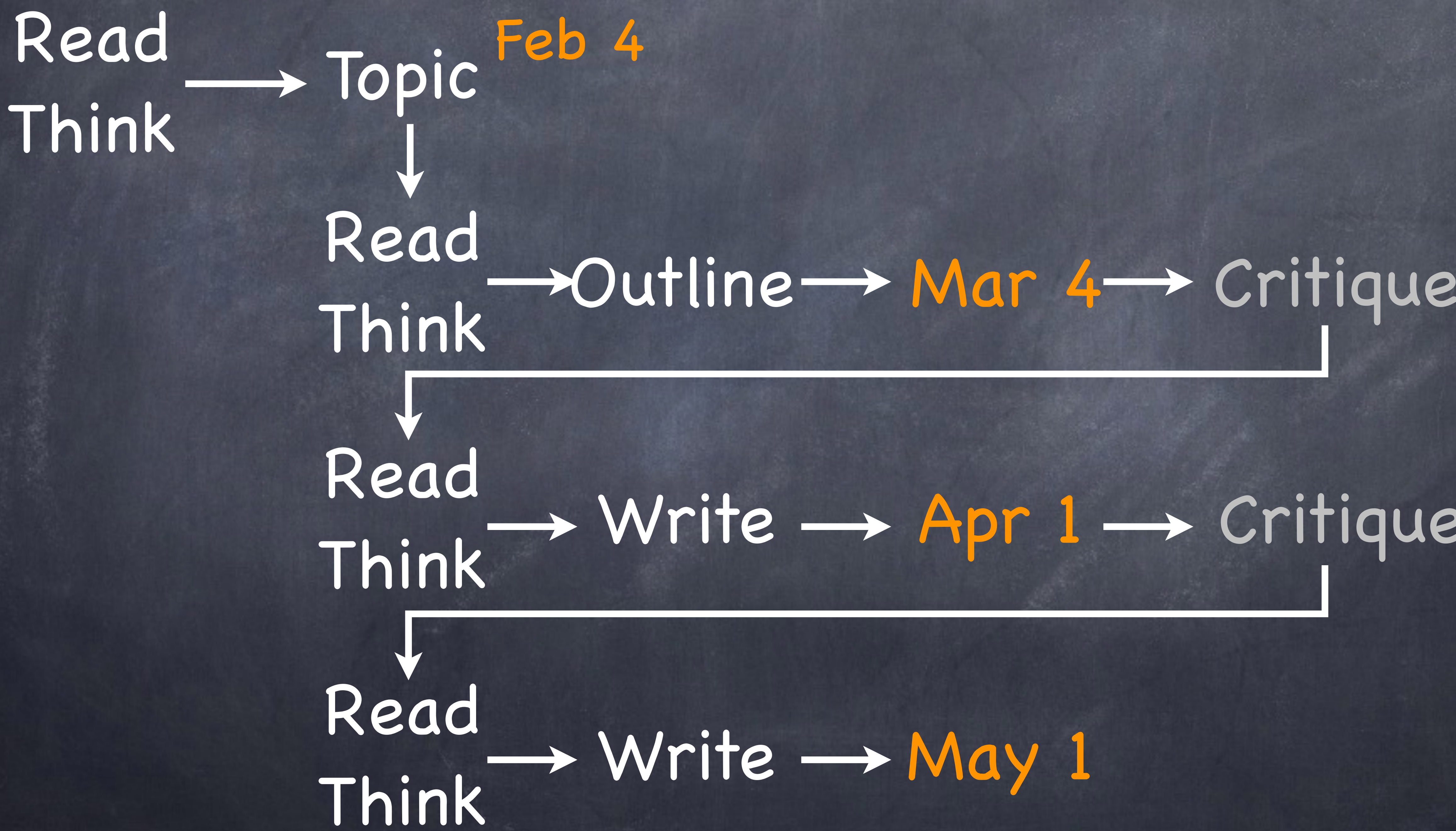
CSC242: Artificial Intelligence

Lecture 2: Problem Solving

Upper Level Writing

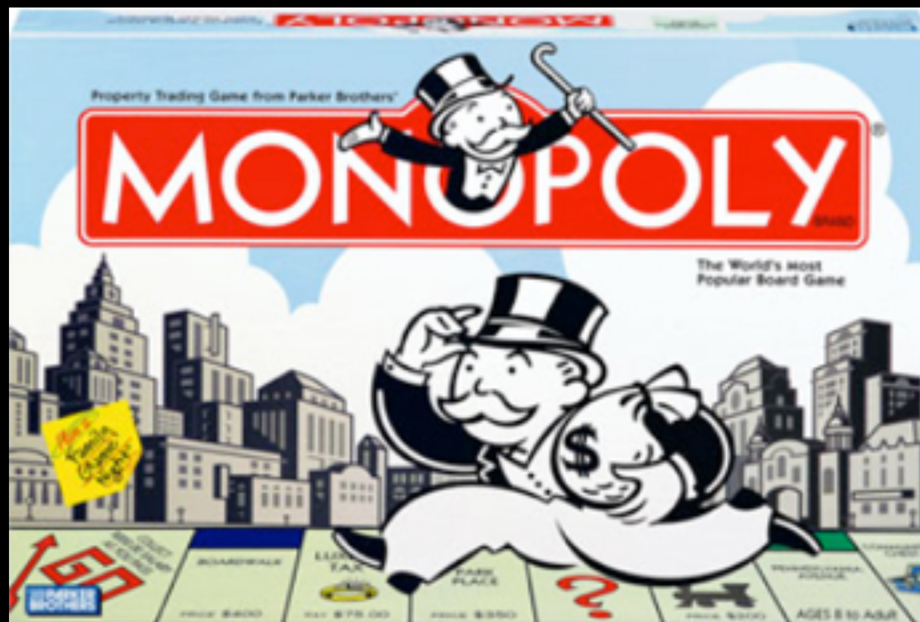


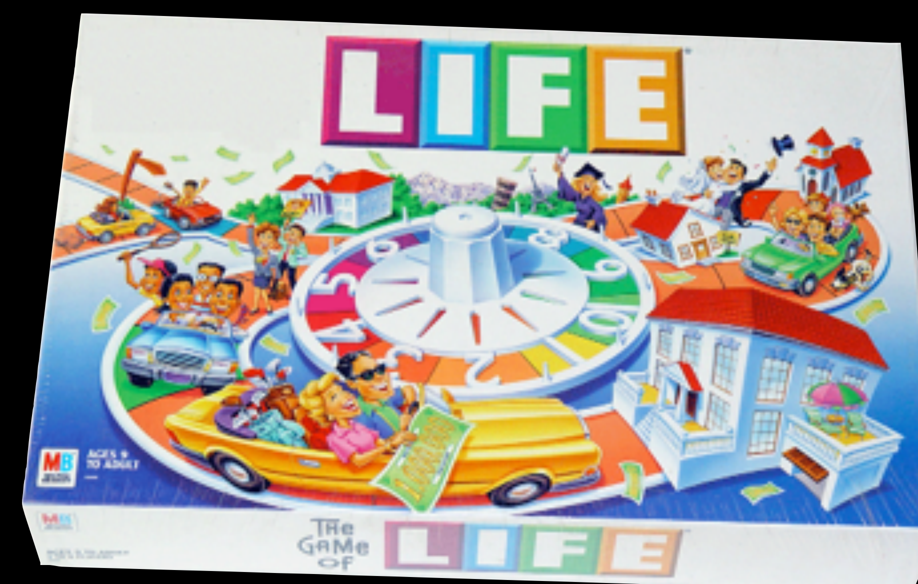
One More Policy

One More Policy

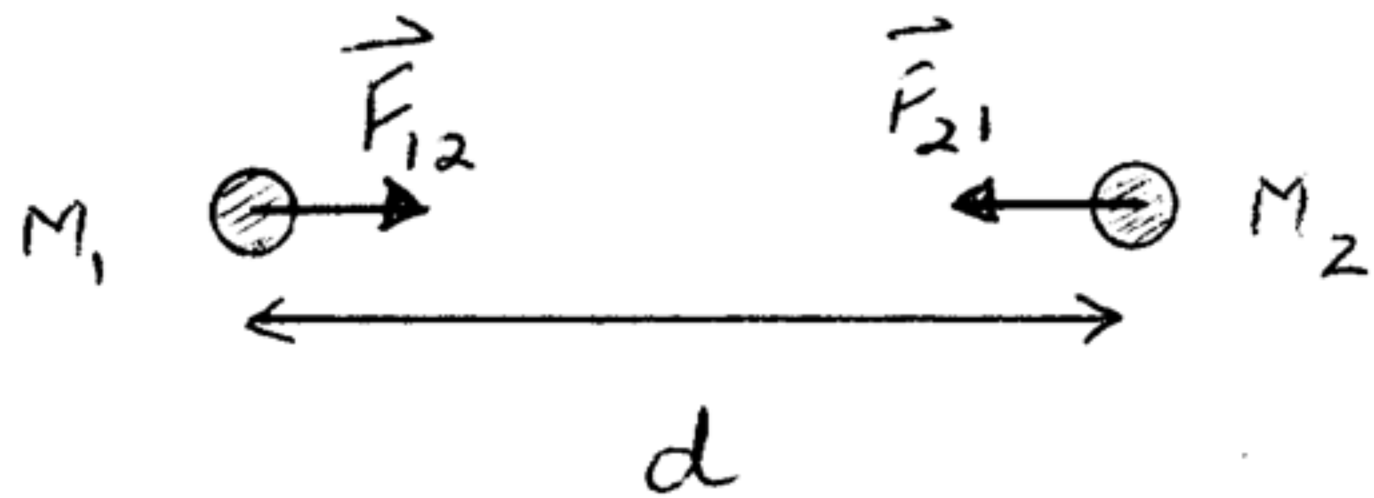
General Problem Solving


WD-40


Property Trading Game from Parker Brothers
MONOPOLY
The World's Most Popular Board Game


LIFE
THE GAME OF LIFE


OPERATION
SKILL GAME
WHERE YOU'RE THE DOCTOR
SPECIALIST



$$|\vec{F}_{12}| = |\vec{F}_{21}| = \frac{G M_1 M_2}{d^2}$$

Cooperative Problem Solving

Cooperative Problem Solving

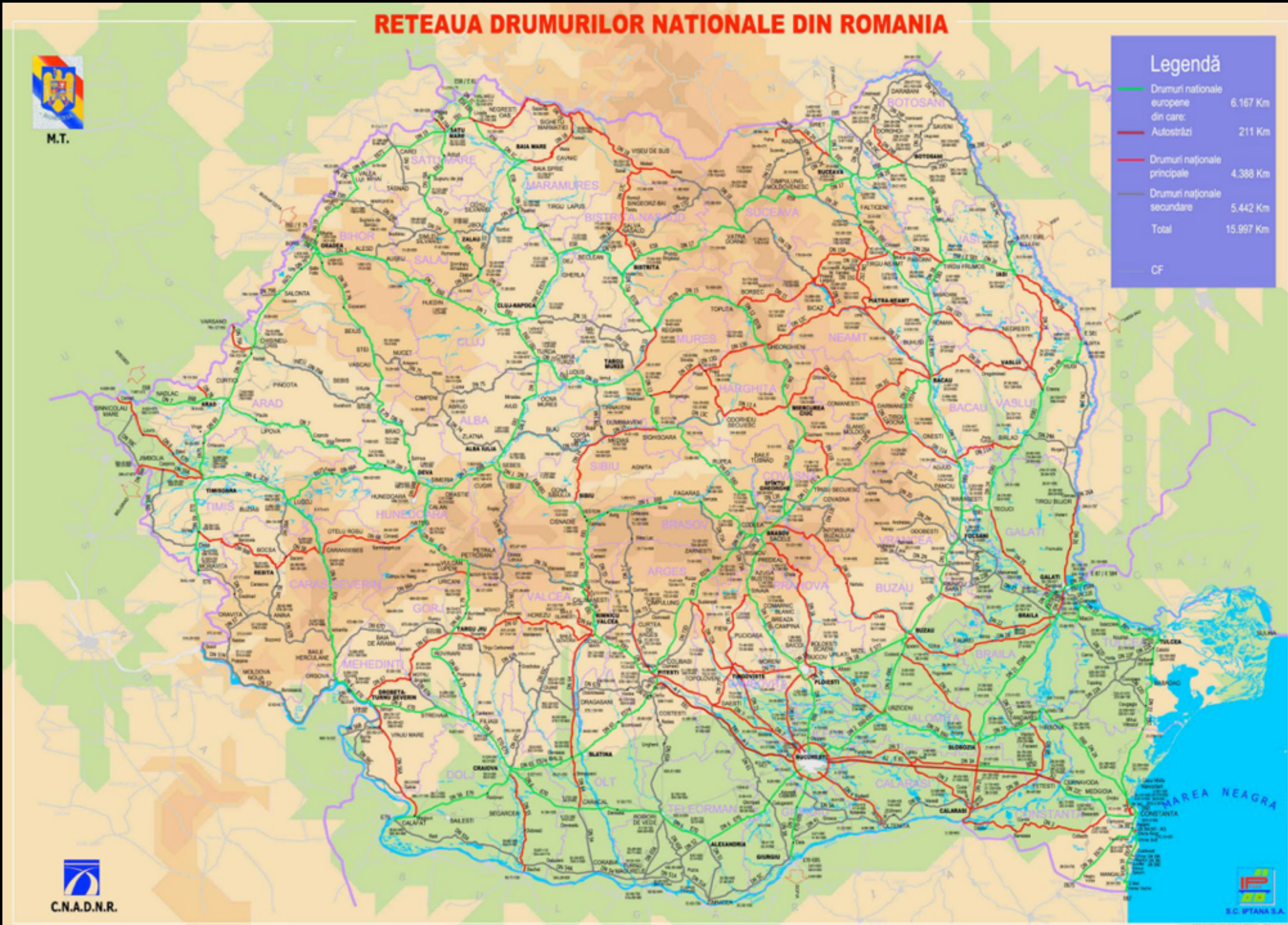
Cooperative Problem Solving

CSC242

We don't make the computers.*
We make the computers solve problems.

*Or the programming languages, compilers, debuggers, databases, graphics pipelines, network protocols, web servers, ...

Our first problem



RETEAUA DRUMURILOR NATIONALE DIN ROMANIA
M.T.
Legendă
Drumuri nationale europene 6.167 Km
din care:
Autostrăzi 211 Km
Drumuri naționale principale 4.388 Km
Drumuri naționale secundare 5.442 Km
Total 15.997 Km
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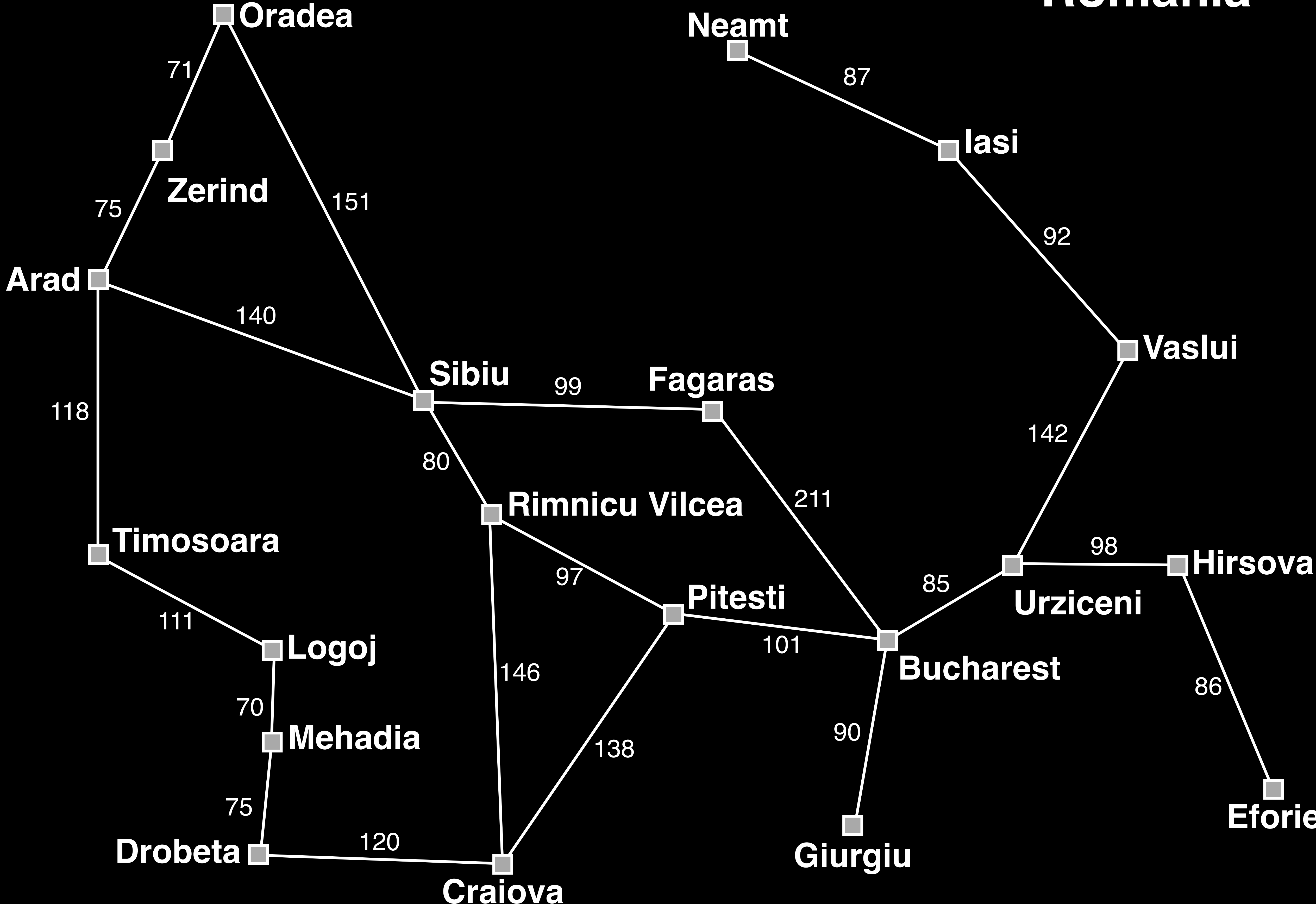
MAREA NEAGRA
C.N.A.D.N.R.
S.C. IPTANA S.A.

