Informed search methods

Uninformed vs. Informed Search

- Uninformed search strategies
  - Find solutions to problems by systematically generating new states and testing for goal
  - Most are incredibly inefficient

Uninformed vs. Informed Search

- Uninformed search strategies
  - Find solutions to problems by systematically generating new states and testing for goal
  - Most are incredibly inefficient
- Informed search strategies
  - Use problem-specific knowledge
  - Find solutions more efficiently

Informed Search

- Informed search strategy
  - One that uses problem-specific knowledge beyond the problem definition itself
- General approach is called "Best First" search
  - Node selected for expansion based on an evaluation function, f(n)
    - Measuring a distance to goal
  - Node with lowest evaluation is selected

Techniques

- Best-first search
  - Expand “minimum cost” nodes first
  - Greedy search
  - A* search

Best-First Search

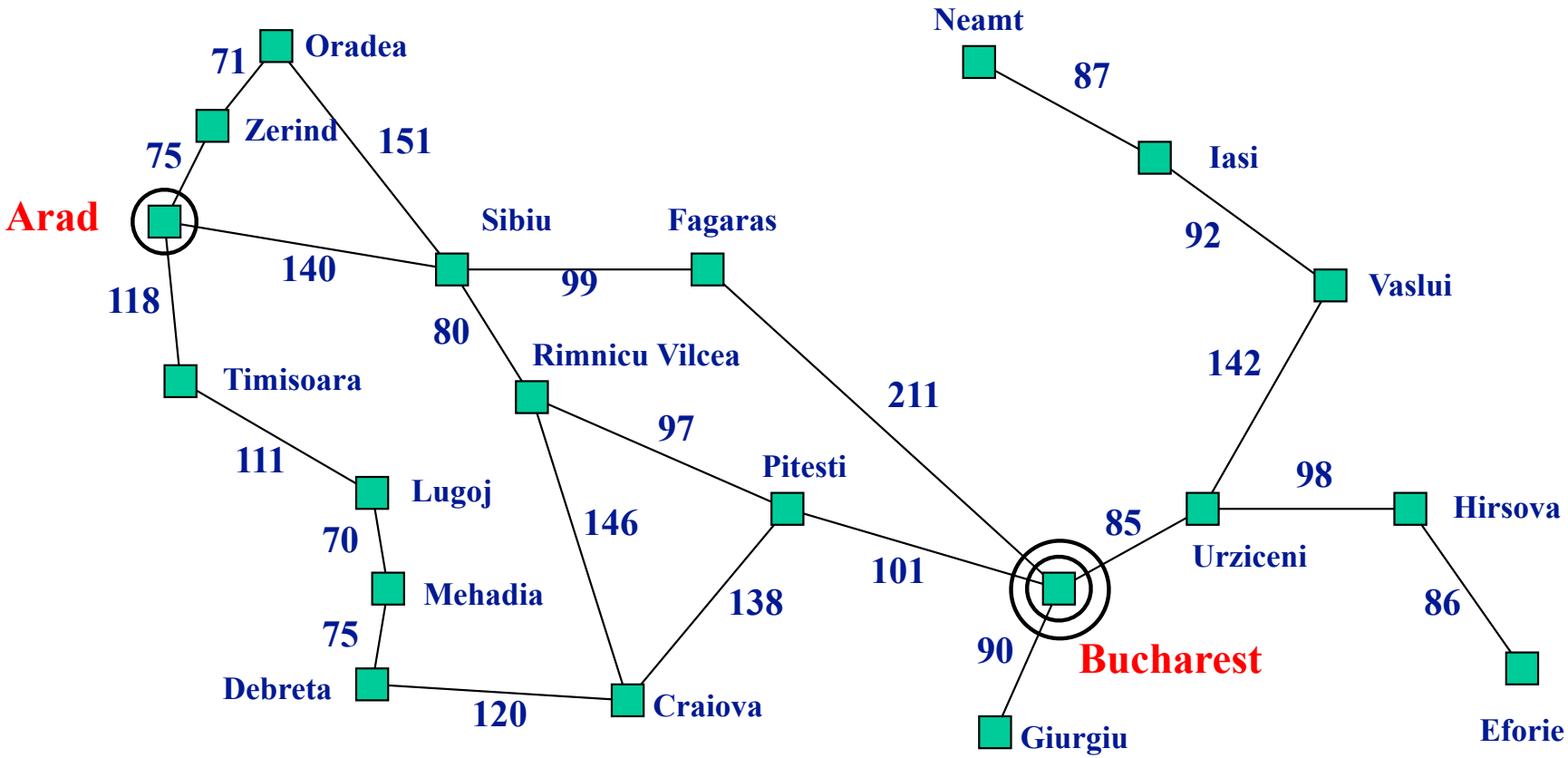
- Expand “minimum cost” nodes first
  - Greedy search
  - A* search
- Open set
  - Priority queue implementation
  - Insert expanded nodes in decreasing order of desirability (most desirable first)

Greedy Search

- Simplest best-first search strategy
- Minimize estimated cost to reach goal
- Heuristic function *h(n)*
  - **Estimate of cost from node *n* to *goal***
    - Require *h(n)* = 0 if *n* is goal

- Greedy search expands the node that *appears* to be closest to the goal
  - Each step tries to get as close to goal as possible
  - Though, will not consider if its action will be the best in the long run

