COMP219: Artificial Intelligence

Lecture 8: Combining Search Strategies and Speeding Up

Overview

- Last time
  - Basic problem solving techniques:
    - **Breadth-first search**
      - complete but expensive
    - **Depth-first search**
      - cheap but incomplete
- Today
  - Variations and combinations
    - **Limited depth search**
    - **Iterative deepening search**
  - Speeding up techniques
    - Avoiding repetitive states
    - Bi-directional search

- Learning outcome covered today:

  Identify, contrast and apply to simple examples the major search techniques that have been developed for problem-solving in AI

Depth Limited Search

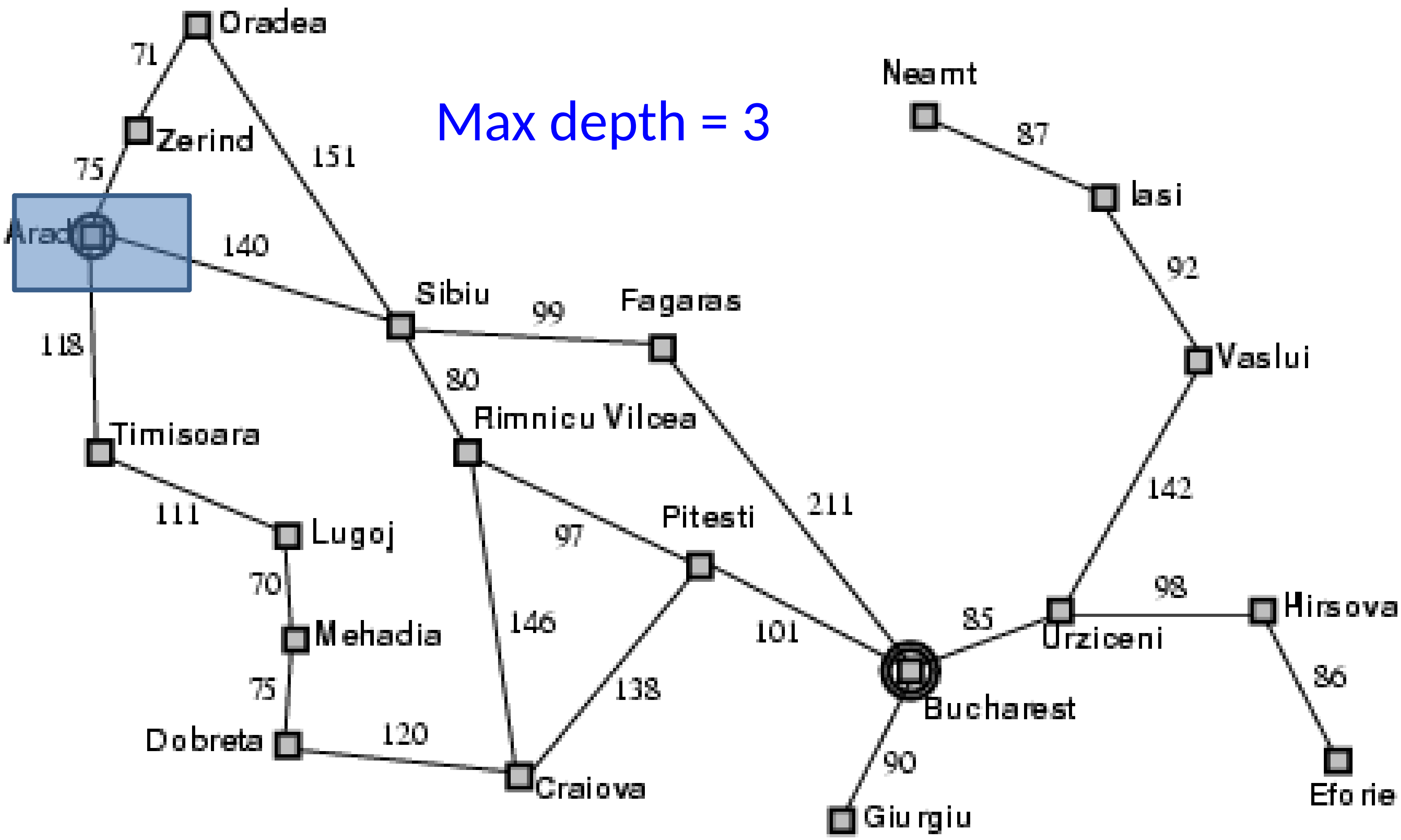
- Depth first search has some desirable properties: space complexity
- But if wrong branch expanded (with no solution on it), then it may not terminate
- Idea: introduce a depth limit on branches to be expanded
- Don’t expand a branch below this depth
- Most useful if you know the maximum depth of the solution

Depth Limited Search

```
depth limit = max depth to search to;
agenda = [initial state];
  if initial state is goal state then
     return solution
  else
    while agenda not empty do
      take node from front of agenda;
      if depth(node) < depth limit then
      {
        new nodes = apply operations to node;
        add new nodes to front of agenda;
        if goal state in new nodes then
          return solution;
      }
```

Example: Romania Problem

Only 20 cities on the map, so no path longer than 19.
In fact, any city can reach any other in at most 9 steps.



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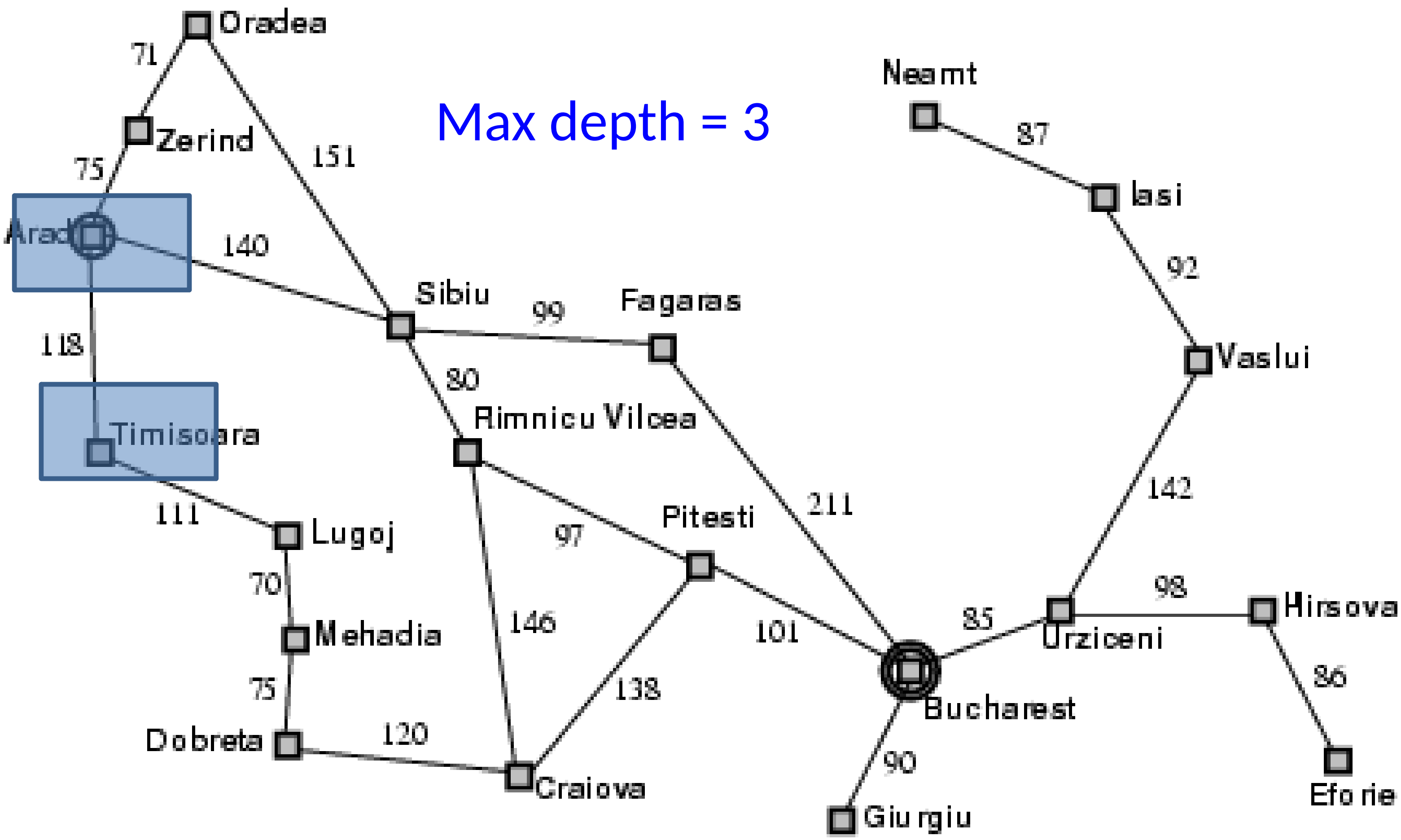

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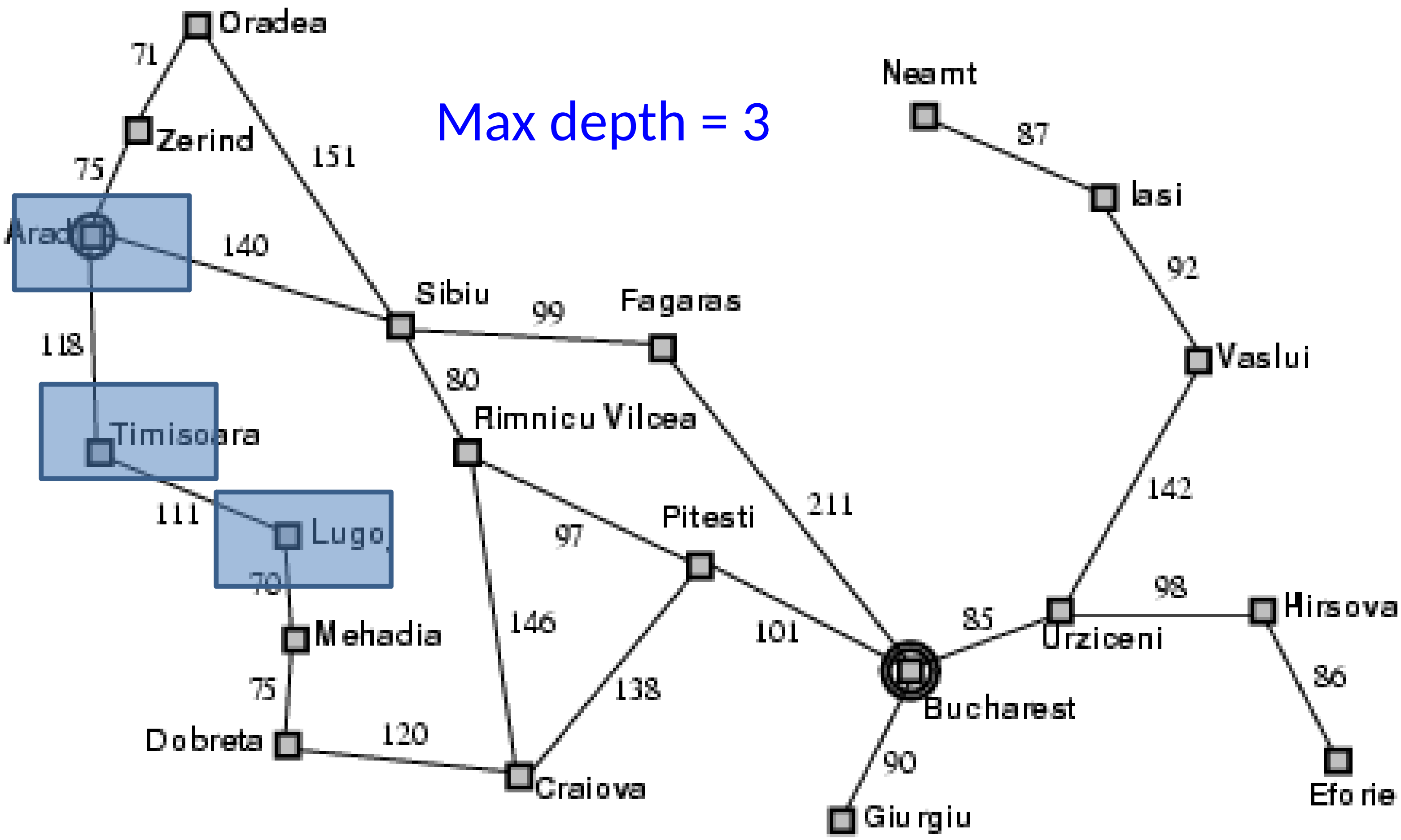

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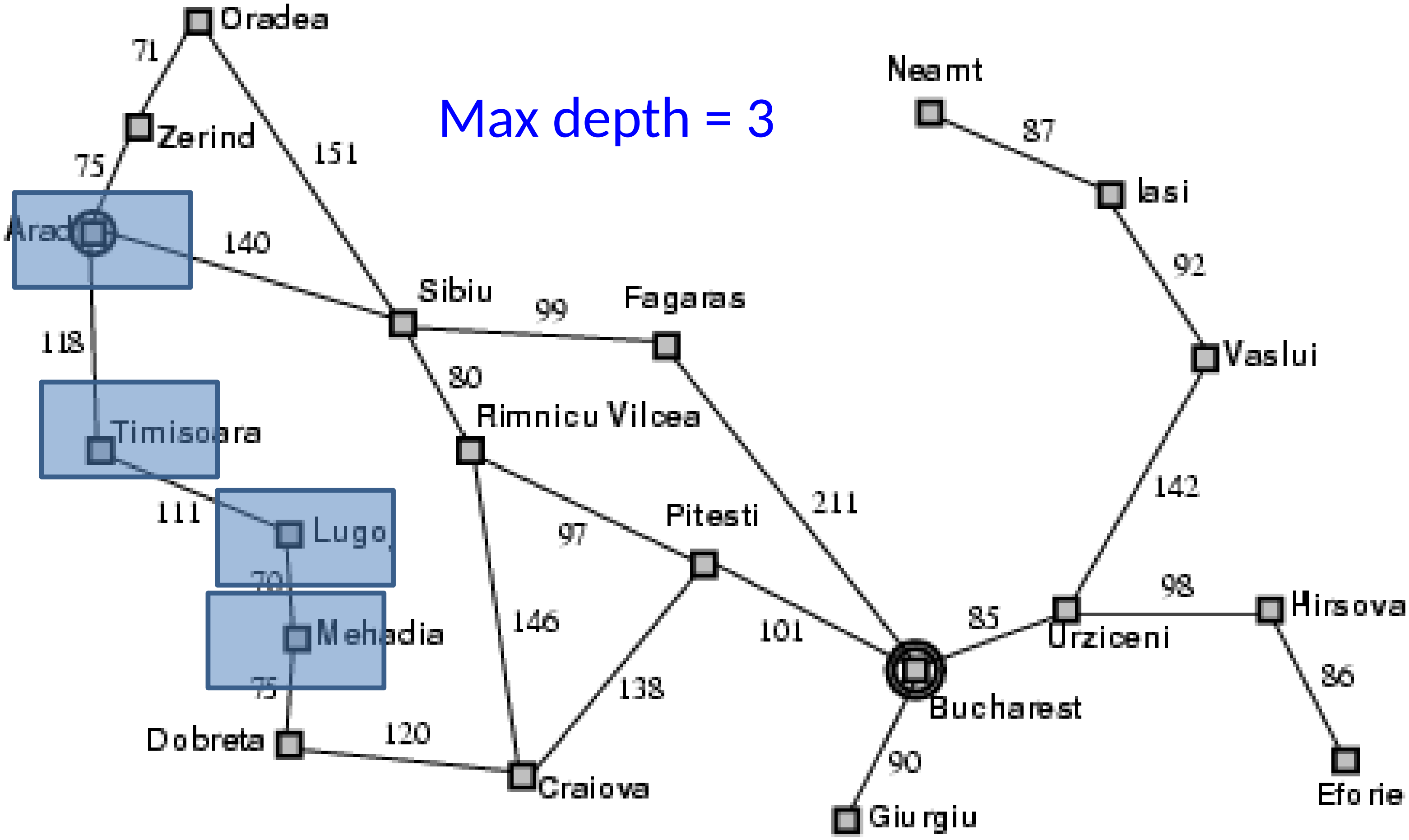