Romania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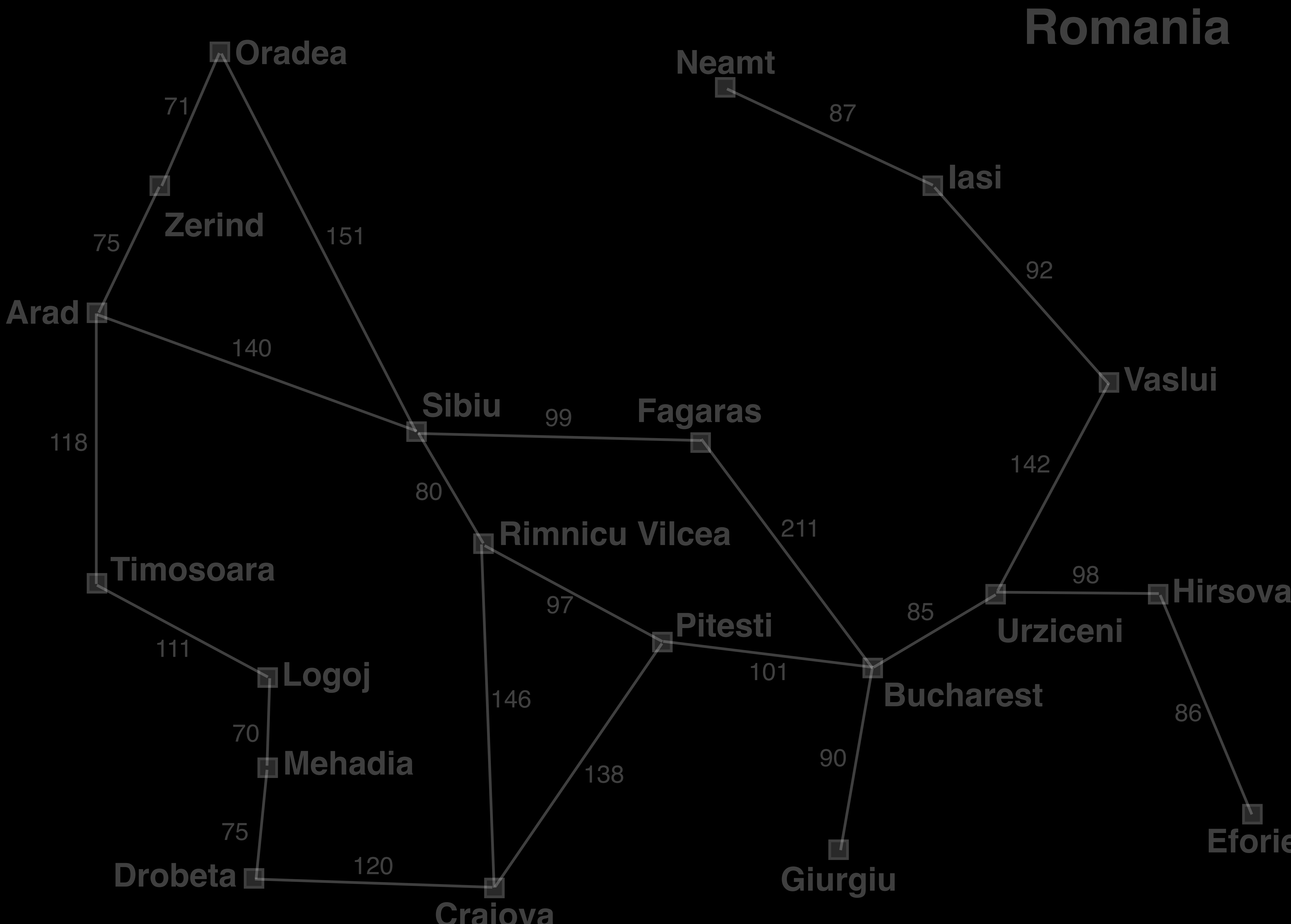
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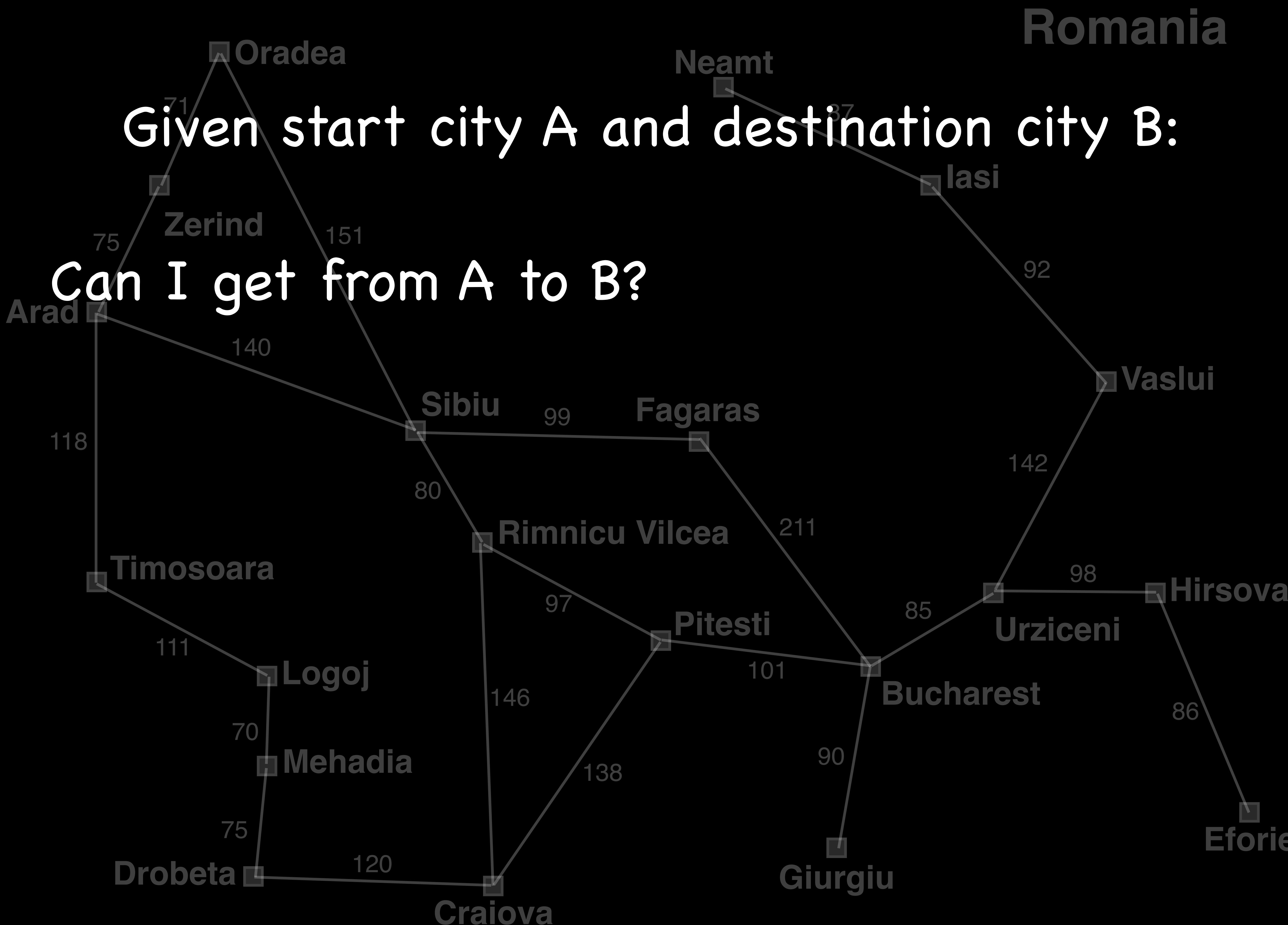
Given start city A and destination city B:

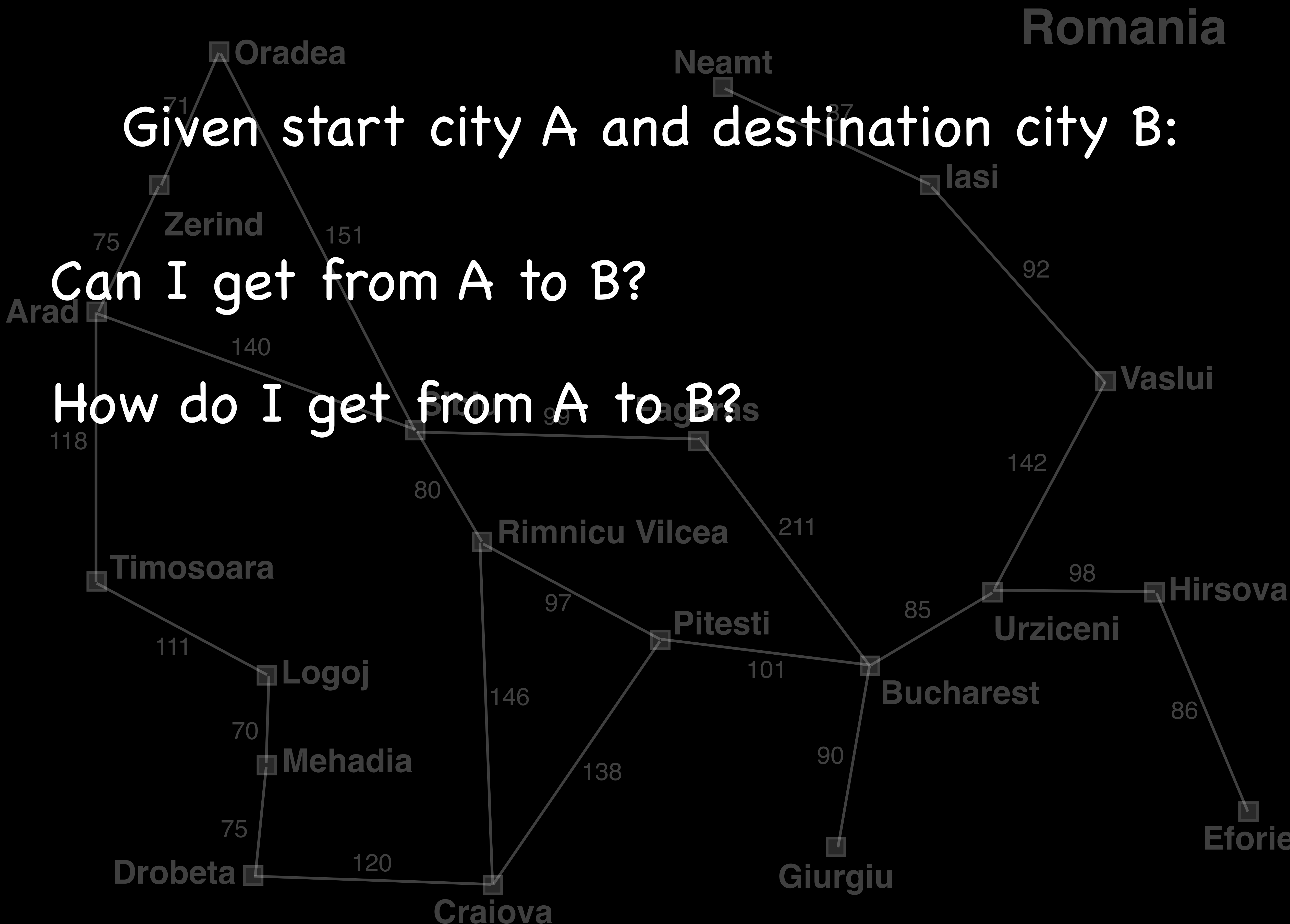
Can I get from A to B?



Given start city A and destination city B:

Can I get from A to B?

How do I get from A to B?



Given start city A and destination city B:

Can I get from A to B?

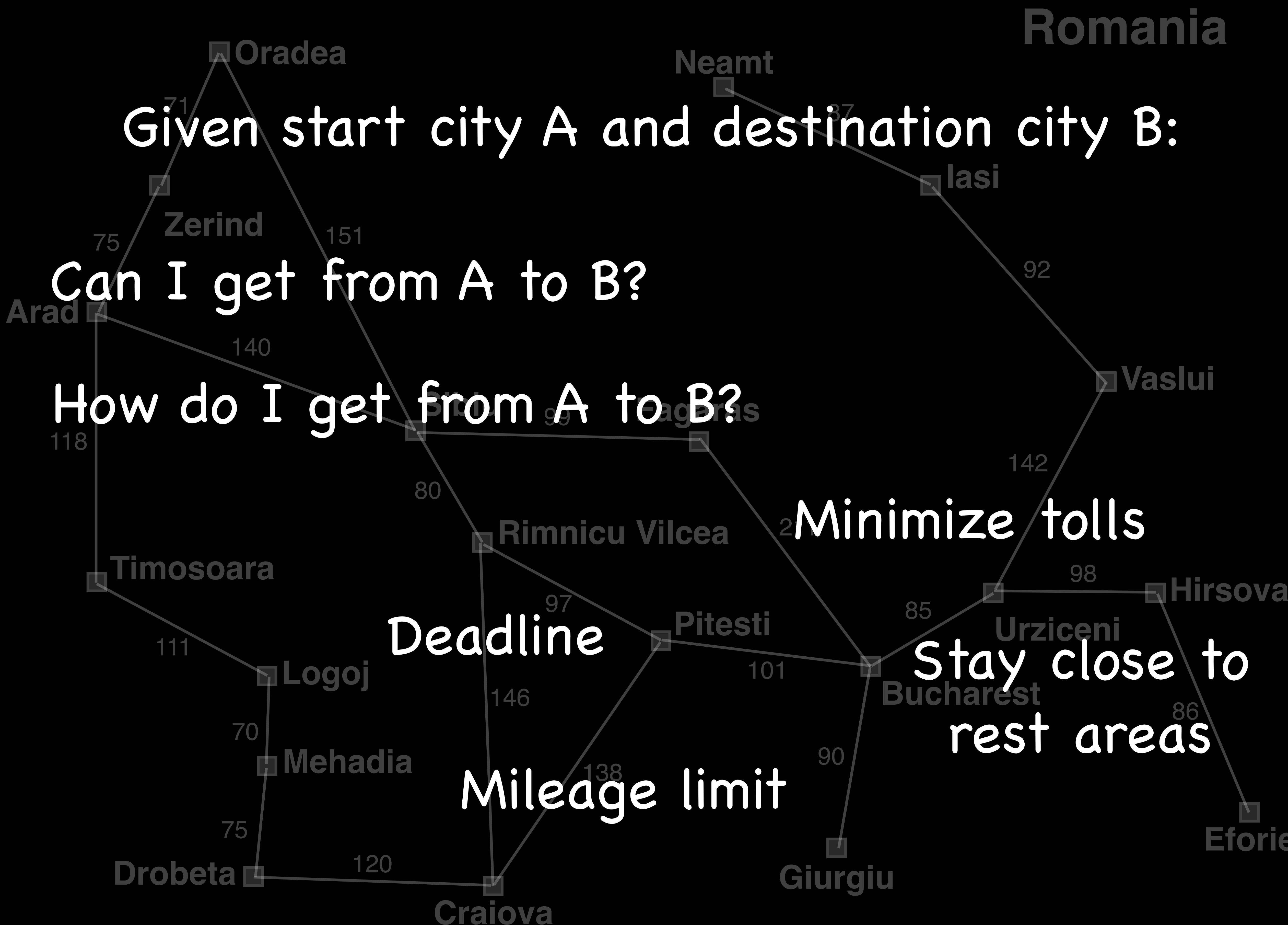
How do I get from A to B?

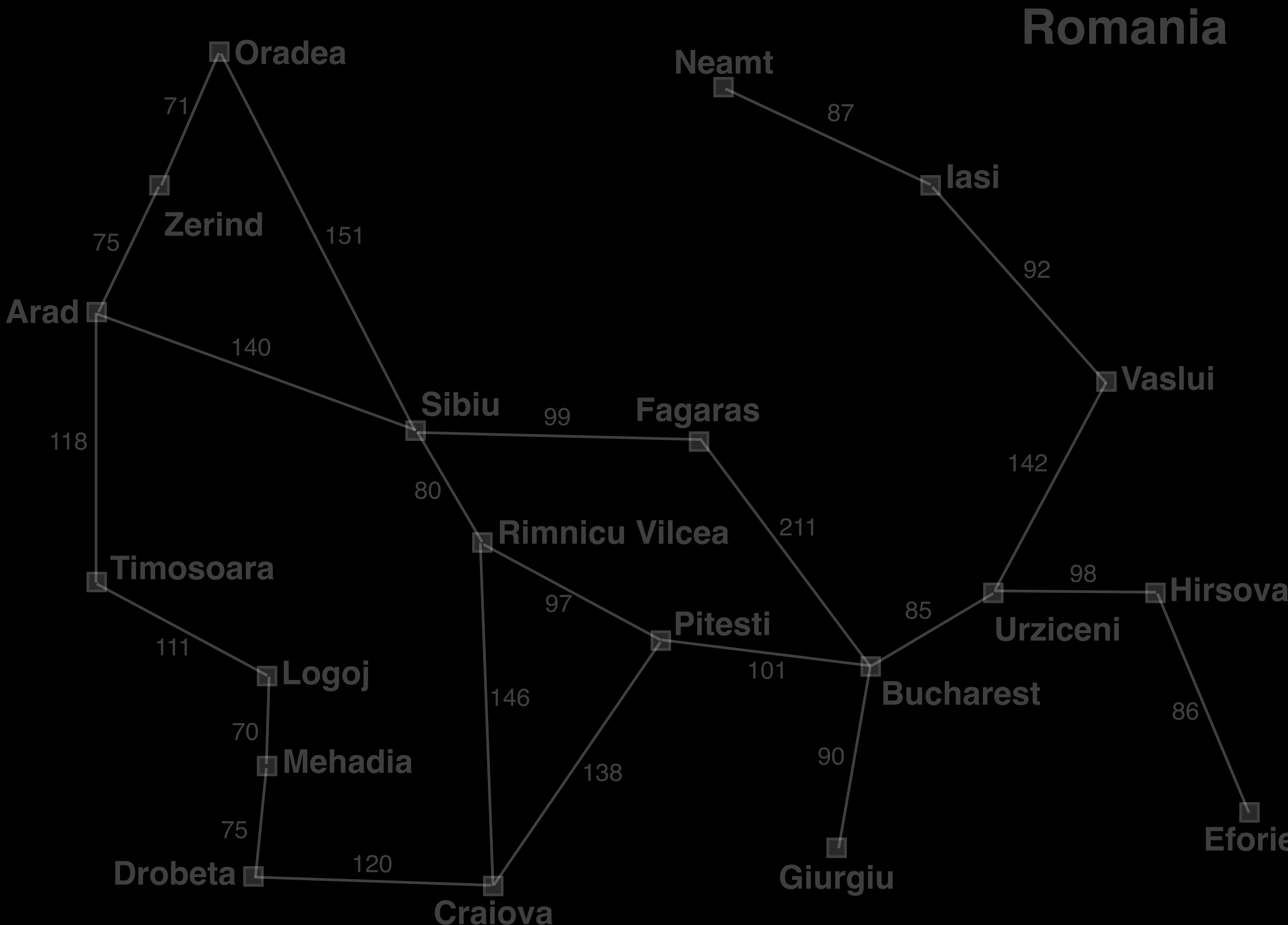
Minimize tolls

Deadline

Stay close to rest areas

Mileage limit

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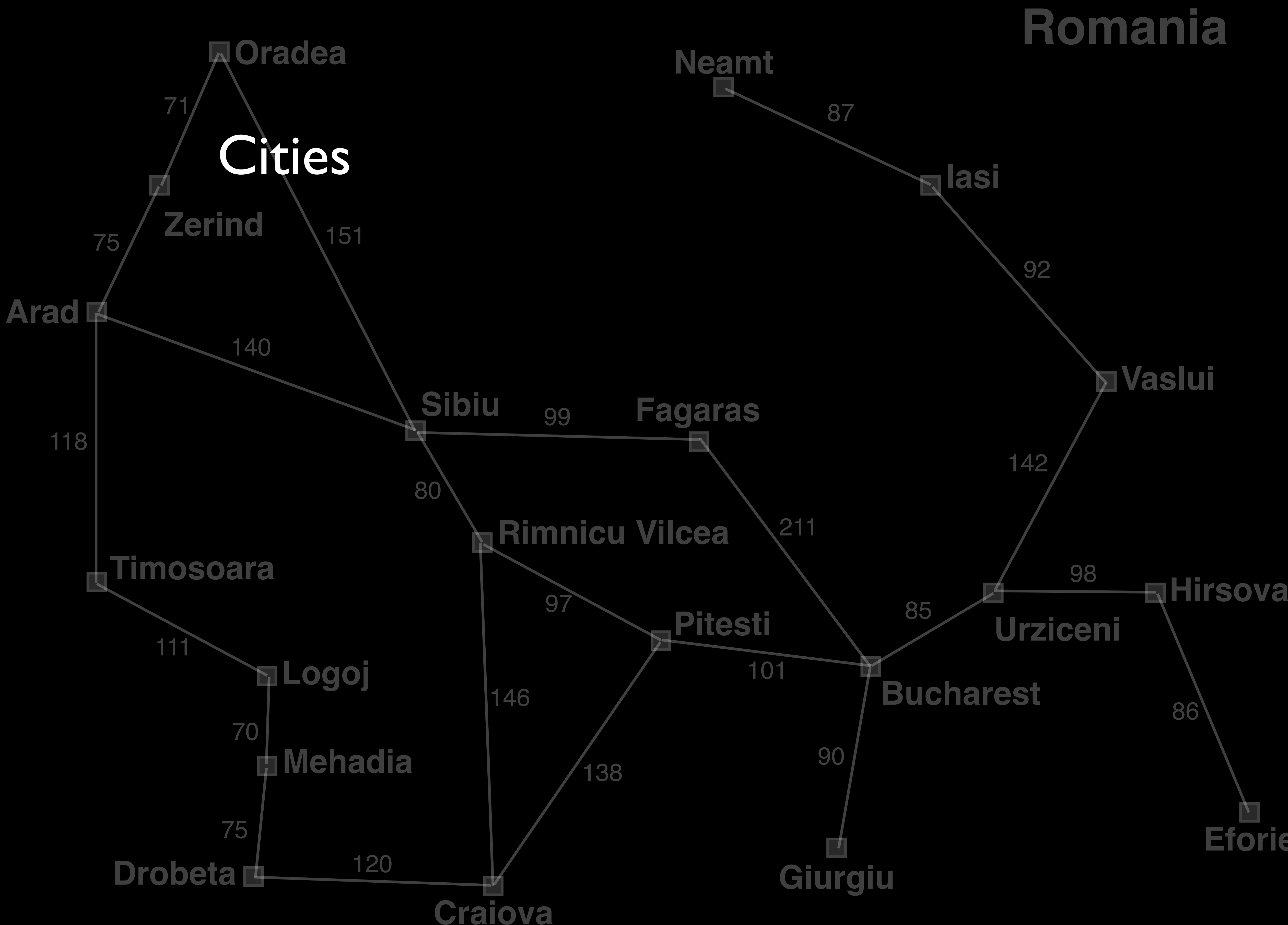
Cities



