Lecture #11 Part A: Planning and Search Methods

COMP3608: Intelligent Systems

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The Need to Plan

- Planning is fundamental human activity
- Given some starting “position” want to series of actions (a path) to some goal “position”
  - Sometimes we have numerous paths, but have a notion of some “best” path
  - Example: want to get from your house to UWI in the least amount of time
  - Example: want to go from a particular shuffle of a Rubik’s cube to a solution state of a Rubik’s cube in the smallest number of steps

Planning

- Start at some start state S_0
- Have a set of goal states G
  - Often G contains only one element
- Want to take a finite series of actions (find a path) $A_1, A_2, \ldots A_n$ such that
  - $\text{do\_action}(S_i, A_i) = S_{i+1}$
  - $\text{do\_action}(S_n, A_n) \in G$ (we arrive at a state in G)
- If no such path exists, we also want to report failure

Planning

- Some of the aforementioned terminology should seem familiar to you
- Remember Data Structures
- What sort of techniques from DS can we use here?

Planning

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Planning as Graph Traversal

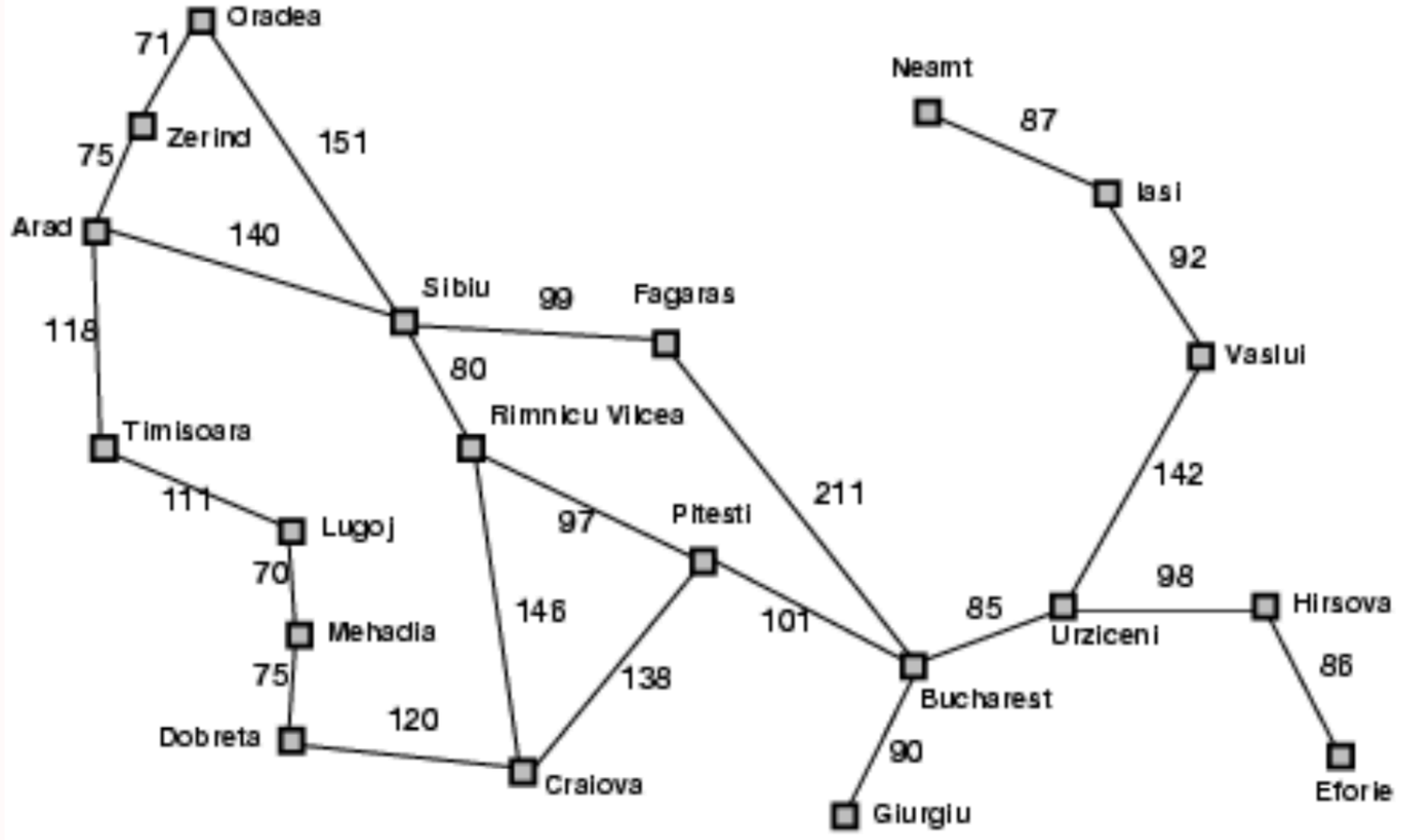
- We can represent the state space as a (potentially infinite) graph
- Available actions from a state to another state are represented by edges
- Travel from state to state through edges in a structured, principled way
- Hoping to reach goal state (goal node)
- Can leverage typical graph traversal algorithms to plan
  - Will even look at a variant of Dijkstra's algorithm