Romania Step Costs in km



Straight-Line Distance to Bucharest

H_{SLD}

Arad	366	Mehadia	241
Bucharest	0	Neamt	234
Craiova	160	Oradea	380
Dobreta	242	Pitesti	100
Eforie	161	Rimnicu Vilcea	193
Fagaras	176	Sibiu	253
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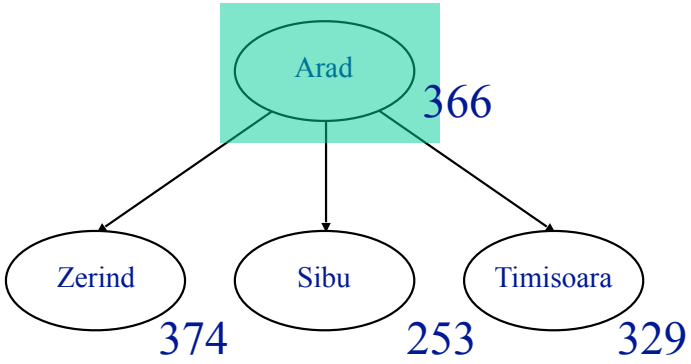
Iasi	226	Vaslui	199
Lugoj	244	Zerind	374

Greedy Search Example: Romania

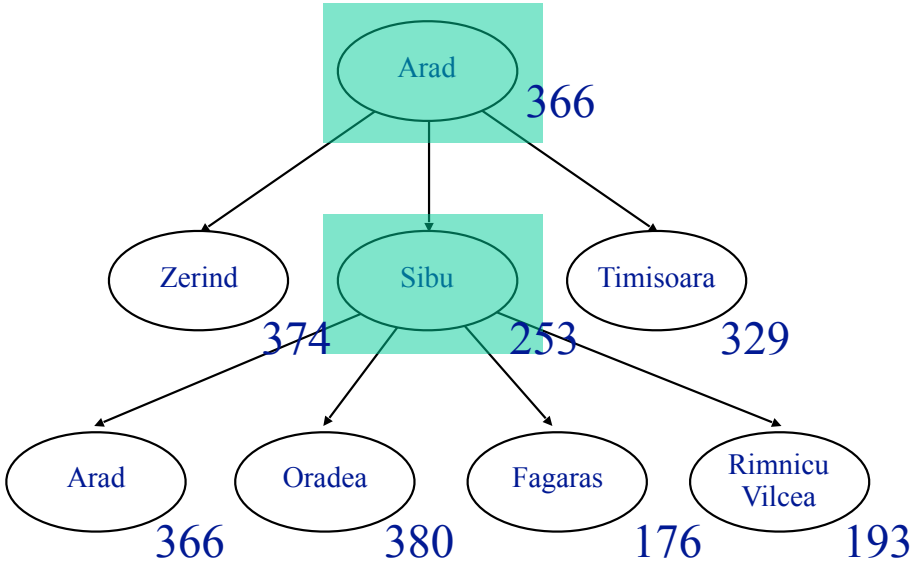
Open = { Arad(366) }

Greedy Search Example: Romania



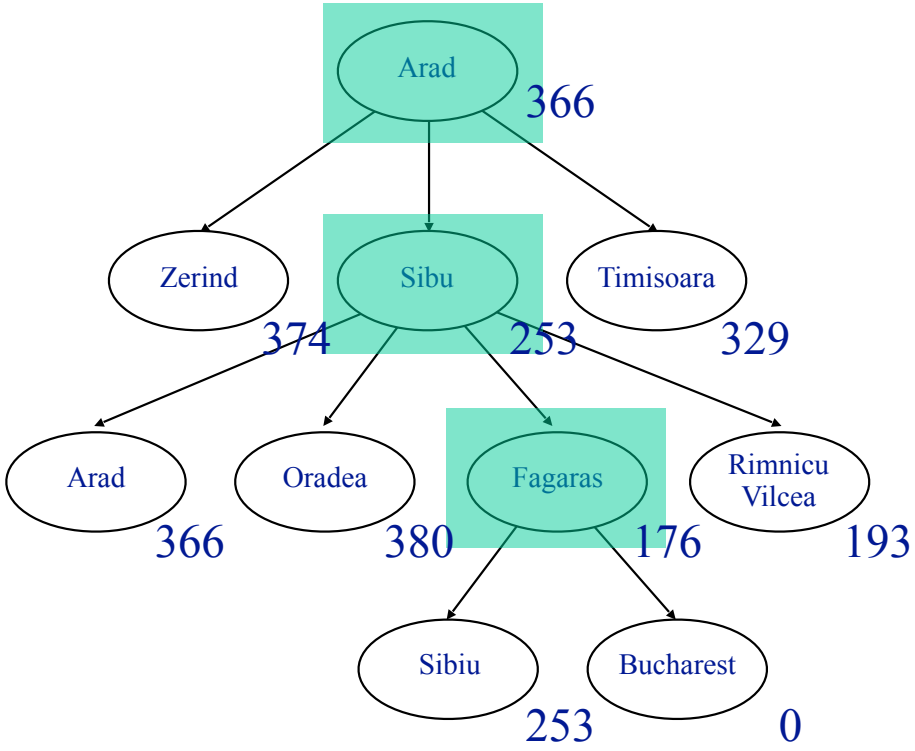
Open = { Sibu(253), Timisoara(329), Zerind(374) }