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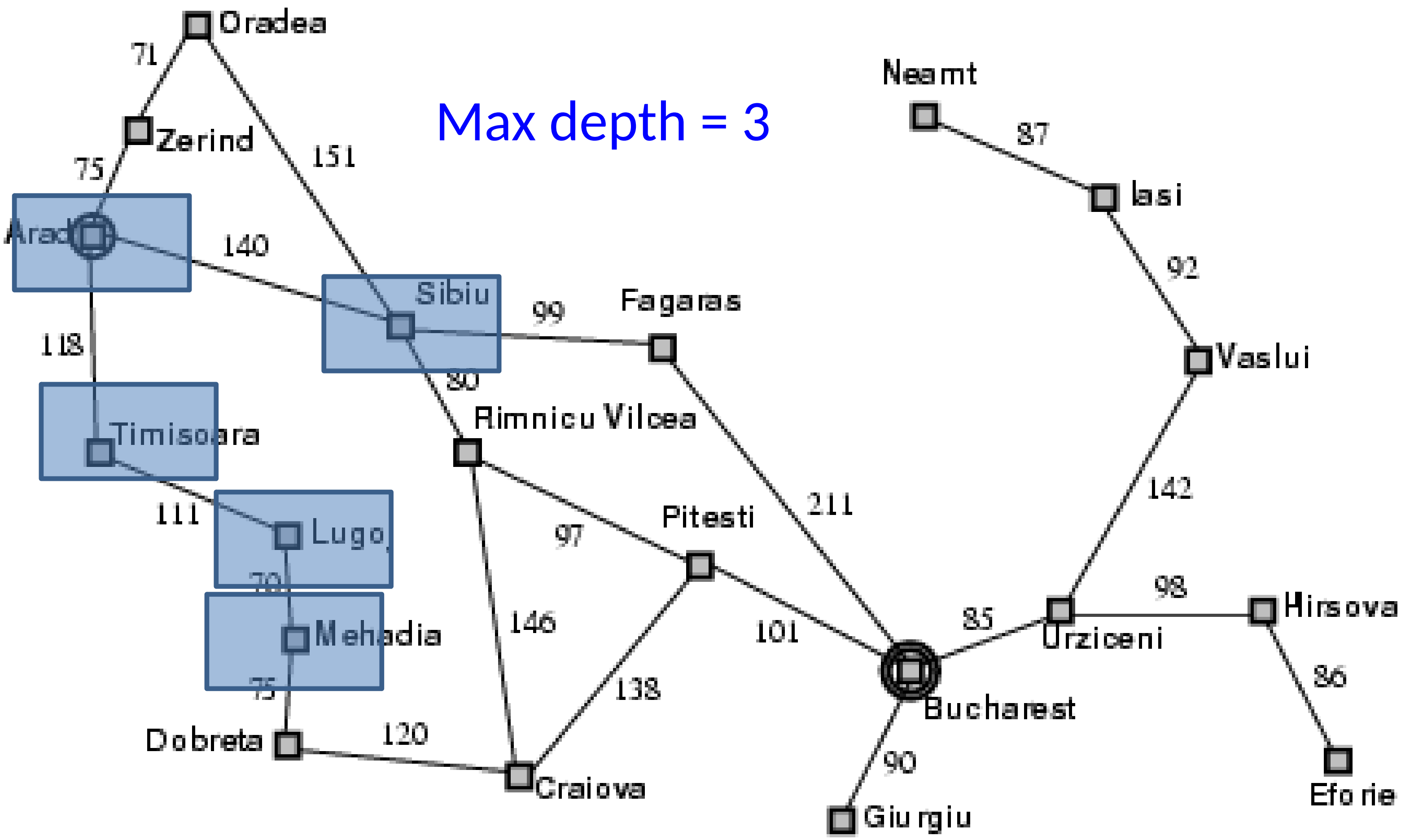

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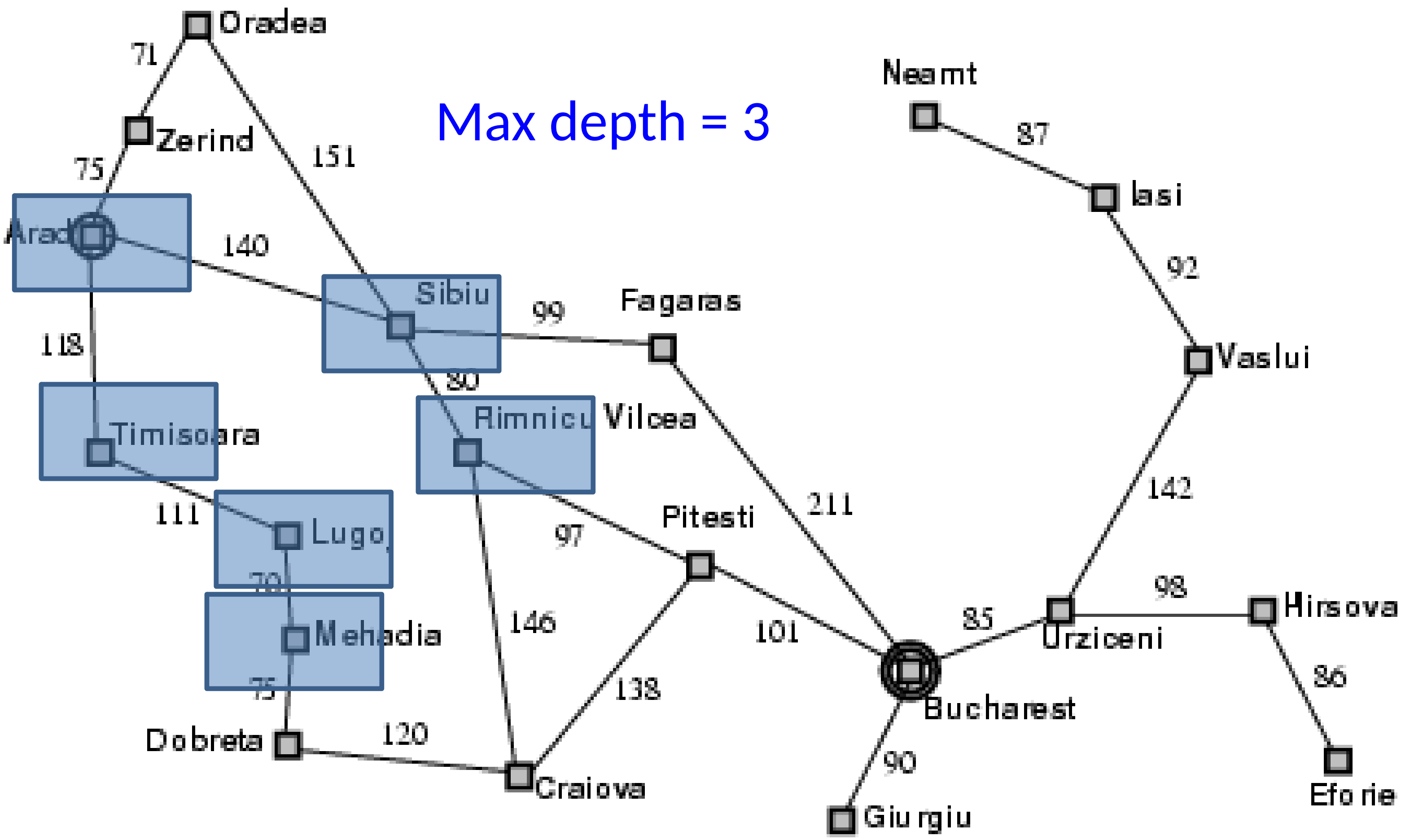

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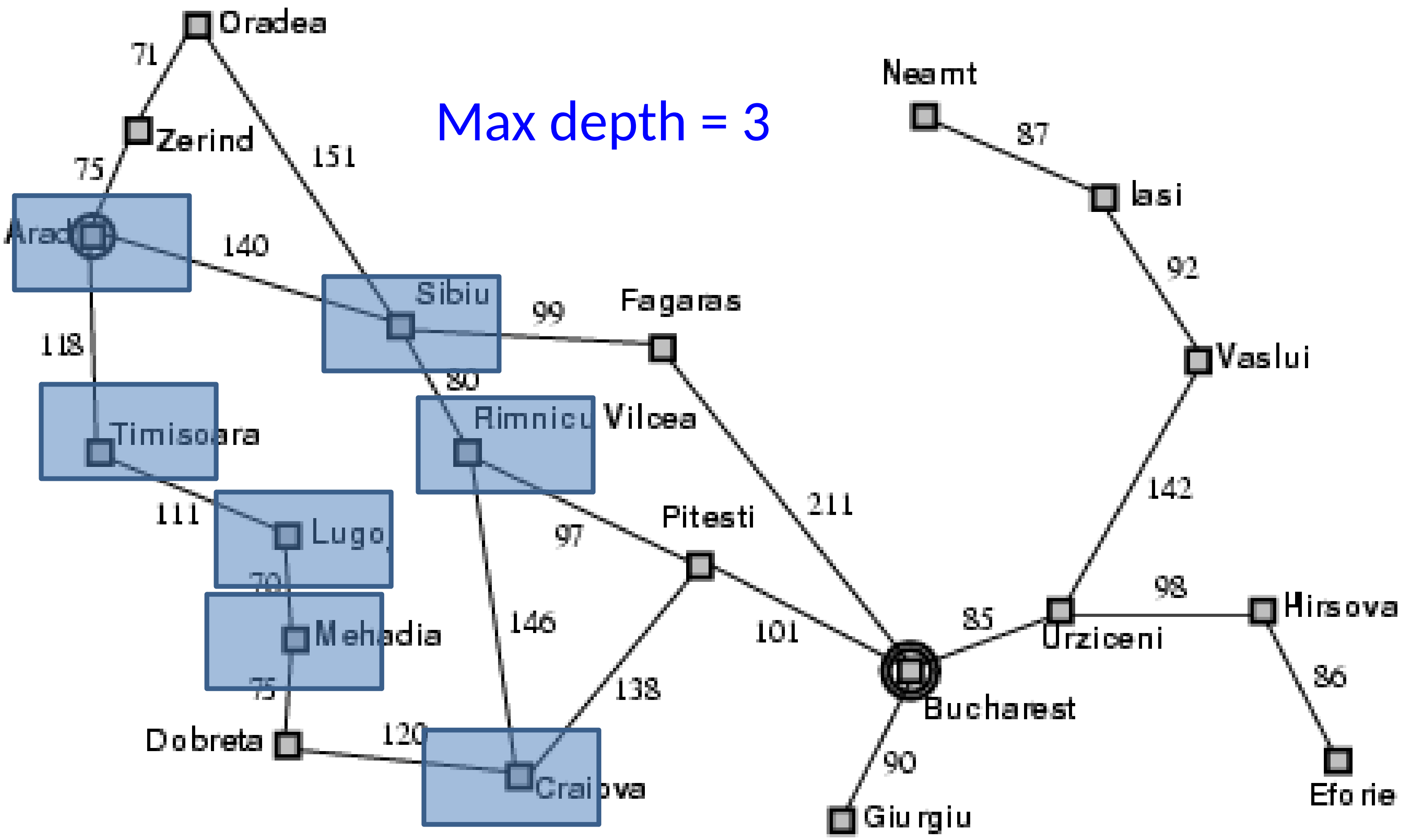

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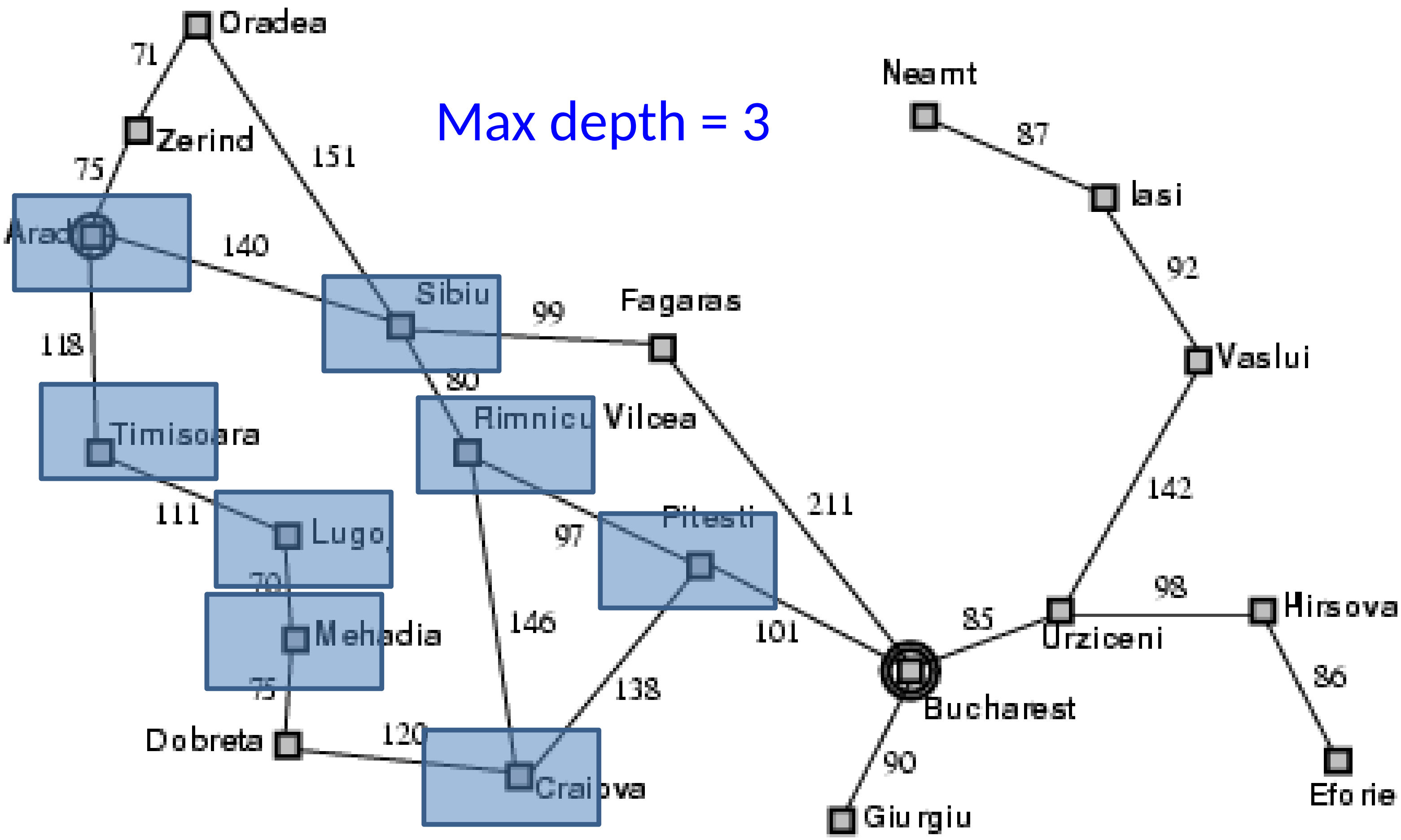

