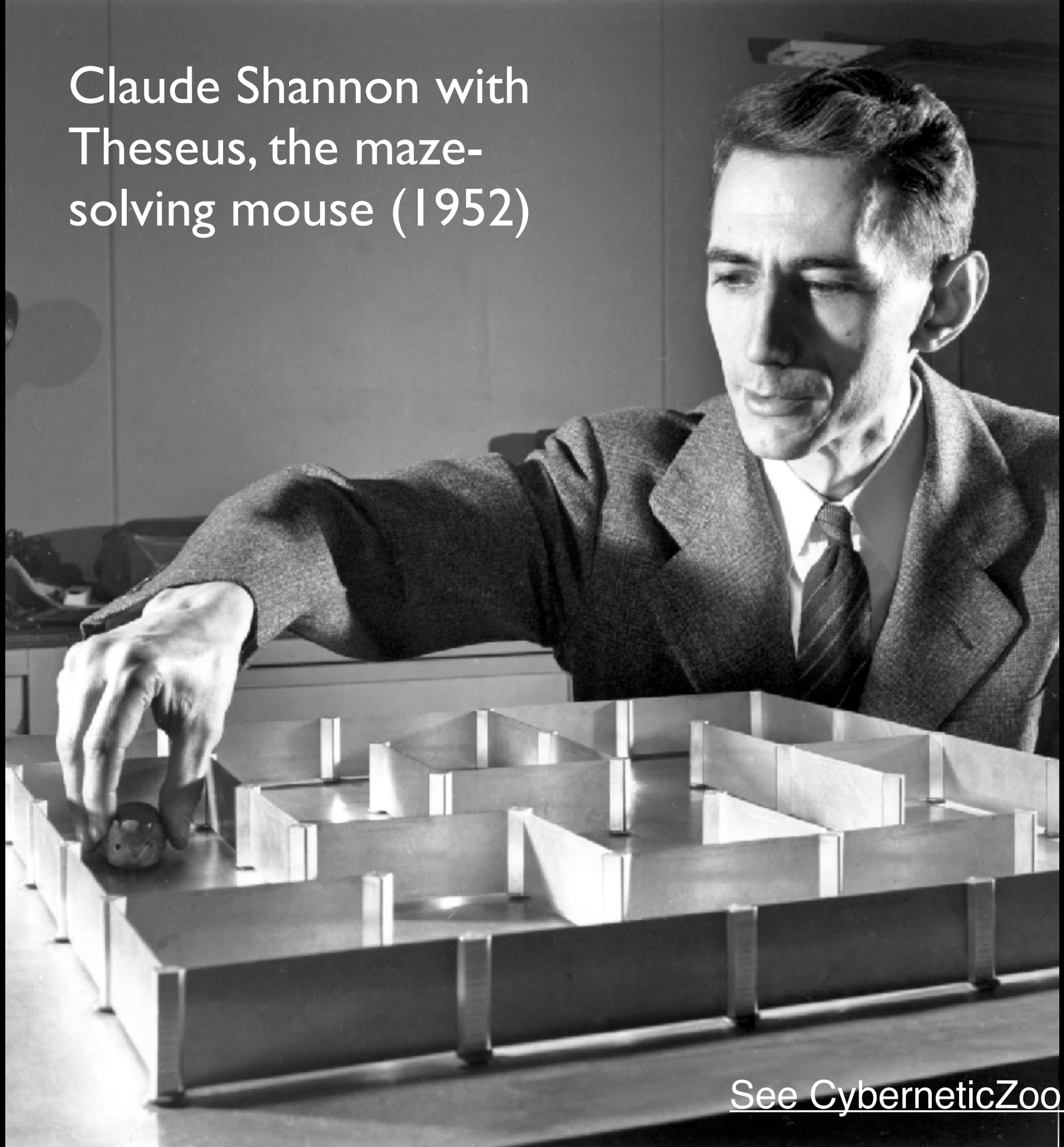
- depth-limited search with gradually increasing depth limit

function ITERATIVE-DEEPENING-SEARCH(*problem*) **returns** a solution
  inputs: *problem*, a problem
  for *depth* ← 0 **to** ∞ **do**
    result ← DEPTH-LIMITED-SEARCH(*problem*, *depth*)
    if *result* ≠ cutoff **then return** *result*
end