Greedy Search Example: Romania



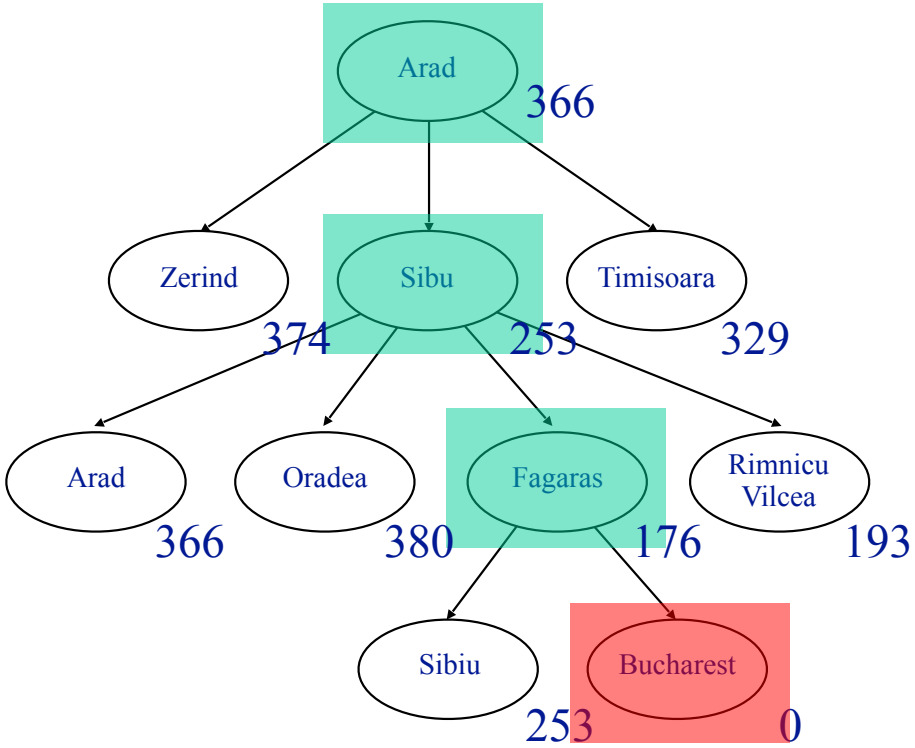
Open = { Fagaras(176), RimnicuVilcea(193), Timisoara(329), Arad(366), Zerind(374), Oradea(380) }

Greedy Search Example: Romania

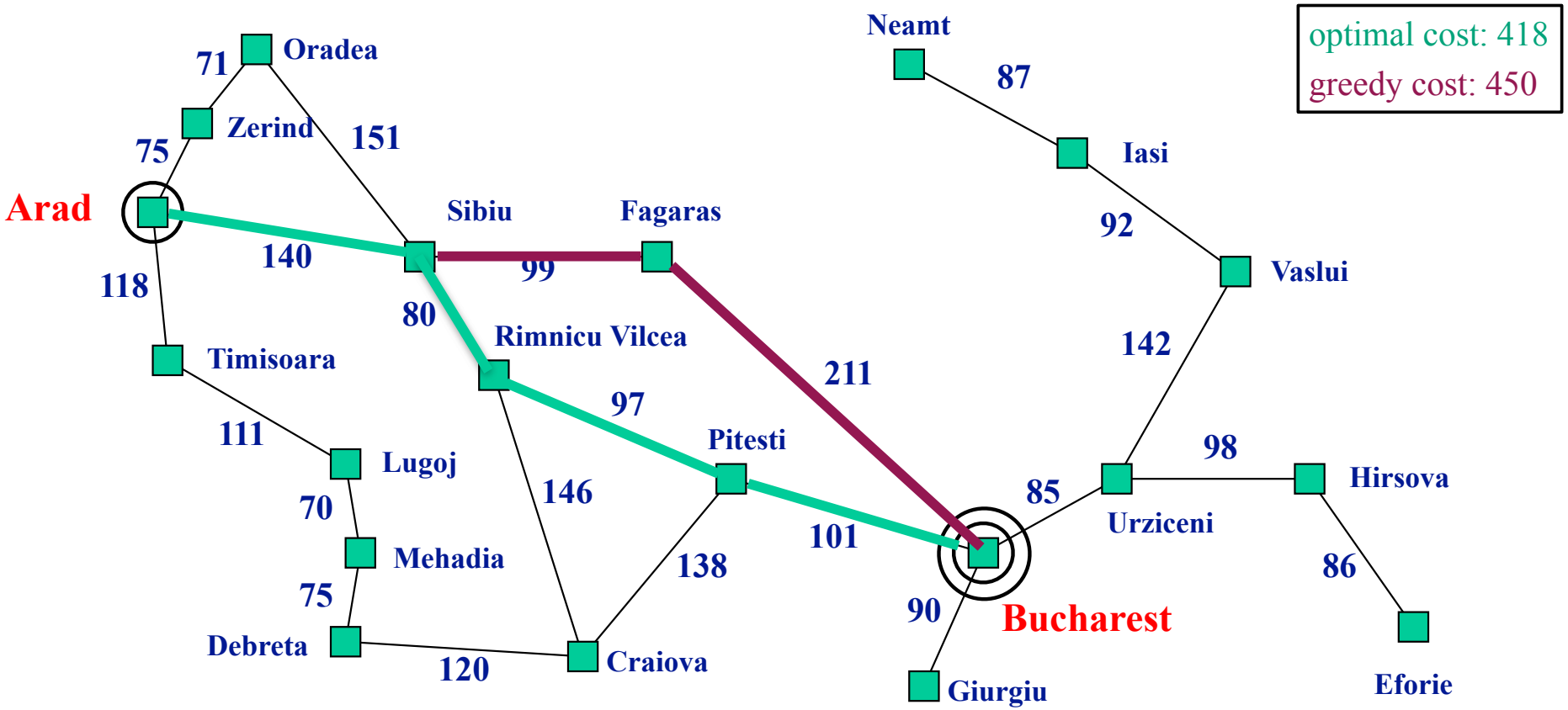


Open = { Bucharest(0), Fagaras(176), RimnicuVilcea(193), Sibu(253), Timisoara(329), Arad(366), Zerind(374), Oradea(380) }

Greedy Search Example: Romania



Romania Step Costs in km



Properties of Greedy Search

- Not complete (can be bad)
  - Can get stuck in loops
  - Complete if check for repeated states
- Time (can be bad)
  - $O(b^m)$, m=maximum depth (worst case, like DFS)
- Space (can be bad)
  - $O(b^m)$, keeps all nodes in memory (worst case)
- Not optimal (can be bad)
  - Heuristic is an estimate

But a good heuristic can give dramatic improvement!