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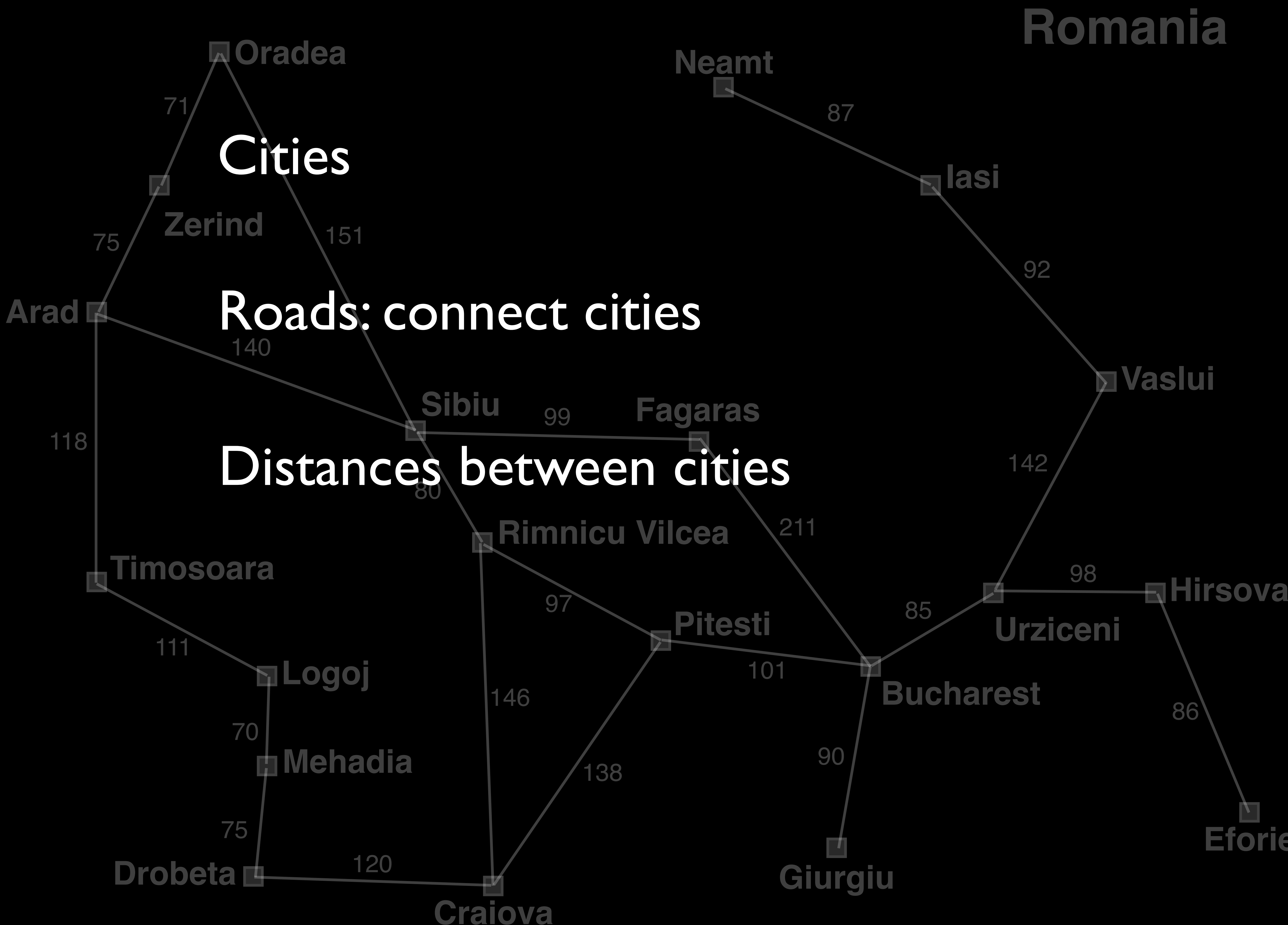
Cities

Roads: connect cities

Cities

Roads: connect cities

Distances between cities



Cities

Roads: connect cities

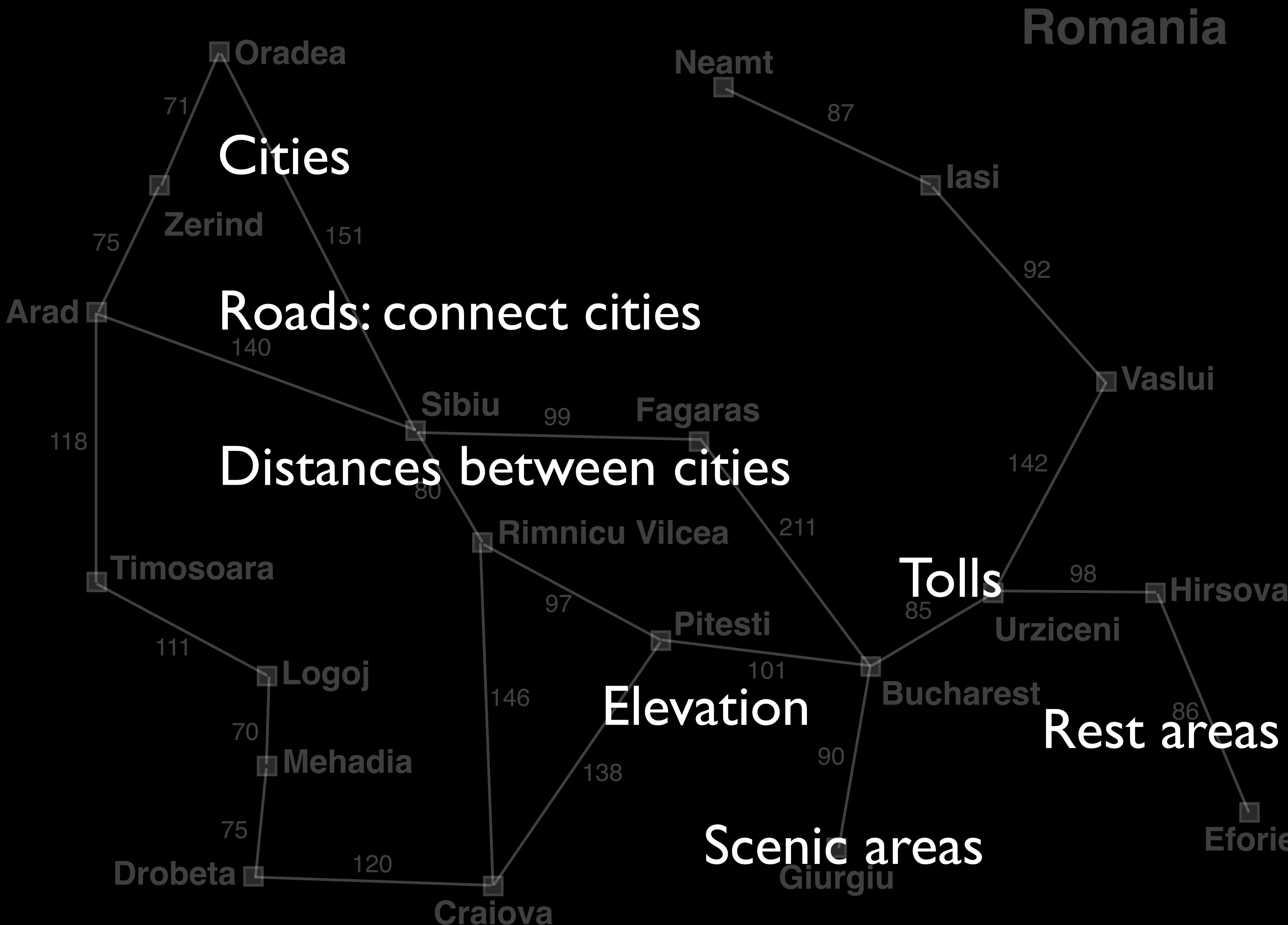
Distances between cities

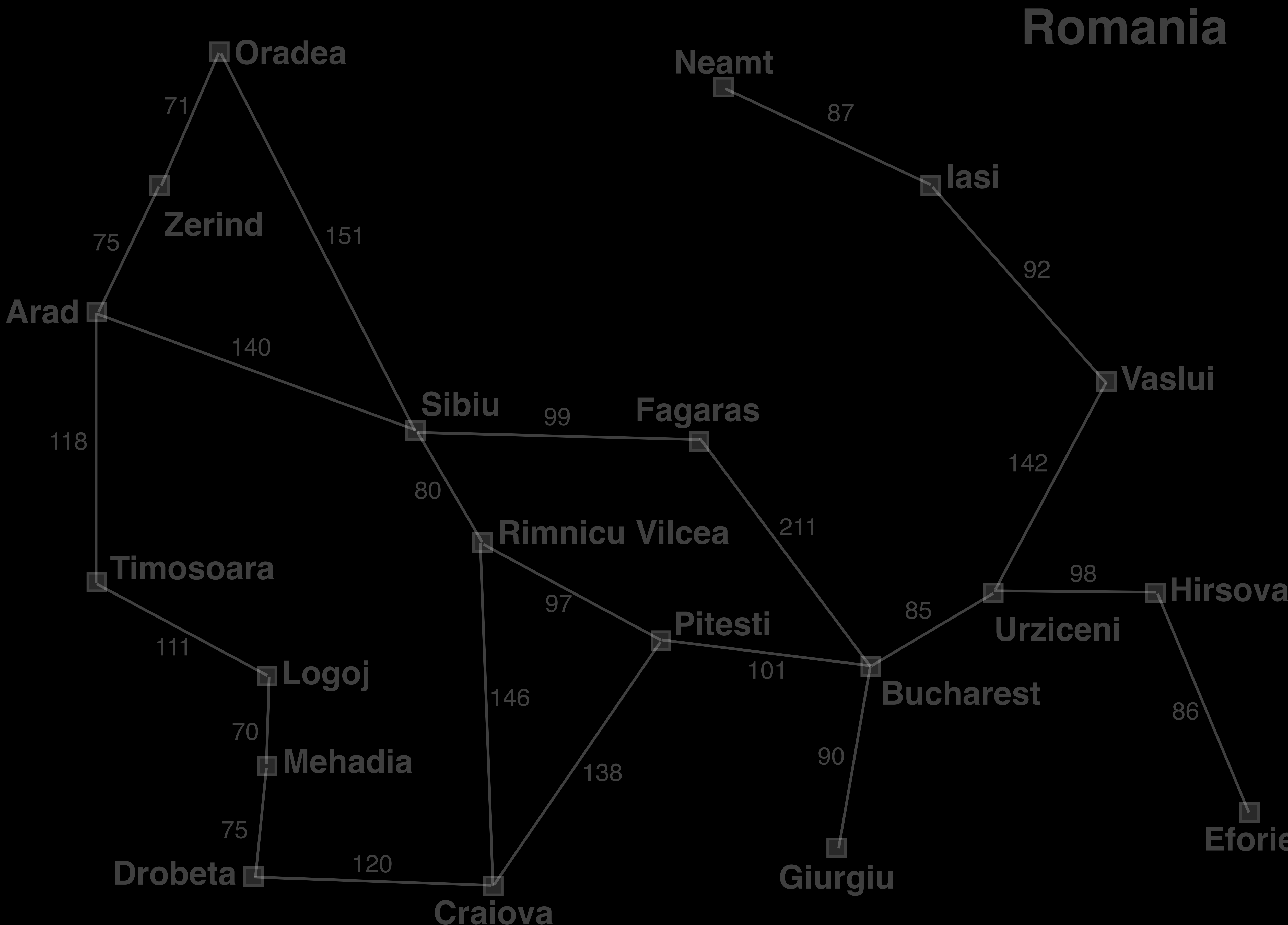
Tolls

Elevation

Rest areas

Scenic areas

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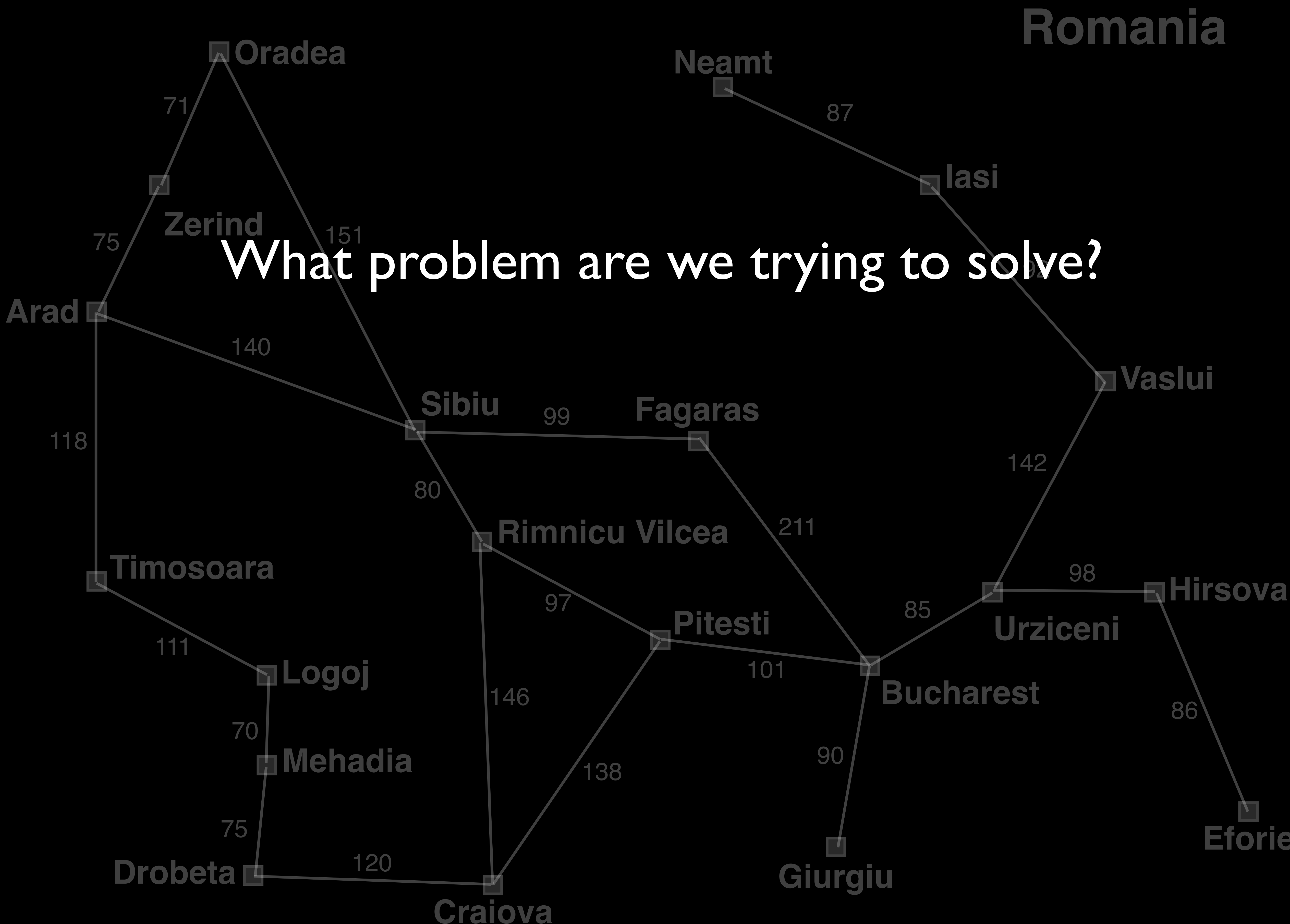
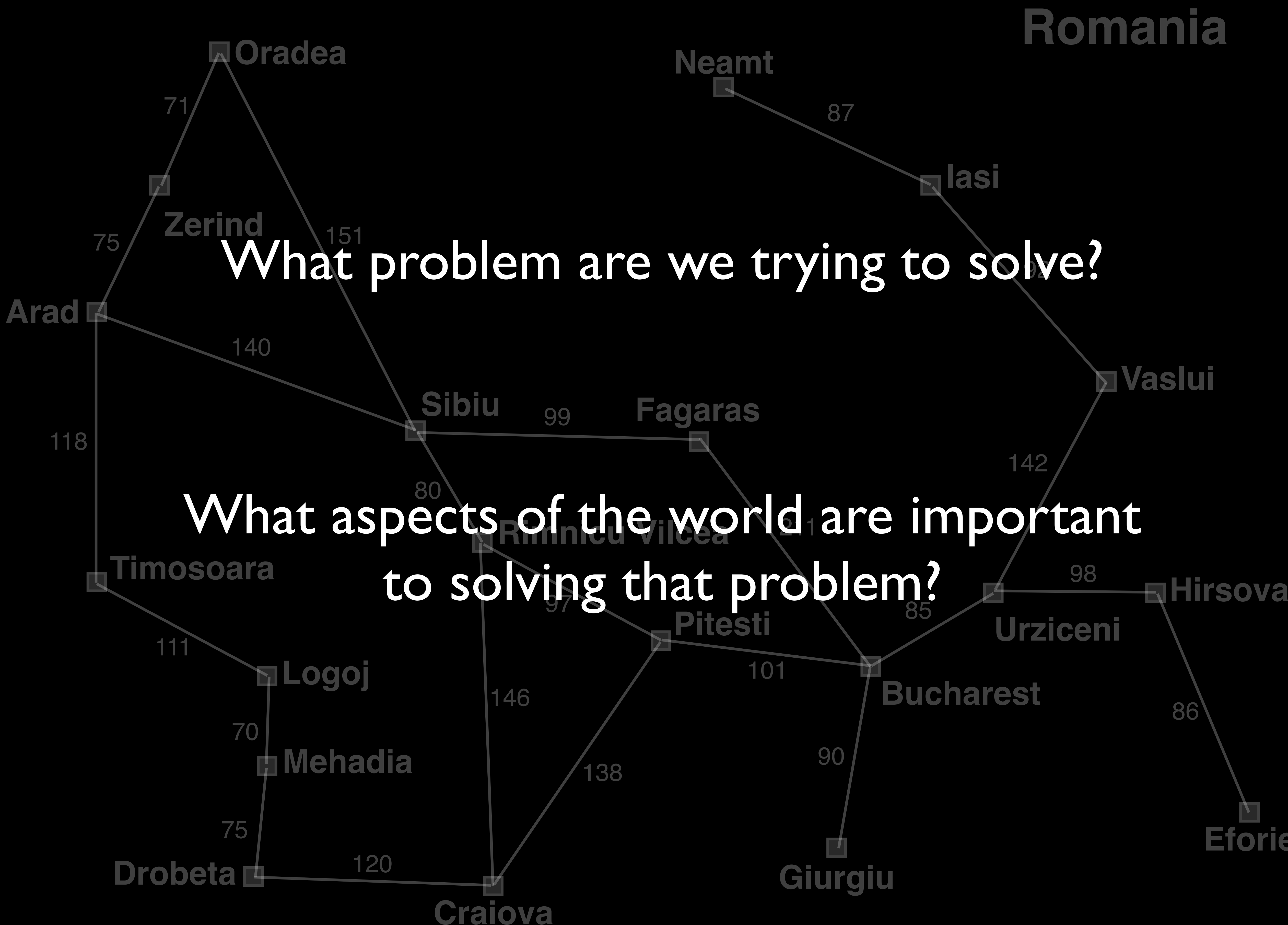
What problem are we trying to solve?