Terminology - Search Algorithm Taxonomy

- Uninformed Search: algorithm only has access to graph topology
  - DFS, BFS, IDS
- Informed Search: algorithm has access to graph topology and side information
  - Best-first, A* heuristic search

Terminology - Search Algorithm Properties

- Action (Edge) cost - the cost of taking a particular action from a particular state
  - Default cost of 1
- Path cost - total cost of an entire path
  - Default cost is the number of actions taken
- Optimality - a search algorithm is optimal if it is guaranteed to find the lowest cost solution if it exists
- Completeness - a search algorithm is complete if it is guaranteed to find a solution if one exists
- Space complexity - the amount of extra memory needed
- Time complexity - number of discrete basic operations needed



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Uninformed Search Methods

- BFS
- DFS
- Depth-limited Search

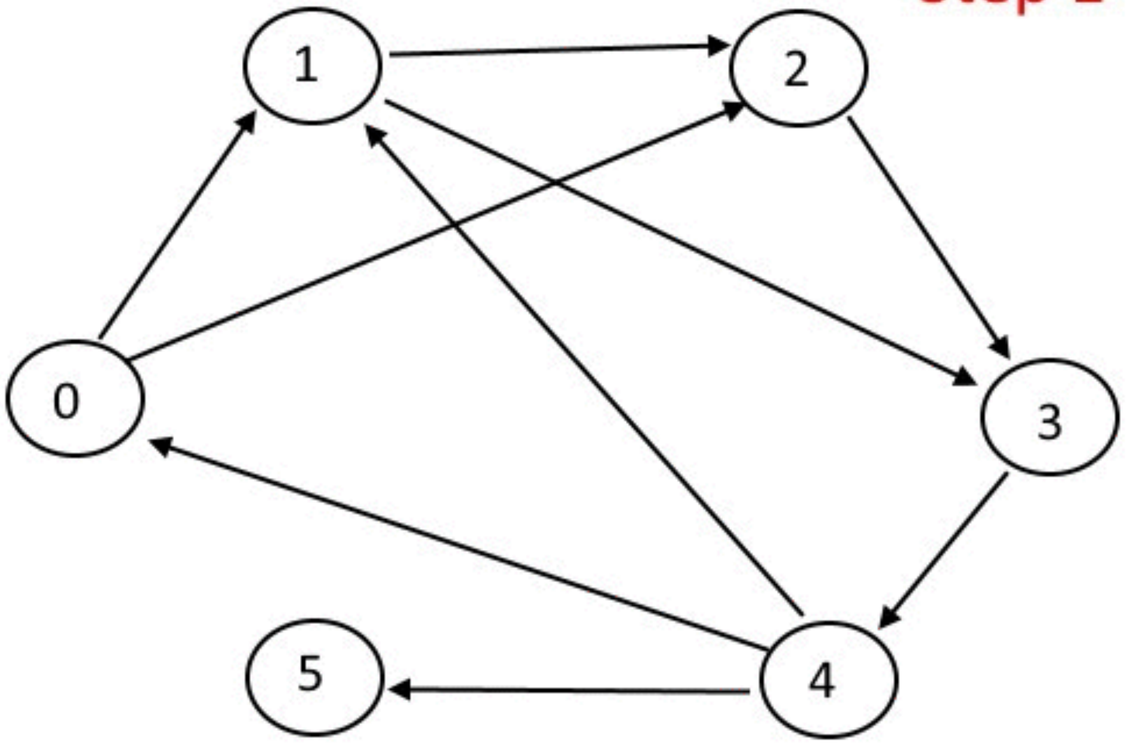
Breadth-first Search

- Children of start state are expanded and explored
- Then their children are expanded and explored
- Then their children are expanded and explored
- ….
- Until we either find the solution or report failure

```
def get_path(parents, goal):
    path = []
    current = goal
    while parents[current] is not None:
        path.push(current)
        current = parents[current]
    path.push(start)
    return path
```

```
def bfs(graph, start, goal):
    parents = {start: None}
    if start == goal:
        return get_path(parents)