A* Search

- Minimizes total estimated path cost
- Avoids expanding paths already expensive
- Evaluation function $f(n) = g(n) + h(n)$
  - Actual cost to reach node n so far → $\boldsymbol{g(n)}$
  - Estimated cost from n to goal → $\boldsymbol{h(n)}$
  - Estimated total cost through n to goal

    → $\boldsymbol{f(n)} = g(n) + h(n)$

- A* search uses *admissible* heuristic
  - i.e., $h(n) \leq h^*(n)$ where $h^*(n)$ is true cost from n to goal
  - e.g., $h_{SLD}(n)$ never overestimates actual distance

A* Search Example: Romania

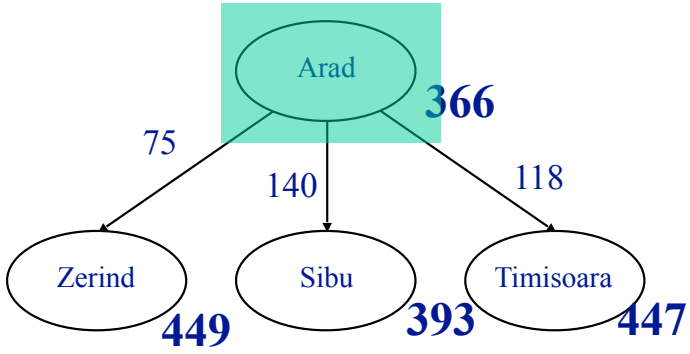
Open = { Arad(366) }

366

g(n): cost so far

f(n)=*g(n)*+*h(n)* = cost so far + estimated cost to goal

A* Search Example: Romania



Open = { Sibu(393), Timisoara(447), Zerind(449) }

f(Zerid)=75+ 374= 449

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Hirsova	151	Urziceni	80
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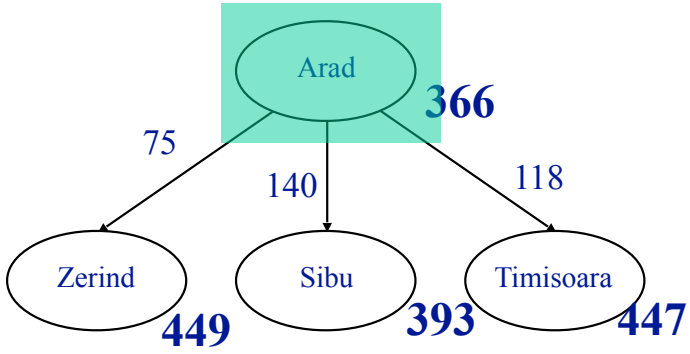
f(n)=*g(n)*+*h(n)* = cost so far + estimated cost to goal

A* Search Example: Romania



Open = { Sibu(393), Timisoara(447), Zerind(449) }

f(Zerid)=75+ 374= 449
f(Sibu)=140+ 253=393

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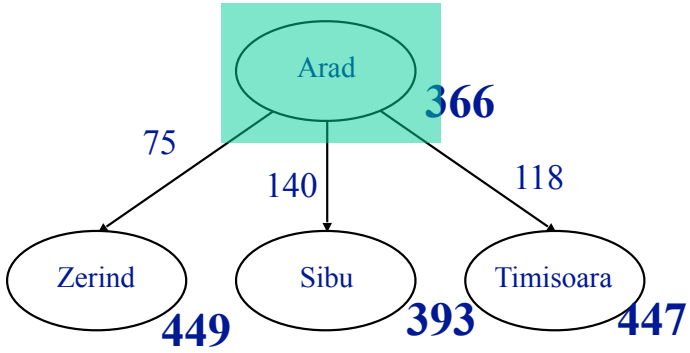
A* Search Example: Romania



Open = { Sibu(393), Timisoara(447), Zerind(449) }

f(Zerid)=75+ 374= 449
f(Sibu)=140+ 253=393
f(Timisoara)=118 + 329 =447

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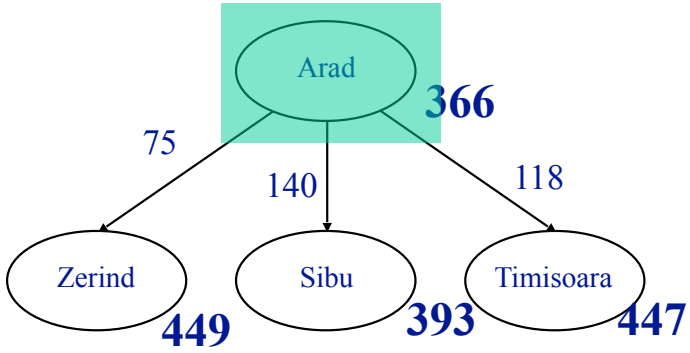