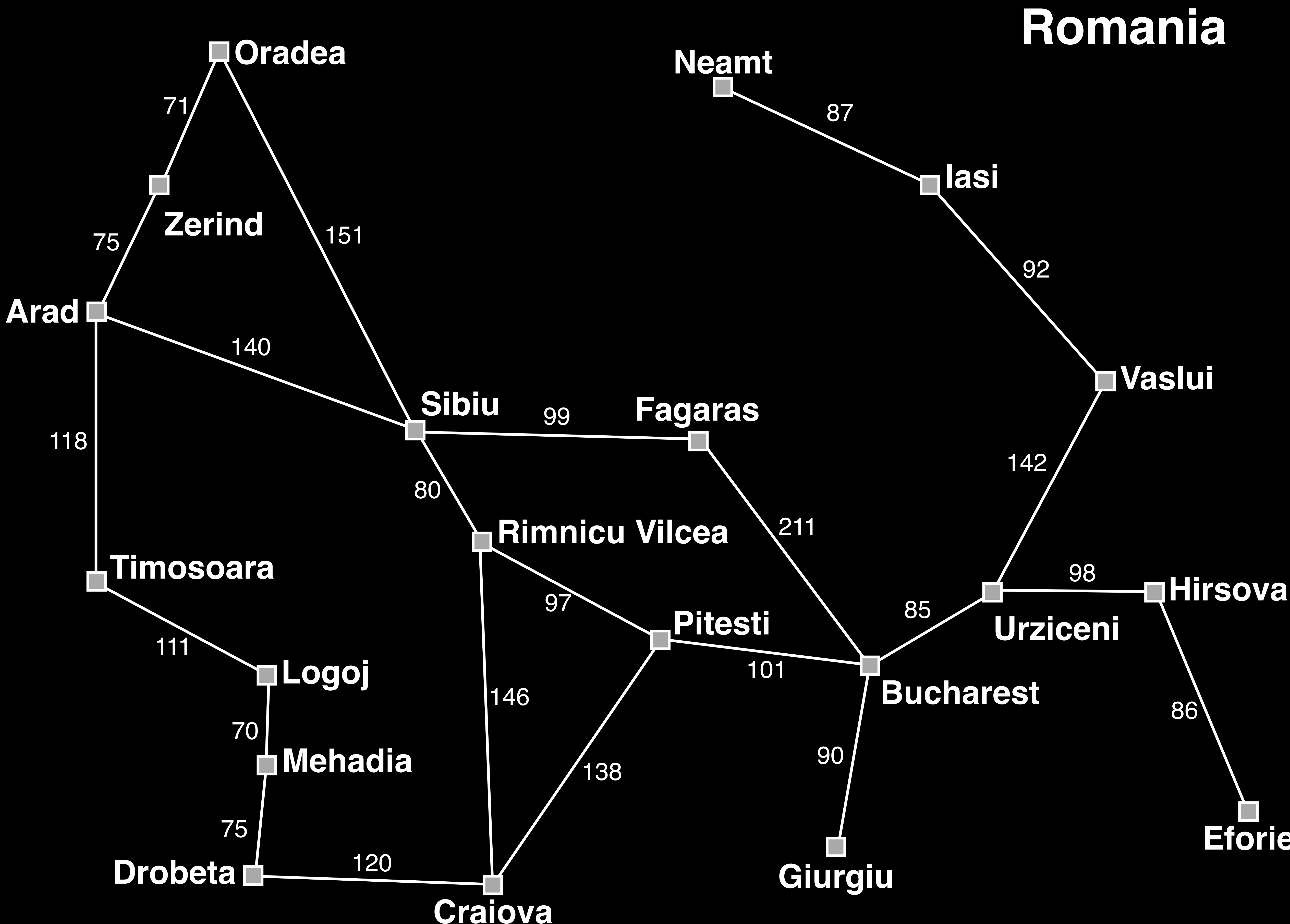


What problem are we trying to solve?

What aspects of the world are important to solving that problem?



Problem Solving by Computers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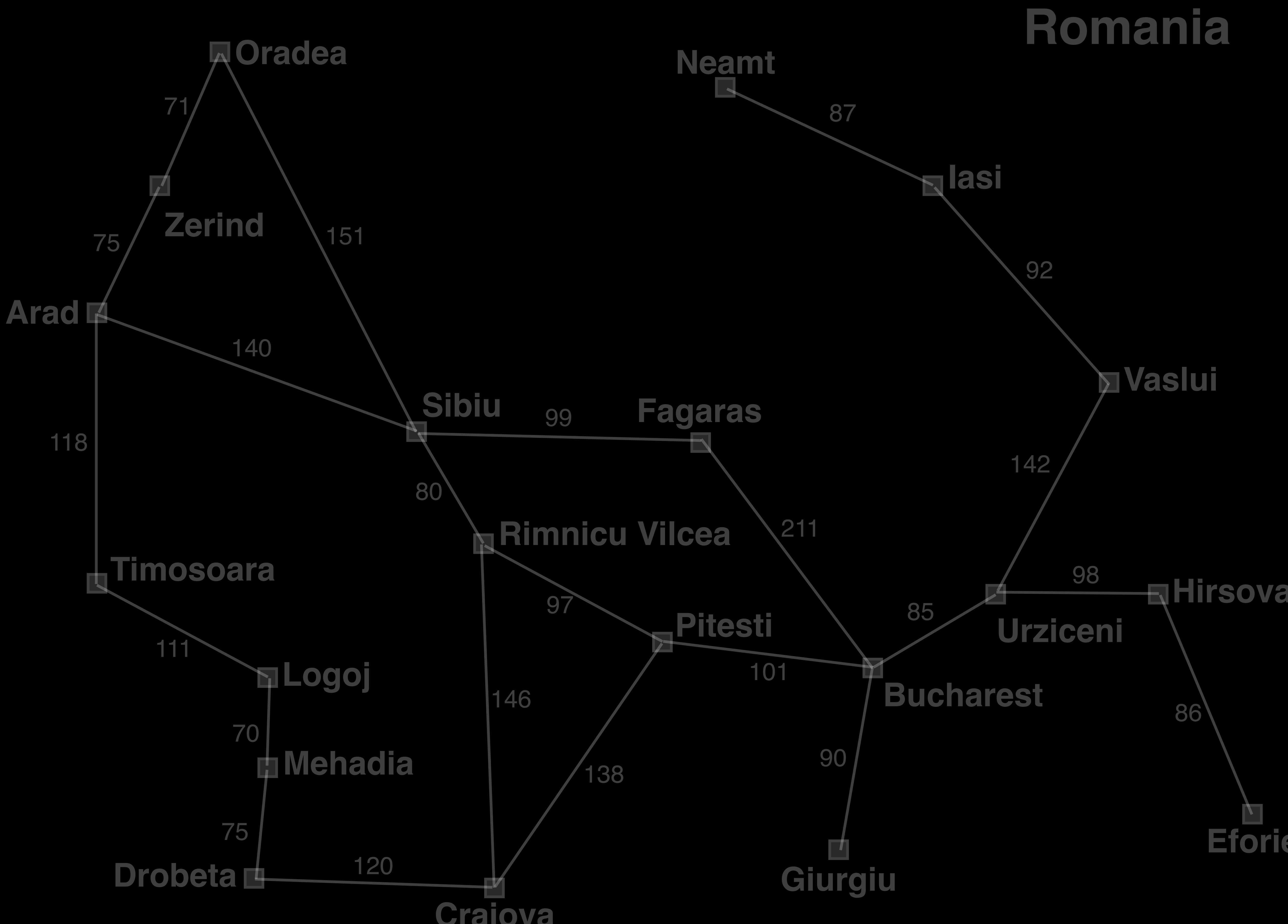
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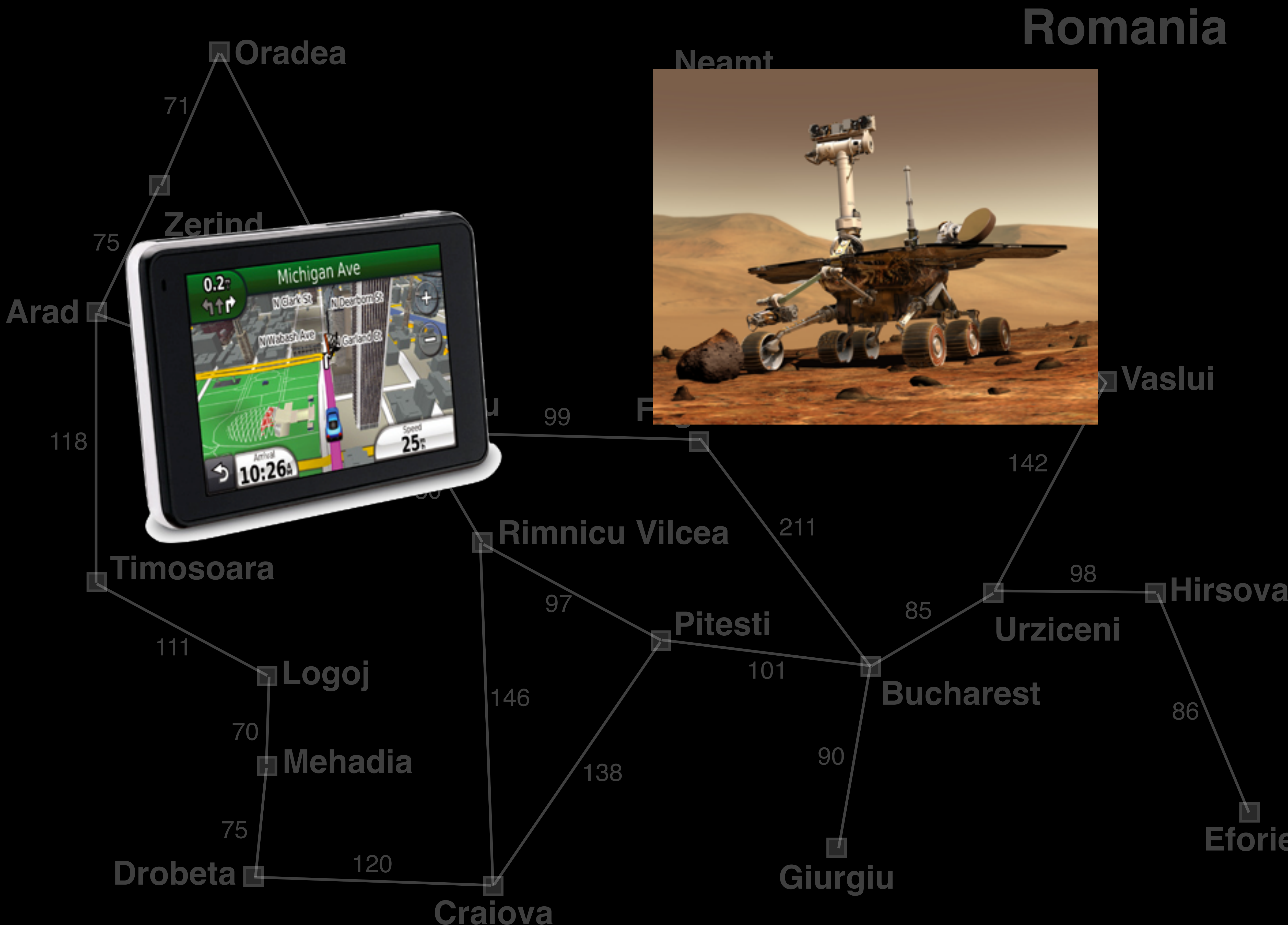
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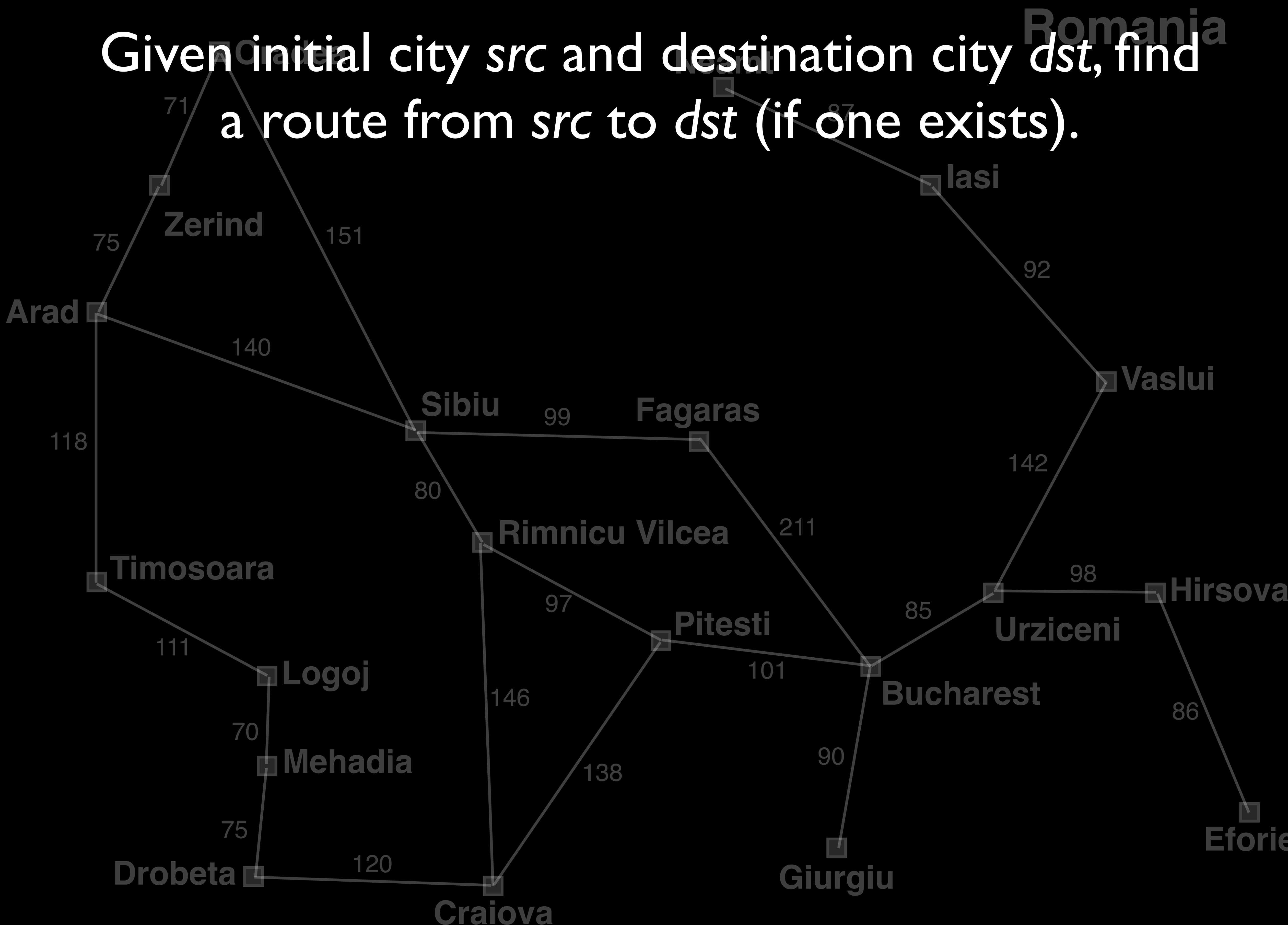
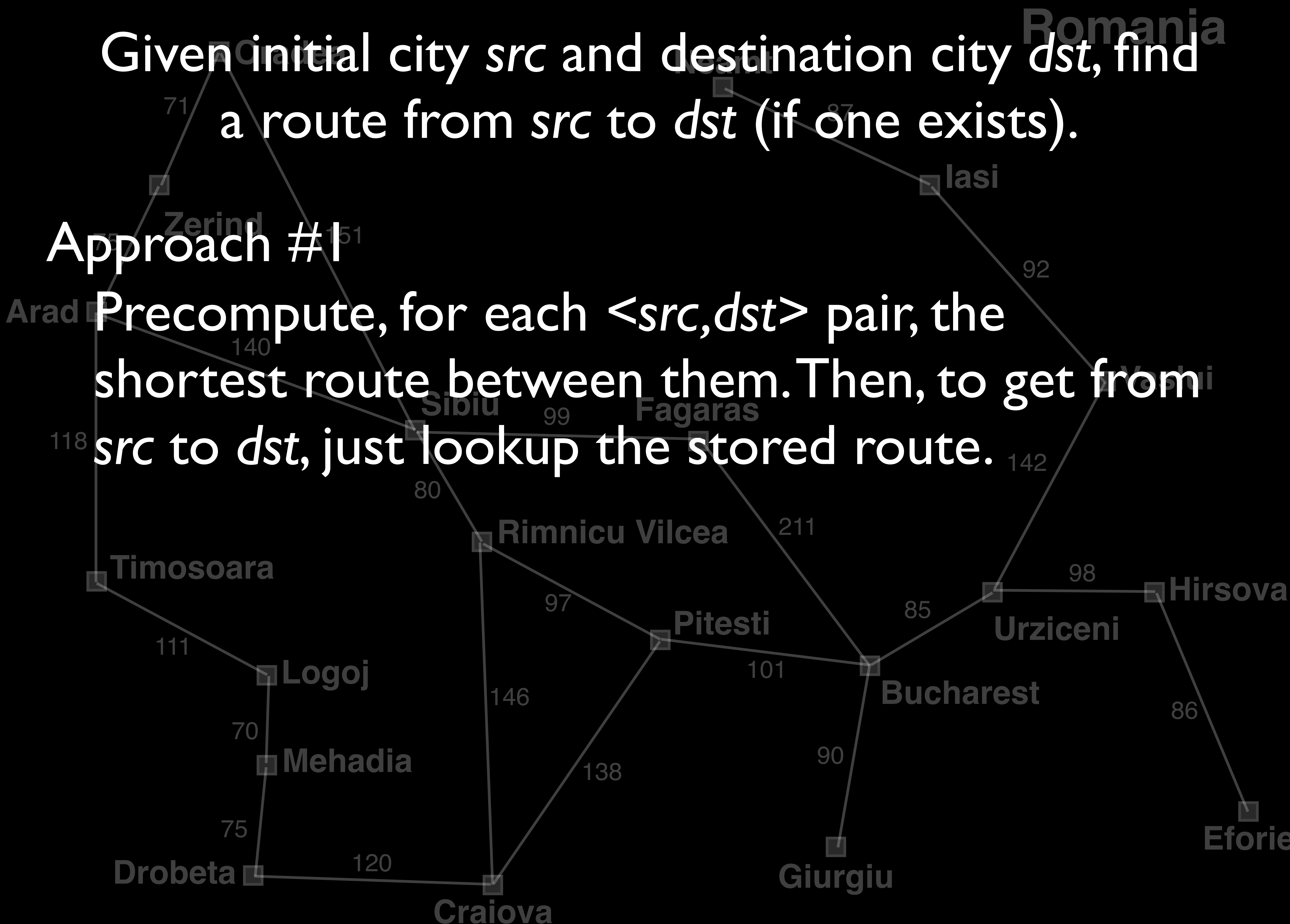
Given initial city *src* and destination city *dst*, find a route from *src* to *dst* (if one exists).



Given initial city *src* and destination city *dst*, find a route from *src* to *dst* (if one exists).

Approach #1

Precompute, for each <*src,dst*> pair, the shortest route between them. Then, to get from *src* to *dst*, just lookup the stored route.



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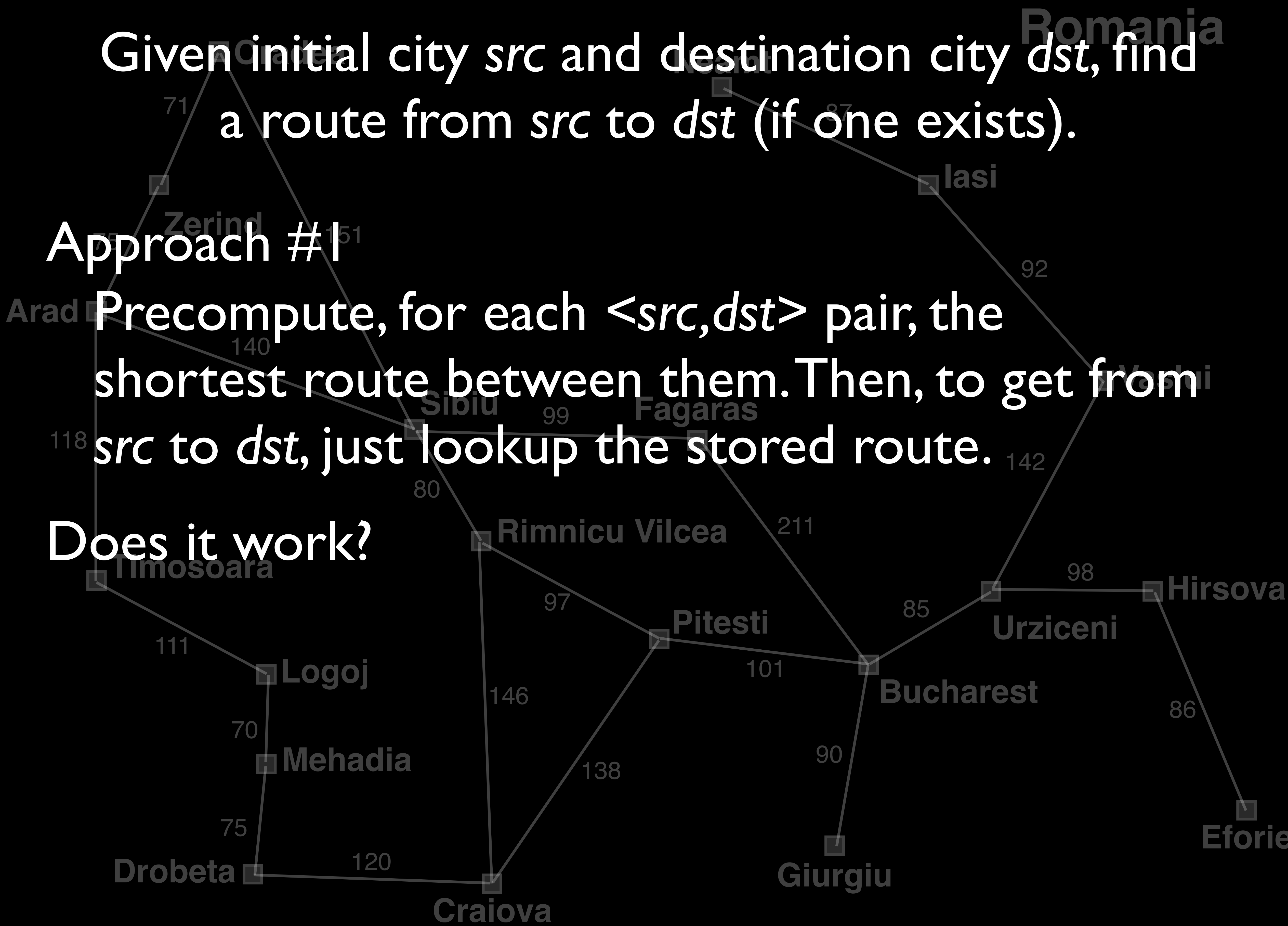
Does it work?