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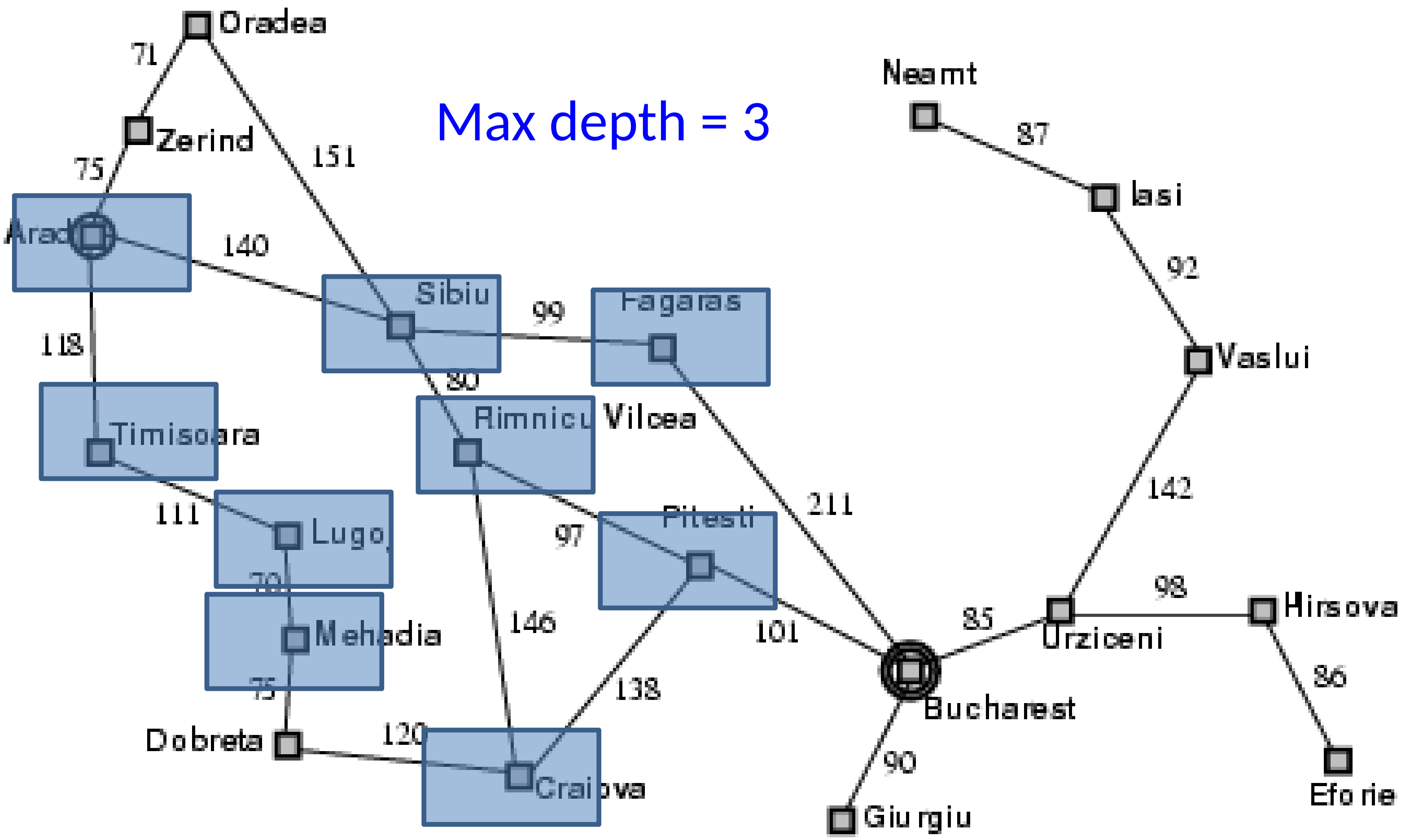

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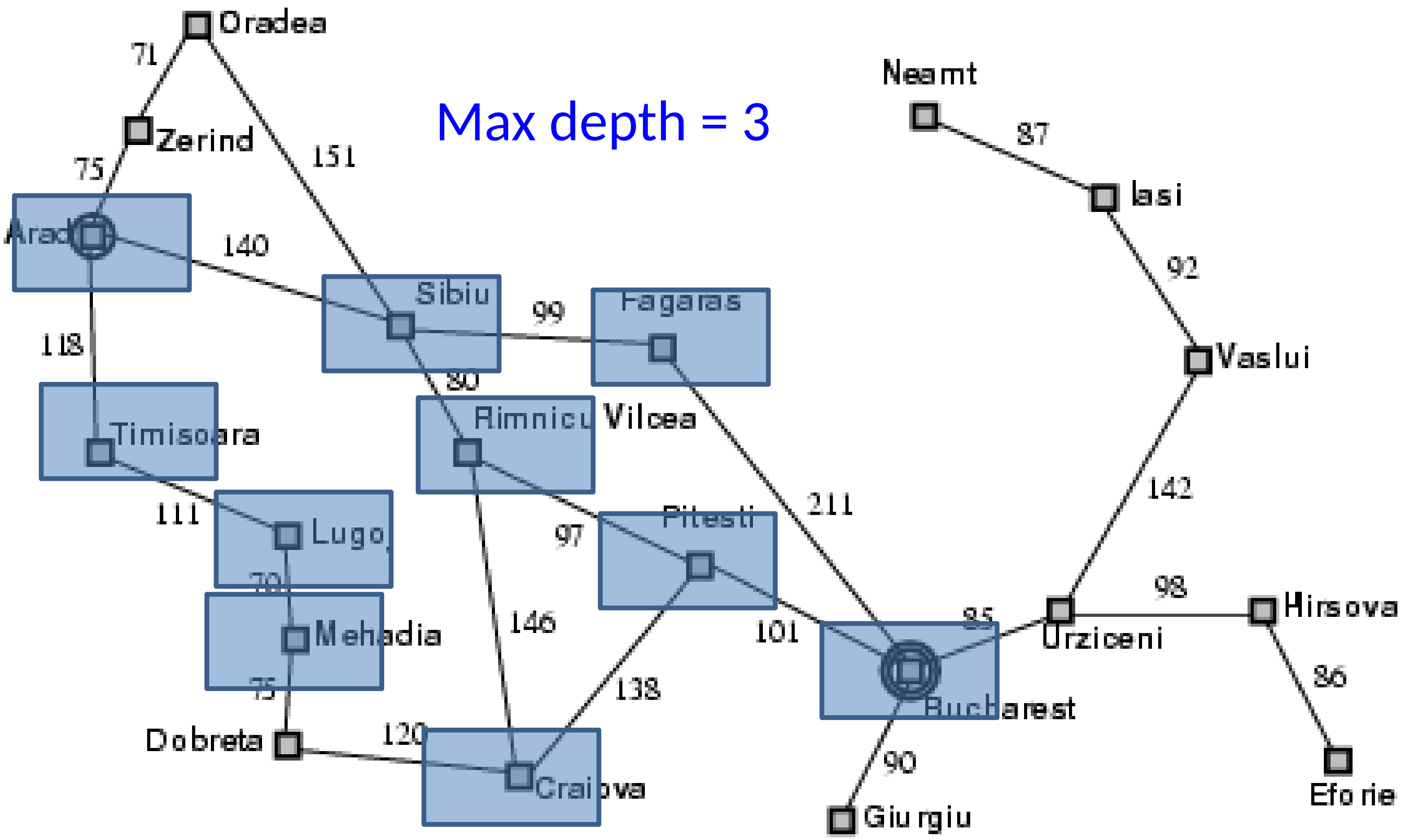

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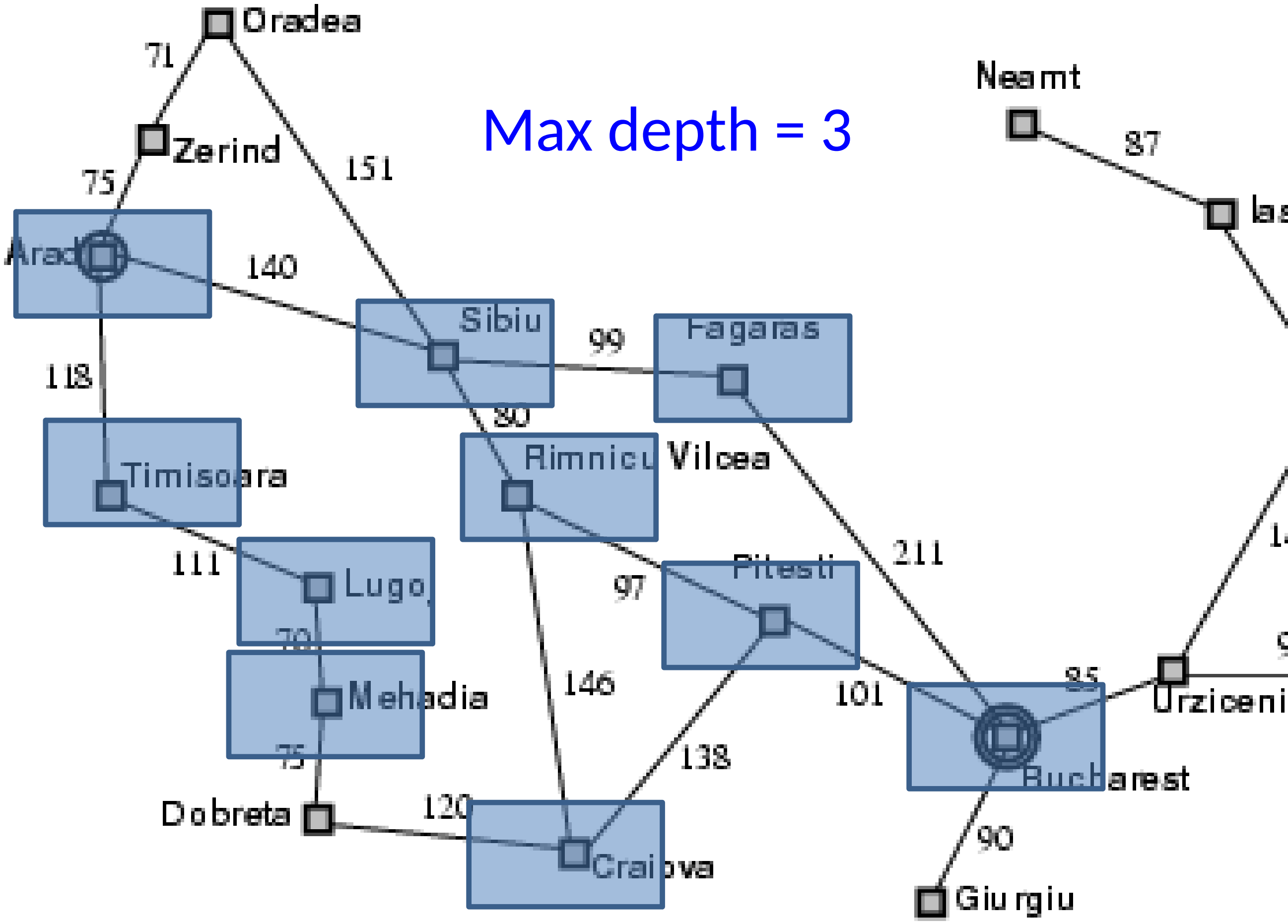


Max depth = 3

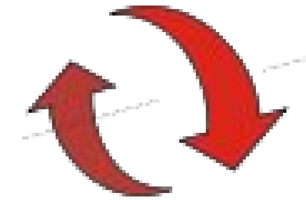
Can't find Eforie with Max depth = 3;
Max depth = 9 would find all cities, but use some bad routes

Depth Limited Search

- Will always terminate.
- Will find solution if there is one in the depth bound.

- But, Goldilocks principle:
  - Too small a depth bound misses solutions ('incomplete')
  - Too large a depth bound may find poor solutions when there are better ones.

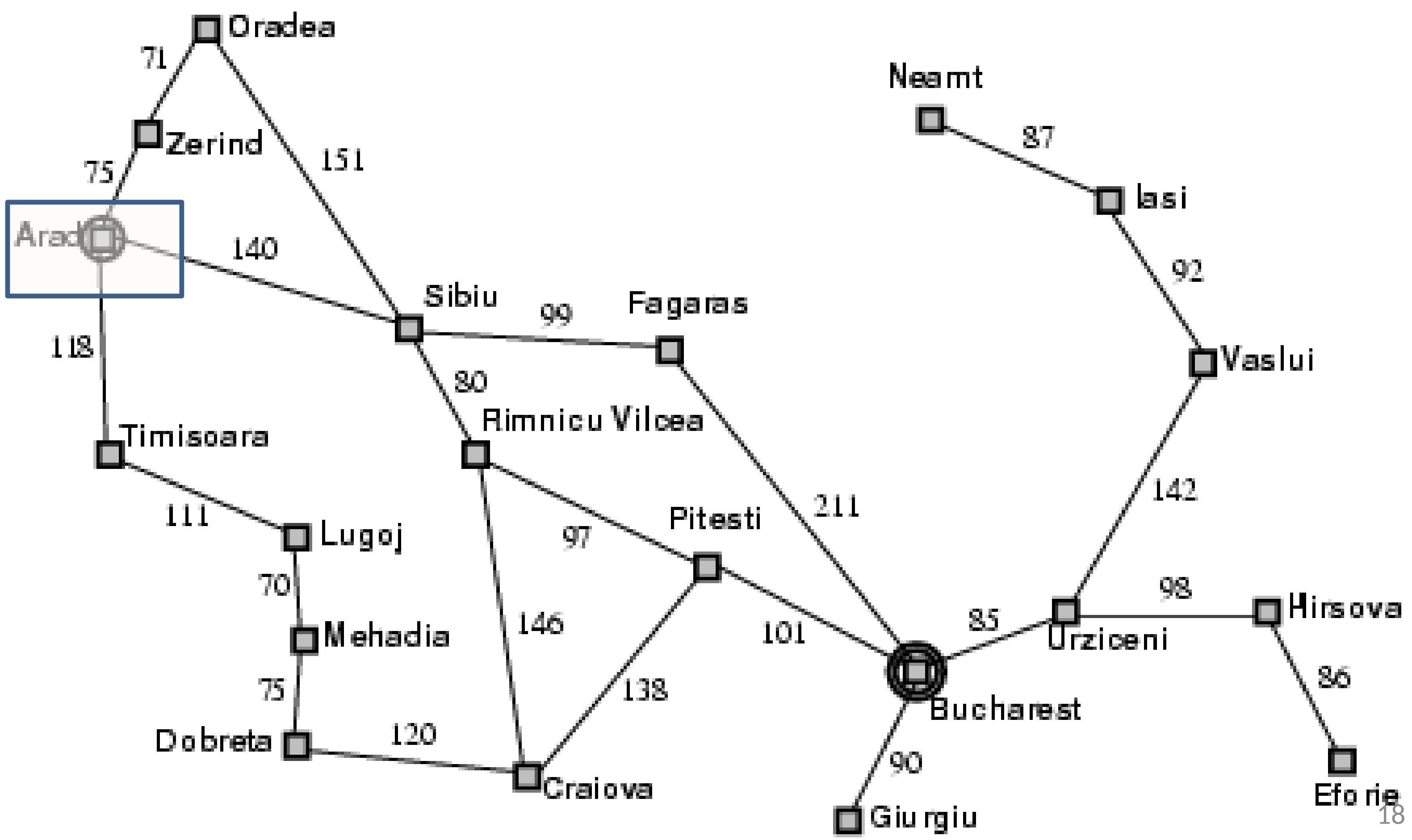
Iterative Deepening



- Iterative deepening
  - addresses problem of choosing depth bound
  - is complete and finds best solution.
- Basic idea is:
  - do d.l.s. for depth $n = 0$; if solution found, return it;
  - otherwise do d.l.s. for depth $n = n + 1$; if solution found, return it, etc;
  - So we repeat d.l.s. for all depths until solution found.
- Useful if the search space is large and the maximum depth of the solution is not known.