    frontier = Queue()
    frontier.enqueue(start)
    explored = []
    while True:
        if frontier.is_empty():
            raise Failure
        current = frontier.dequeue()
        explored.add(current)
        for action in graph.edges_from(current):
            child = do_action(action, current)
            if child not in explored and child not in frontier:
                parents[child] = current
                if child == goal:
                    return get_path(parents)
                frontier.enqueue(child)
    raise Failure
```

Step 1



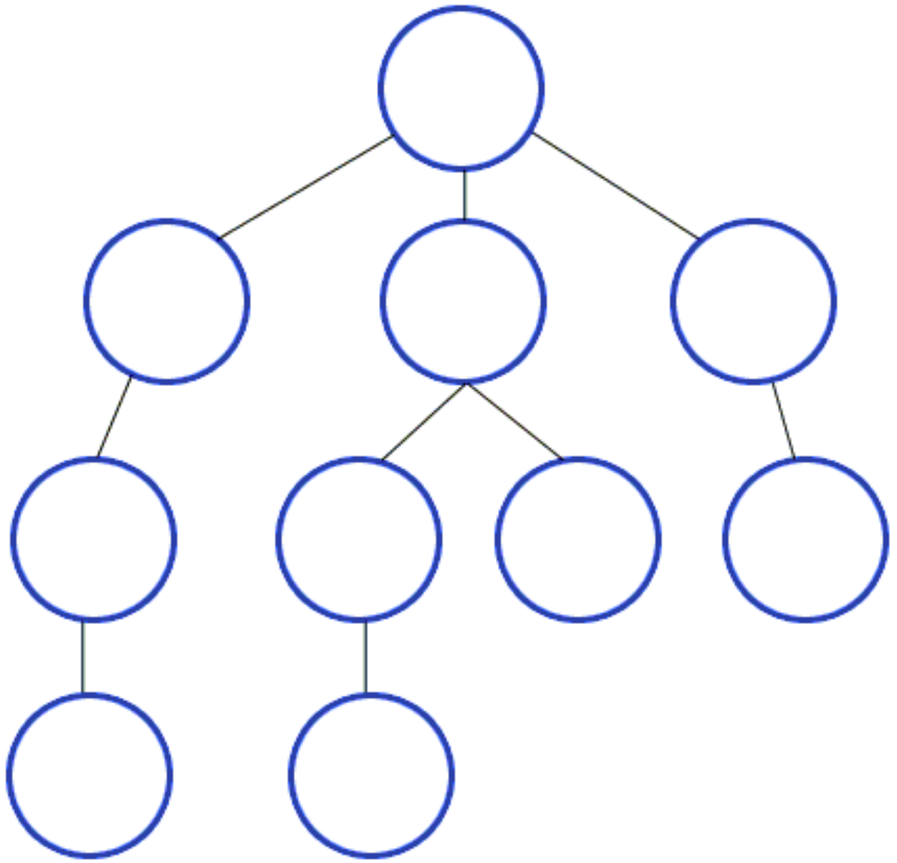
BFS

MakeAGIF.com

Depth-first search

- Instead of going level by level
- Traverse graph by exploring down paths as much as possible
- And then **backtracking** if we don't find a solution
- This is really just another name for a backtracking approach

```
def dfs(graph, start, goal):
    parents = {start: None}
    if start == goal:
        return get_path(parents)
    frontier = Stack()
    frontier.push(start)
    explored = []
    while True:
        if frontier.is_empty():
            raise Failure
        current = frontier.pop()
        explored.add(current)
        for action in graph.edges_from(current):
            child = do_action(action, current)
            if child not in explored and child not in frontier:
                parents[child] = current
                if child == goal:
                    return get_path(parents)
                frontier.push(child)
    raise Failure
```