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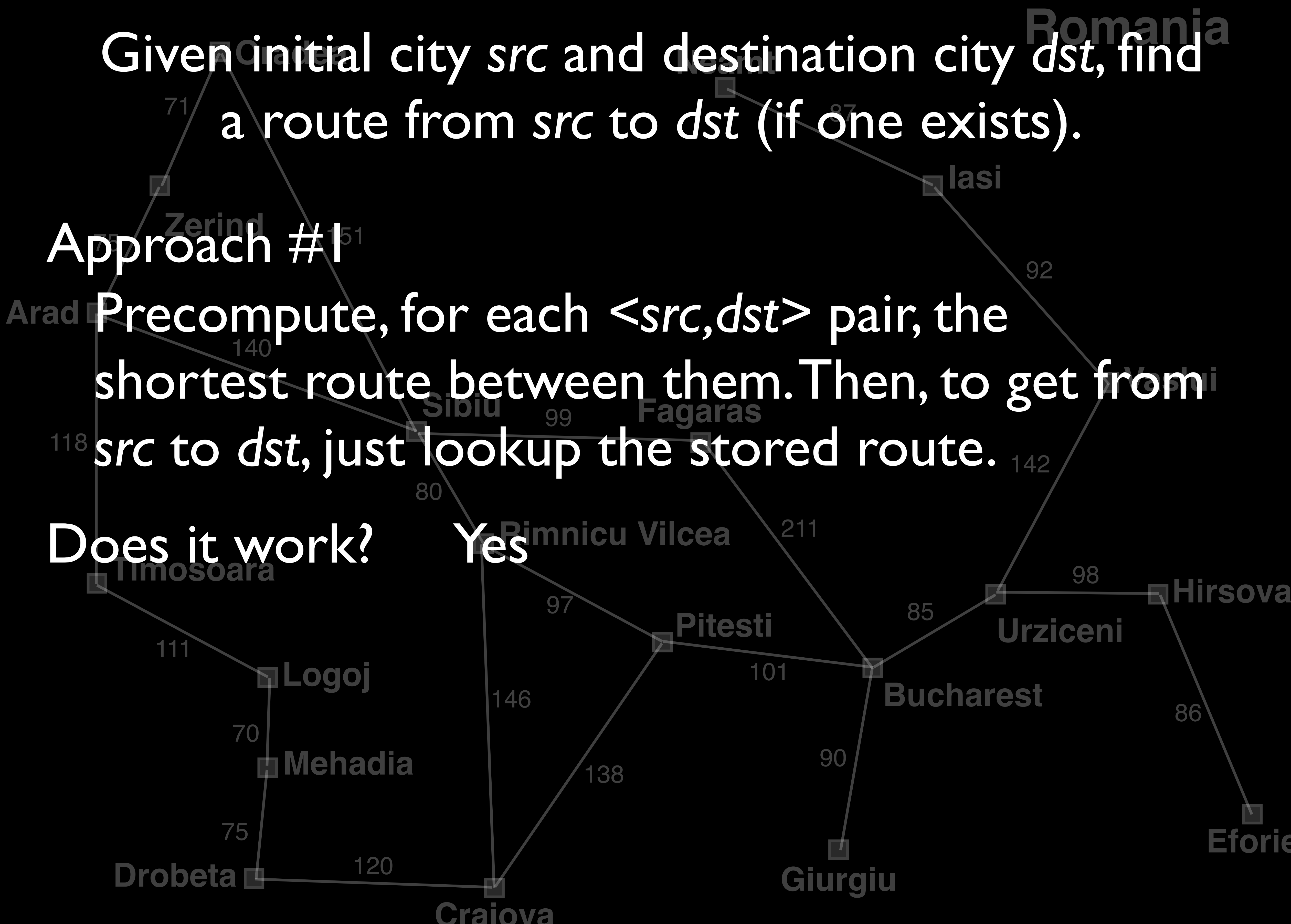
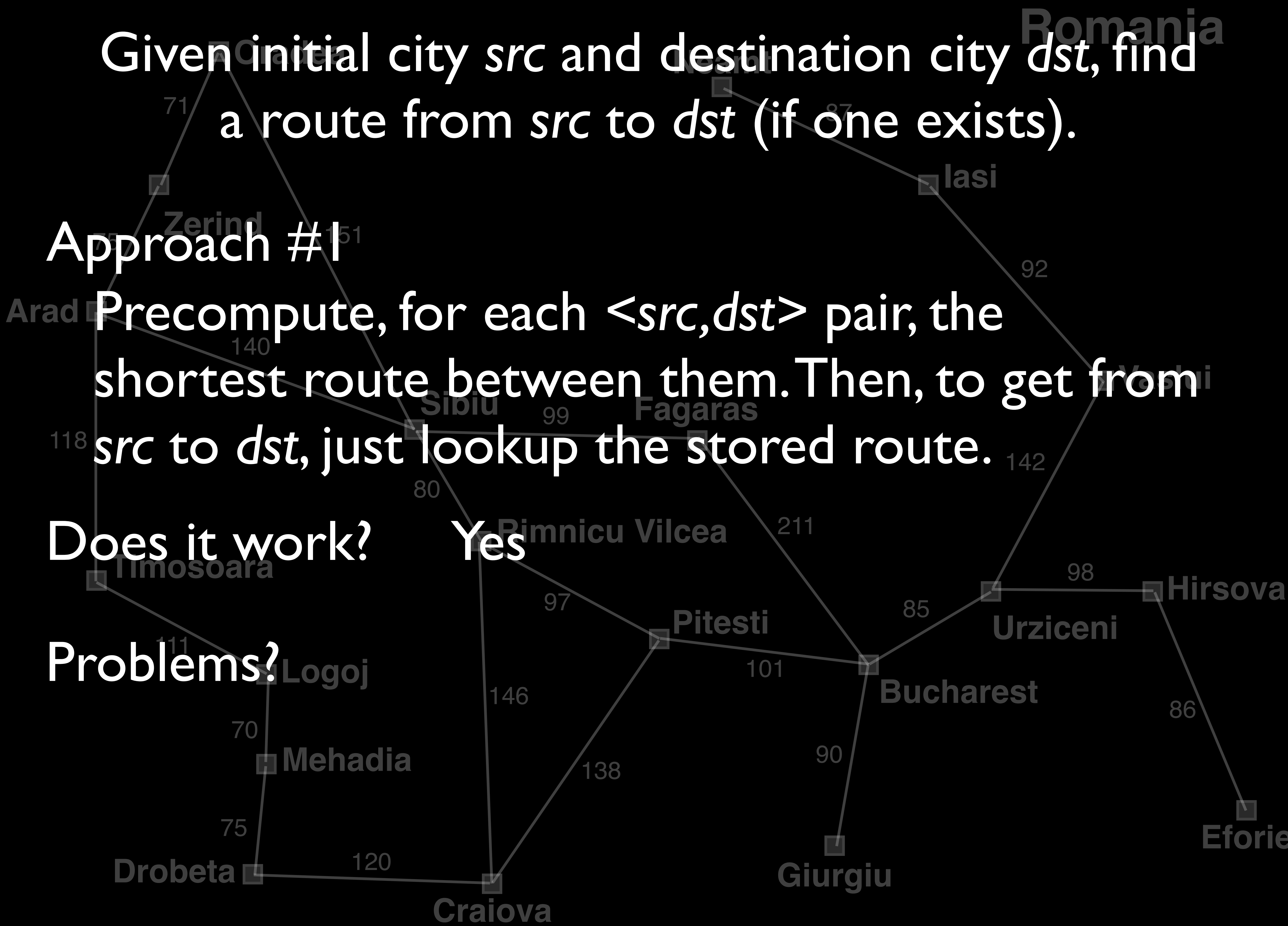
Approach #1

Precompute, for each <*src*,*dst*> pair, the shortest route between them. Then, to get from *src* to *dst*, just lookup the stored route.

Does it work? Yes





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Does it work? Yes

Problems?

Given initial city *src* and destination city *dst*, find a route from *src* to *dst* (if one exists).

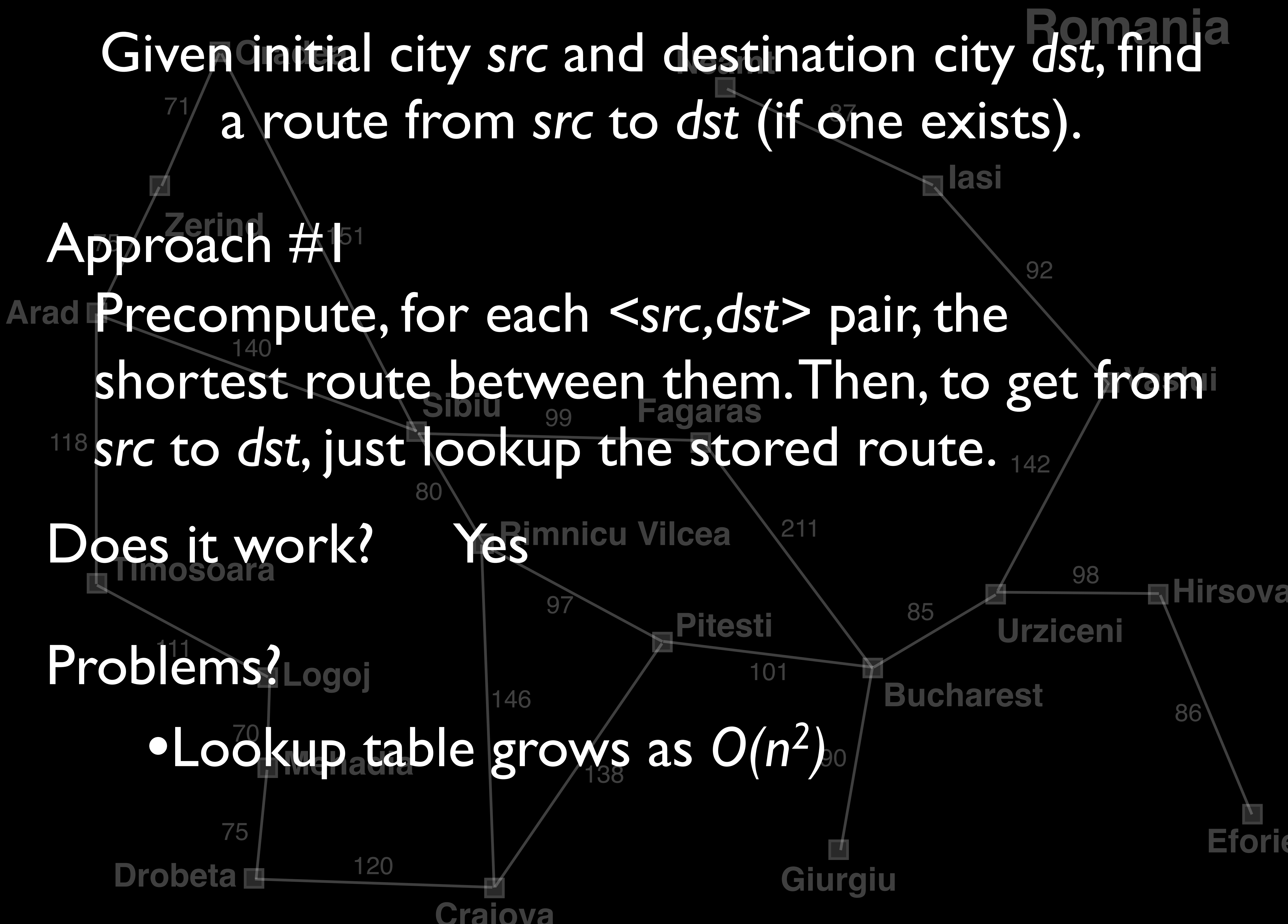
Approach #1

Precompute, for each <*src*,*dst*> pair, the shortest route between them. Then, to get from *src* to *dst*, just lookup the stored route.

Does it work? Yes

Problems?

- Lookup table grows as $O(n^2)$



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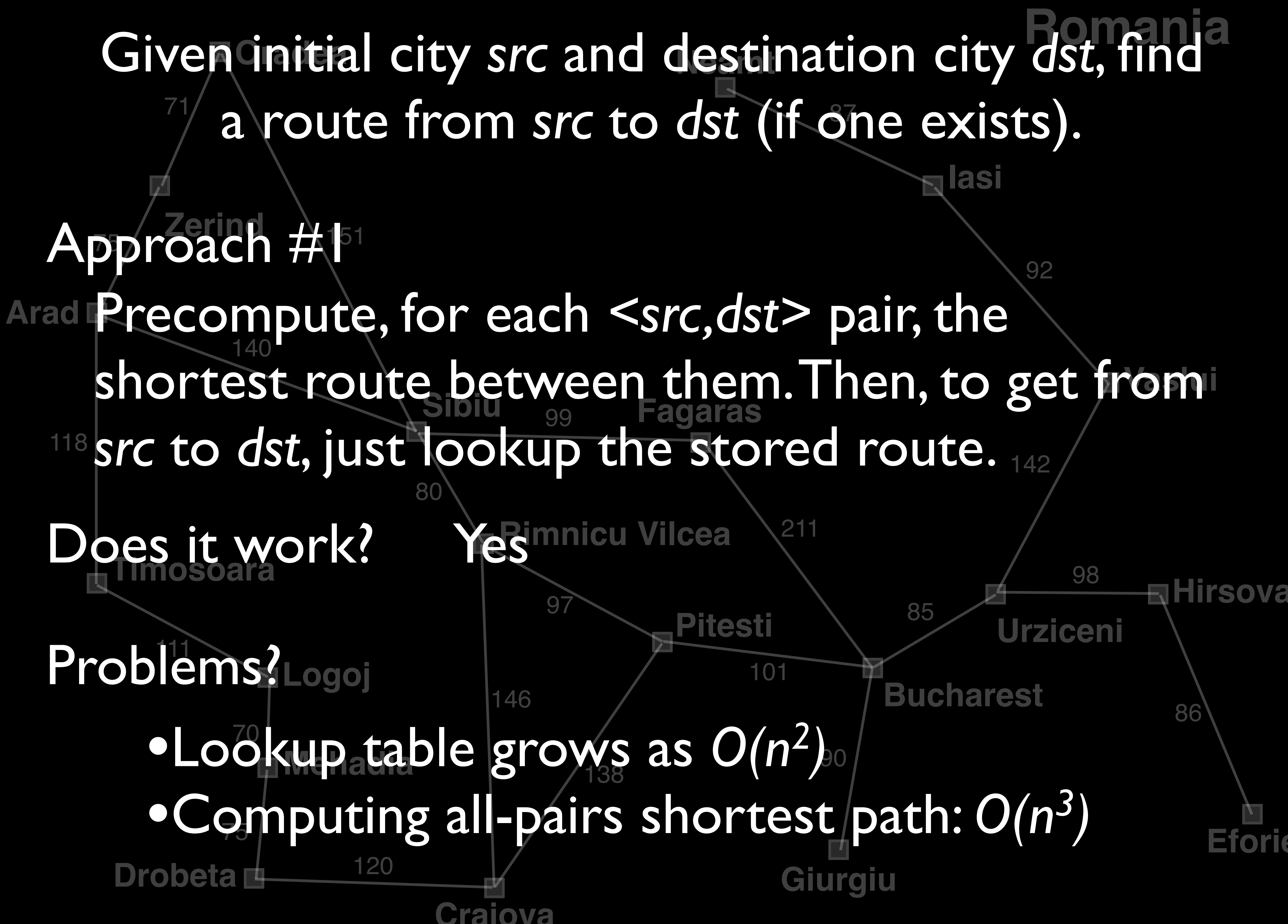
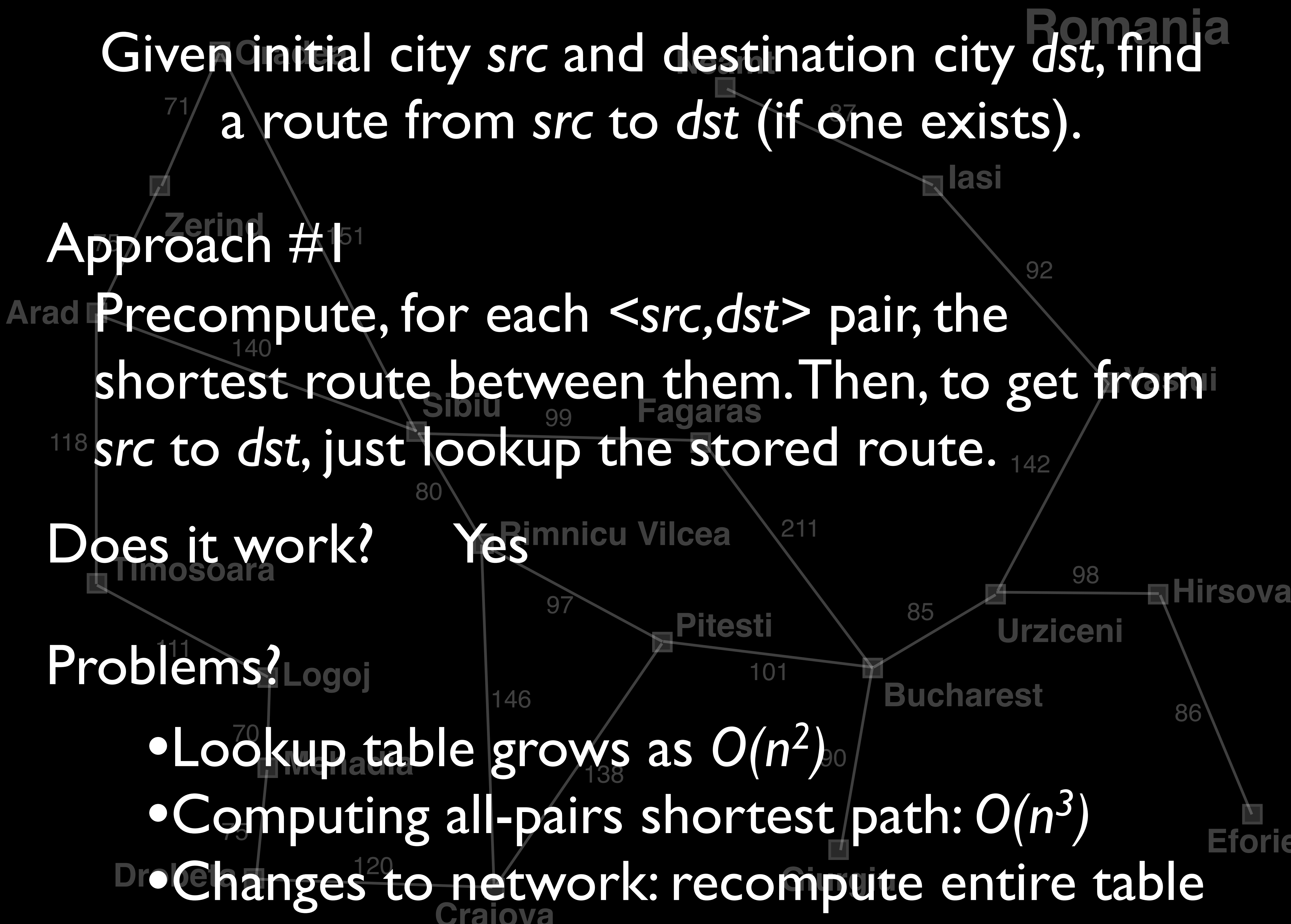
Does it work?   Yes

Problems?

- Lookup table grows as $O(n^2)$
- Computing all-pairs shortest path: $O(n^3)$





Given initial city *src* and destination city *dst*, find a route from *src* to *dst* (if one exists).

Approach #1

Precompute, for each <*src*,*dst*> pair, the shortest route between them. Then, to get from *src* to *dst*, just lookup the stored route.