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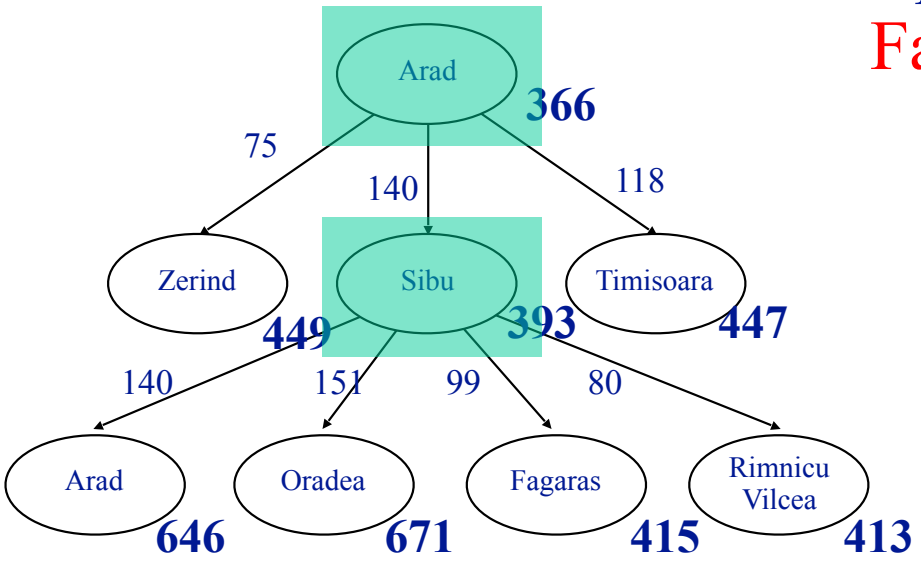

Open = { RimnicuVilcea(413), Fagaras(415), Timisoara(447), Zerind(449), Arad(646), Oradea(671) }

Arad	366	Mehadia	241
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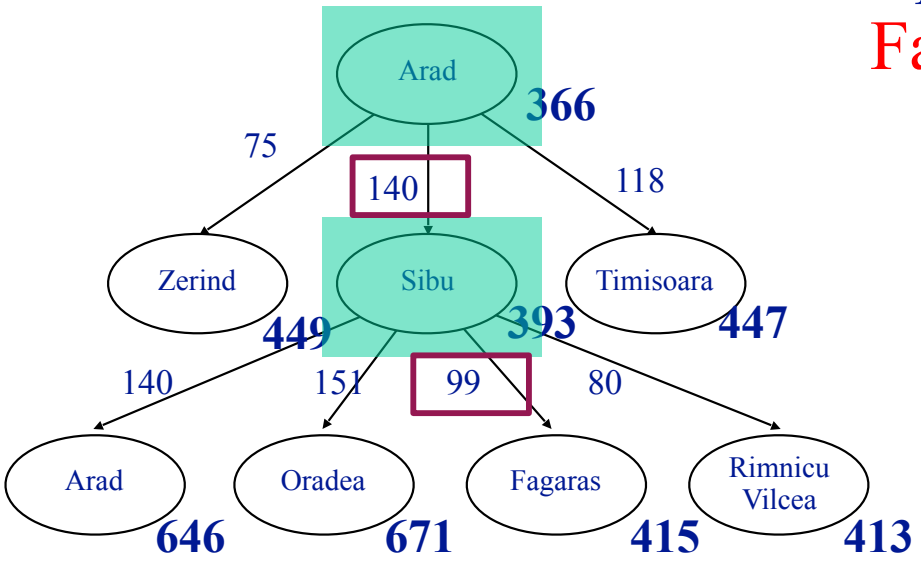
f(Fagaras)=(140+99) + 176=415

$g(n)$: cost so far

$\boldsymbol{f(n)}=g(n)+h(n)$ = cost so far + estimated cost to goal

A* Search Example: Romania



Open = { RimnicuVilcea(413), Fagaras(415), Timisoara(447), Zerind(449), Arad(646), Oradea(671) }

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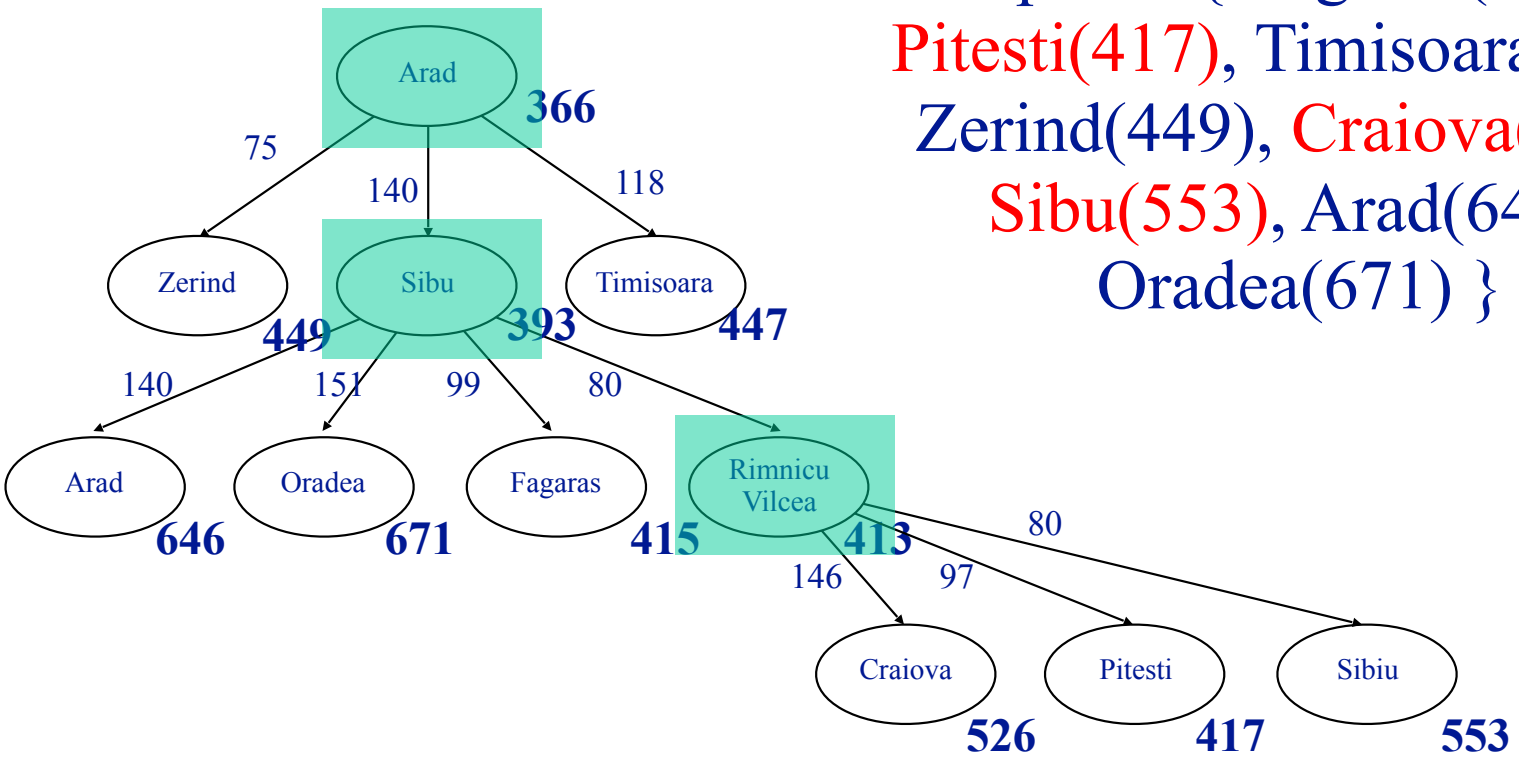
f(Fagaras)=(140+99) + 176=415