Depth-Limited Search

- DFS might not converge in reasonable time if graph is infinite or very large
- Sometimes if the solution is very costly, it might as well not exist
- Core idea: traverse a total of d - called the limit - of edges away from the start node

```
def depth_limited_s(graph, start, goal, limit):
    parents = {start: None}
    levels = {start: 0}
    if start == goal:
        return get_path(parents)
    frontier = Stack()
    frontier.push(start)
    explored = []
    while True:
        if frontier.is_empty():
            raise Failure
        current = frontier.pop()
        if levels[current] <= limit:
            explored.add(current)
            for action in graph.edges_from(current):
                child = do_action(action, current)
                if child not in explored and child not in frontier:
                    parents[child] = current
                    if child == goal:
                        return get_path(parents)
                    frontier.push(child)
                    levels[child] = levels[current] + 1
    raise Failure
```

Informed Search Methods

- Suppose that we have some heuristic $h(s) : S \rightarrow \mathbb{R}$ that gives an approximate cost from a state to a goal state
- Obviously $h(s) = 0$ if $s \in G$
- Suppose $h^*(s) : S \rightarrow \mathbb{R}$ is the function that gives the **exact** cost from a state to a goal state
- A heuristic is called admissible if $\forall s \in S, h(s) \leq h^*(s)$
  - An admissible heuristic always underestimates the cost from state to a goal state
  - The informed search method we will consider, A* search is guaranteed to be optimal if you use a heuristic that is admissible

Informed Search Methods

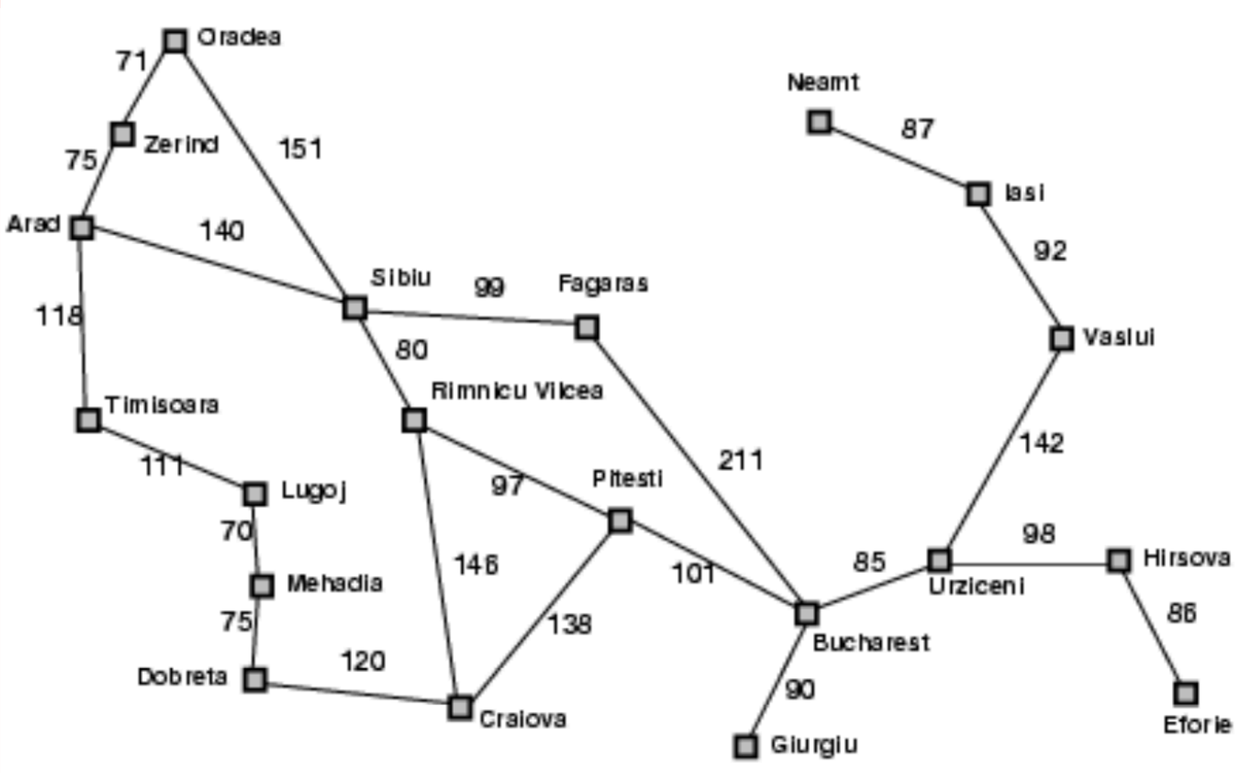
- Suppose that we have a heuristic function h that approximates distance from current state to goal state, and a function f that gives the **exact** cost from start state to current state