Example: Romania Problem

D =1



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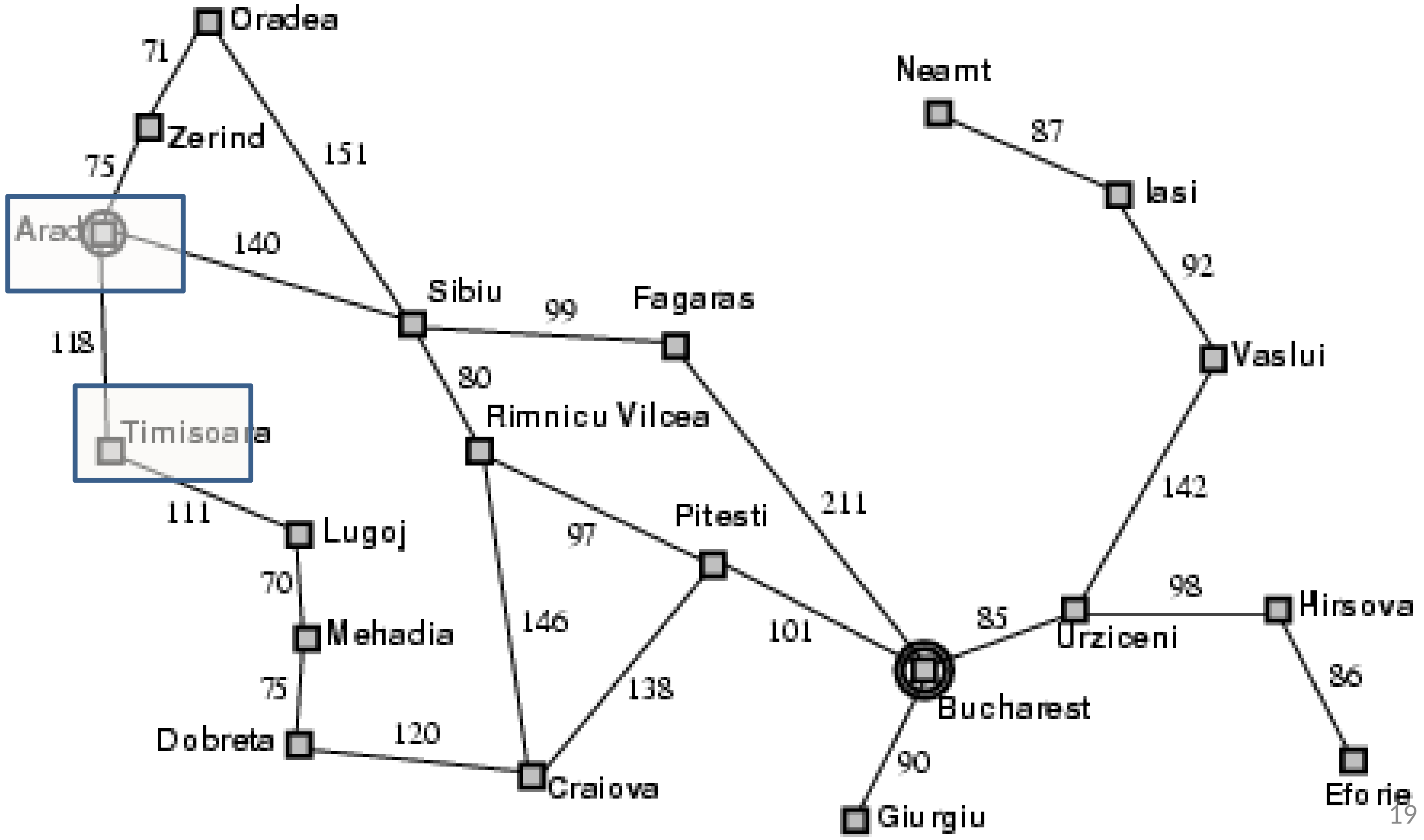

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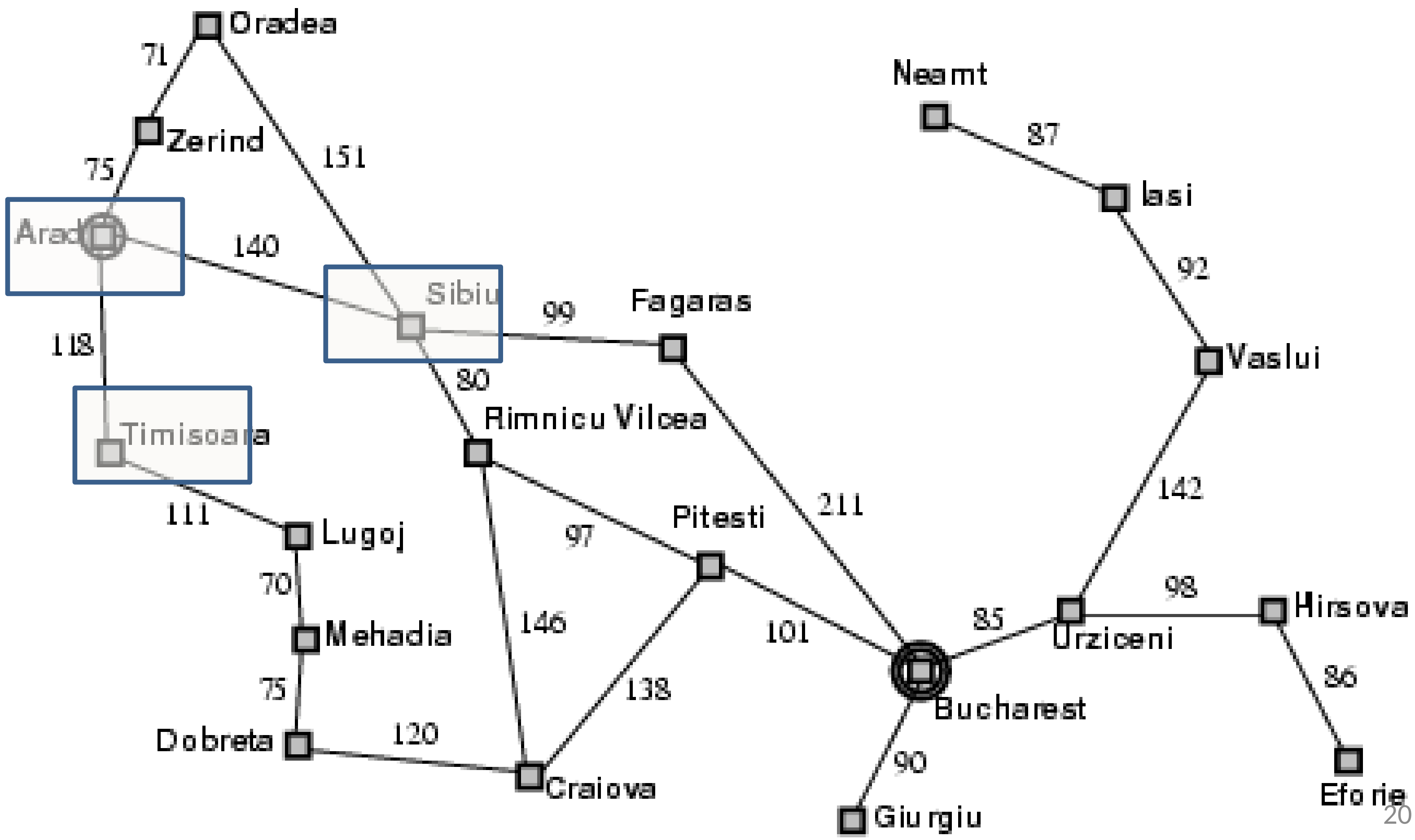

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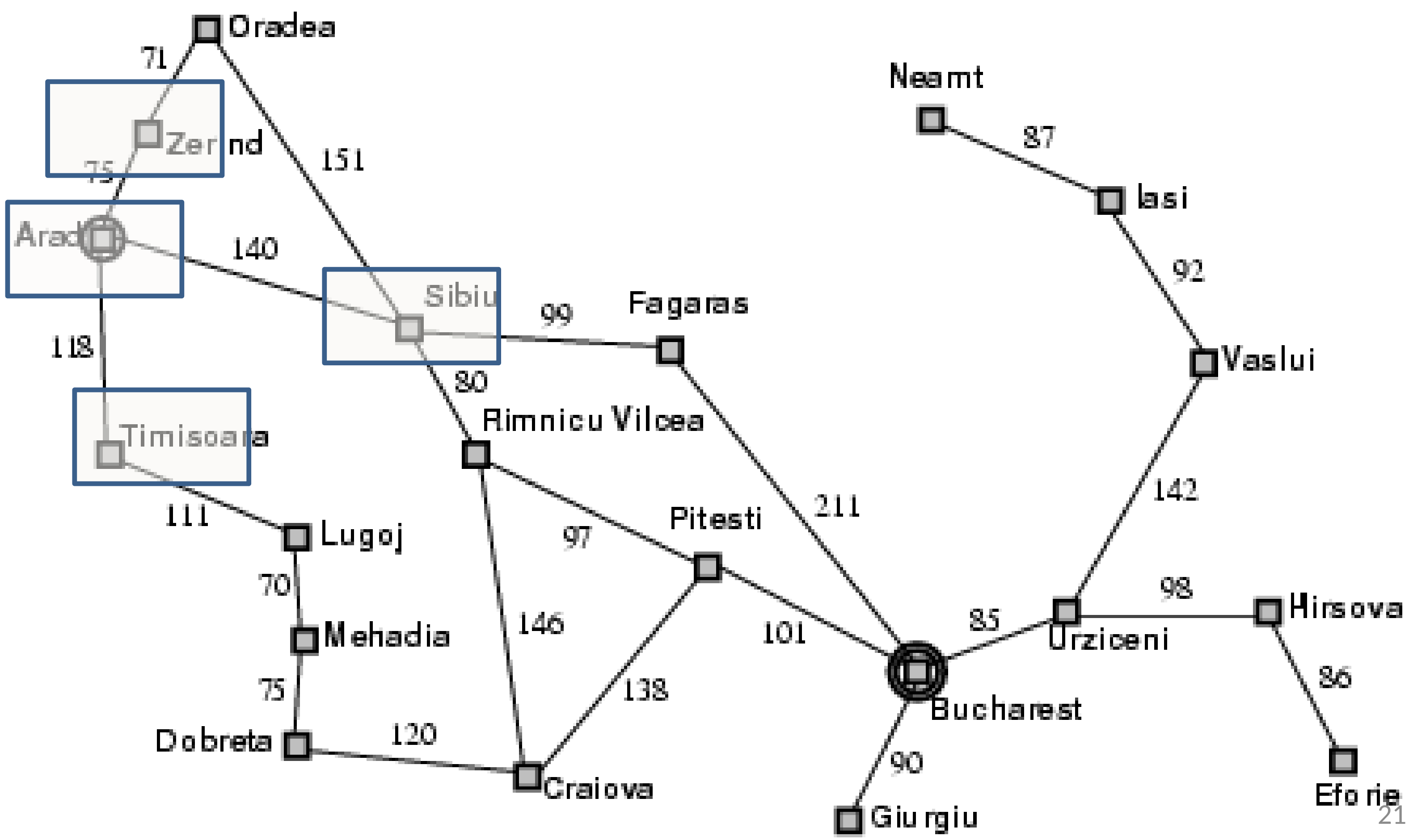
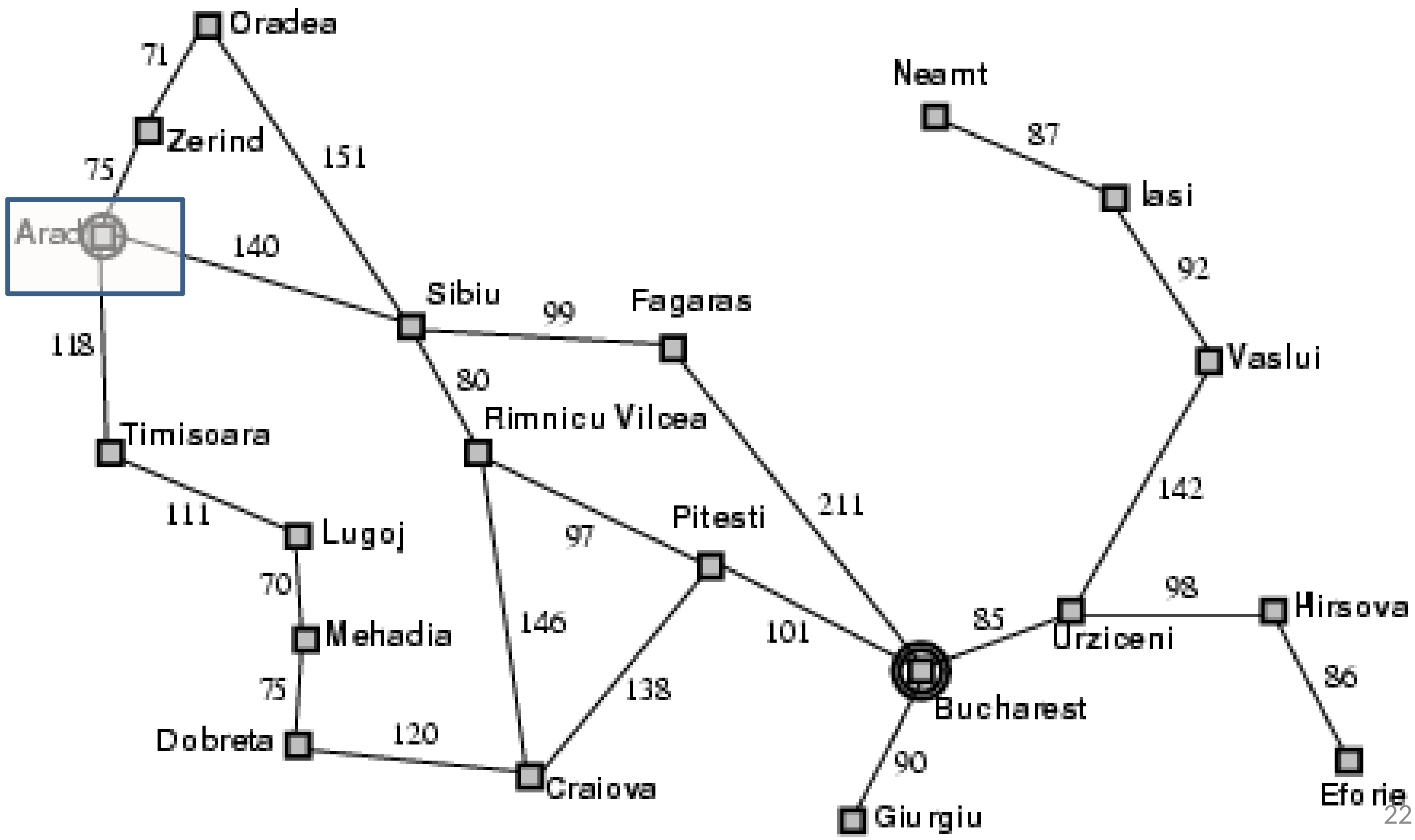