$g(n)$: cost so far

$\boldsymbol{f(n)}=g(n)+h(n)$ = cost so far + estimated cost to goal

A* Search Example: Romania

Open = { Fagaras(415), Pitesti(417), Timisoara(447), Zerind(449), Craiova(526), Sibu(553), Arad(646), Oradea(671) }

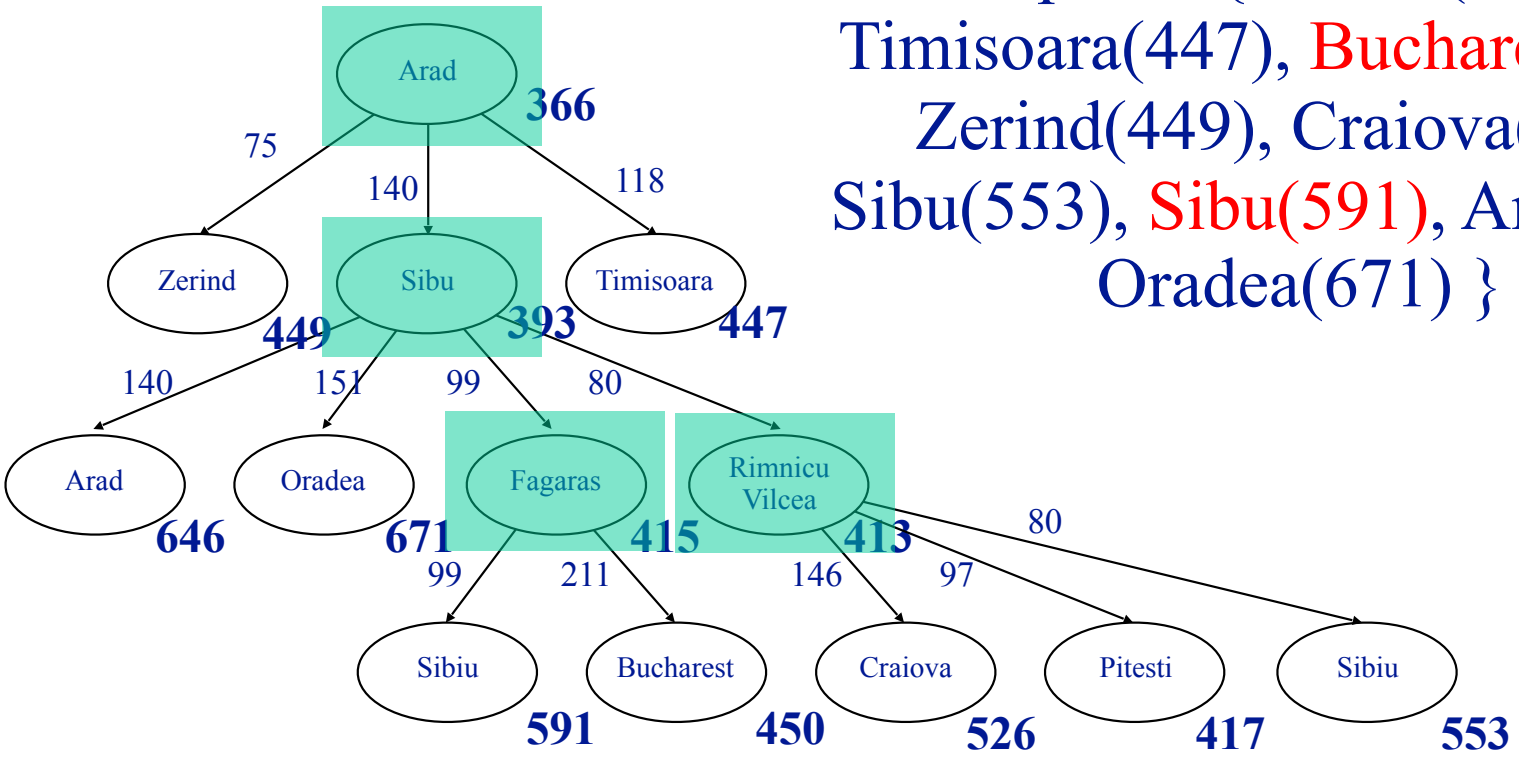


g(n): cost so far

f(n)=*g(n)*+*h(n)* = cost so far + estimated cost to goal

A* Search Example: Romania

Open = { Pitesti(417), Timisoara(447), Bucharest(450), Zerind(449), Craiova(526), Sibu(553), Sibu(591), Arad(646), Oradea(671) }