Bi-directional search

- perform two simultaneous searches: one from start, one from goal
- stop when search paths meet
- Complexity $O(b^{d/2}) << O(b^d)$ (checking constant time with hash table)



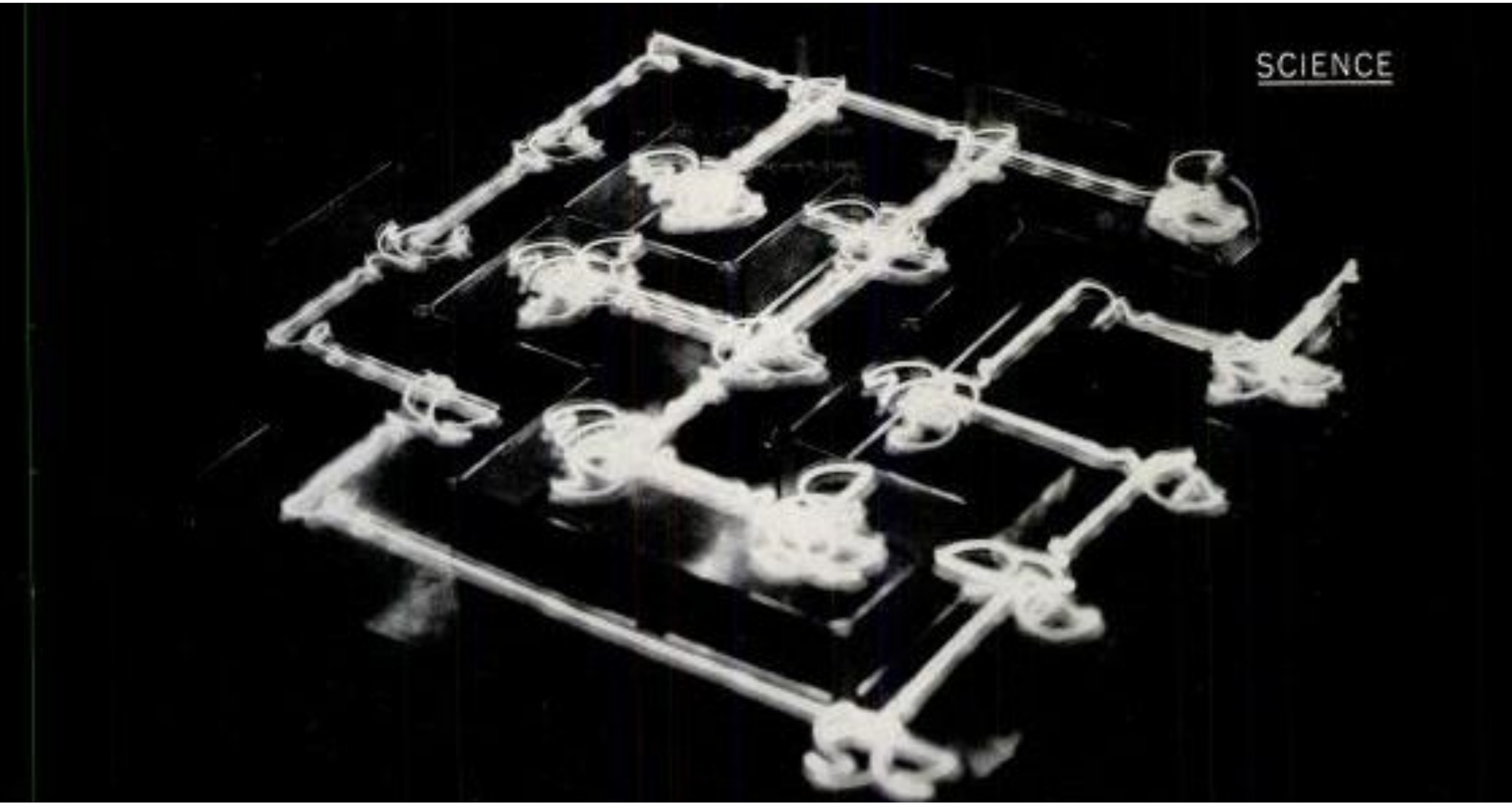


See CyberneticZoo.com article

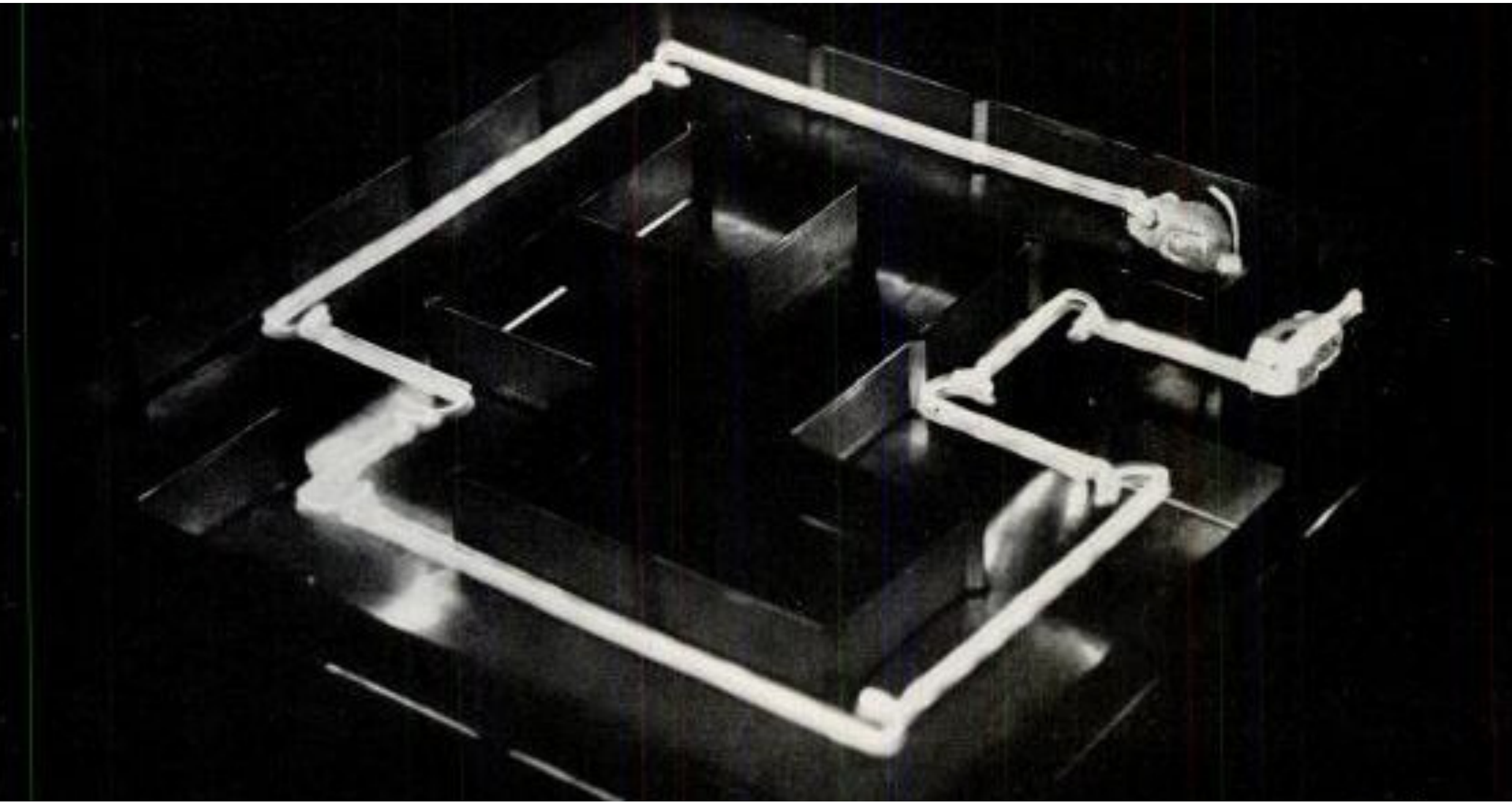
Theseus algorithm:

