Informed State Space Search

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State Space

Formulation

- **Problem**
- **Initial state** – s_0
- **Successor function** – $x \in S \rightarrow succ(x) \in 2^S$
- **Goal test** –$x \in S \rightarrow goal(x) = T \mid F$
- **Arc cost** –$c(x, succ(x))$

- **Solution** is set of actions leading from initial state to a goal state

Tree Search Algorithm

Formulation

```
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 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
```

Tree Search Algorithm

Formulation

```
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 node
        fringe ← INSERTALL(EXPAND(node, problem), fringe)
```

BFS
Insert at the end

DFS
Insert at the beginning

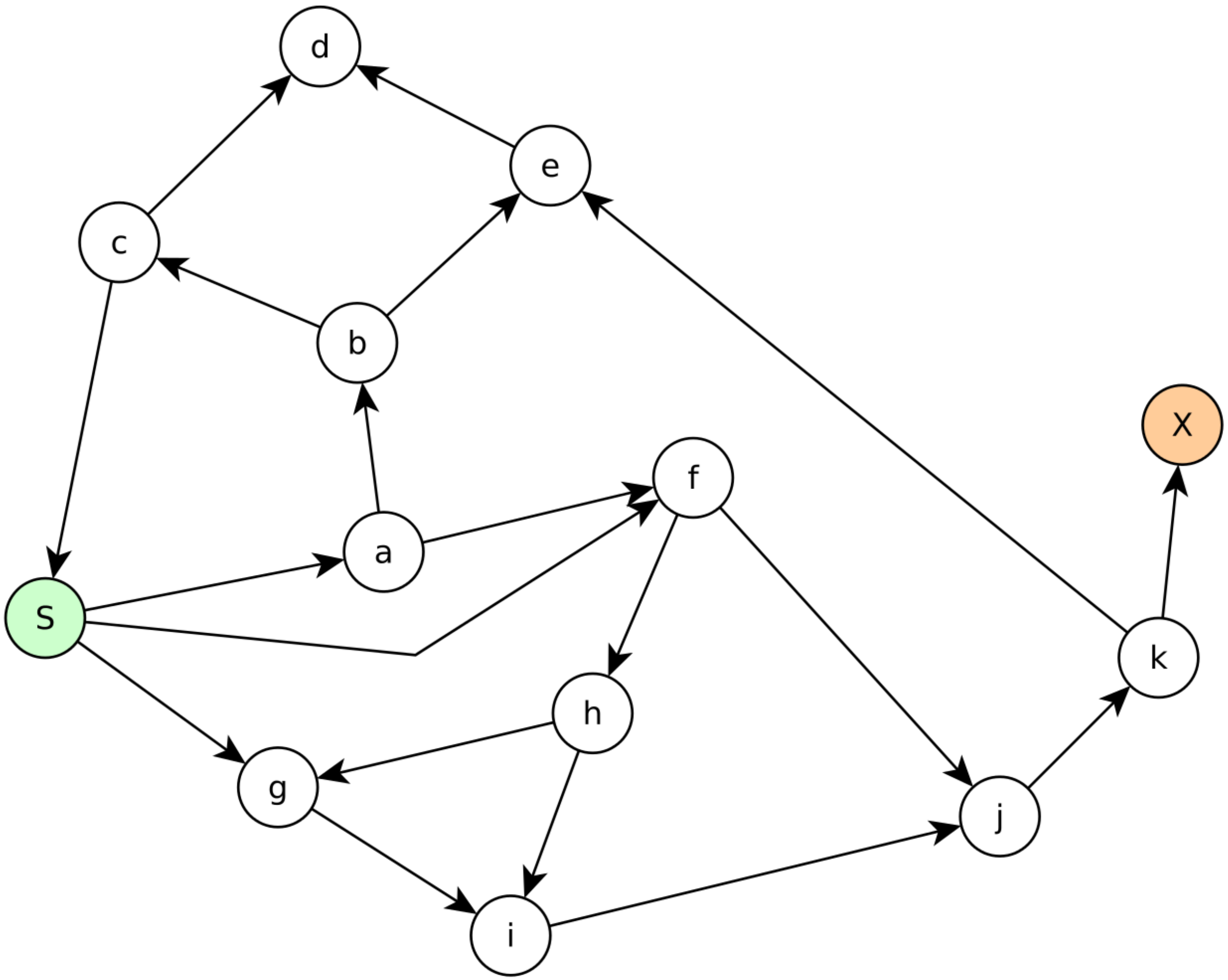
```
        s ← a new NODE
        PARENT-NODE[s] ← node;  ACTION[s] ← action;  STATE[s] ← result
        PATH-COST[s] ← PATH-COST[node] + STEP-COST(node, action, s)
        DEPTH[s] ← DEPTH[node] + 1
        add s to successors
    return successors
```