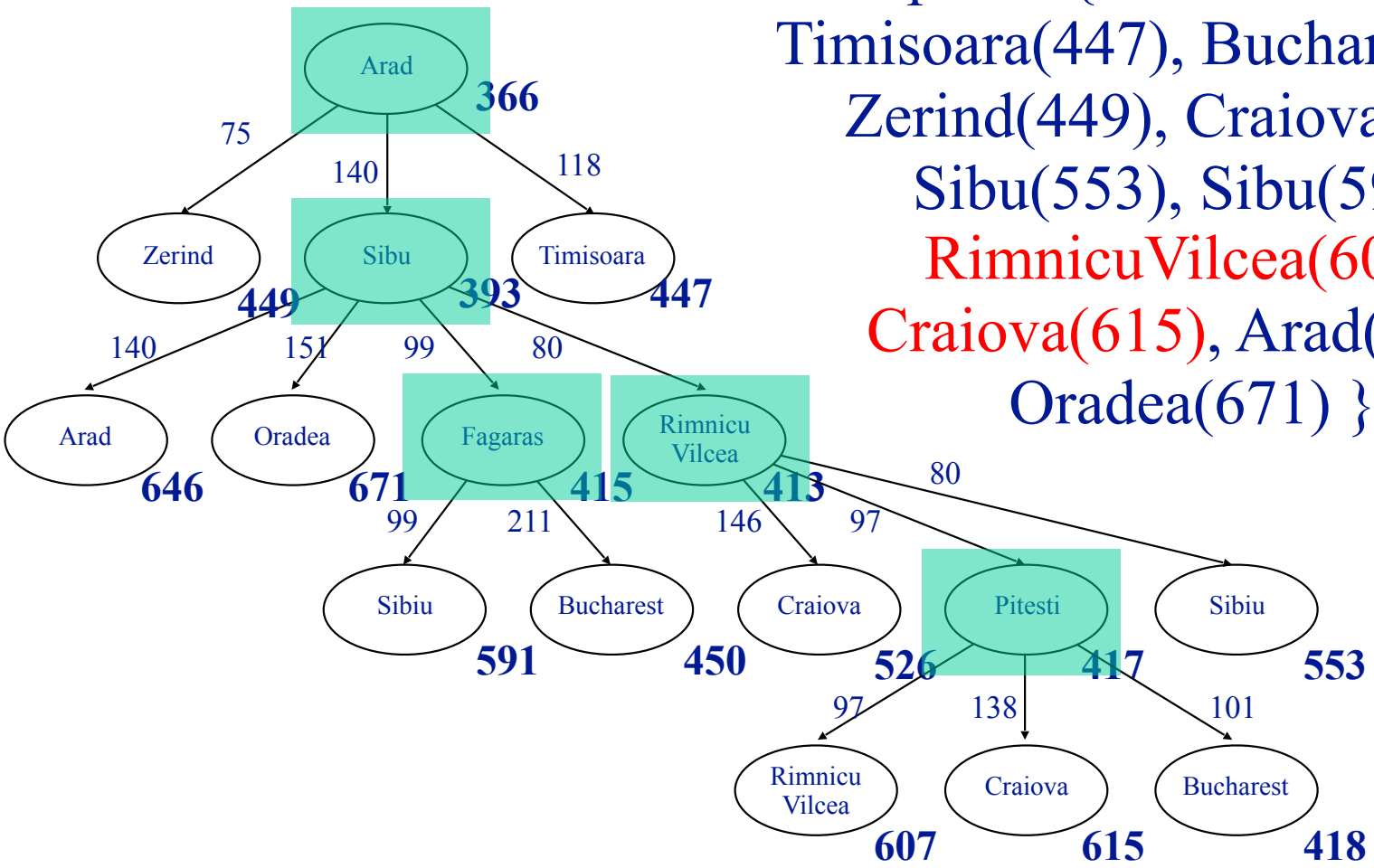


g(n): cost so far

f(n)=*g(n)*+*h(n)* = cost so far + estimated cost to goal

A* Search Example: Romania

Open = { Bucharest(418), Timisoara(447), Bucharest(450), Zerind(449), Craiova(526), Sibu(553), Sibu(591), RimnicuVilcea(607), Craiova(615), Arad(646), Oradea(671) }