Example: Romania Problem

D =1

D =2



Example: Romania Problem

D =1

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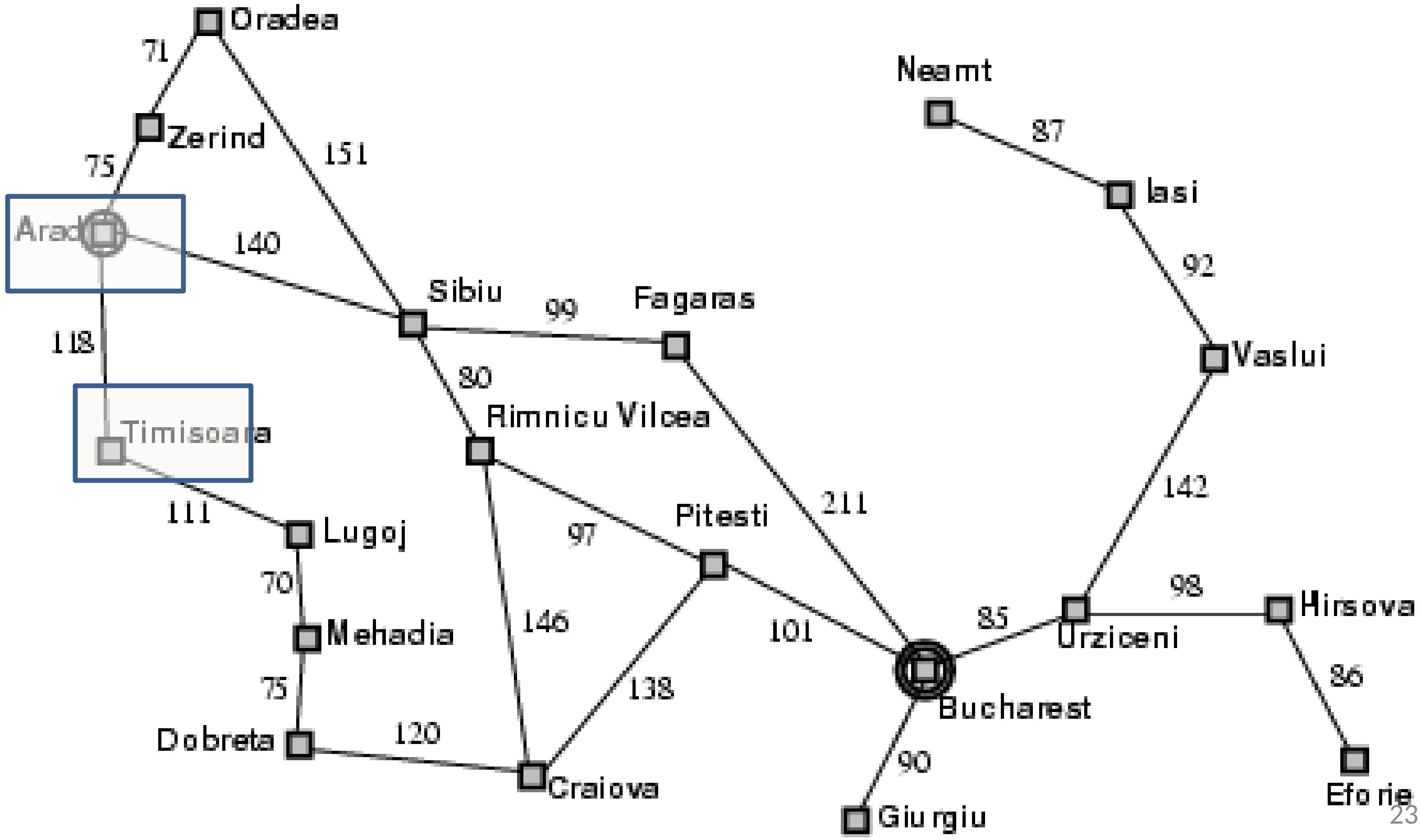
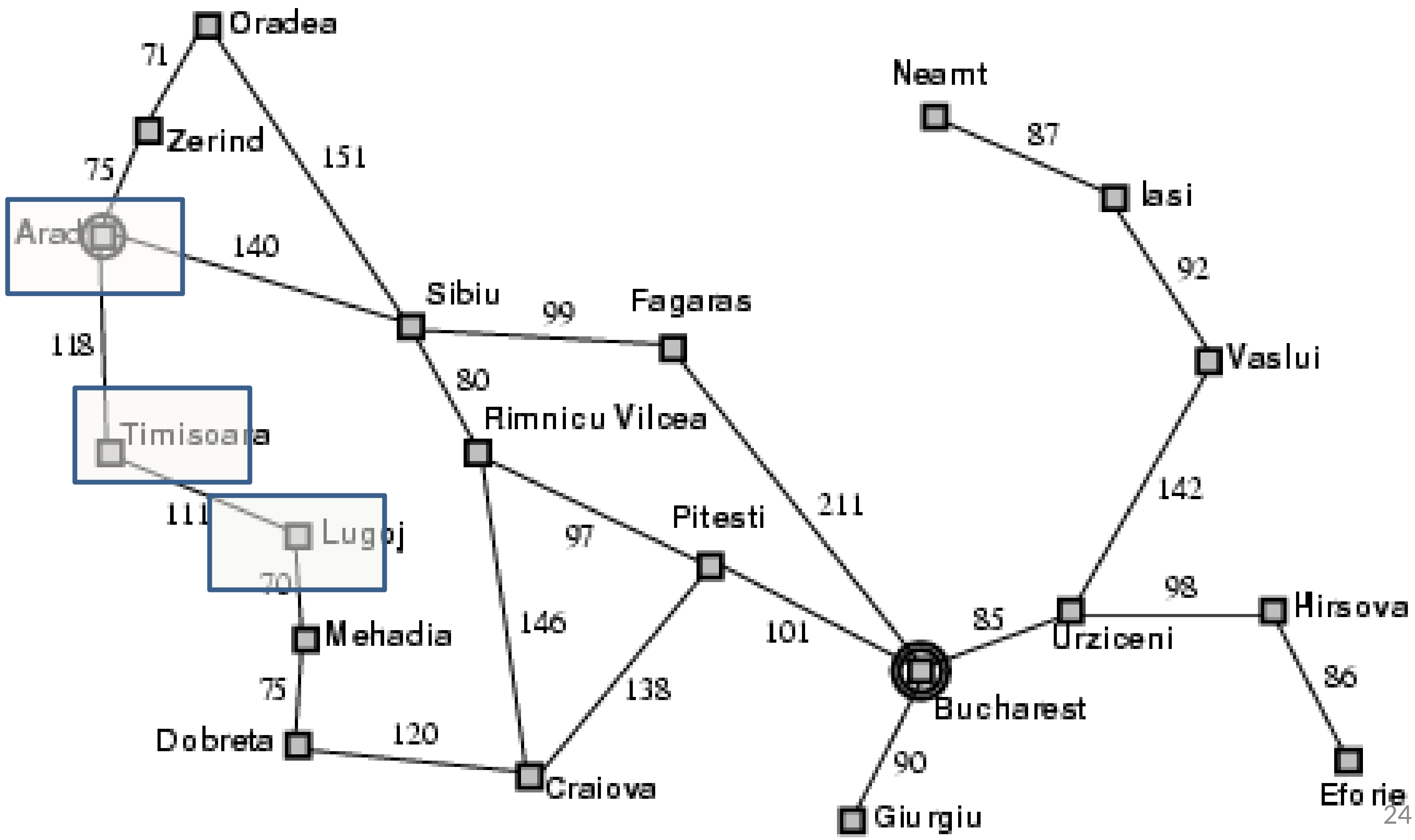


Example: Romania Problem

D =1 D =2



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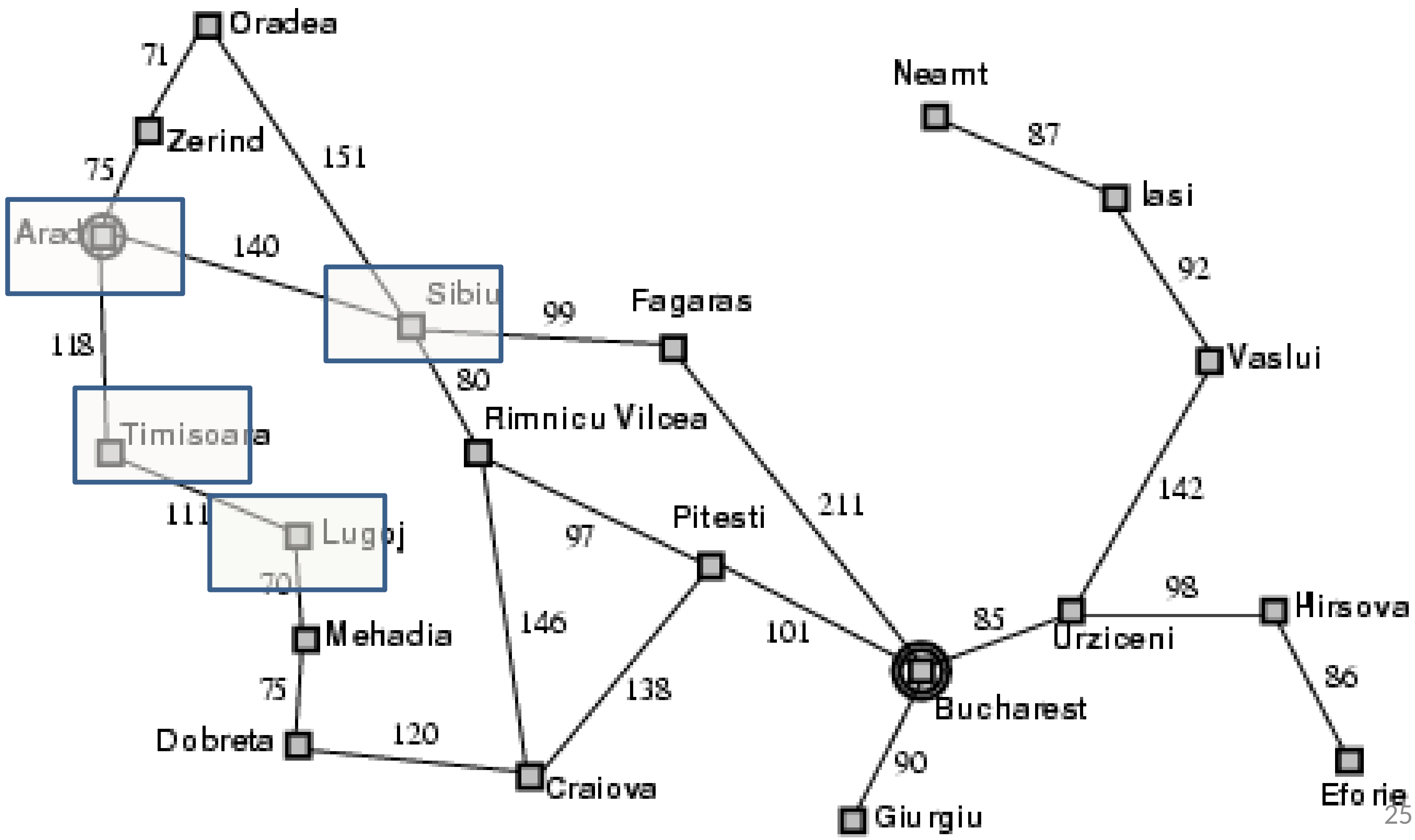
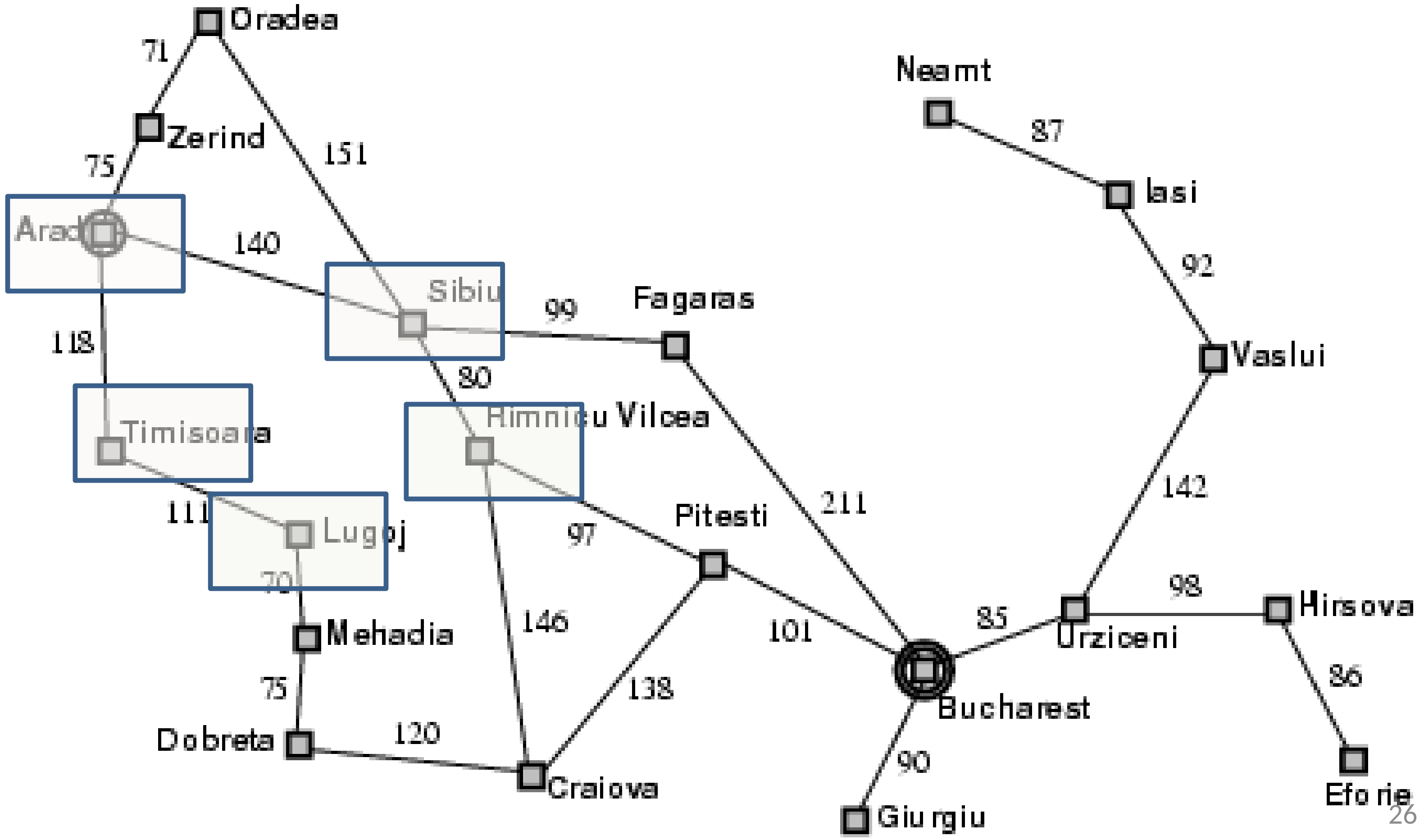


Example: Romania Problem

D =1   D =2



Example: Romania Problem

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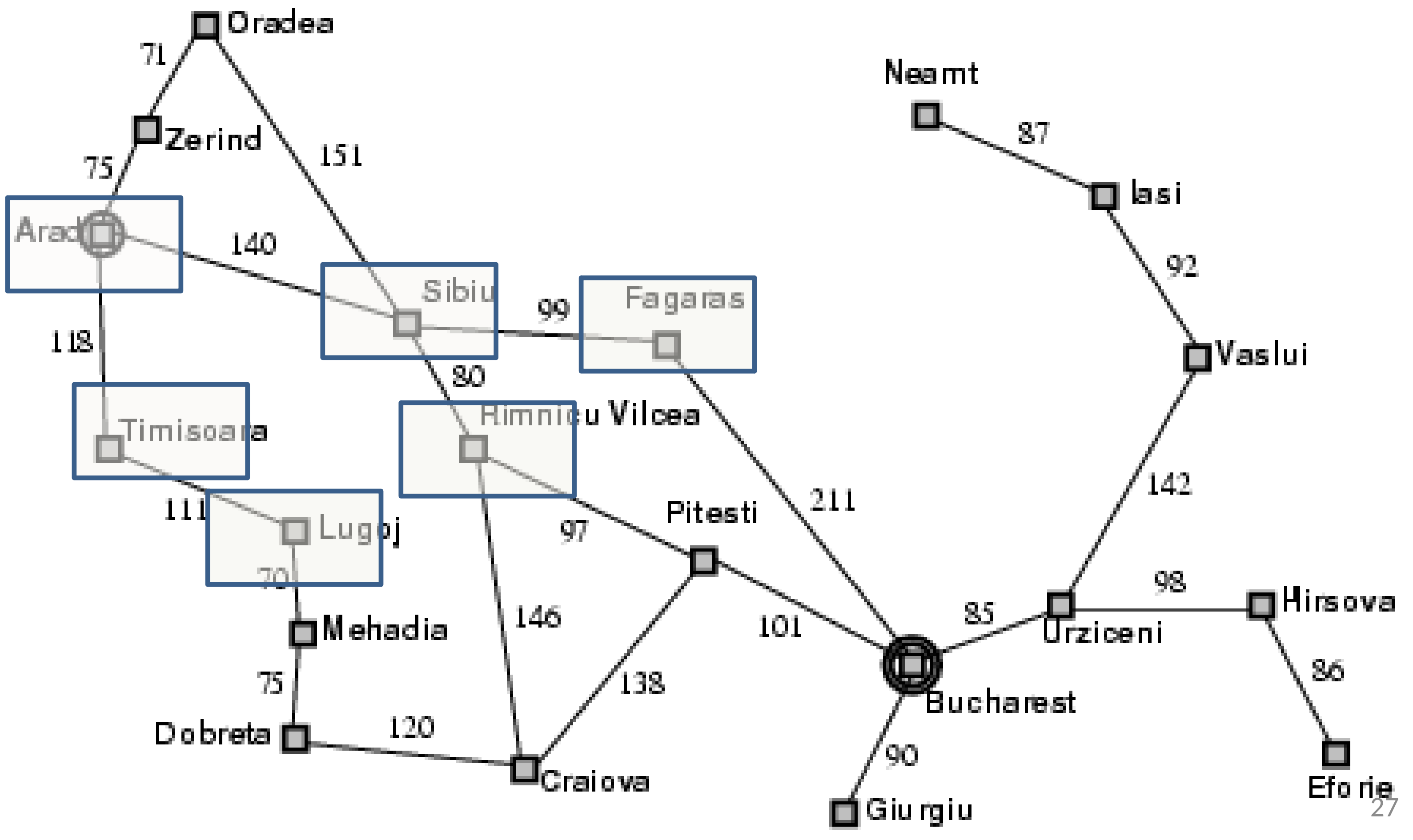
D =2