Searching the State Space

Algorithms

- Breadth first search **BFS**
- Depth first search **DFS**
- Depth limited search (DFS with search limit *l*)
- Iterative deepening search (Iteratively increase *l*)

BFS/DFS Exercises



Graph Search

Using a closed list

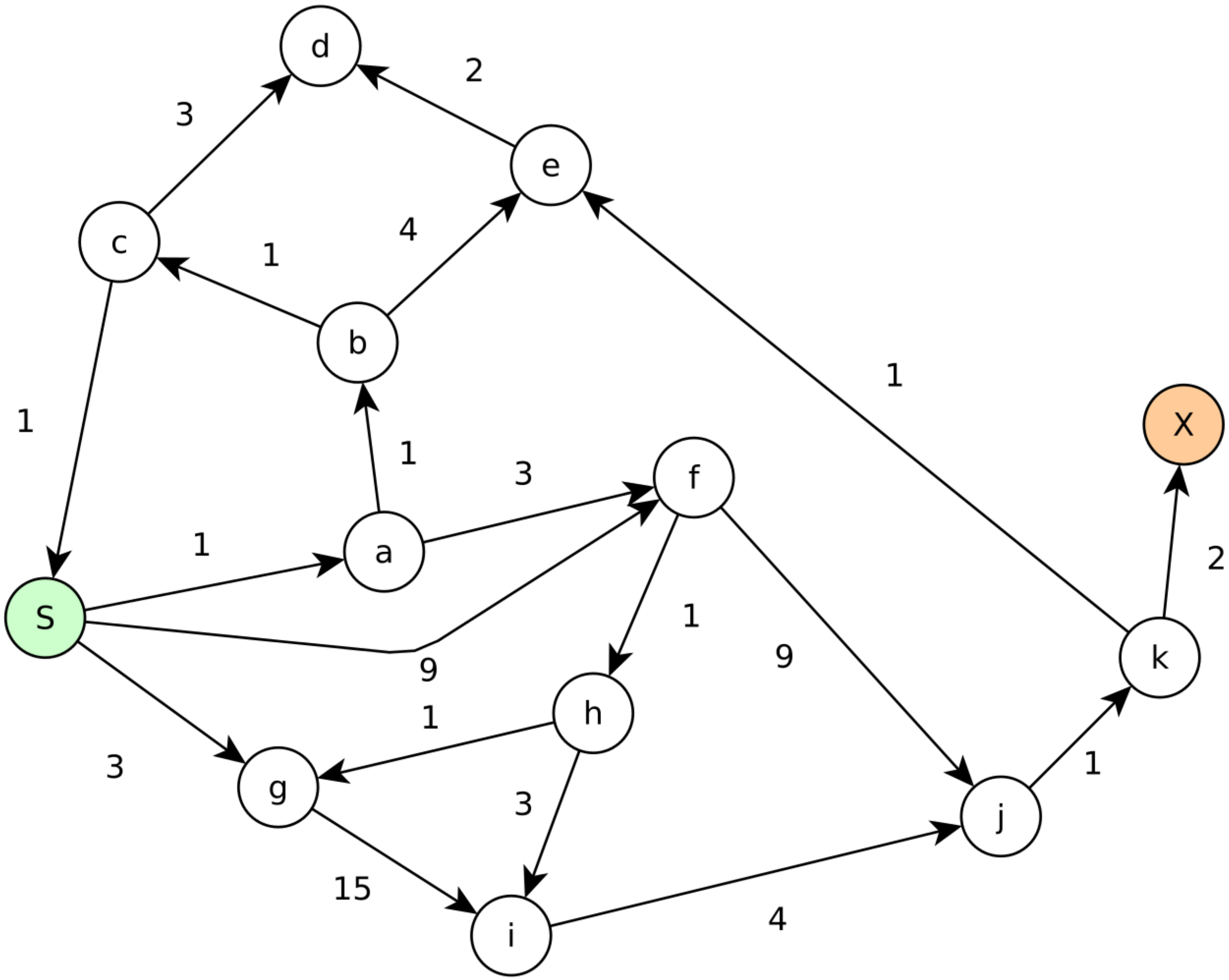
```
function GRAPH-SEARCH( problem, fringe) returns a solution, or failure
  closed ← an empty set
  fringe ← INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
  loop do
      if fringe is empty then return failure
      node ← REMOVE-FRONT(fringe)
      if GOAL-TEST(problem, STATE[node]) then return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

Searching the State Space

Algorithms

- Breadth first search **BFS**
- Depth first search **DFS**
- Depth limited search (DFS with search limit *l*)
- Iterative deepening search (Iteratively increase *l*)
- **Uniform cost search**

Uniform-Cost Search Exercise



Informed Search Problems

- **Problem**
- **Initial state** – s_0
- **Successor function** – $x \in S \rightarrow succ(x) \in 2^S$
- **Goal test** –$x \in S \rightarrow goal(x) = T \mid F$
- **Arc cost** –$c(x, succ(x))$

Heuristic $\boldsymbol{s \in S: h(s) \rightarrow R}$