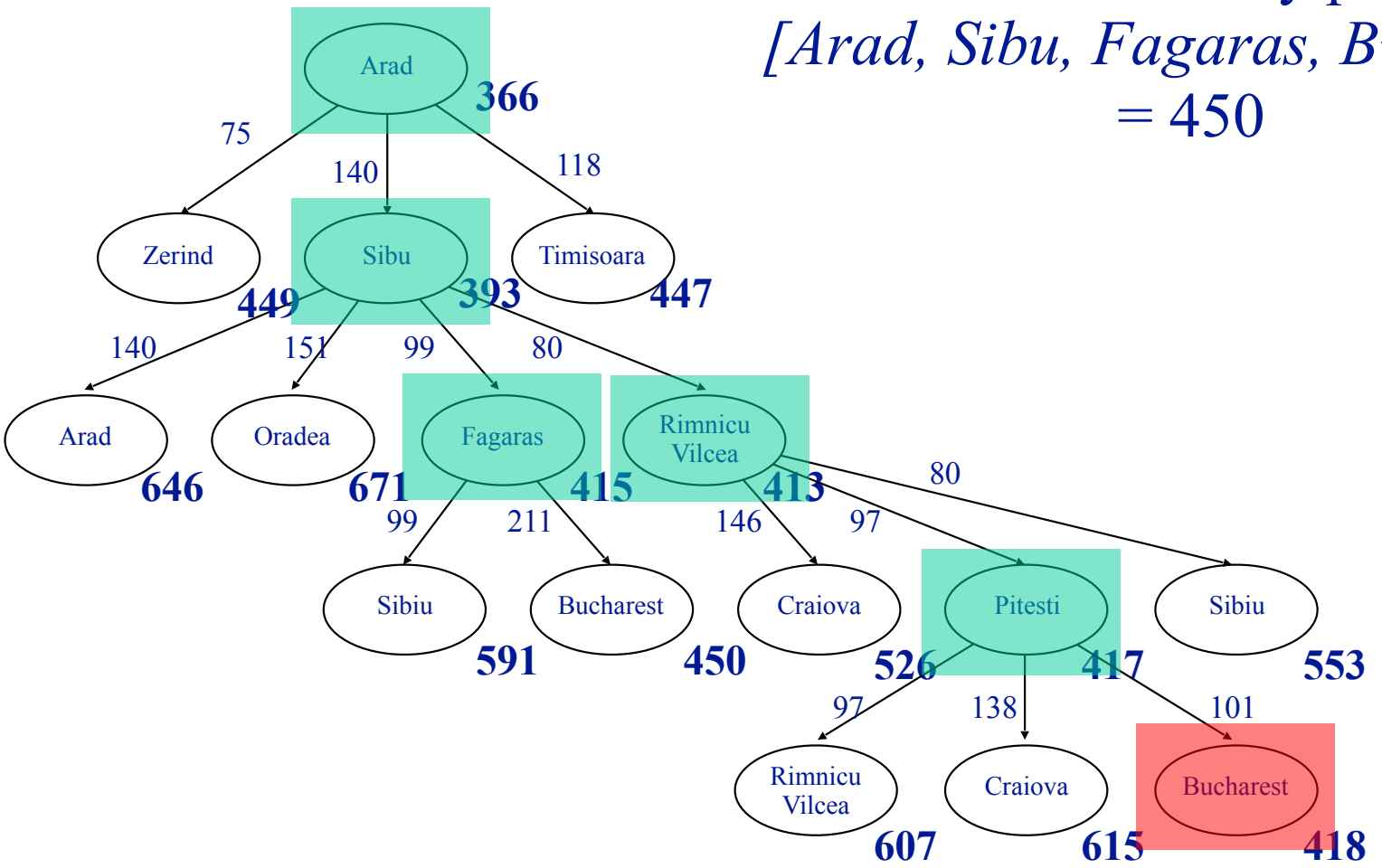


g(n): cost so far

f(n)$=g(n)+h(n)$ = cost so far + estimated cost to goal

A* Search Example: Romania

Recall that Greedy path was
[Arad, Sibu, Fagaras, Bucharest]
= 450

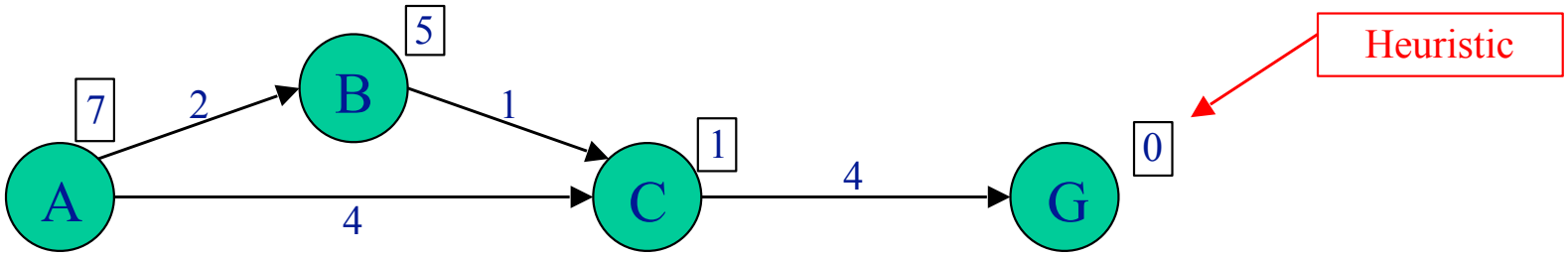


g(n): cost so far

f(n)=*g(n)*+*h(n)* = cost so far + estimated cost to goal

Repeated states in A*

- Contrary to greedy search algorithms, avoiding repeated states can actually harm A*
- Consider:



A(0+7=7) B(2+5=7) C(4+1=5) G(4+4+0=8)

- Goal is discovered before finding shortest path to it!
- Depending on algorithm construction, could return sub-optimal path
  - At best, devolves to BFS-like performance

Consistent Heuristics

– Consistency: The difference in heuristic values between two connected states is always smaller than (or equal to) the actual cost:

$$cost(x, y) \geq \left| h(x) - h(y) \right|$$

For two connected states x and y

Consistent Heuristics

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$$cost(x, y) \geq \left| h(x) - h(y) \right|$$

For two connected states x and y

- Consistency ensures that the total estimated path cost always increases (or stays the same) as we get closer to a goal state
  - For this reason, sometimes also called a monotonic heuristic
  - Guarantees that shortest path is always expanded first

Properties of A*

- Complete (good)
  - Unless infinitely many nodes
- Time and space (not good)
  - Still exponential in worst case (keeps all nodes in memory)
  - Strongly depends on choice of heuristic
- Optimal (good)
  - Expands fewest nodes