- Then $g(s) = f(s) + h(s)$ gives the approximate cost to goal state if we pass through state s

- This observation is the core idea of A* search

A* Search

- Core idea: use a priority queue (min heap) to manage current node
- Node priority based on g
- As we expand in new directions we might need to update priority value for nodes
  - Update priority if we have not visited not yet
  - Similar to Dijkstra's algorithm



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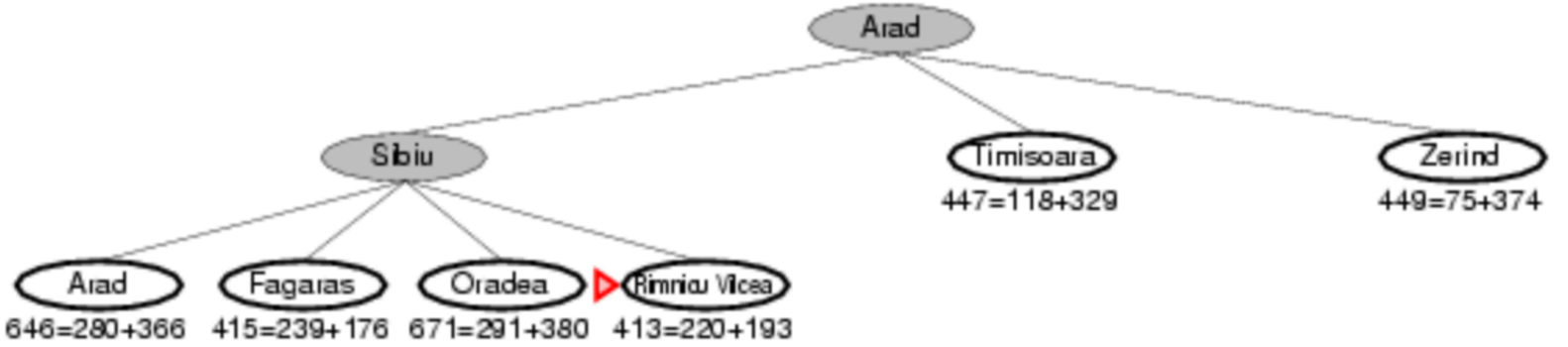