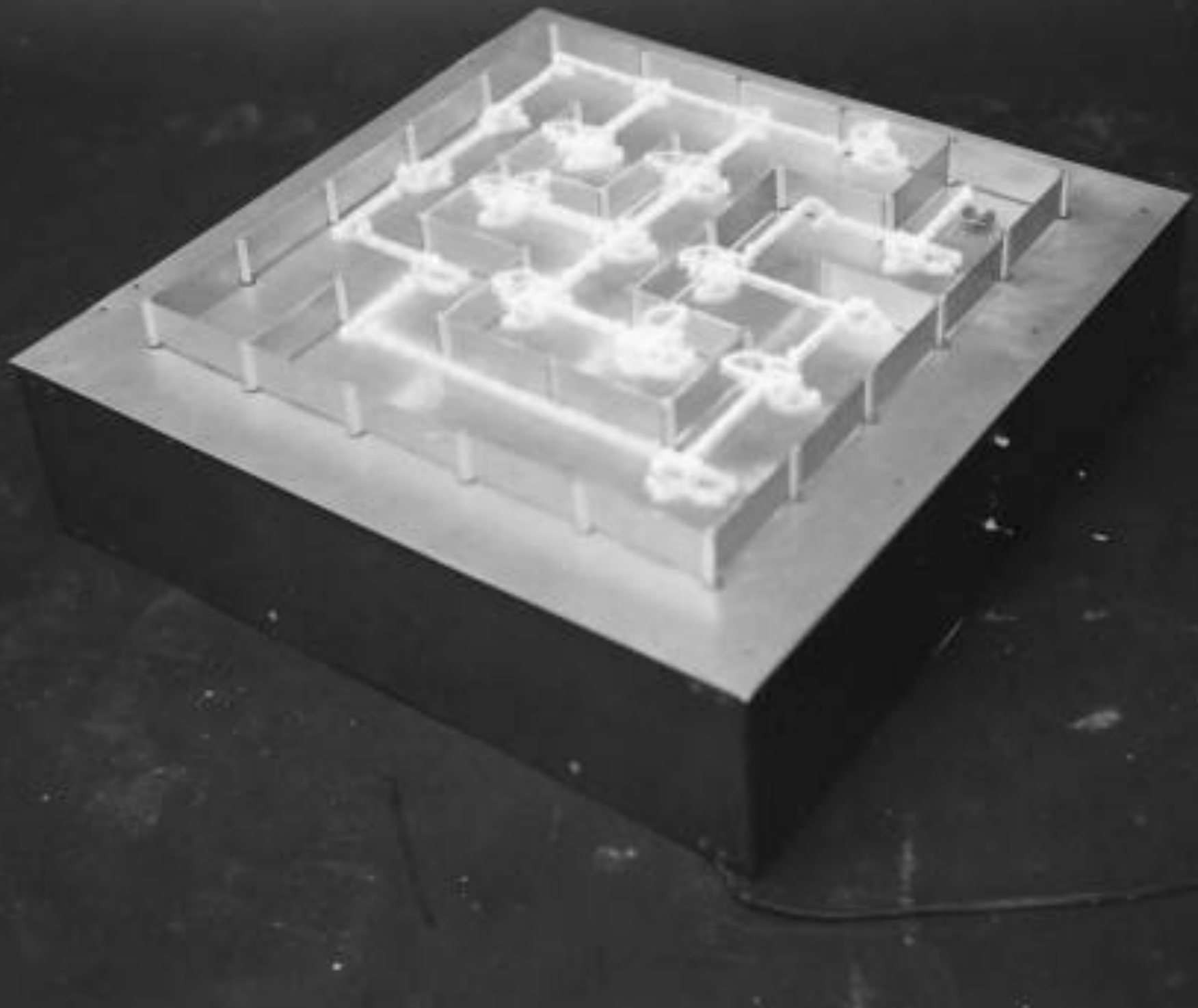
- Trémaux's algorithm:
  - unroll a ball of string to backtrace
  - mark locations visited to avoid looping
  - done when no options remain
- equivalent to depth first search
- an efficient way to find a way out of a maze
- Theseus the mouse was named after the mythical Greek hero Theseus who entered Labyrinth to kill the Minotaur
- Theseus used a ball of string to find his way back out