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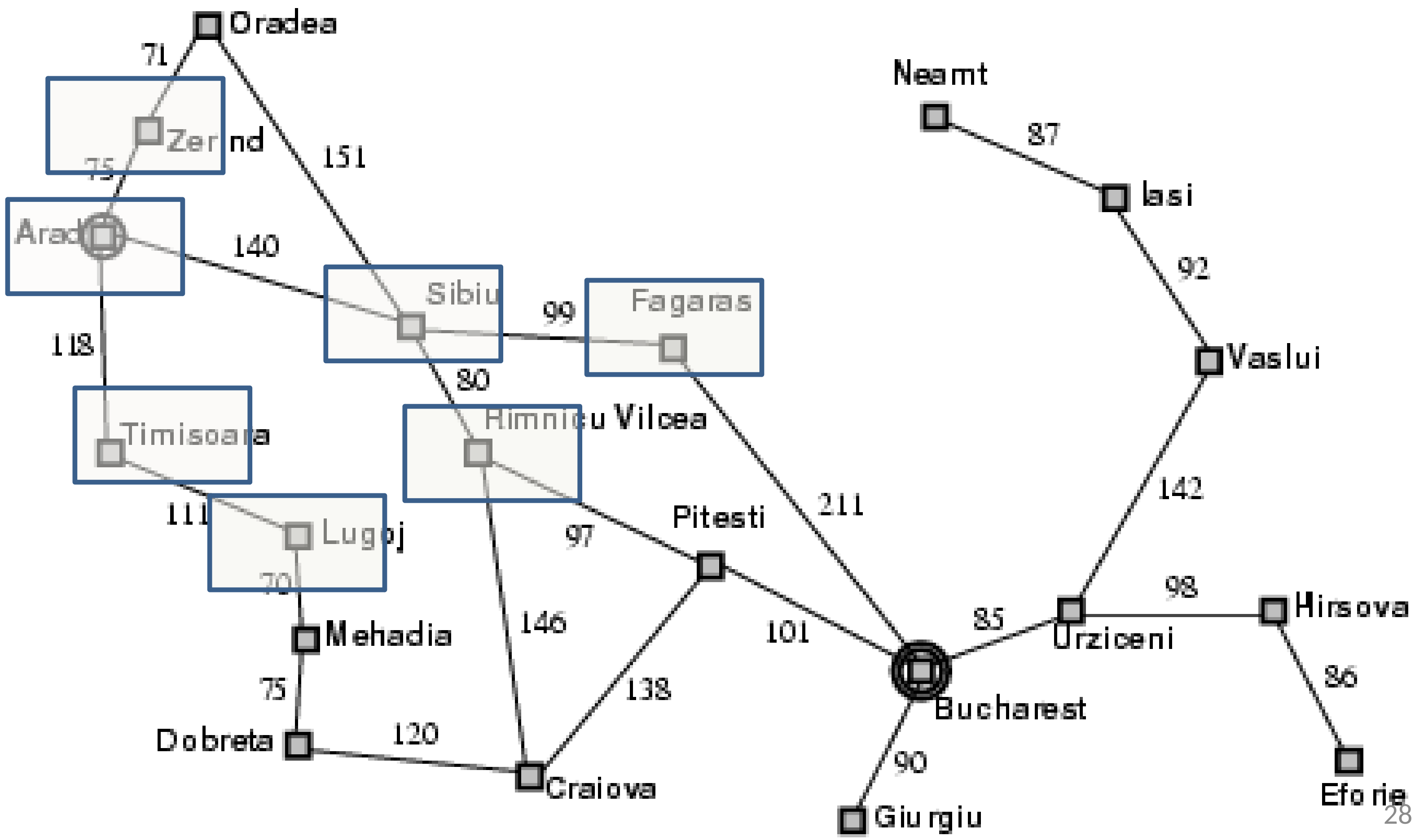

Example: Romania Problem

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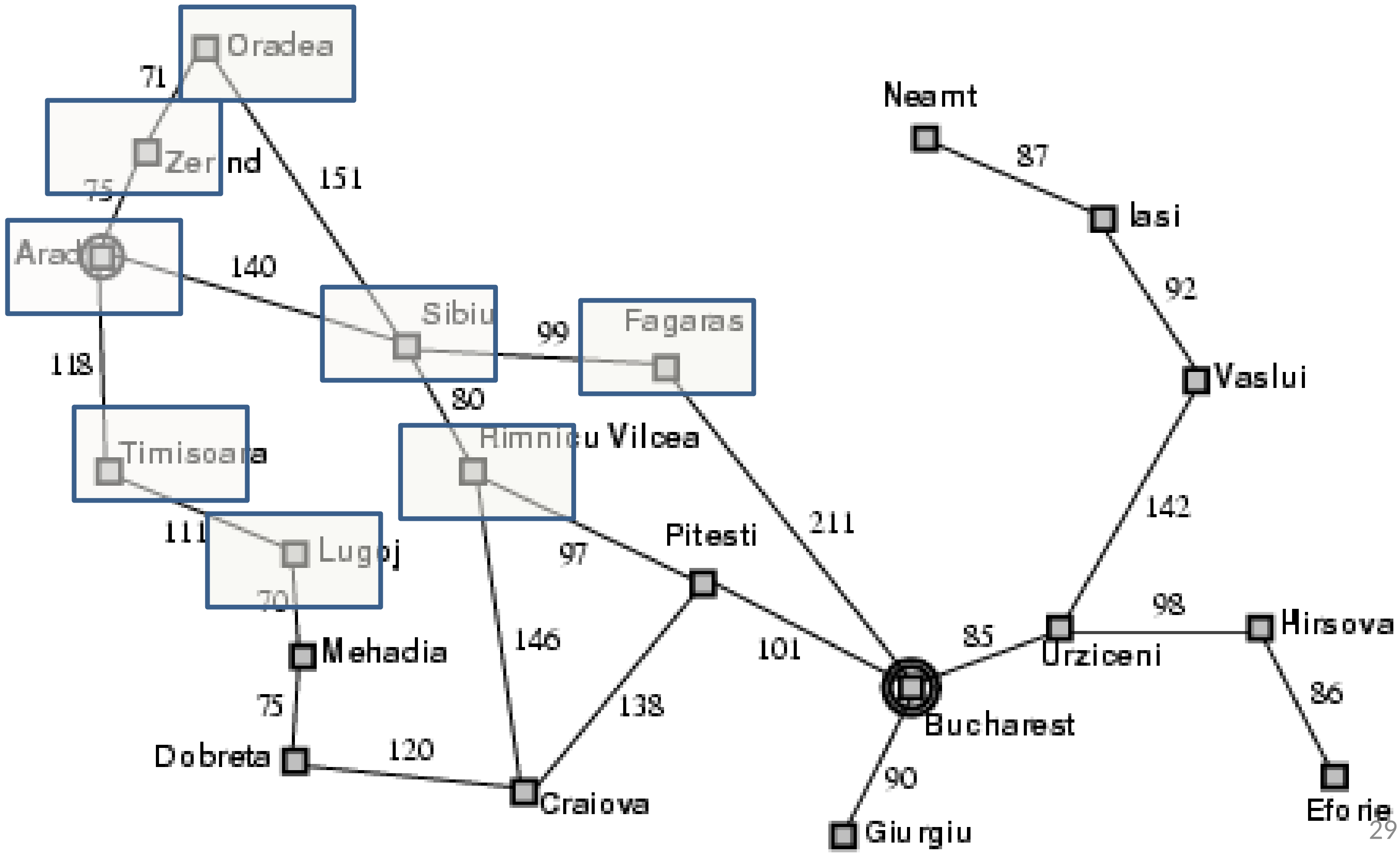
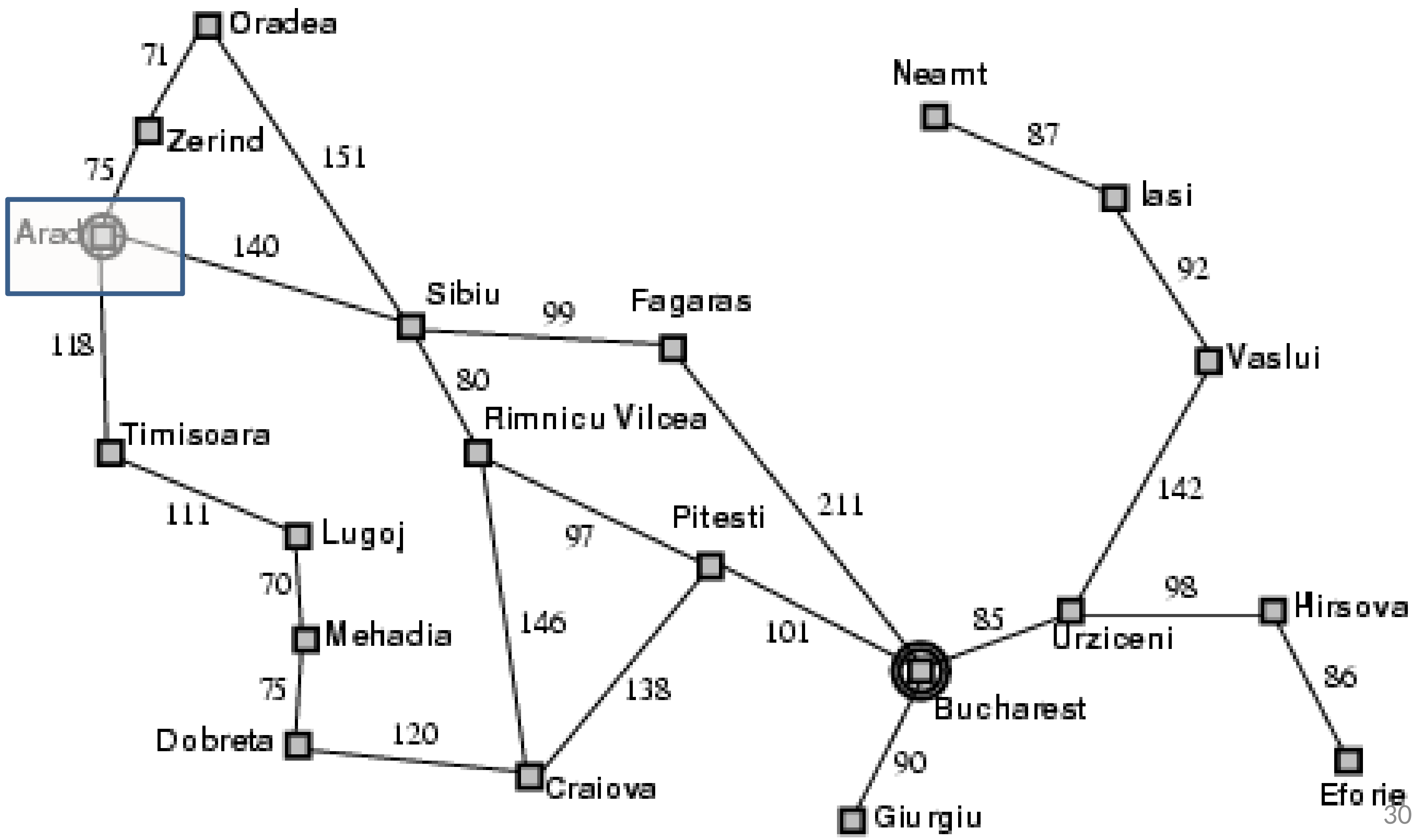
D =2



Example: Romania Problem

D =1 D =2 D =3

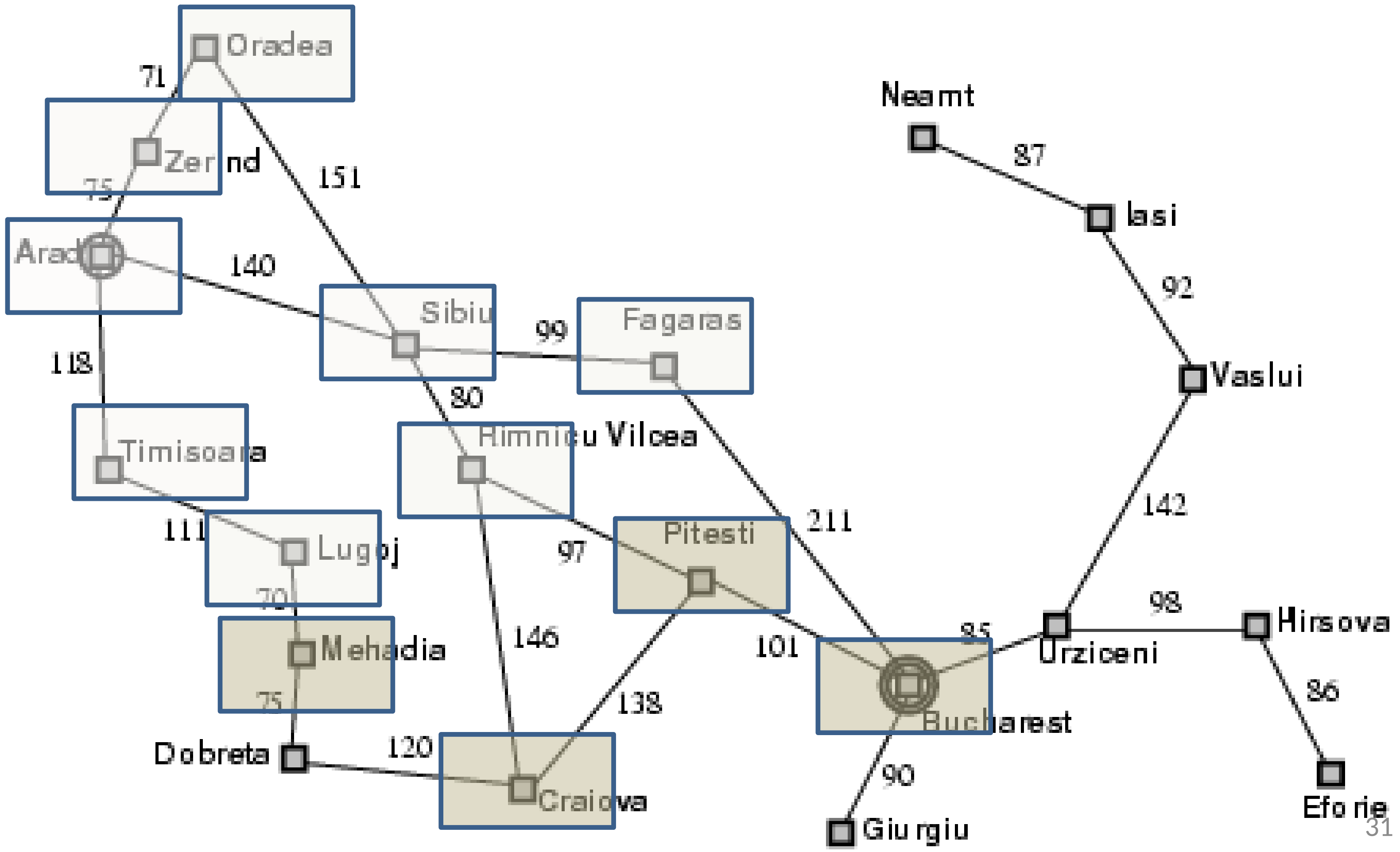


Example: Romania Problem

D =1

D =2

D =3



General Algorithm for Iterative Deepening

```
depth_limit = 0;
while(true)              /* infinite loop */
{
  result = depth_limited_search(
                  max_depth = depth limit,
                  agenda = initial node);
  if result contains goal then
     return result;
  depth limit = depth limit + 1;
}
```

- Calls d.l.s. as subroutine.