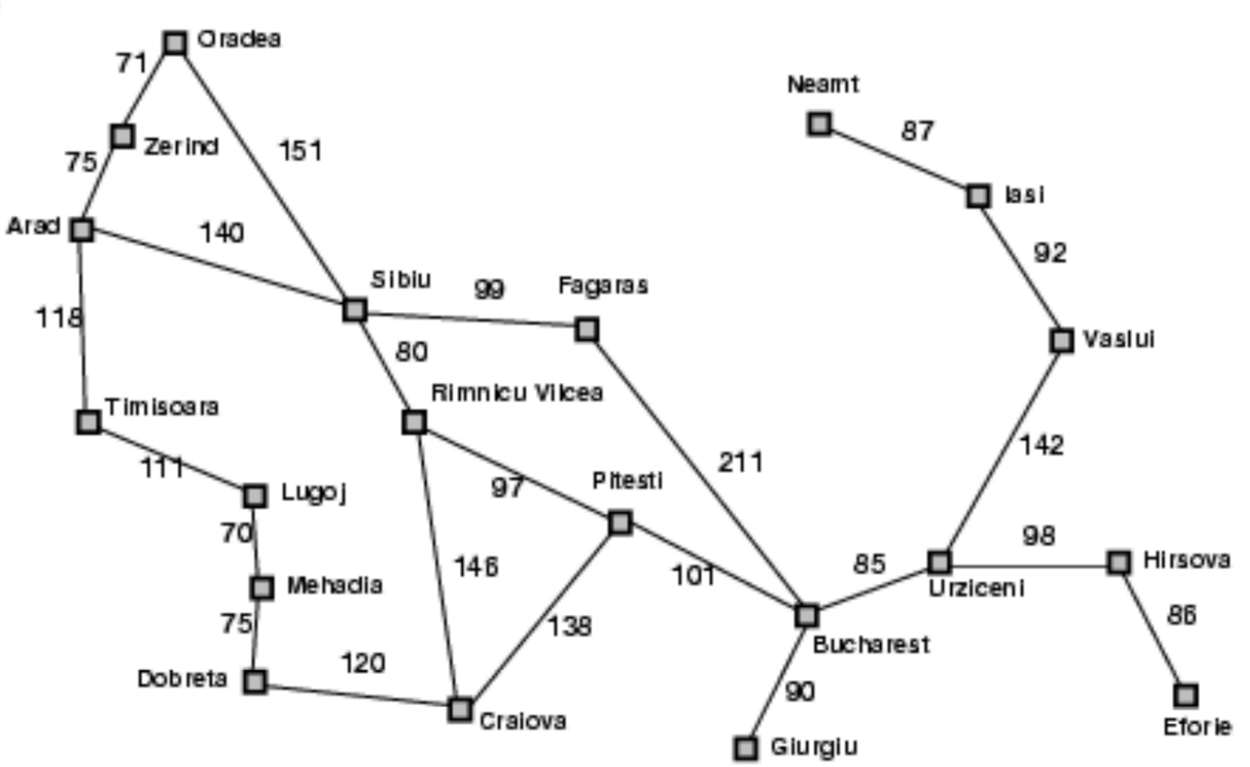

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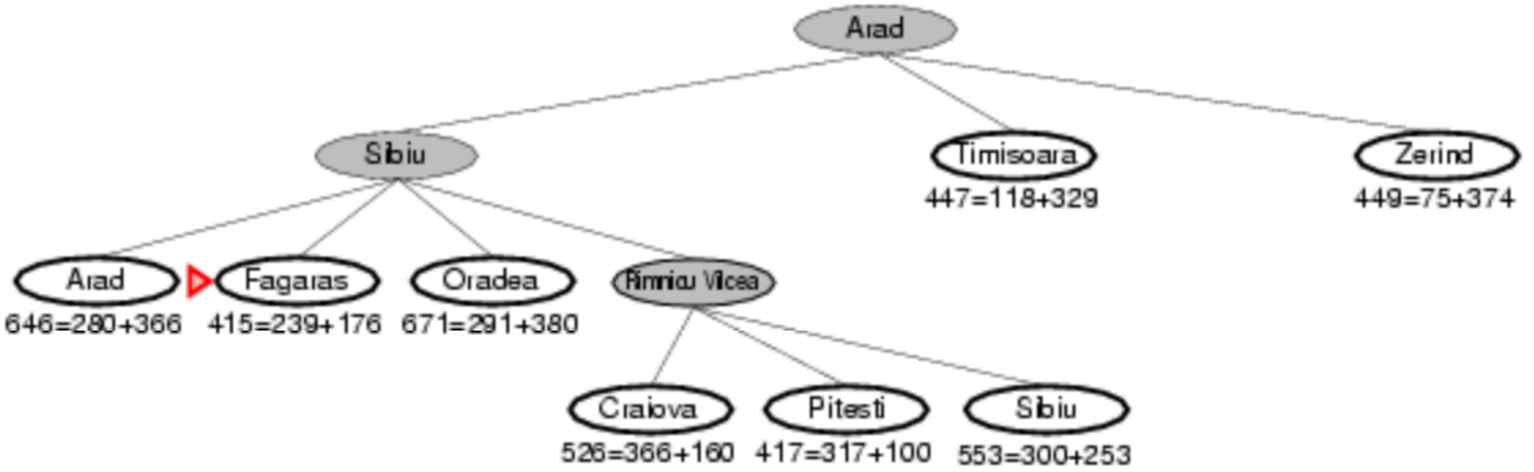