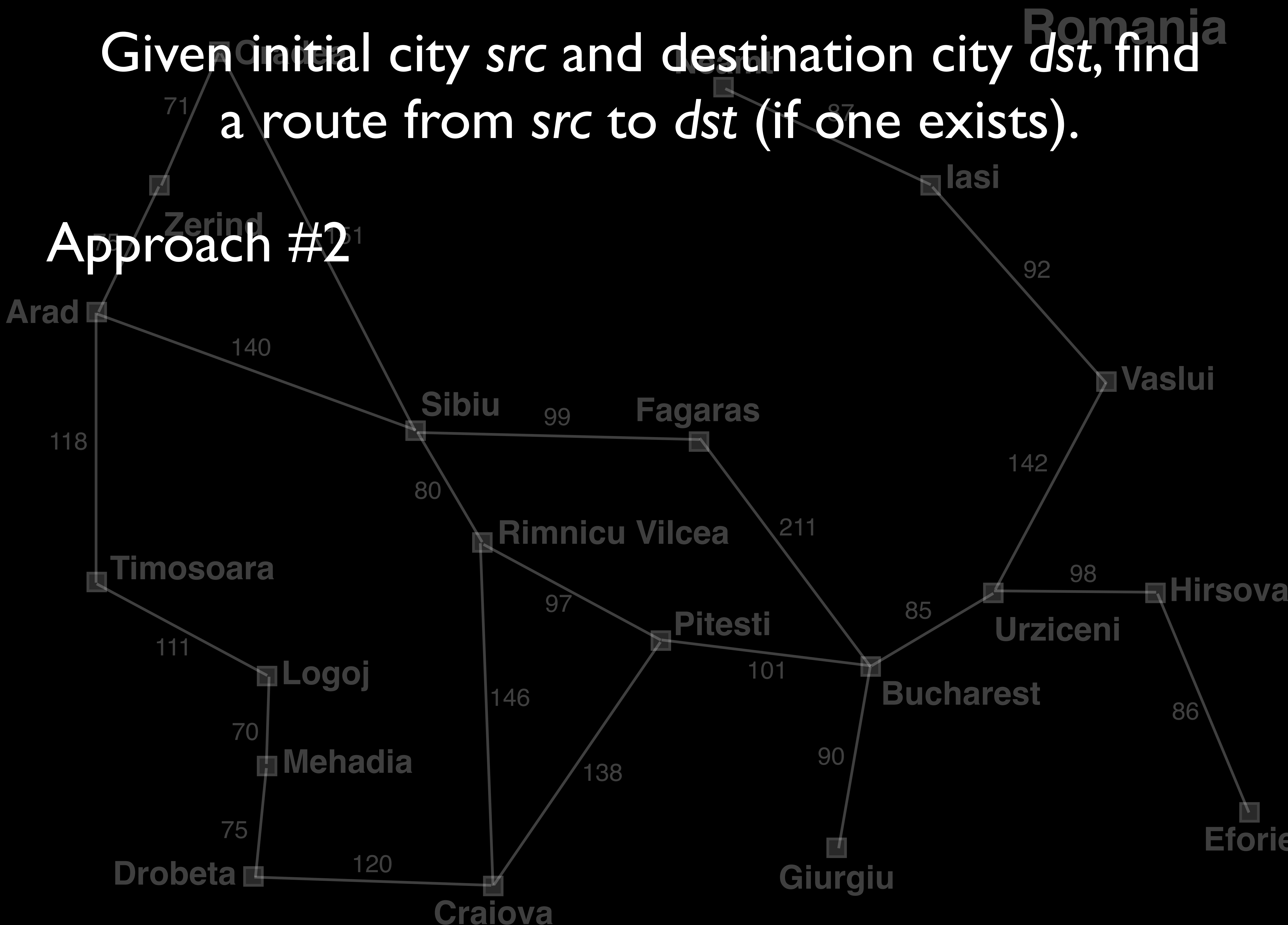
Does it work? Yes

Problems?

- Lookup table grows as $O(n^2)$
- Computing all-pairs shortest path: $O(n^3)$
- Changes to network: recompute entire table

Given initial city *src* and destination city *dst*, find a route from *src* to *dst* (if one exists).

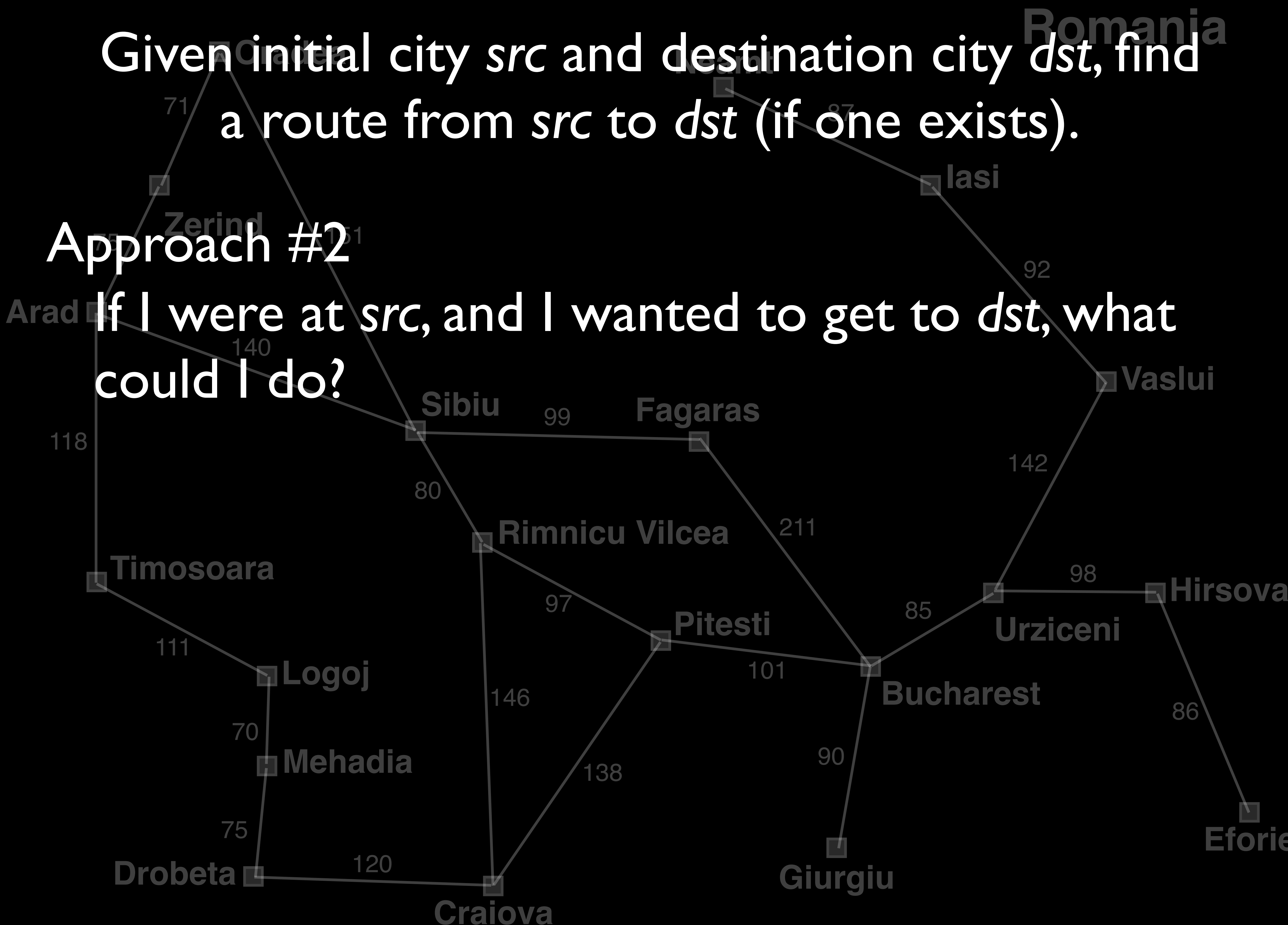
Approach #2



Given initial city *src* and destination city *dst*, find a route from *src* to *dst* (if one exists).

Approach #2

If I were at *src*, and I wanted to get to *dst*, what could I do?

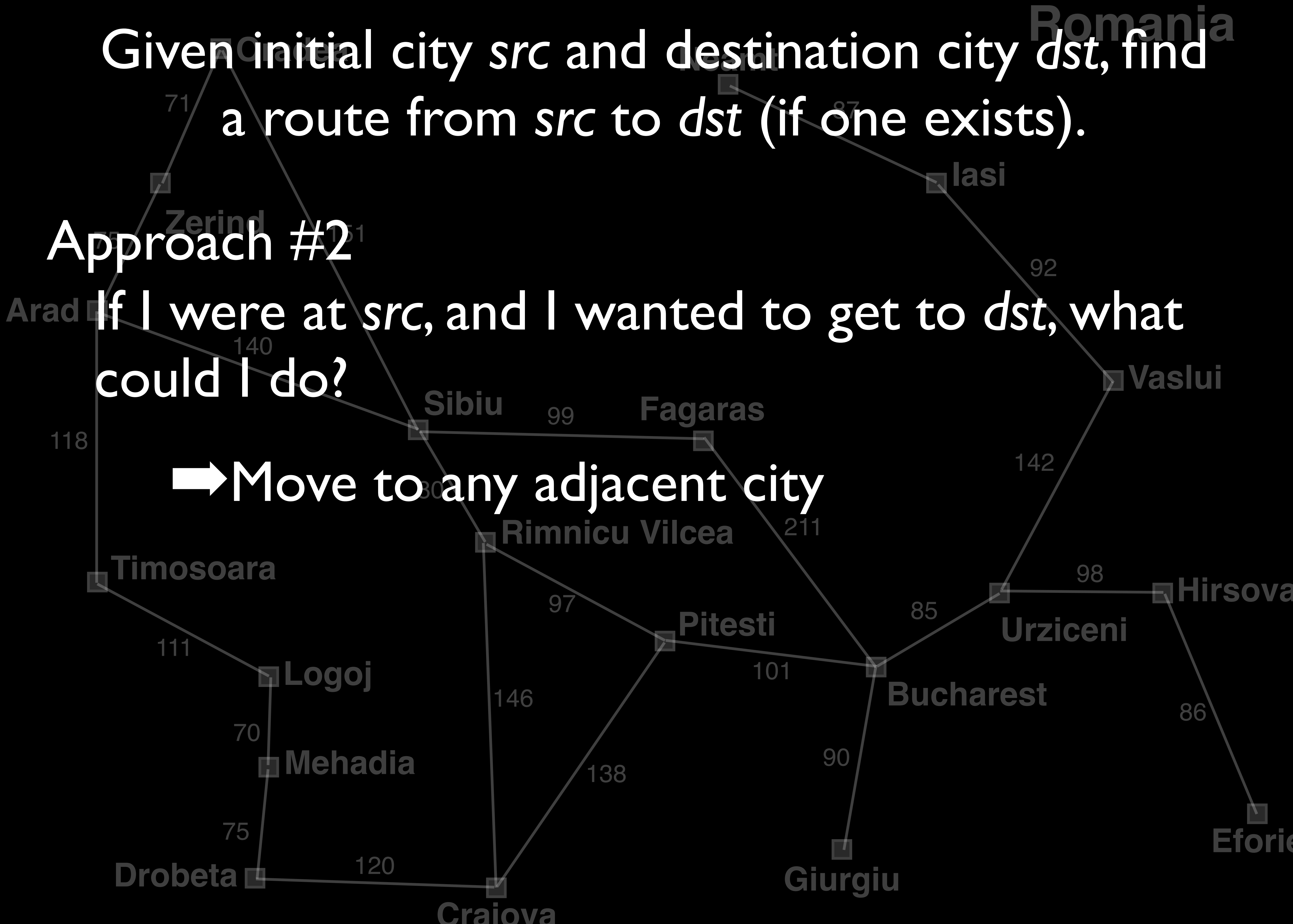


Given initial city *src* and destination city *dst*, find a route from *src* to *dst* (if one exists).

Approach #2

If I were at *src*, and I wanted to get to *dst*, what could I do?

➡Move to any adjacent city



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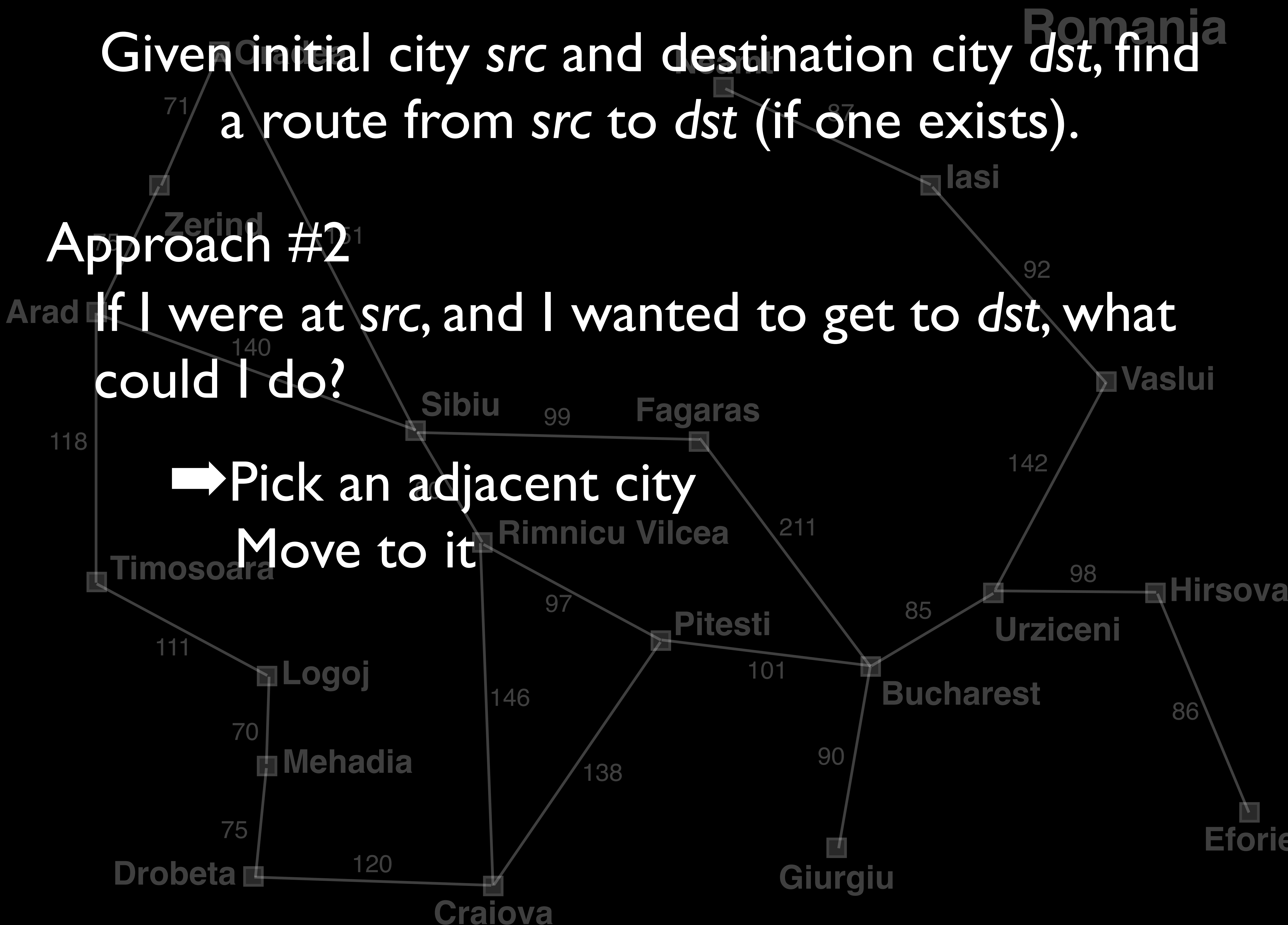


Approach #2

If I were at *src*, and I wanted to get to *dst*, what could I do?

➡ Pick an adjacent city
Move to it

Given initial city *src* and destination city *dst*, find a route from *src* to *dst* (if one exists).

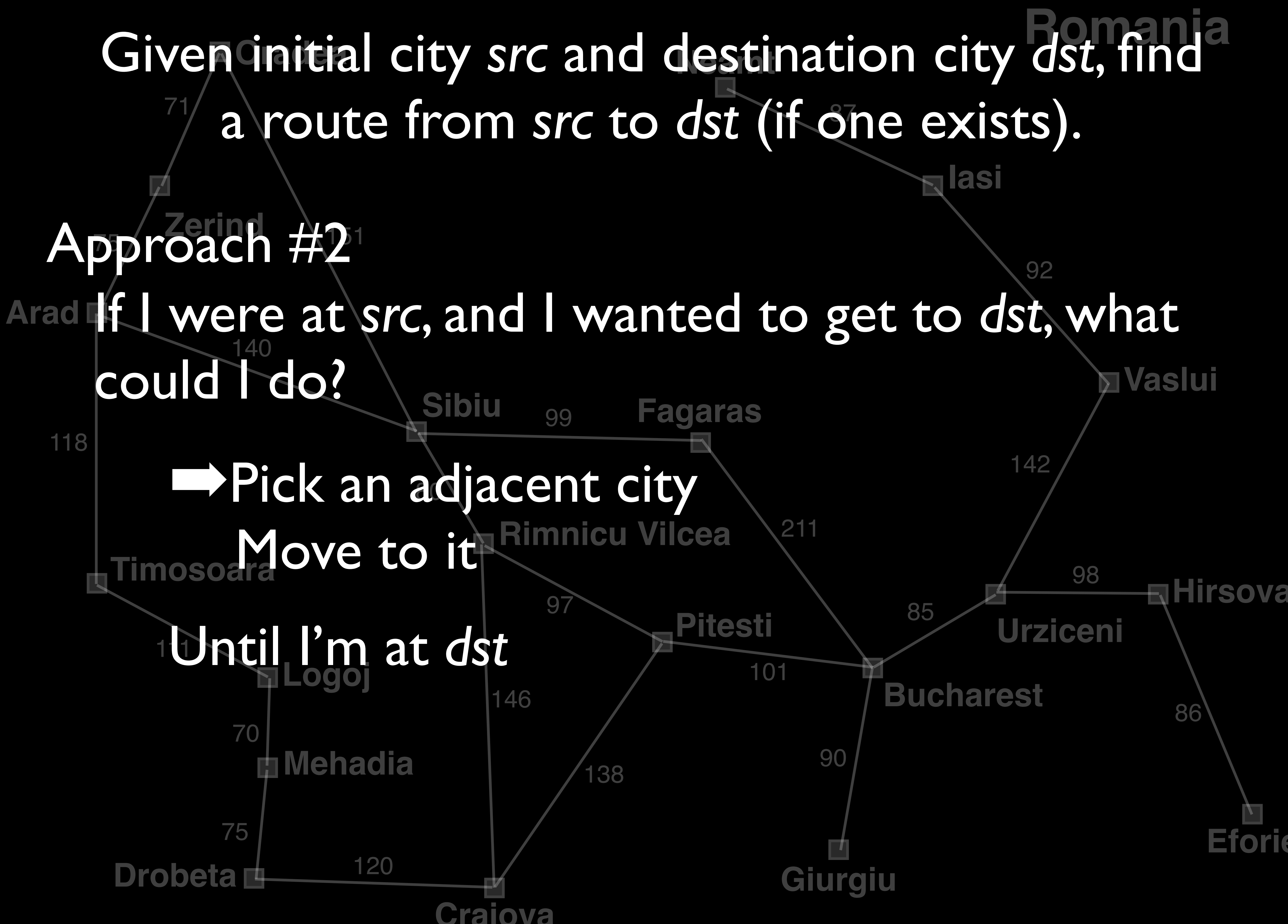
Approach #2

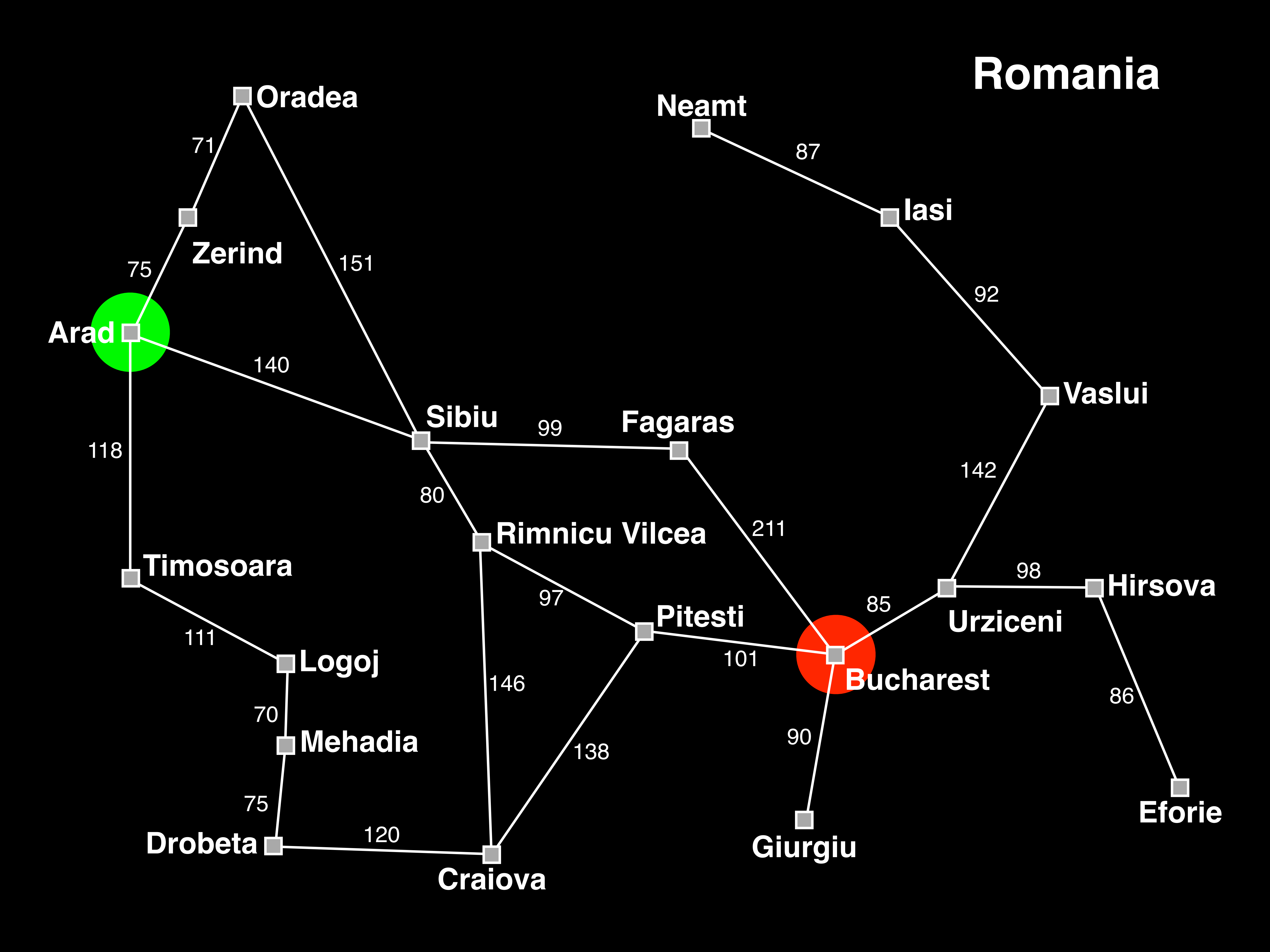
If I were at *src*, and I wanted to get to *dst*, what could I do?