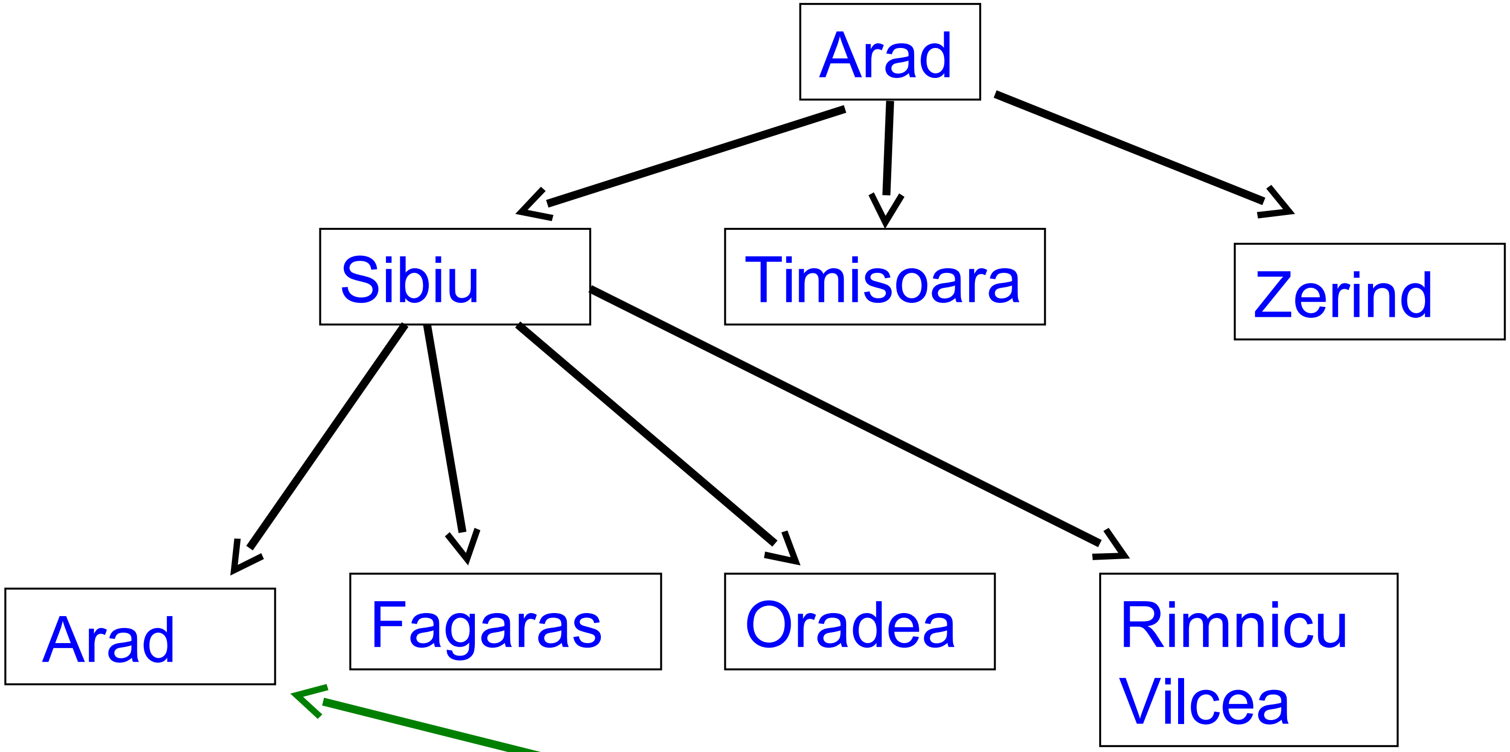
IDS Properties

- Note that in iterative deepening, we re-generate nodes *on the fly*.
- Each time we do a call on depth limited search for depth d, we need to regenerate the tree to depth $d - 1$.
- Trade off time for memory.

- In general we might take a little more time, but we save a lot of memory.
  - Example: Suppose $b = 10$ and $d = 5$.
  - Breadth first search would require examining 111,110 nodes, with memory requirement of 100,000 nodes.
  - Iterative deepening for same problem: 123,450 nodes to be searched, with memory requirement of only 50 nodes.
  - Takes 11% longer in this case, but savings on memory are immense.

Techniques for Speeding Up

Repeated States – The Search Tree



Blind search may ***repeat*** nodes; if the search path contains cycles we may get into an infinite loop when doing depth first search

Avoiding Repeated States

- There are three ways to deal with this (in order of increasing effectiveness and computational overhead):
  - do not return to the state you have just come from
  - do not create paths with cycles in them
  - do not generate any state that was ever generated before
- Note there is a trade-off between the cost of extra search and the cost of checking for repeated states

The Impact of Branching

- In analyses branching is often assumed to be uniform
- But in practice this is often not so
- This can make a big difference to the search space

Goal vs Data driven search

- We can choose to search from
  - the initial state to the goal (data driven, forward)
  - the goal to the initial state (goal driven, backward)

- The branching may be very different...
- Goal driven search is very often very much more efficient (few paths reach the goal)
- Often used in expert systems (and Prolog)

Example – Blocks World

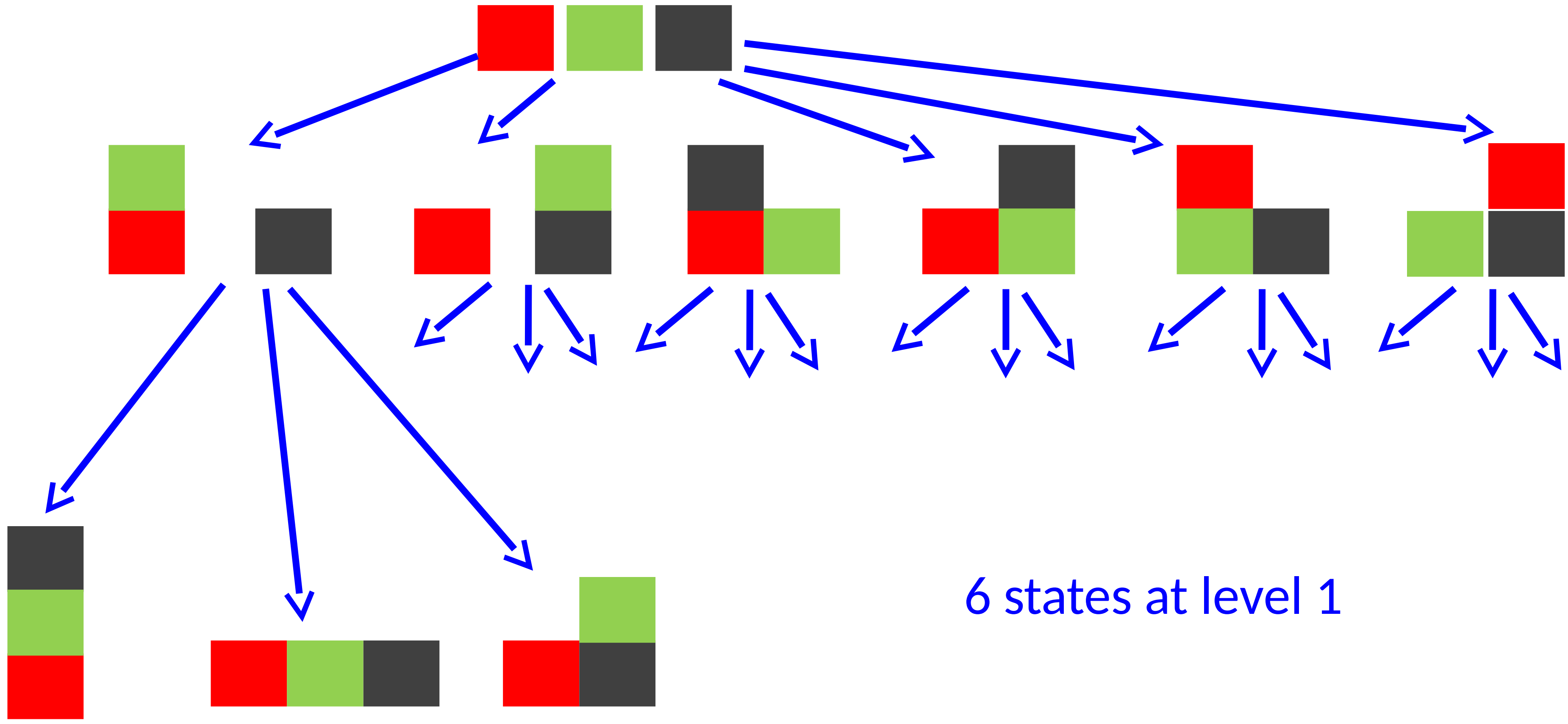
- Consider the blocks world:

  Blocks are laid out on a table and a robot can move any ***clear*** block to another ***clear*** block. Suppose the initial state and goal state are as follows:

Initial

Goal

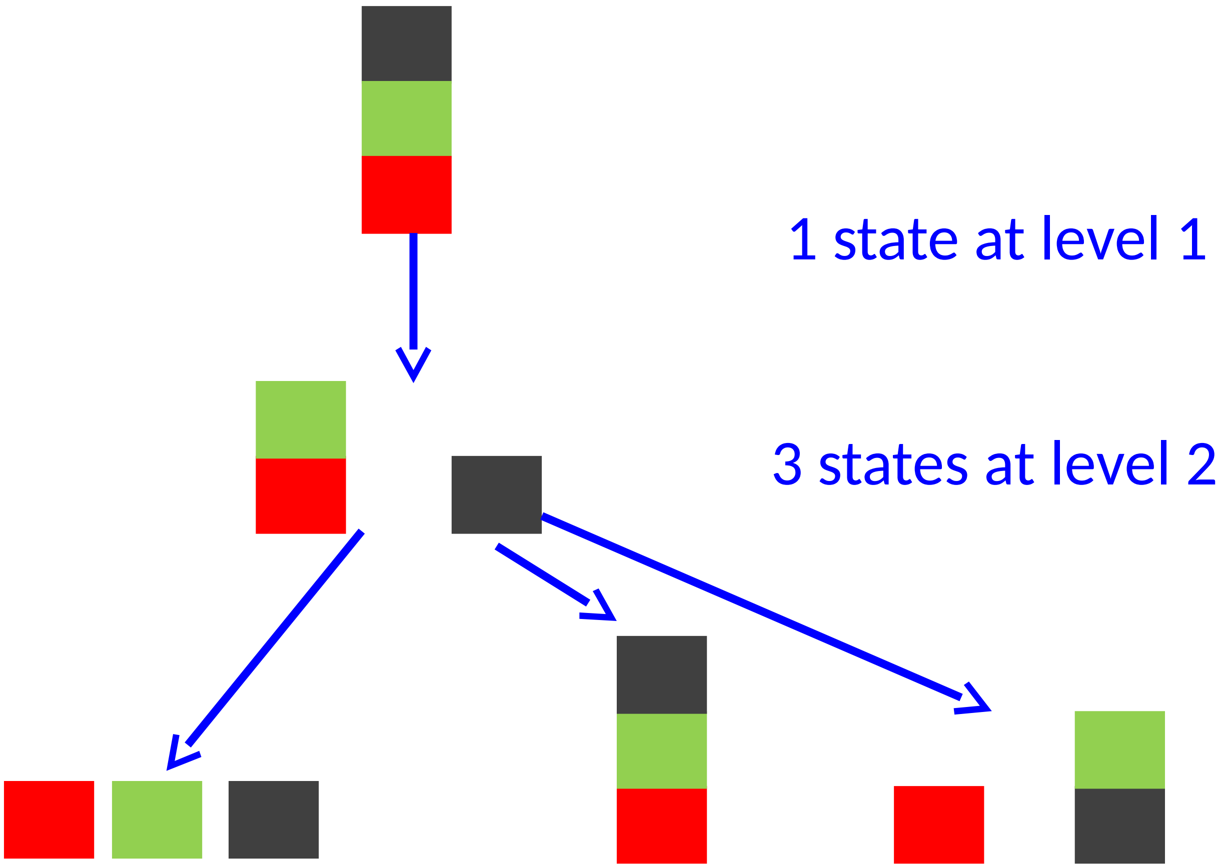
Forward Search Space: Initial → Goal



6 states at level 1

18 states at level 2

Backward Search Space: Goal → Initial



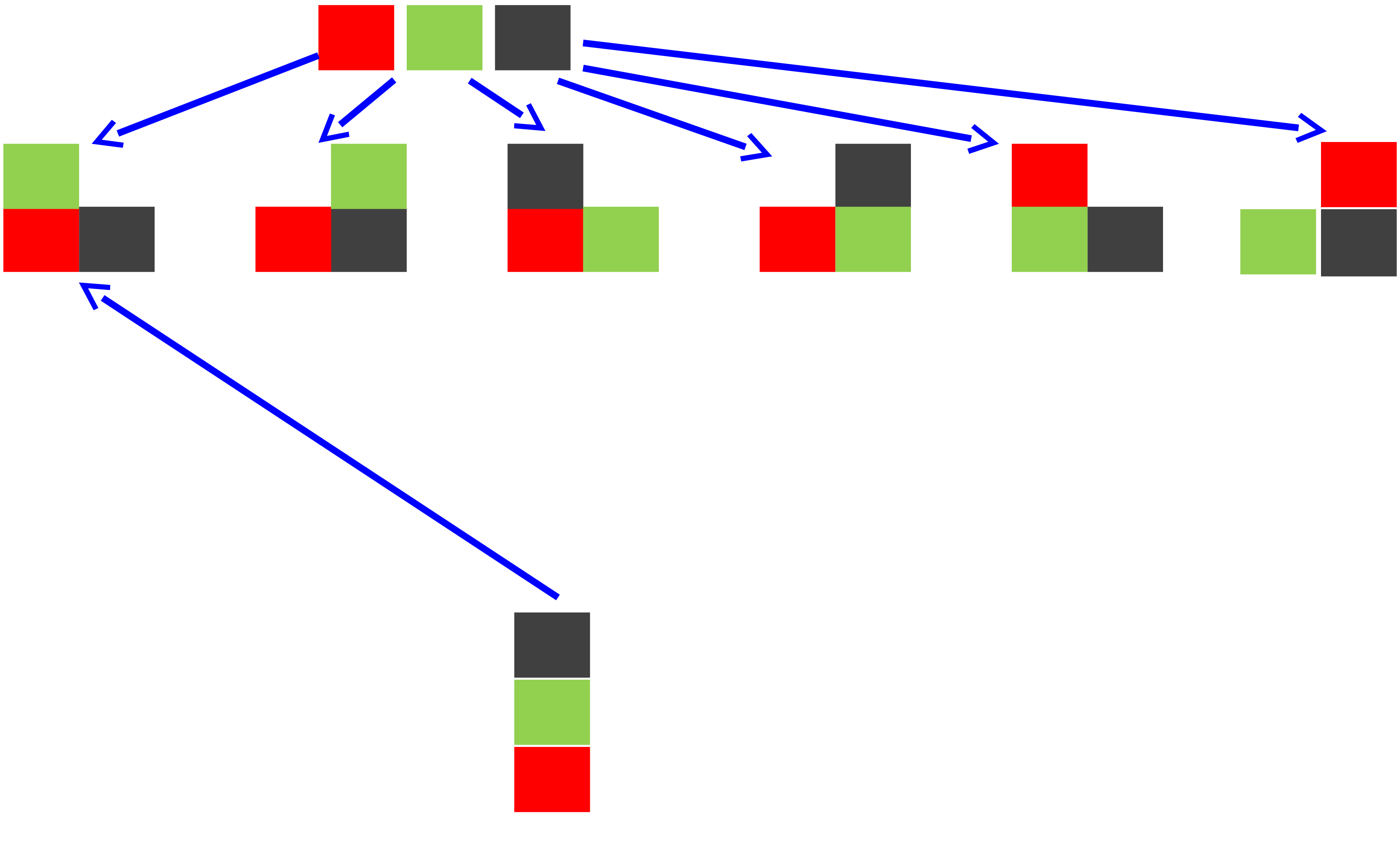
About Backward Search

- Backward (goal driven) search can be more effective…
  …but may not always be applicable!
- need to be able to
  - generate predecessors
    (can be difficult, there could be many)
  - effectively describe the goal
    ("no queen attacks another queen"…?)