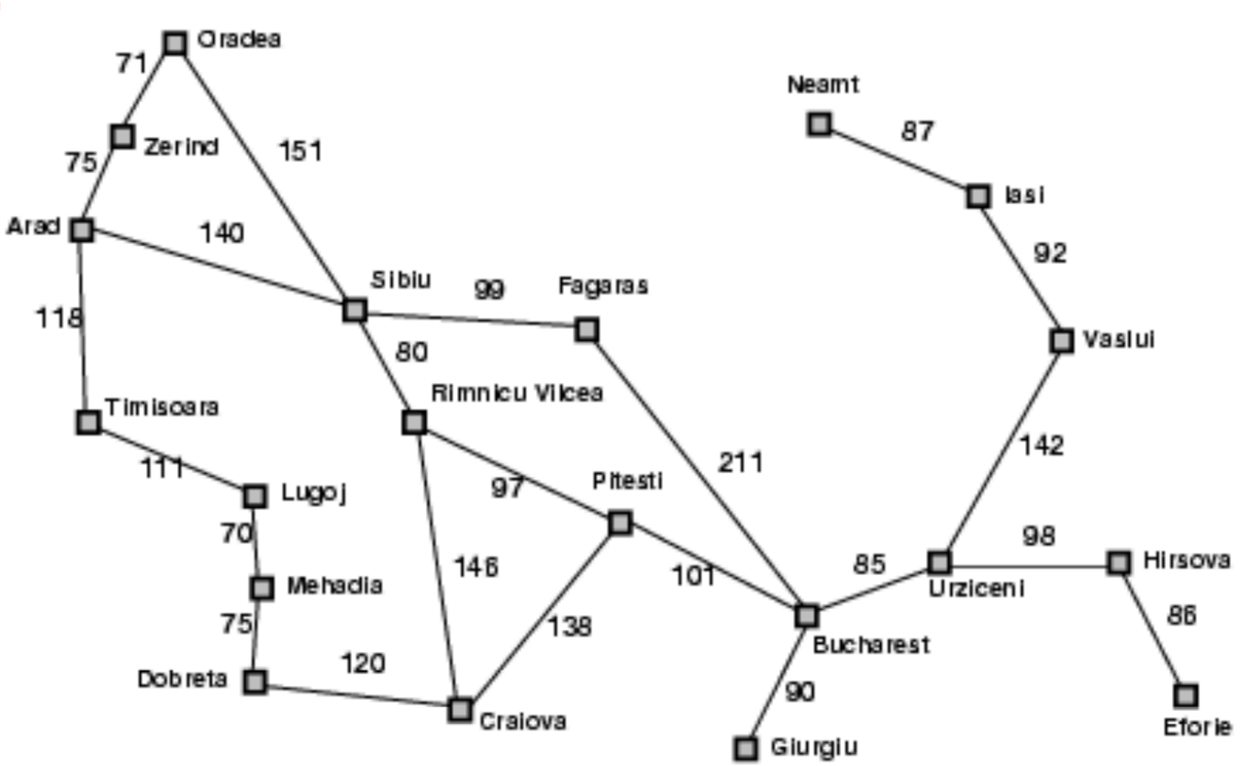

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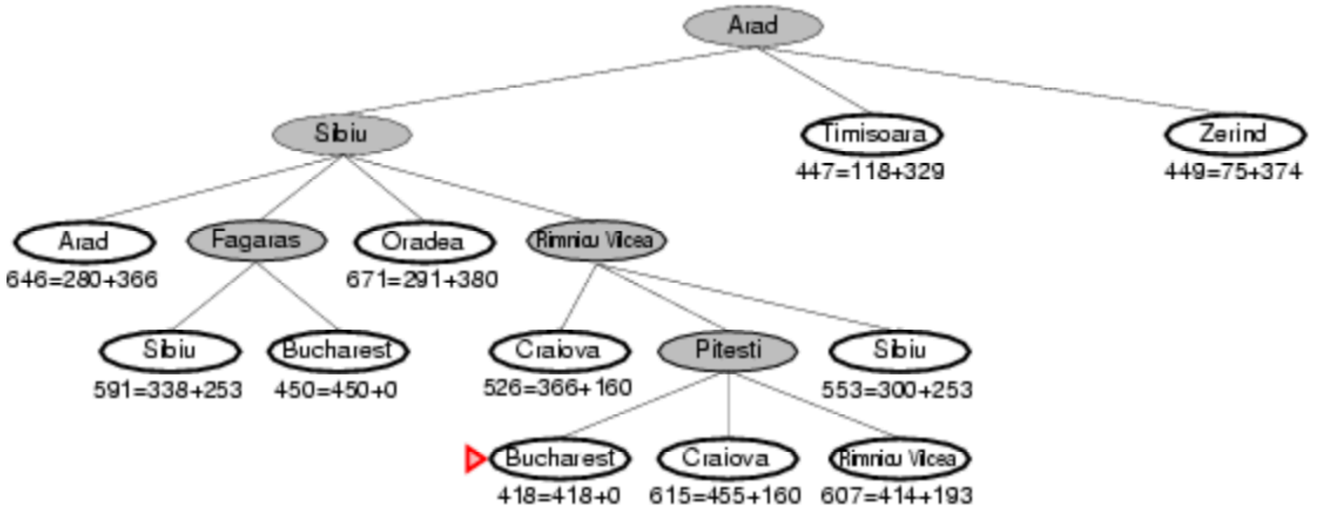