➡ Pick an adjacent city

Move to it

Until I'm at *dst*

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```
find_solution(City src, City dst) {
  City[] solution = [];
  City c = src;
  while (c != dst) {
    City[] neighbors = adjacent_cities(c);
    City next_c = select_one(neighbors);
    solution.add(next_c);
    c = next_c;
  }
  return solution;
}
```

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  }
  return solution;
}
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Problems?

Intelligence and Generality

- Intelligence includes the ability to solve many kinds of problems
- Including problems we haven't seen before
- Every new problem-solving method needs to be designed, implemented, tested, and debugged


ThinkFun
Fifteen Puzzle
INCLUDES:
INSTRUCTION BOOK WITH OVER 30 CHALLENGES
HANDY TRAVEL CASE
SCRAMBLE
SOLVE
STAINLESS STEEL CONSTRUCTION
8 to adult
Fifteen Puzzle

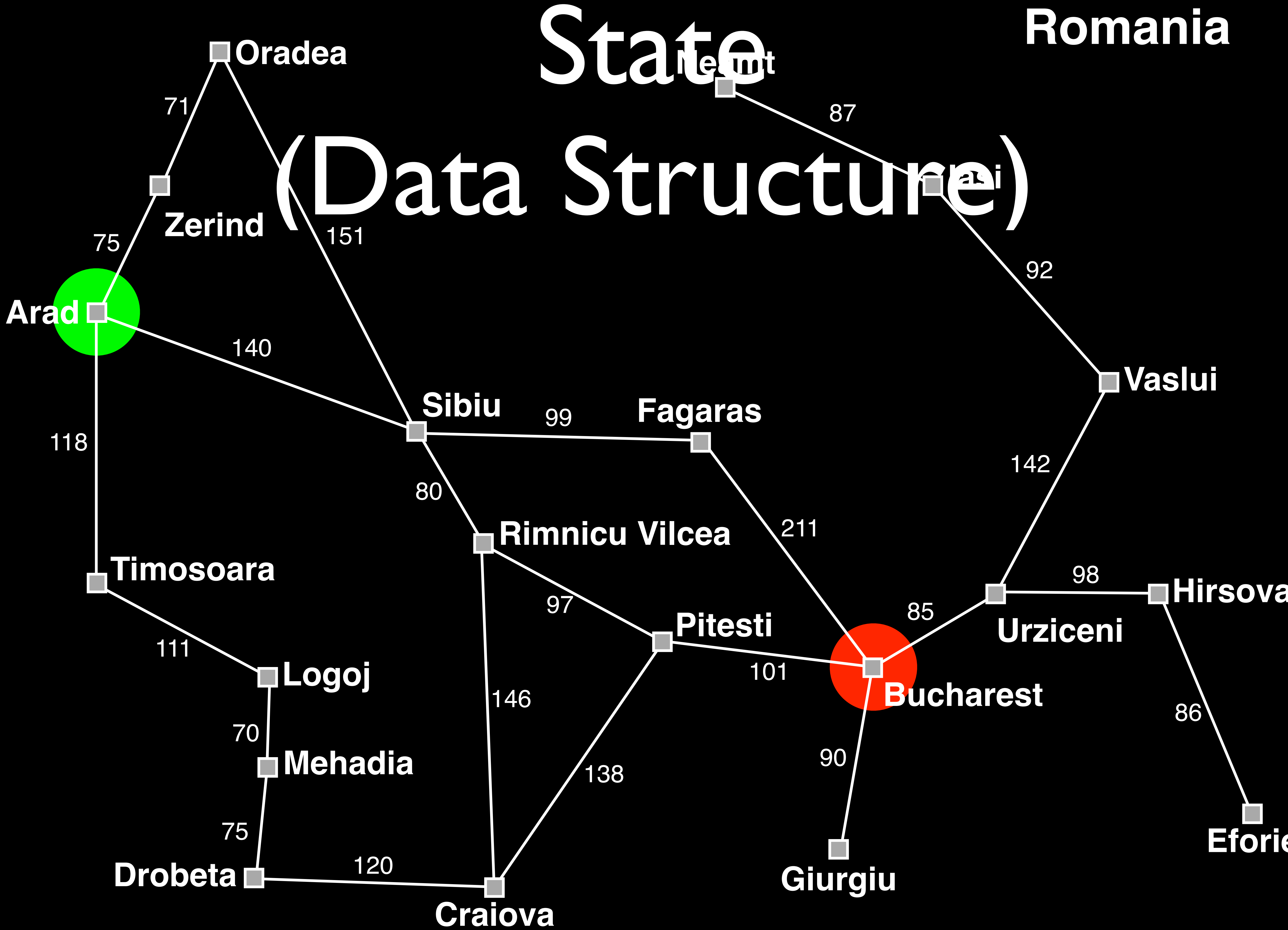
1	2	3
4	5	6
7	8	

Given initial puzzle configuration *start* and desired configuration *goal*, find a sequence of moves that goes from from *start* to *goal* (if one exists).

1	2	3
4	5	6
7	8	

State
(Data Structure)

State
(Data Structure)



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  }
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}
```

State
(Data Structure)

7		1
6	2	8
3	4	5

State
(Data Structure)

7		1
6	2	8
3	4	5

$$M_{i,j} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix}$$

State
(Data Structure)

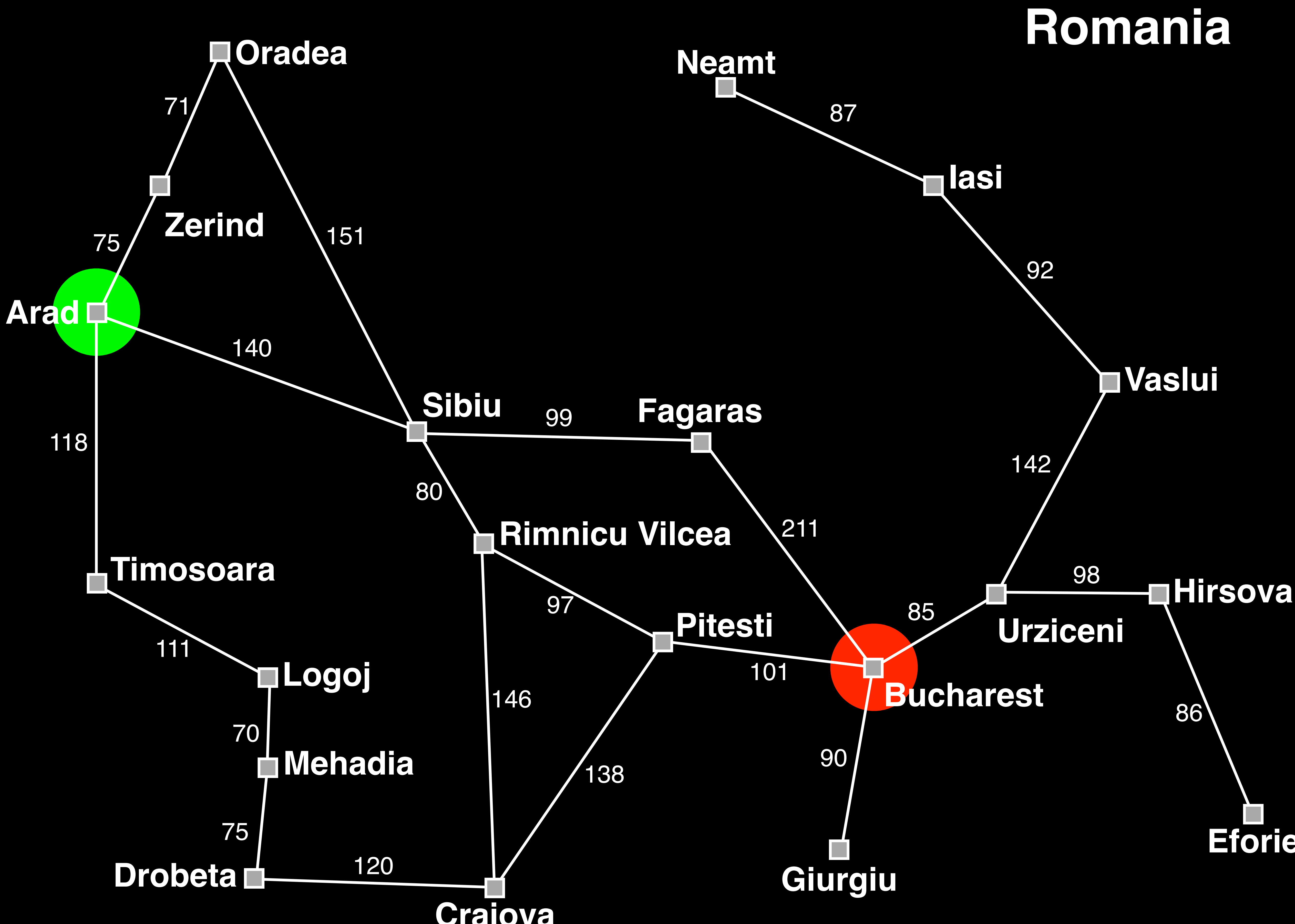
7		1
6	2	8
3	4	5

$$M_{i,j} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix}$$

```
int[][] M = new int[3][3];
M[0][0] = 7;
M[0][1] = 0;
...
M[2][2] = 5;
```

Actions

- Can be performed in a state
- Change the state to a resulting state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Urziceni
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Logoj
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Bucharest
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Mehadia
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Eforie
Drobeta
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Giurgiu
Craiova

```
find_solution(City src, City dst) {
  City[] solution = [];
  City c = src;
  while (c != dst) {
    City[] neighbors = adjacent_cities(c);
    City next_c = select_one(neighbors);
    solution.add(next_c);
    c = next_c;
  }
  return solution;
}
```

7		1
6	2	8
3	4	5

Path:

7	1	
6	2	8
3	4	5

Path: 1

7	1	8
6	2	
3	4	5

Path: 1- 8

7	1	8
6		2
3	4	5

Path: 1- 8 - 2

7	1	8
	6	2
3	4	5

Path: 1- 8 - 2 - 6

7		1
6	2	8
3	4	5

Path:

7	1	
6	2	8
3	4	5

Path: East

7	1	8
6	2	
3	4	5

Path: East - South

7	1	8
6		2
3	4	5

Path: East - South - West -

7	1	8
	6	2
3	4	5

Path: East - South - West - West

Actions

- For any state and action:
  - Can I perform this action in this state?
    - “Applicability”
  - How do I update the state if this action is performed?
    - “Result” or “transition” function

$$M^{\mathrm{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\mathrm{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

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Approach #1

Precompute, for each <M^{in},M^{G}> pair, a sequence of moves that transforms M^{in} into M^{G}. Then, to solve M^{in}, just lookup the stored sequence.

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #1

Precompute, for each <M^{in},M^G> pair, a sequence of moves that transforms M^{in} into M^G. Then, to solve M^{in}, just lookup the stored sequence.

Does it work?

$$M^{\mathrm{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\mathrm{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #1

Precompute, for each <M^{in},M^{G}> pair, a sequence of moves that transforms M^{in} into M^{G}. Then, to solve M^{in}, just lookup the stored sequence.

Does it work? No

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #1

Precompute, for each <M^{in},M^{G}> pair, a sequence of moves that transforms M^{in} into M^{G}. Then, to solve M^{in}, just lookup the stored sequence.

Does it work? No

Problems?

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Approach #1

Precompute, for each <M^{in},M^{G}> pair, a sequence of moves that transforms M^{in} into M^{G}. Then, to solve M^{in}, just lookup the stored sequence.

Does it work? No

Problems?

- There are 9! = 362880 (*O(n!)* in general) cases

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #1

Precompute, for each <M^{in},M^{G}> pair, a sequence of moves that transforms M^{in} into M^{G}. Then, to solve M^{in}, just lookup the stored sequence.

Does it work? No

Problems?

- There are 9! = 362880 (*O(n!)* in general) cases
- No obvious way to solve the <M^{in},M^{G}> cases

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #1

Precompute, for each <M^{in},M^G> pair, a sequence of moves that transforms M^{in} into M^G. Then, to solve M^{in}, just lookup the stored sequence.

Does it work? No

Problems?

- There are 9! = 362880 ($O(n!)$ in general) cases
- No obvious way to solve the <M^{in},M^G> cases
- This problem is known to be NP-complete

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #2

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #2

- If the puzzle is currently M, and I want it to be M^G, what could I do?

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #2

If the puzzle is currently M, and I want it to be M^G, what could I do?

➡Move the blank to an adjacent space

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #2

If the puzzle is currently M, and I want it to be M^G, what could I do?

➡Pick an adjacent space
Move the blank to it

$$M^{\text{in}} = \begin{bmatrix} 7 & 0 & 1 \\ 6 & 2 & 8 \\ 3 & 4 & 5 \end{bmatrix} \qquad M^{\text{G}} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

Approach #2

If the puzzle is currently M, and I want it to be M^G, what could I do?

➡Pick an adjacent space
Move the blank to it

Until $M == M^G$

Given initial city *src* and destination city *dst*, find a route from *src* to *dst* (if one exists).

Approach #2

If I were at *src*, and I wanted to get to *dst*, what could I do?

➡Pick an adjacent city
Move to it

Until I'm at *dst*

Initial state: S^{IN} Goal state: S^{G}

If the problem state is currently S, and I want it to be S^{G}, what could I do?

➡Pick an applicable action A
Update S with the result of applying A

Until $S == S^{G}$

```
find_solution(State initial) {
  State s = initial;
  Action[] solution = [];
  while (!is_goal(s)) {
    Action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

state

```
find_solution(State initial) {
  State s = initial;
  Action[] solution = [];
  while (!is_goal(s)) {
    Action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

initial state

```
find_solution(State initial) {
  State s = initial;
  Action[] solution = [];
  while (!is_goal(s)) {
    Action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

```
find_solution(State initial) {
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  while (!is_goal(s)) {
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  return solution;
}
```

goal test

```
find_solution(State initial) {
  State s = initial;
  Action[] solution = [];
  while (!is_goal(s)) {
    Action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

action

```
find_solution(State initial) {
  State s = initial;
  Action[] solution = [];
  while (!is_goal(s)) {
    Action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

applicable actions

```
find_solution(State initial) {
  State s = initial;
  Action[] solution = [];
  while (!is_goal(s)) {
    Action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

transition function

```
find_solution(State initial) {
  State s = initial;
  Action[] solution = [];
  while (!is_goal(s)) {
    Action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

solution

```
find_solution(State initial) {
  State s = initial;
  Action[] solution = [];
  while (!is_goal(s)) {
    Action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

Problem (Domain): $\langle \mathcal{S}, \mathcal{A}, \textsc{Actions}, \textsc{Result} \rangle$

$$\textsc{Actions} : s \in \mathcal{S} \rightarrow$$

$$\{a \in \mathcal{A} : a \text{ can be executed (is applicable) in } s\}$$

$$\textsc{Result} : s \in \mathcal{S}, a \in \mathcal{A} \rightarrow$$

$$s' : s' \in \mathcal{S} \text{ s.t. } s' \text{ is the result of performing } a \text{ in } s$$

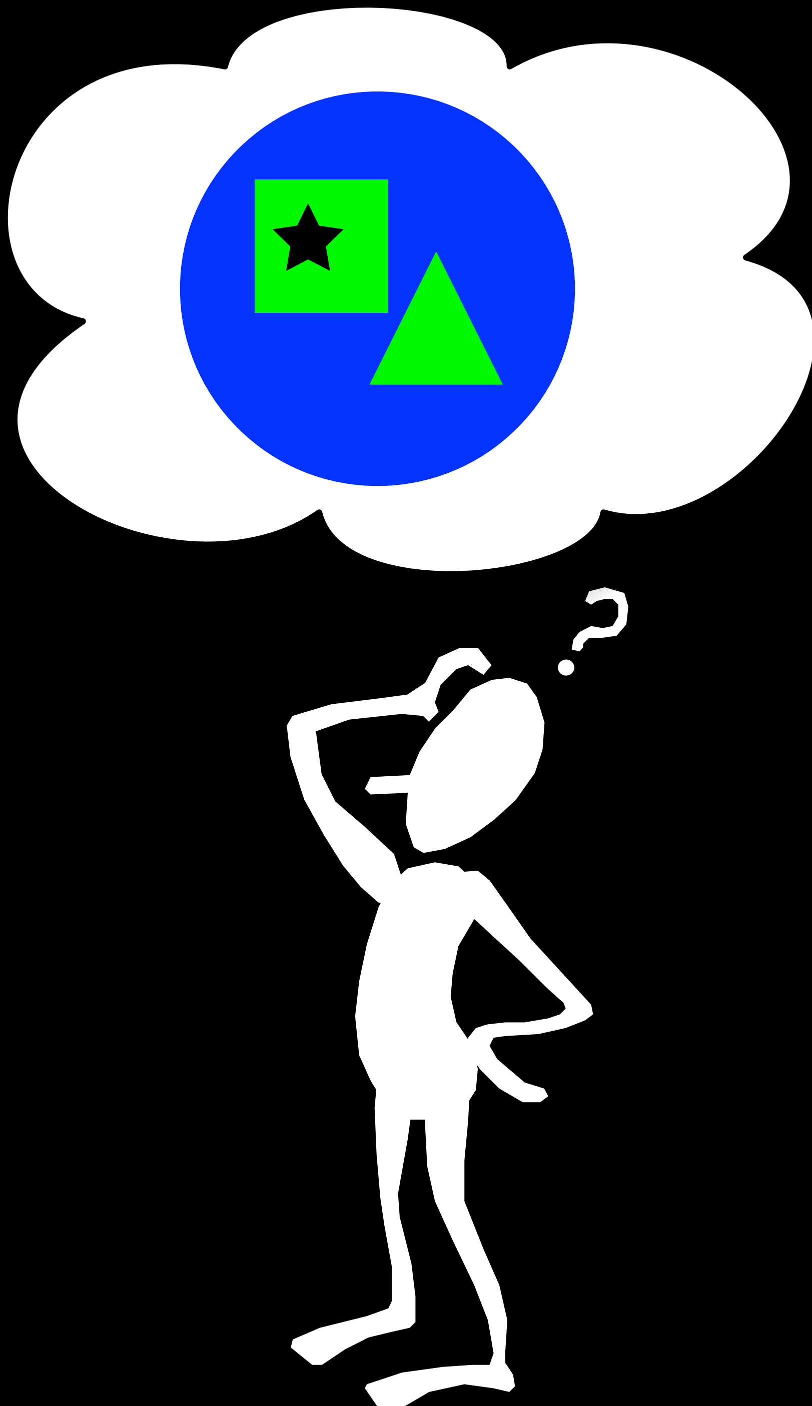
Problem (Instance): $\langle \mathcal{I} \in \mathcal{S}, \mathcal{G} \subseteq \mathcal{S} \rangle$