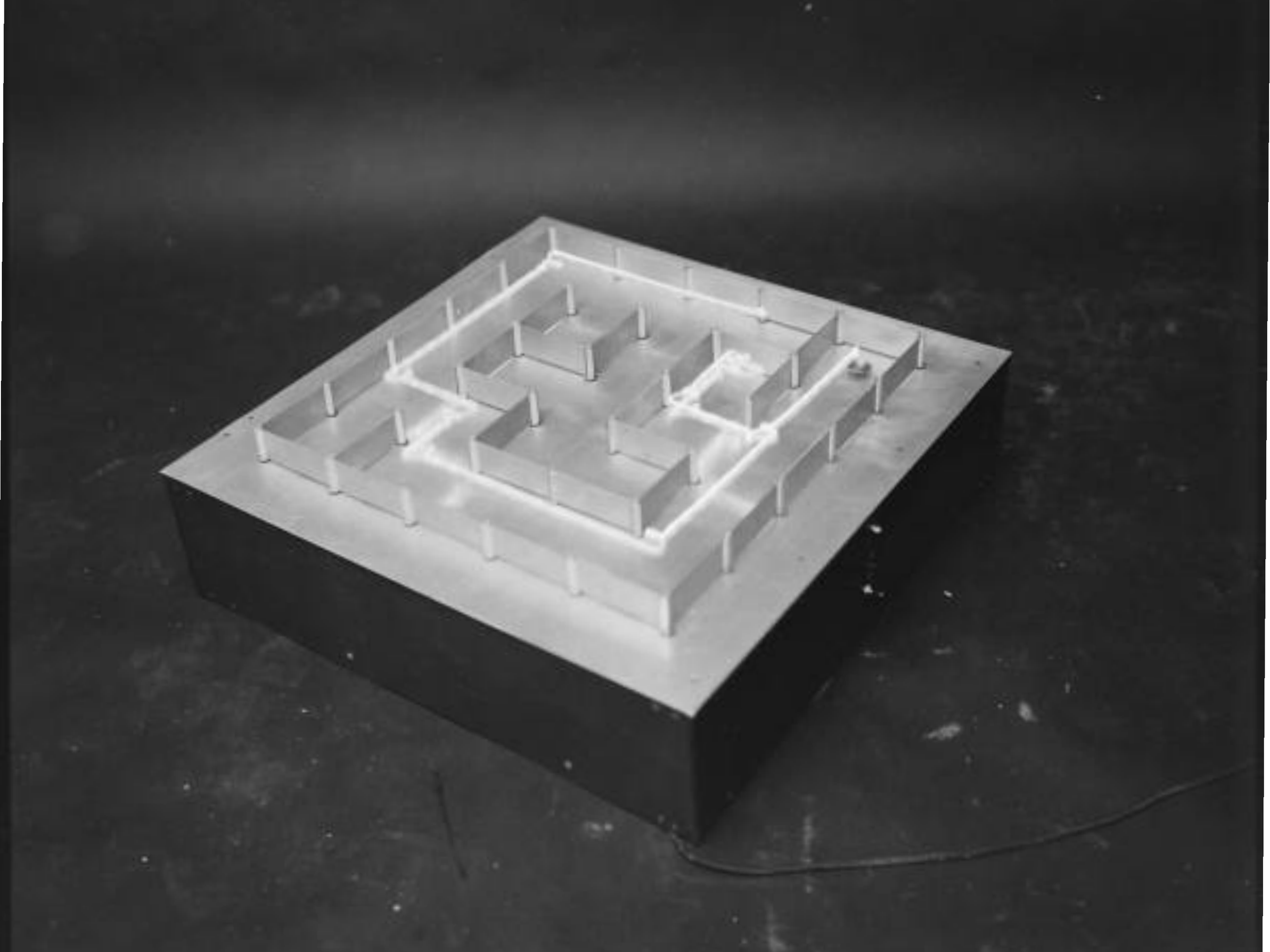
From 1952 *Life* magazine article: trace of Theseus' first pass

