HEURISTIC SEARCH STRATEGIES

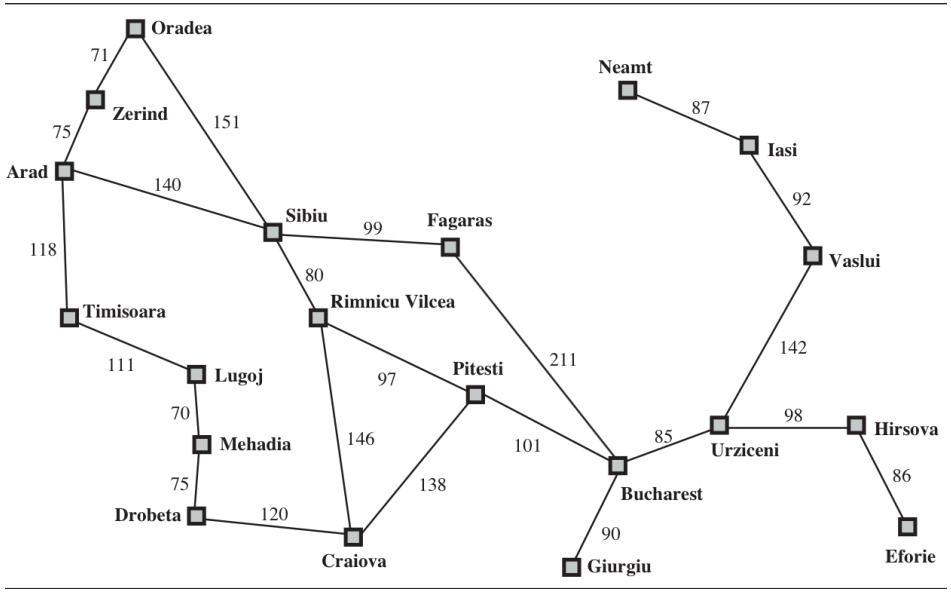
- **Informed (Heuristic) search** strategy—one that uses problem-specific knowledge beyond the definition of the problem itself—can find solutions more efficiently than can an uninformed strategy.

- Most algorithms include a **heuristic function**, denoted by h(n), where h(n) = estimated cost of the cheapest path from the state at node *n* to a goal state.

- For example, in Romania, one might estimate the cost of the cheapest path from Arad to Bucharest via the **straight-line distance function**.

Greedy best-first search

- **Greedy best-first search** tries to expand the node that is closest to the goal by using the **straight- line distance** heuristic h_{SLD}. If the goal is Bucharest, we need to know the straight-line distances to Bucharest, which are shown in Figure on RHS.



Arad	366	**Mehadia**	241
Bucharest	0	**Neamt**	234
Craiova	160	**Oradea**	380
Drobeta	242	**Pitesti**	100
Eforie	161	**Rimnicu Vilcea**	193
Fagaras	176	**Sibiu**	253
Giurgiu	77	**Timisoara**	329
Hirsova	151	**Urziceni**	80
Iasi	226	**Vaslui**	199
Lugoj	244	**Zerind**	374

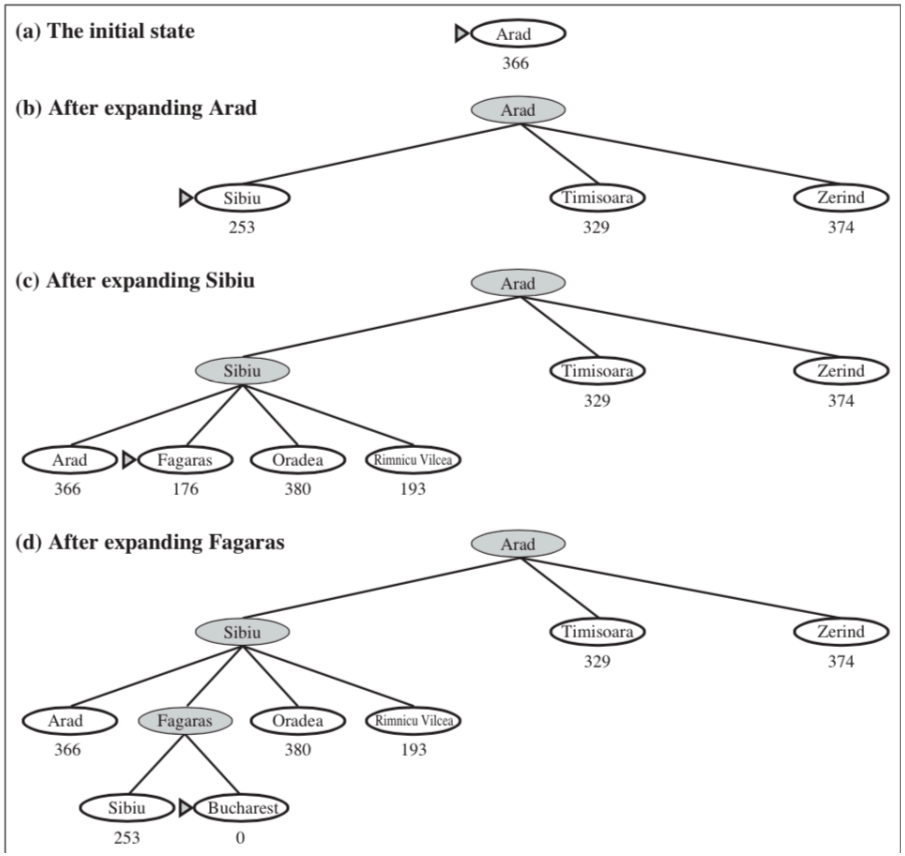
Values of h_{SLD}—straight-line distances to Bucharest.