- g(s): cost to reach the state s
- h(s): <u>**estimated**</u> cost to get from state s to goal state

Heuristic

Wikipedia: “A **heuristic function**, or simply a **heuristic**, is a function that ranks alternatives in various search algorithms at each branching step based on the available information (heuristically) in order to make a decision about which branch to follow during a search.”

Heuristic

- Evaluation function for each node h(N)
- Value is independent of the current search tree
- Expressing desirability
  - Estimates the cost from N to a goal state G
  - $h(N) \geq 0$

Goal of heuristic design:
As close to the real cost as possible!

Best-first Search Algorithms

- Evaluation function f(n) for each state/node

$$f(n) = g(n) + h(n)$$

COST HEURISTIC

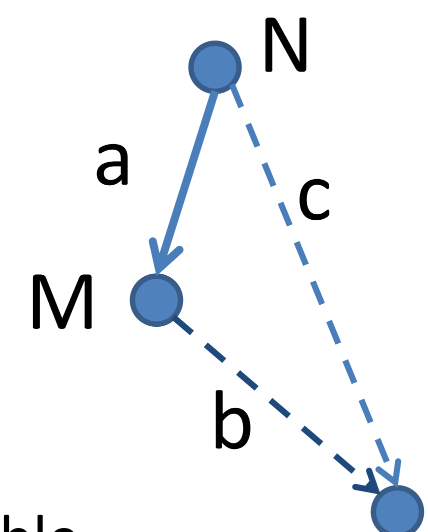
- → Selecting **best** node first – “best-first search”

Uniform cost search: h(N) = 0
Greedy search: g(N) = 0, h(N) arbitrary
A search: g(N), h(N) arbitrary
A* search: g(N), h(N) admissible

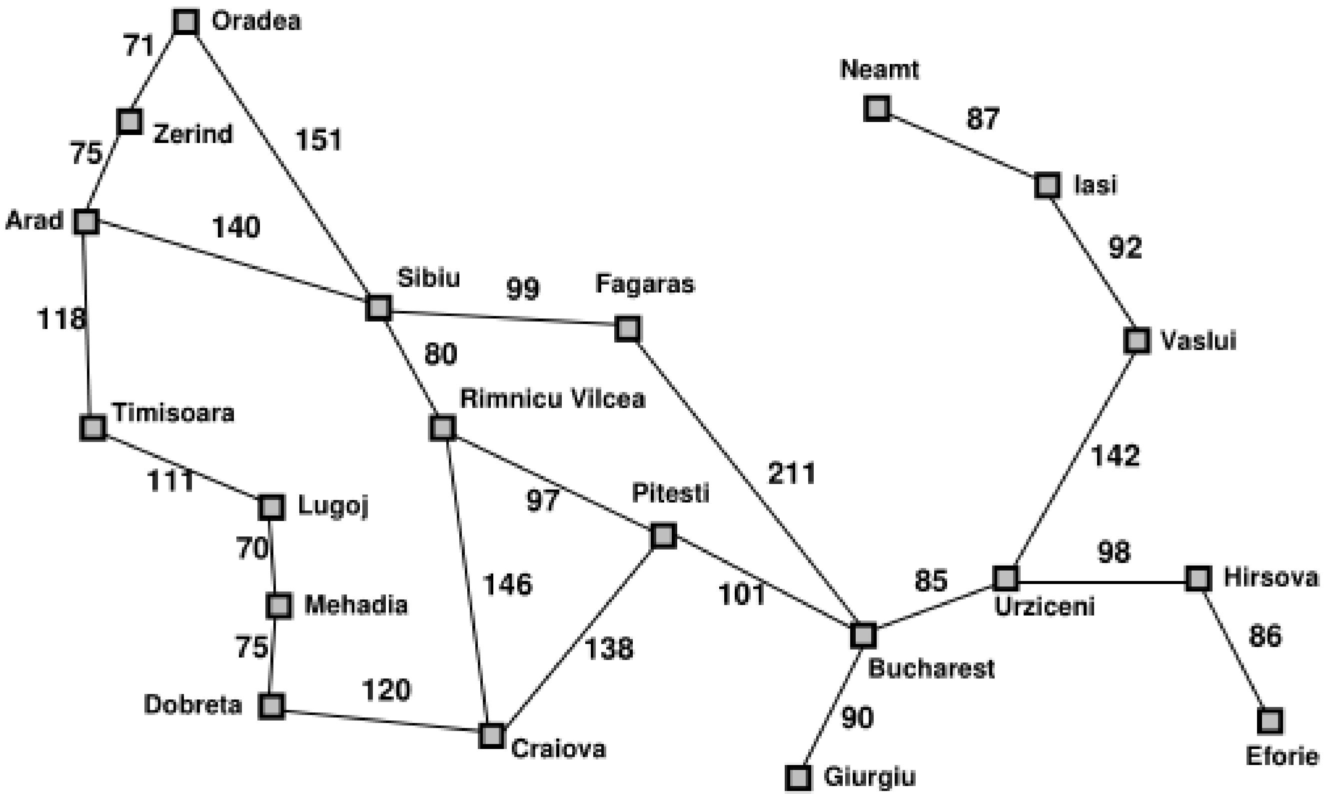
H(N) – Heuristic function

- We know the cost to the node g(n) – nothing to tune here
- We don’t know the exact cost from n to goal h(n) – if we knew, no need to search – **estimate it!**