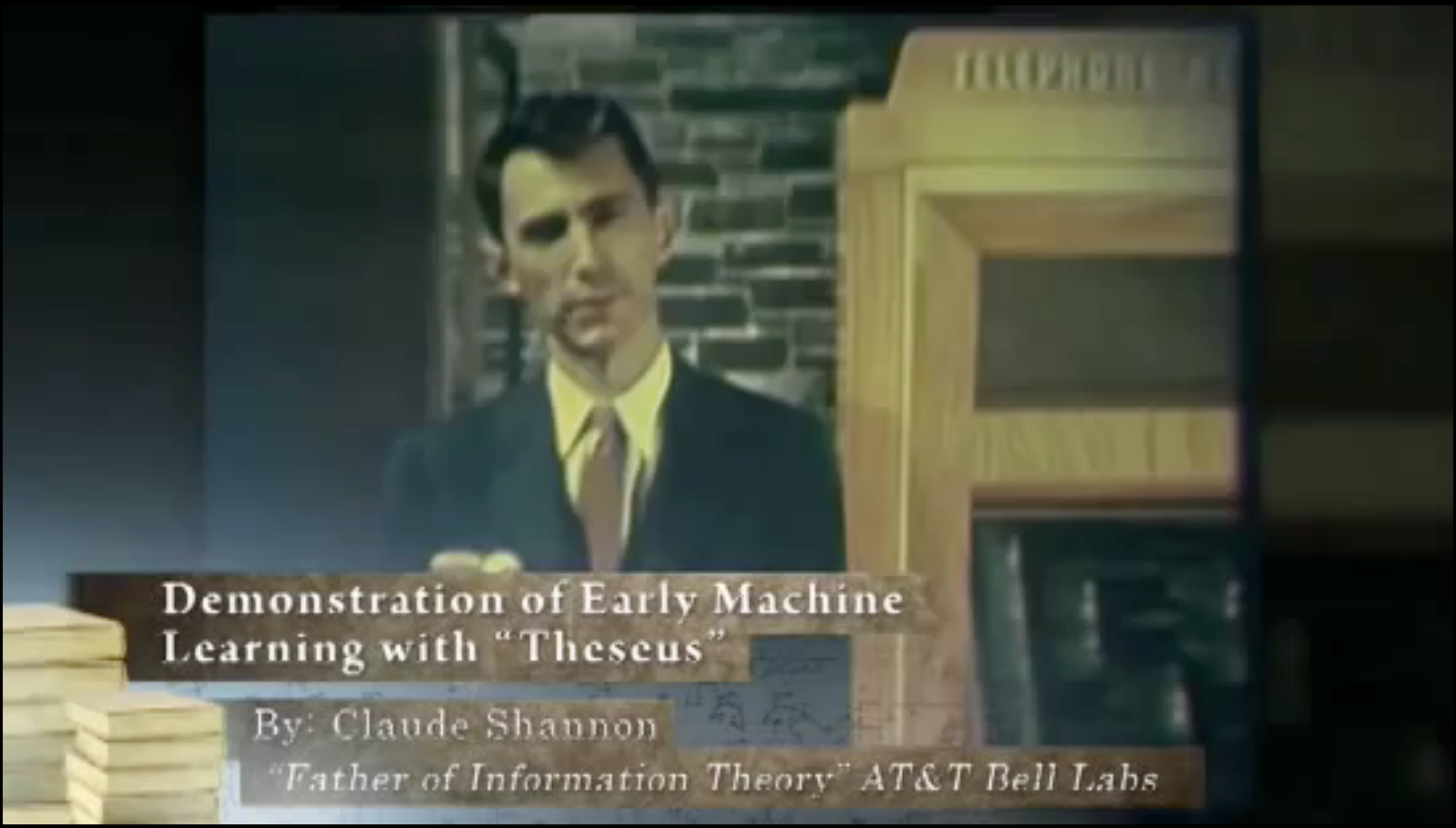


Trace of Theseus' second pass, after learning









https://www.youtube.com/watch?v=vPKkXibQXGA