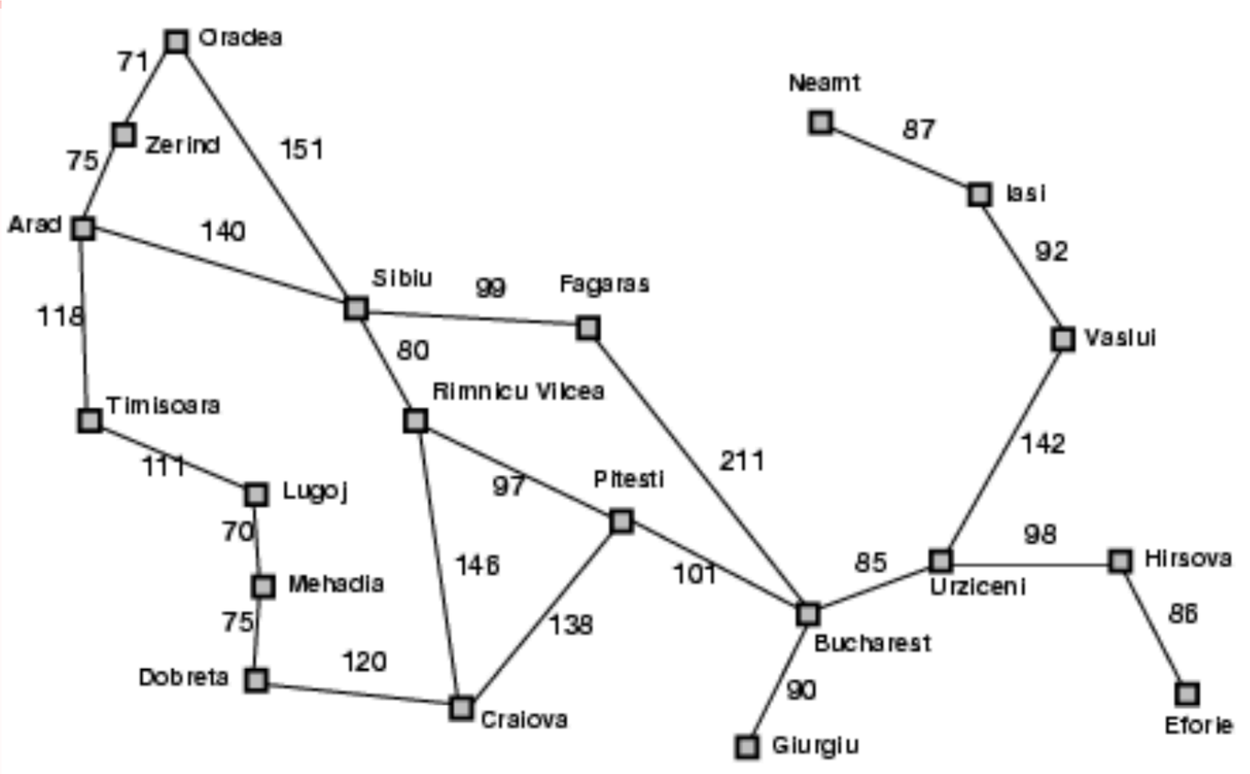

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