- H(N) – **admissible** and **consistent** heuristic
- Admissible = *optimistic* – it never overestimates the cost to the goal
  - $0 \leq h(N) \leq h^*(N)$
- Consistent = Triangle inequality is valid
  - $a + b \geq c$
  - $g(N, M) + h(M) \geq h(N)$
  - ➔ once a node is expanded, the cost by which it was reached is the lowest possible



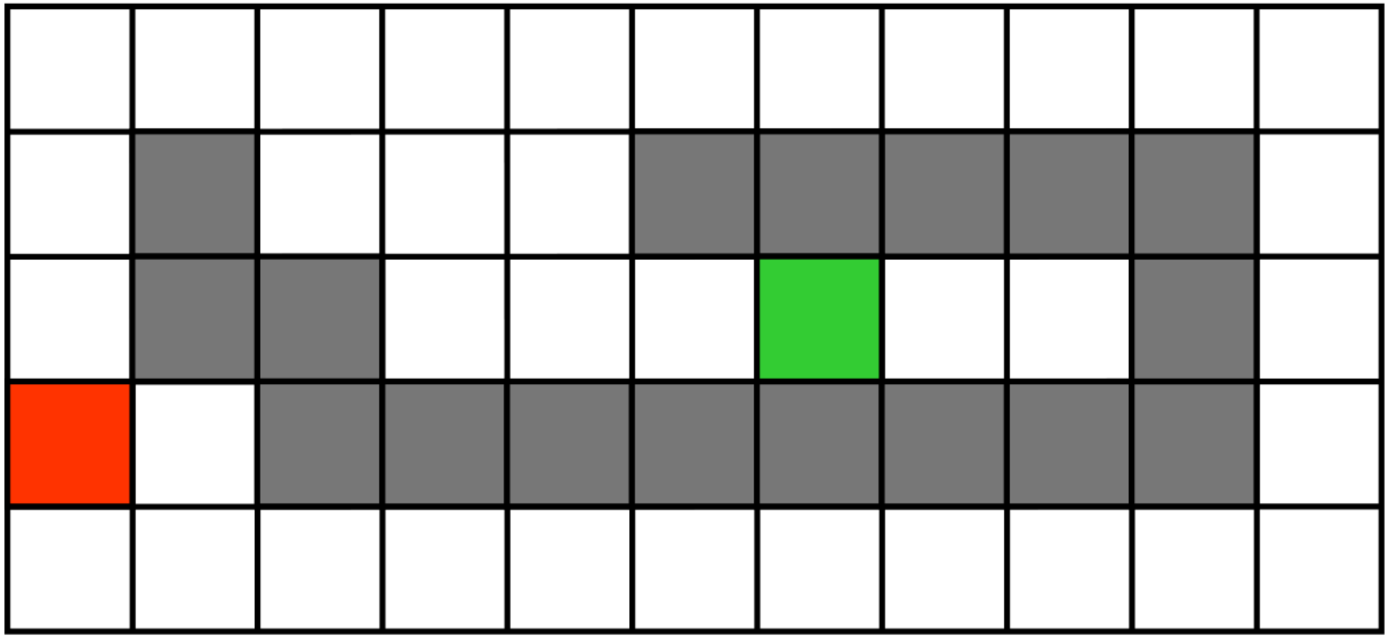
Informed Search Exercises



Straight–line distance to Bucharest

Arad	366
Bucharest	0
Craiova	160
Dobreta	242
Eforie	161
Fagaras	178
Giurgiu	77
Hirsova	151
Iasi	226
Lugoj	244
Mehadia	241
Neamt	234
Oradea	380
Pitesti	98
Rimnicu Vilcea	193
Sibiu	253
Timisoara	329
Urziceni	80
Vaslui	199
Zerind	374

Path in a maze



What are possible heuristics?

Roomba Robot path planning

The ferryman problem

Escaping the World Trade Center

- Imagine a huge skyscraper with several elevators. As the input you have:
- set of elevators, where for each you have:
- - range of the floors that this elevator is operating in
- - how many floors does this elevator skip (e.g. an elevator can stop only on every second floor, or every fifth floor, etc.)
- - speed (time in seconds to go up/down one floor)
- - starting position (number of the floor)

Escaping the World Trade Center

- Let us assume, that transfer from one elevator to another one takes the same time (given as input - t).
- You are starting in kth floor and you want to find the quickest way to the ground floor.
- You can assume that you are alone in the building and elevators do not run by themselves.

1. What are the states?
2. What is the initial state and the goal state?
3. What is the cost function?

Stock Exchange Problem

- As the input data you have a set of requests that contains a set of 4-tuples:
- (STOCK_BUY/STOCK_SELL, STOCK_ID, STOCK_AMOUNT, STOCK_PRICE)
- that describe a request to either sell or buy given amount of given stock for given price. The price is interpreted as minimal in case the request is to sell stocks and maximal, in case the request is to buy.

- Your task is to find appropriate price for each STOCK_ID that would maximize the sum of amount of the traded stocks.

State Space

More examples

- “Perfect” Spam filter
- Spellcheck suggestion design
- Solving a puzzle
- Rubik’s cube
- Monkey & Bananas
- Crossword puzzles
- Knapsack problem
- Traveling Salesman p
- Baking a chicken
- App. Moving with friends