Greedy best-first search

- Following Figure shows the progress of a greedy best-first search using h_{SLD}

- It is not optimal as the path via Sibiu and Fagaras to Bucharest is 32 kilometers longer than the path through Rimnicu Vilcea and Pitesti.

- This shows why the algorithm is called “greedy”—at each step it tries to get as close to the goal as it can.



Greedy best-first search

```
// This pseudocode is adapted from below // source: //https://courses.cs.washington.edu/
Best-First-Search(Grah g, Node start)
    1) Create an empty PriorityQueue
        PriorityQueue pq;
    2) Insert "start" in pq.
        pq.insert(start)
    3) Until PriorityQueue is empty
        u = PriorityQueue.DeleteMin
        If u is the goal
            Exit
        Else
            Foreach neighbor v of u
                If v "Unvisited"
                    Mark v "Visited"
                    pq.insert(v)
                Mark u "Examined"
End procedure
```

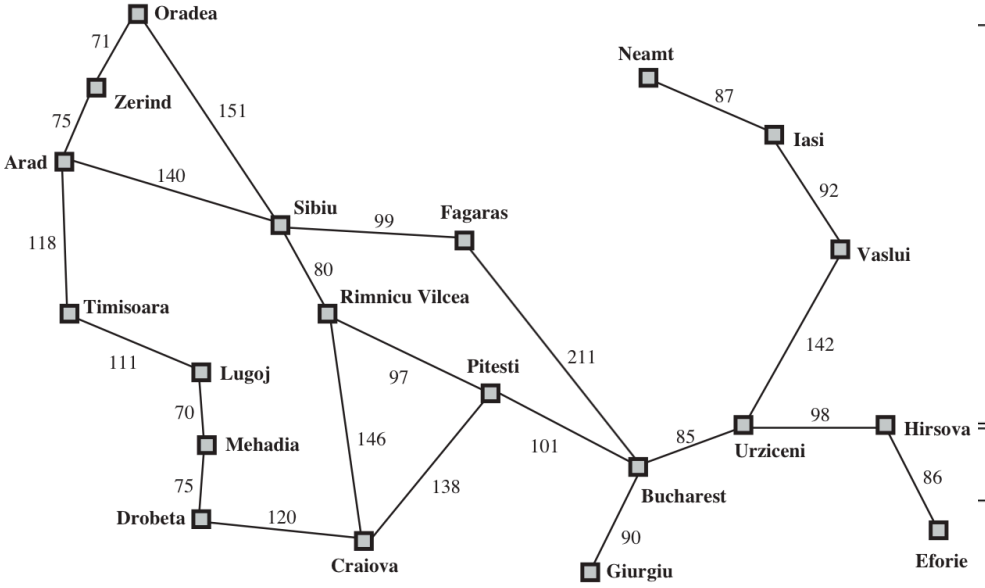
Properties of greedy search

- Complete?? No–it can get stuck in loops, e.g., Iasi → Neamt → Iasi → Neamt → … if we want to reach from Lasi to Fagaras.
  - Complete in finite space with repeated-state checking (Graph Search)
- Time?? $O(b^m)$, but a good heuristic can give dramatic improvement
- Space?? $O(b^m)$—keeps all nodes in memory
- Optimal?? No

- With a good heuristic function, however, the complexity can be reduced substantially.

A* search

- Idea: avoid expanding paths that are already expensive.
  - Evaluation function f(n) = g(n) + h(n)
  - g(n) = cost so far to reach n
    h(n) = estimated cost to goal from n
    f(n) = estimated total cost of path through n to goal
- A* search uses an admissible heuristic:
  - $h_{SLD}(n)$ never overestimates the actual road distance.