Bi-directional Search

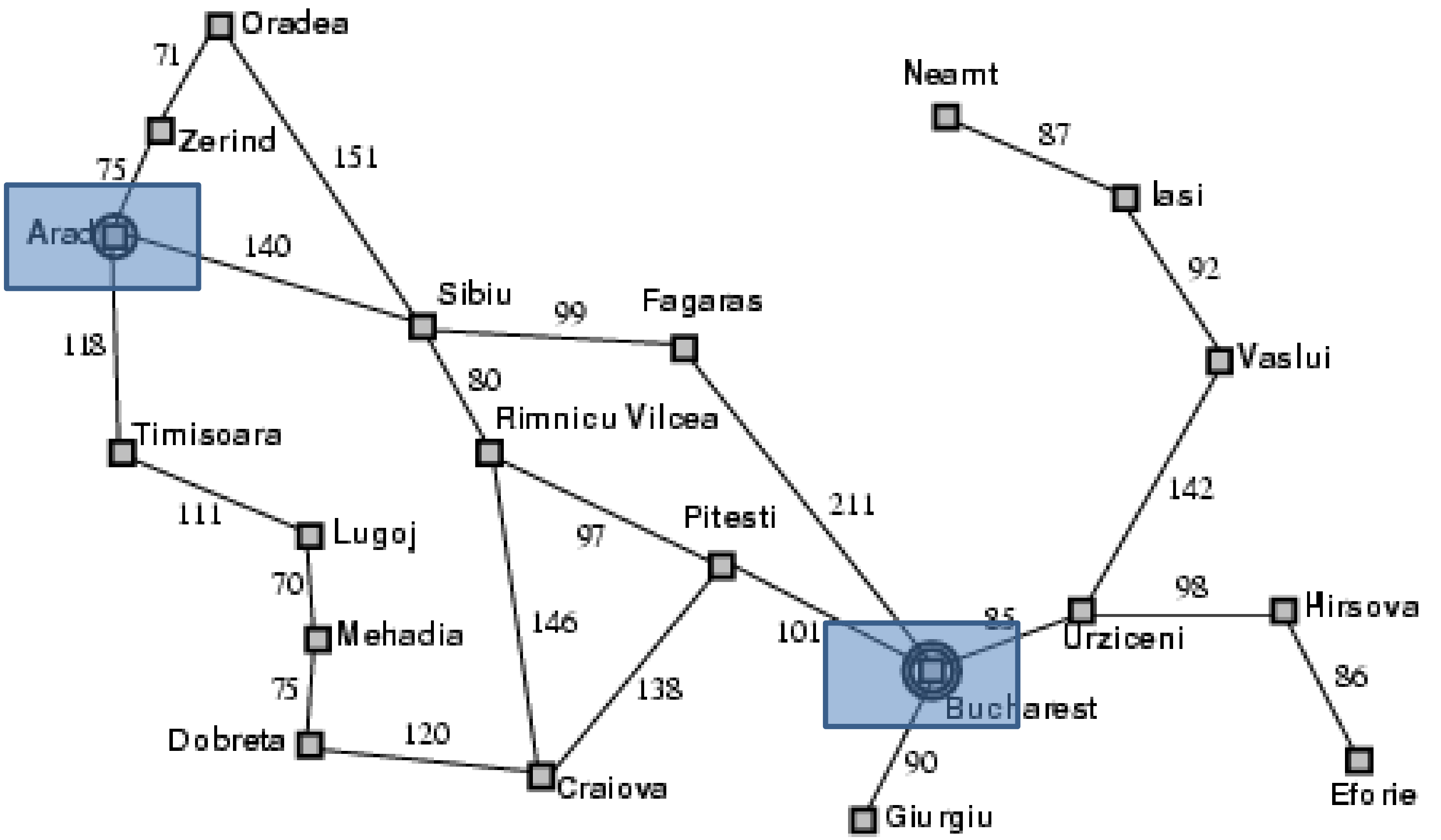
- If we are unsure of the branching factor, then searching from both ends may be best

Bidirectional Search



Example: Romania

- On holiday in Romania; currently in Arad
- Flight leaves tomorrow from Bucharest



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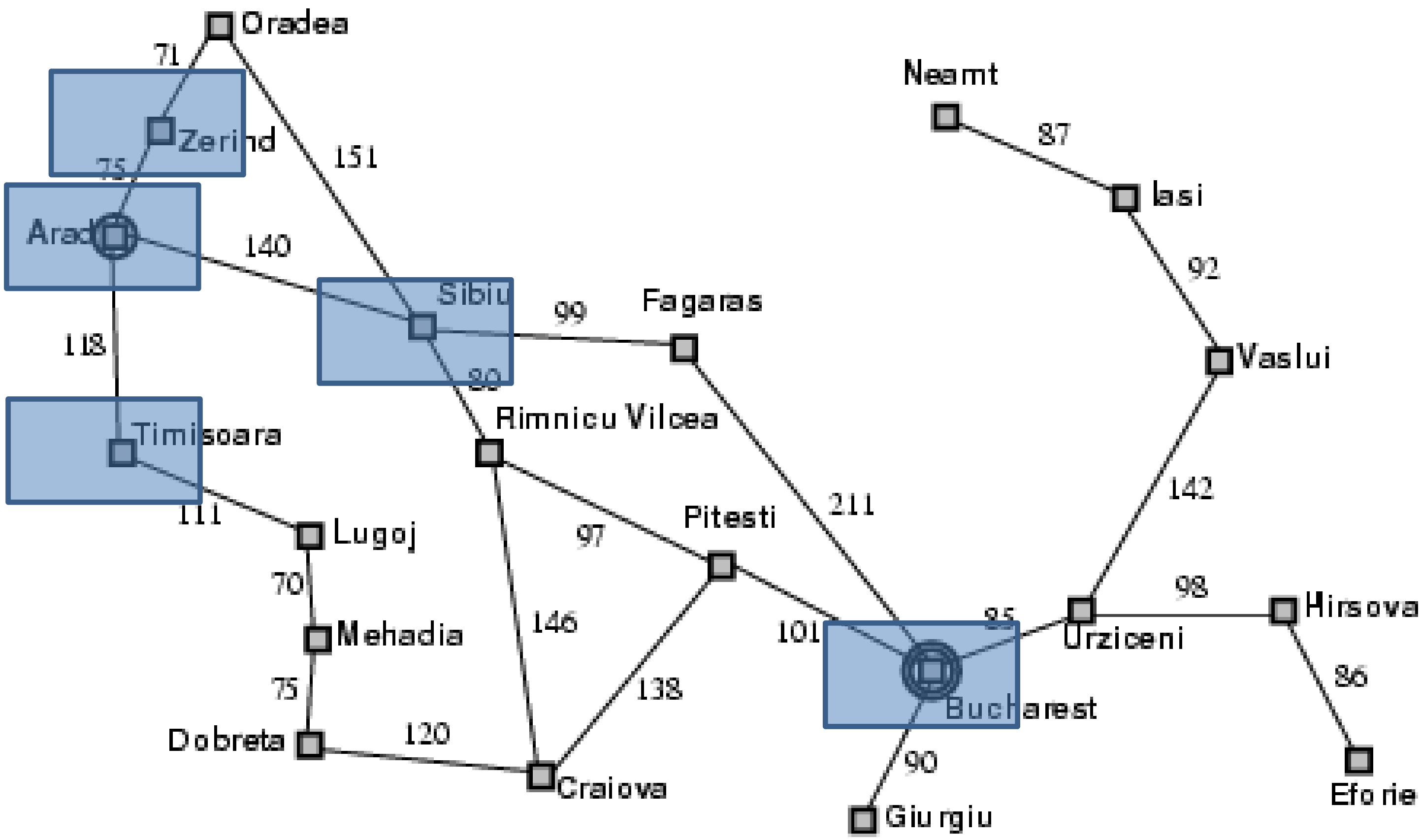

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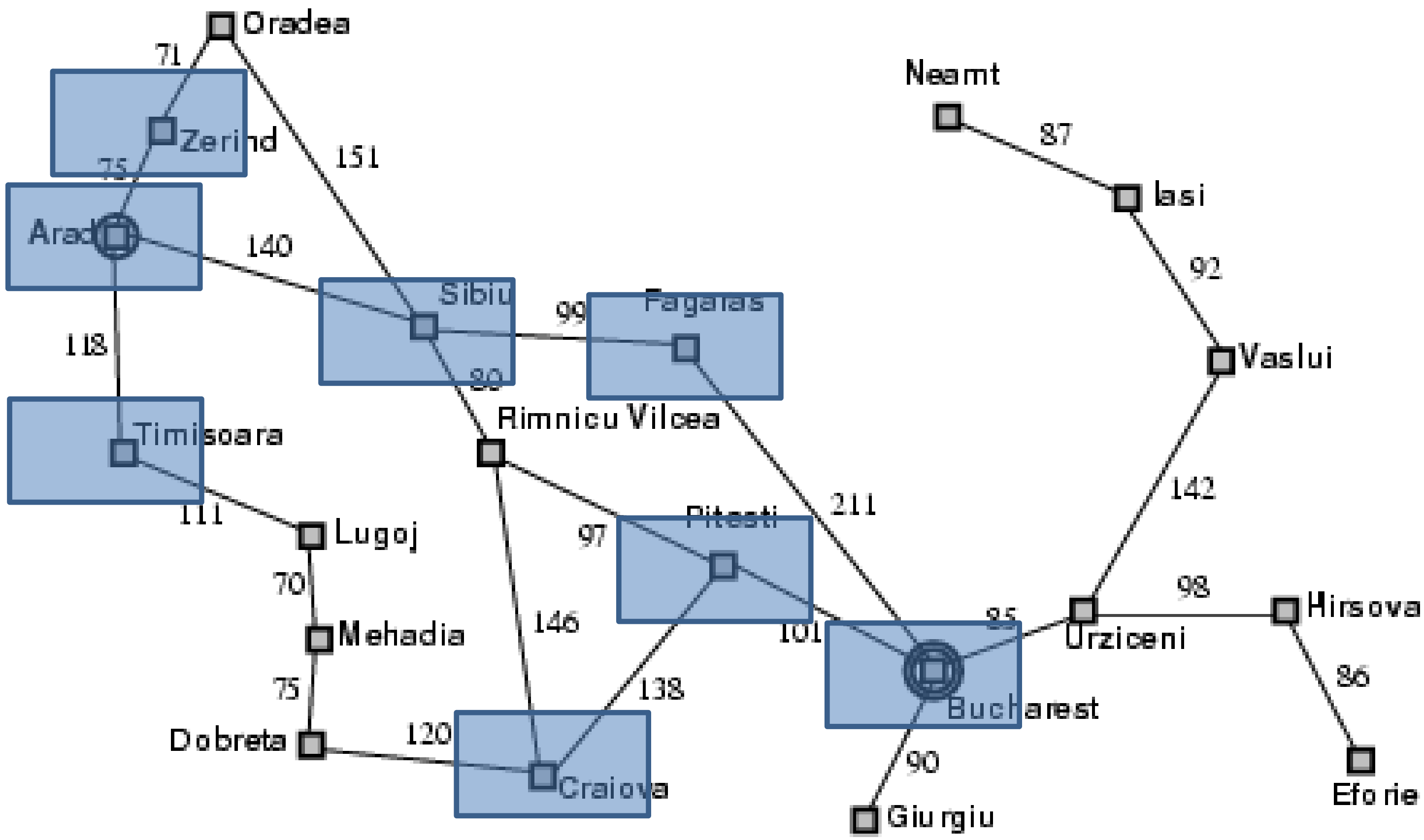
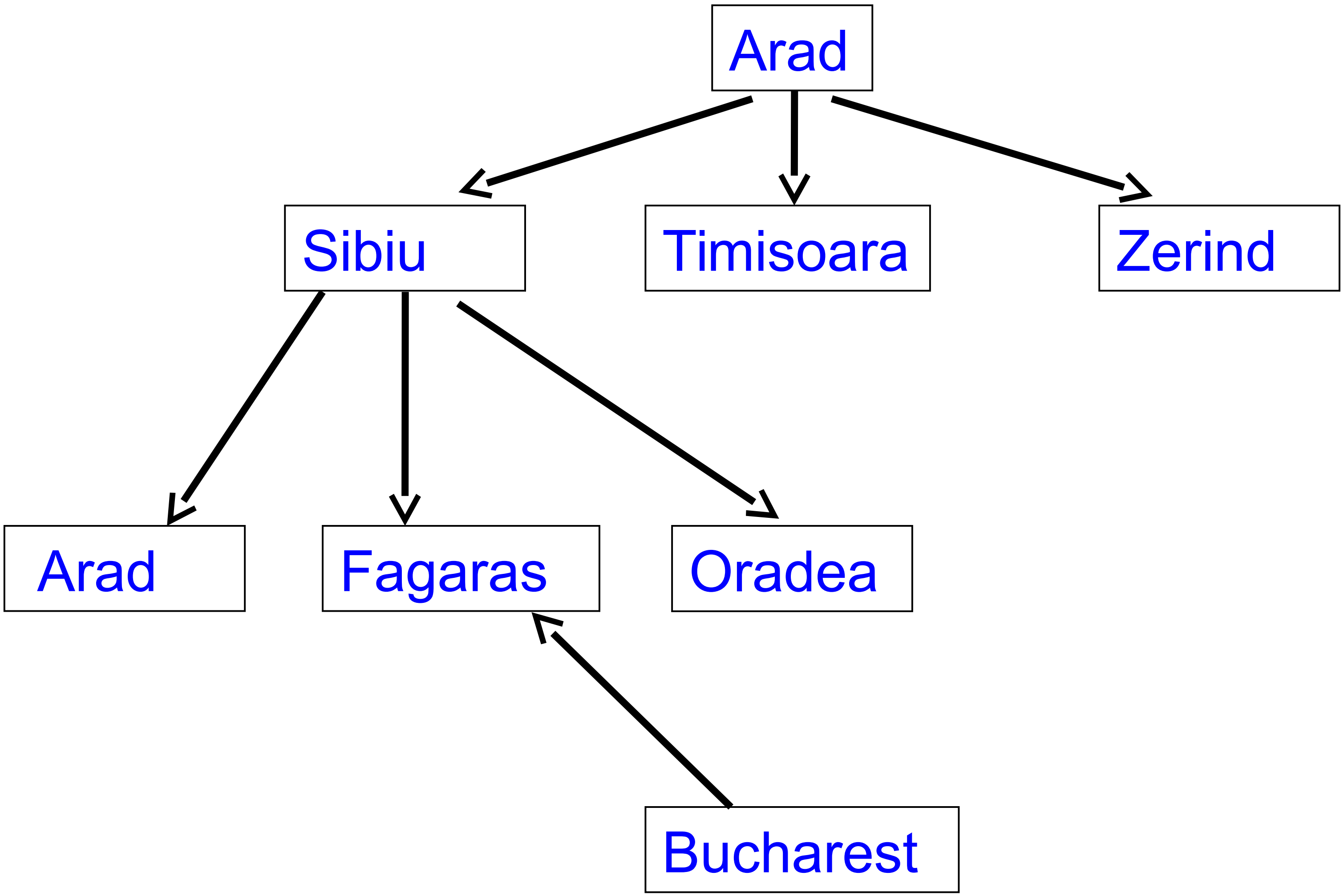


Bi-directional Search



Bi-directional Search: Good

- *Much* more efficient
- Rather than doing one search of b^d …

  …we do *two* $b^{d/2}$ searches

  – E.g., Suppose $b = 10$, $d = 6$
    - Breadth first search will examine 10^6 = 1,000,000 nodes
    - Bidirectional search will examine 2×10^3 = 2,000 nodes

- Can combine different search strategies in different directions

Bi-directional Search: Bad

- Depends on applicability of backward search

- Needs an efficient way to check whether each new node appears in the other search:
  - need to store nodes in frontier, so large memory requirements
  - For example, for
    - two bi-directional breadth-first searches,
    - branching factor *b*,
    - depth of the solution *d*,
      → memory requirement of $b^{d/2}$ for each search

  - For large *d*, is still impractical

Summary

- More advanced problem-solving techniques:
  - Depth-limited search
  - Iterative deepening
  - Bi-directional search
  - Avoiding repeated states

- These improve on basic techniques like breadth-first and depth-first search
- However, they still aren't always powerful enough to give solutions for realistic problems
- Are there more improvements we can make…?

- Next time
  - Lists in Prolog