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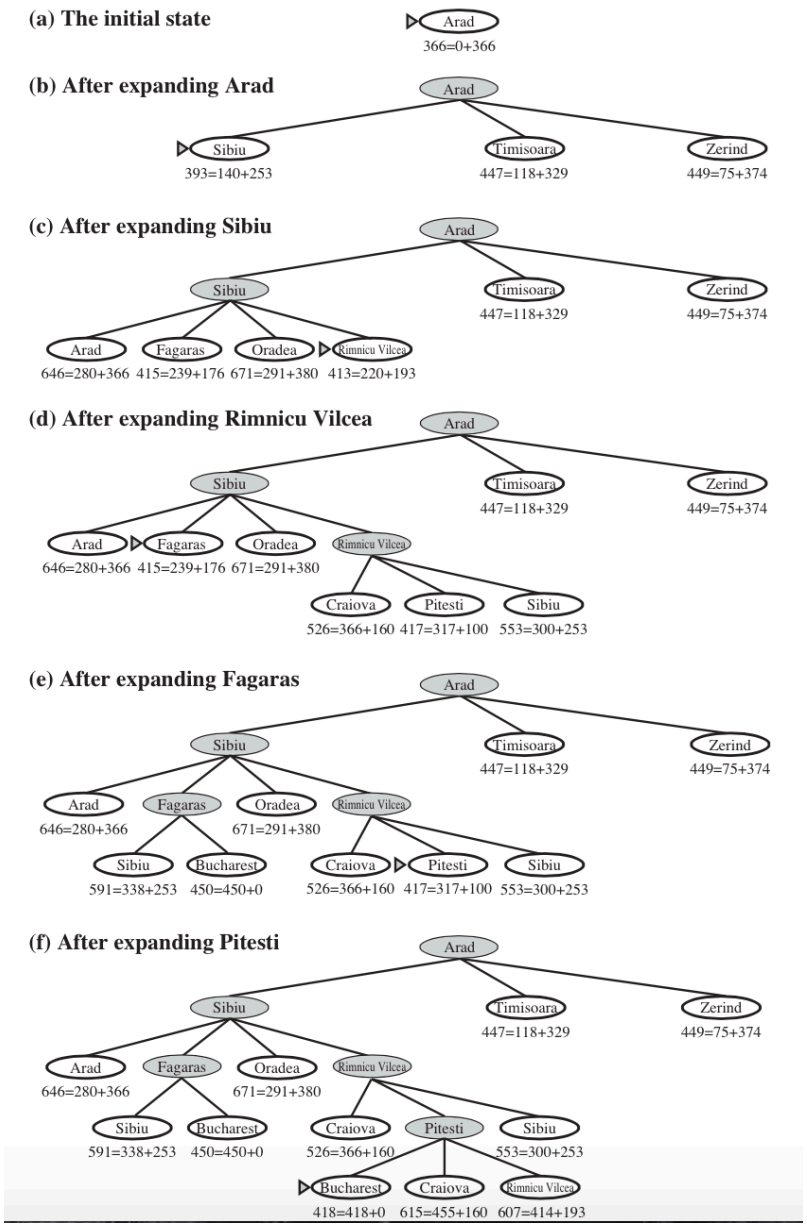
Values of h_{SLD}—straight-line distances to Bucharest.

Following figure explain it's execution using the information given in previous two figures.



Pseudo code for A* search

```
1  Put node_start in the OPEN list with f(node_start) = h(node_start) (initialization)
2  while the OPEN list is not empty {
3    Take from the open list the node node_current with the lowest
4         f(node_current) = g(node_current) + h(node_current)
5    if node_current is node_goal we have found the solution; break
6    Generate each state node_successor that come after node_current
7    for each node_successor of node_current {
8      Set successor_current_cost = g(node_current) + w(node_current, node_successor)
9      if node_successor is in the OPEN list {
10       if g(node_successor) ≤ successor_current_cost continue (to line 20)
11     } else if node_successor is in the CLOSED list {
12       if g(node_successor) ≤ successor_current_cost continue (to line 20)
13       Move node_successor from the CLOSED list to the OPEN list
14     } else {
15       Add node_successor to the OPEN list
16       Set h(node_successor) to be the heuristic distance to node_goal
17     }
18     Set g(node_successor) = successor_current_cost
19     Set the parent of node_successor to node_current
20   }
21   Add node_current to the CLOSED list
22 }
23 if(node_current != node_goal) exit with error (the OPEN list is empty)
```

Properties of A*

- **Complete**?? Yes, unless there are infinitely many nodes.

- **Time**?? $O(b^{\varepsilon m})$—where $\varepsilon = (h^* - h)/h^*$ is the relative error in h. where h^* is the optimal heuristic, the exact cost to get from *x* to the goal.
  - If h = 0, then ε = 1 and we get uniform-cost search
  - If h = h^*, then it is perfect and we find the solution immediately

- **Space**?? $O(b^m)$—it keeps all nodes in memory

- **Optimal**?? Yes
  - A^* expands all nodes with $f(n) < C^*$
  - A^* expands some nodes with $f(n) = C^*$
  - A^* expands no nodes with $f(n) > C^*$

Issues in A* search

- Exponential complexity of A* with respect to depth of goal often makes it impractical in finding an optimal solution.

- Computation time is not the main drawback of A*. As A* keeps all generated nodes in memory (as do all GRAPH-SEARCH algorithms), and usually runs out of space long before it runs out of time.

- For this reason, A* is not practical for many large-scale problems.

Read it Yourself

- 3.5.3 Memory-bounded heuristic search
- 3.5.4 Learning to search better
- 3.6 Heuristic functions

Lab Work No.3

- Design a program for the greedy best first search and A* search
  - Implement the greedy best first search using the following link https://www.geeksforgeeks.org/best-first-search-informed-search/
  - Implement the A* search using the following link https://www.geeksforgeeks.org/a-search-algorithm/