Solution: $\langle a_0, a_1, \ldots, a_n \rangle \in \mathcal{A}$ s.t.

$$\textsc{Result}(\cdots \textsc{Result}(\textsc{Result}(\mathcal{I}, a_0), a_1) \cdots, a_n) \in \mathcal{G}$$

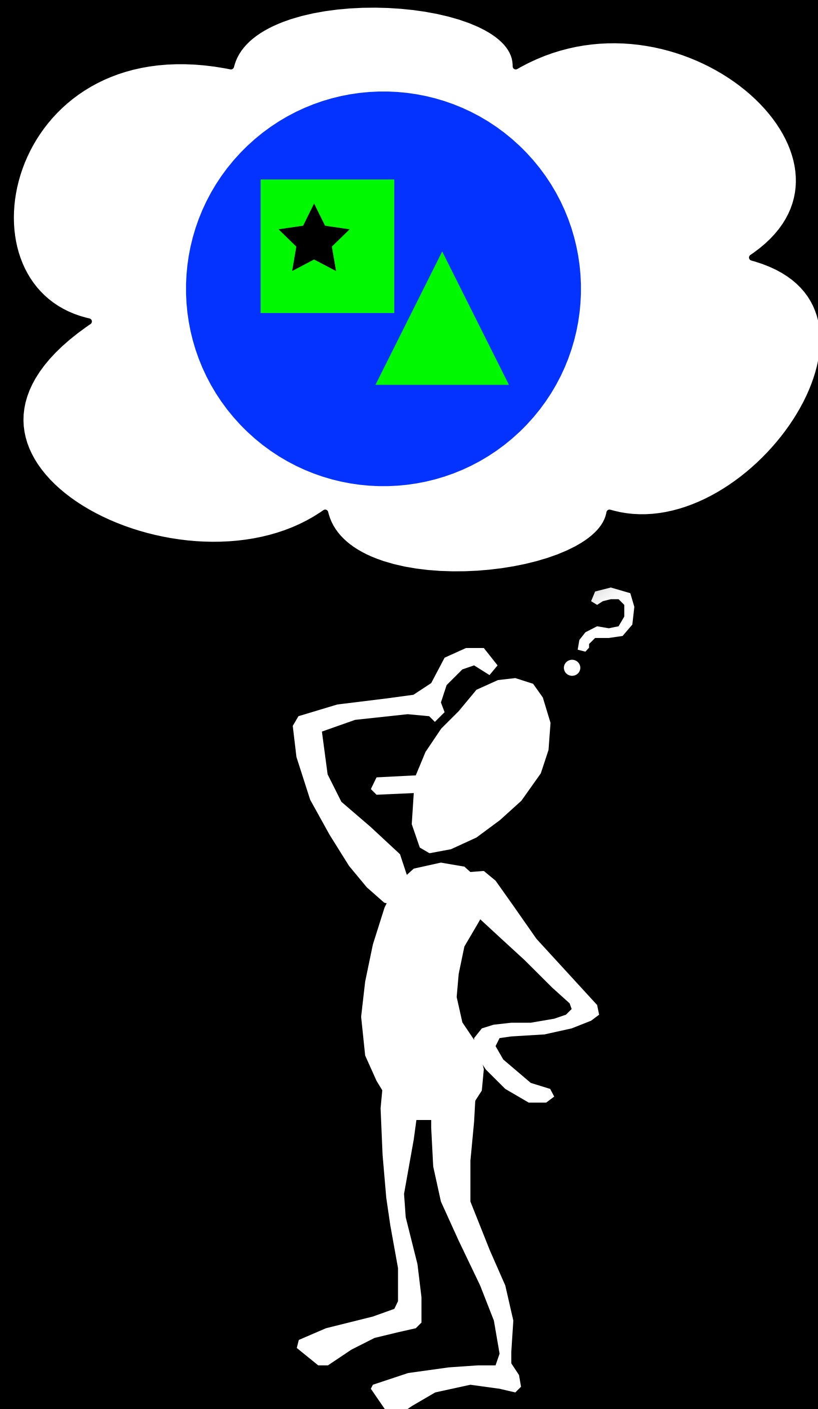
World state

World state



Problem-solving state

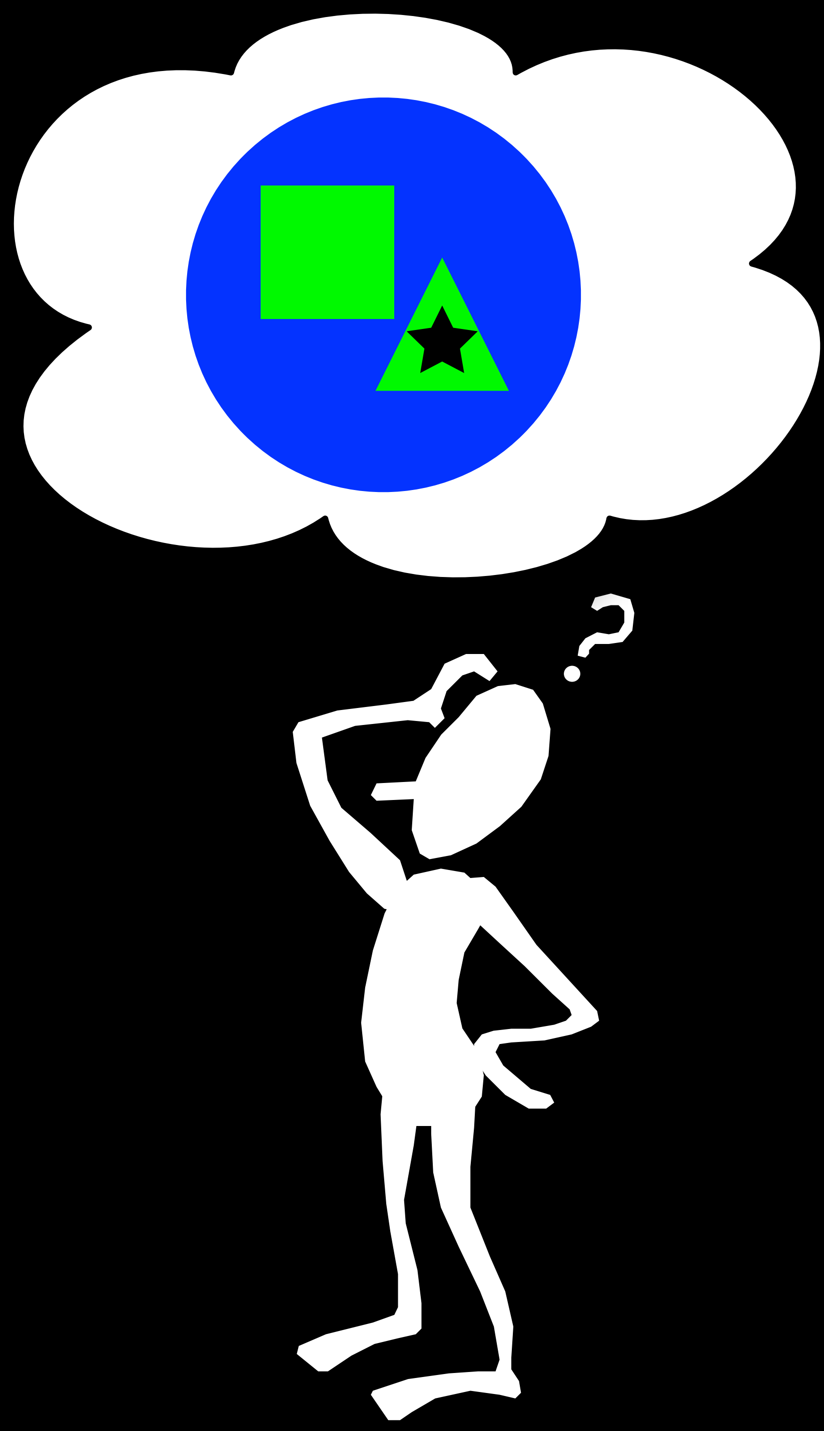
World state



Problem-solving state

World state

Action



Problem-solving state

Transition Model

World state

Action

Universal Problem-Solving Procedure

```
find_solution(initial) {
  state s = initial;
  action[] solution = [];
  while (!is_goal(s)) {
    action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

Are We Done Yet?

```
find_solution(initial) {
  state s = initial;
  action[] solution = [];
  while (!is_goal(s)) {
    action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```


FAILARMY


FAILARMY

Are We Done Yet?

```
find_solution(initial) {
  state s = initial;
  action[] solution = [];
  while (!is_goal(s)) {
    action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

Are We Done Yet?

```
find_solution(initial) {
  state s = initial;
  action[] solution = [];
  while (!is_goal(s)) {
    action a = pick(actions(s));
    solution.add(a);
    s = result(s, a);
  }
  return solution;
}
```

FAIL

State-Space Search

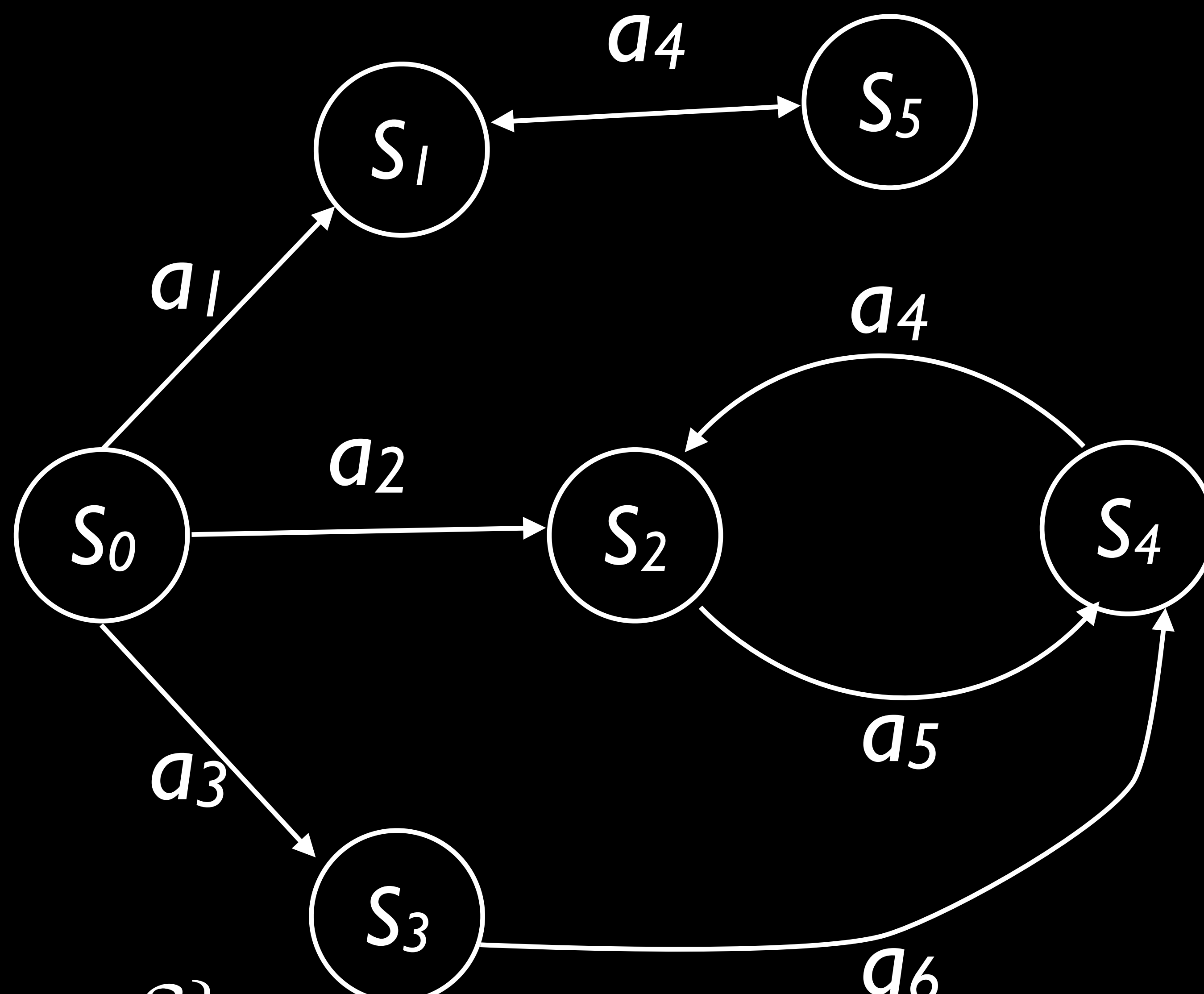
States + Actions + Transition Model

=

State Space

The set of all states reachable from the initial state by some sequence of actions

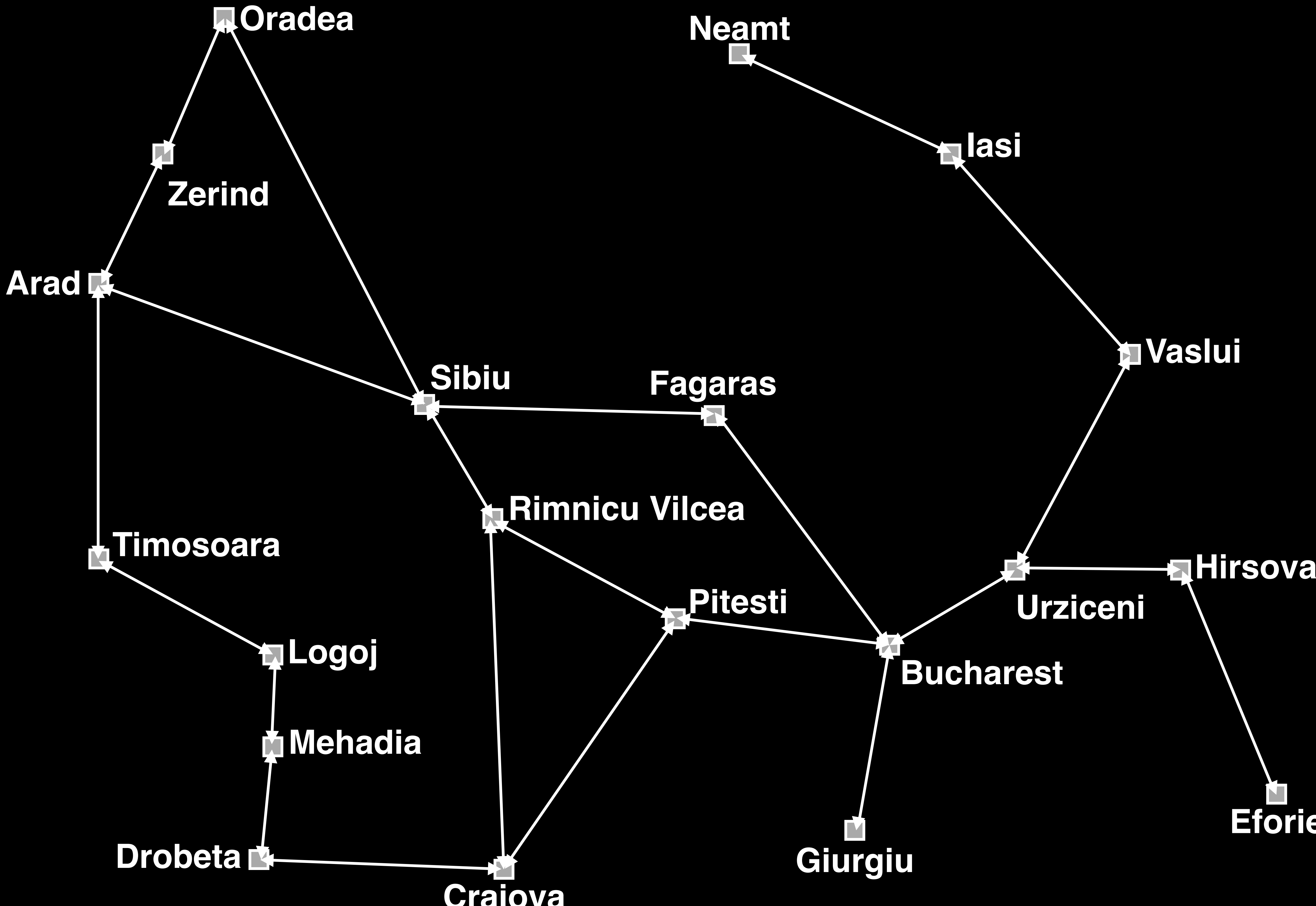
State Space



$\langle V, E \rangle :$

$$V = \{v_i \mid s_i \in \mathcal{S}\}$$

$$E = \{\langle v_i, v_j, a \rangle \mid s_j = \textsc{Result}(s_i, a)\}$$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Drobeta
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7	2	1
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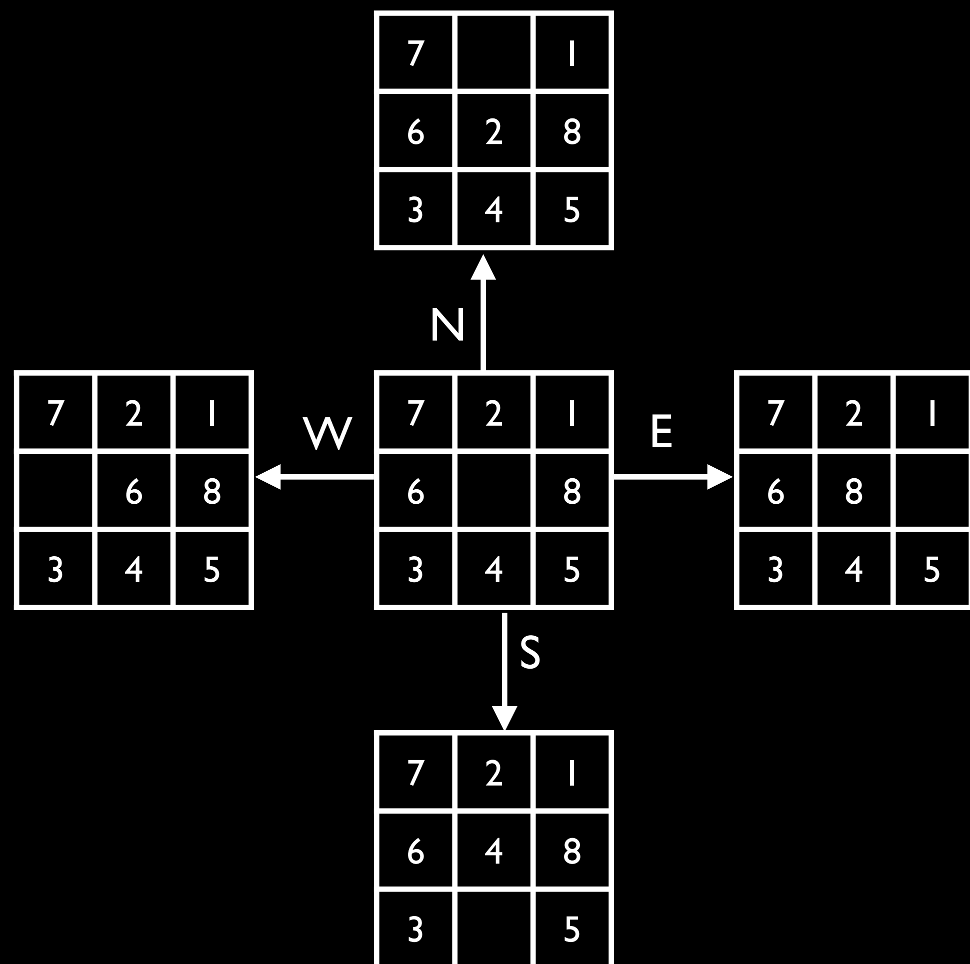

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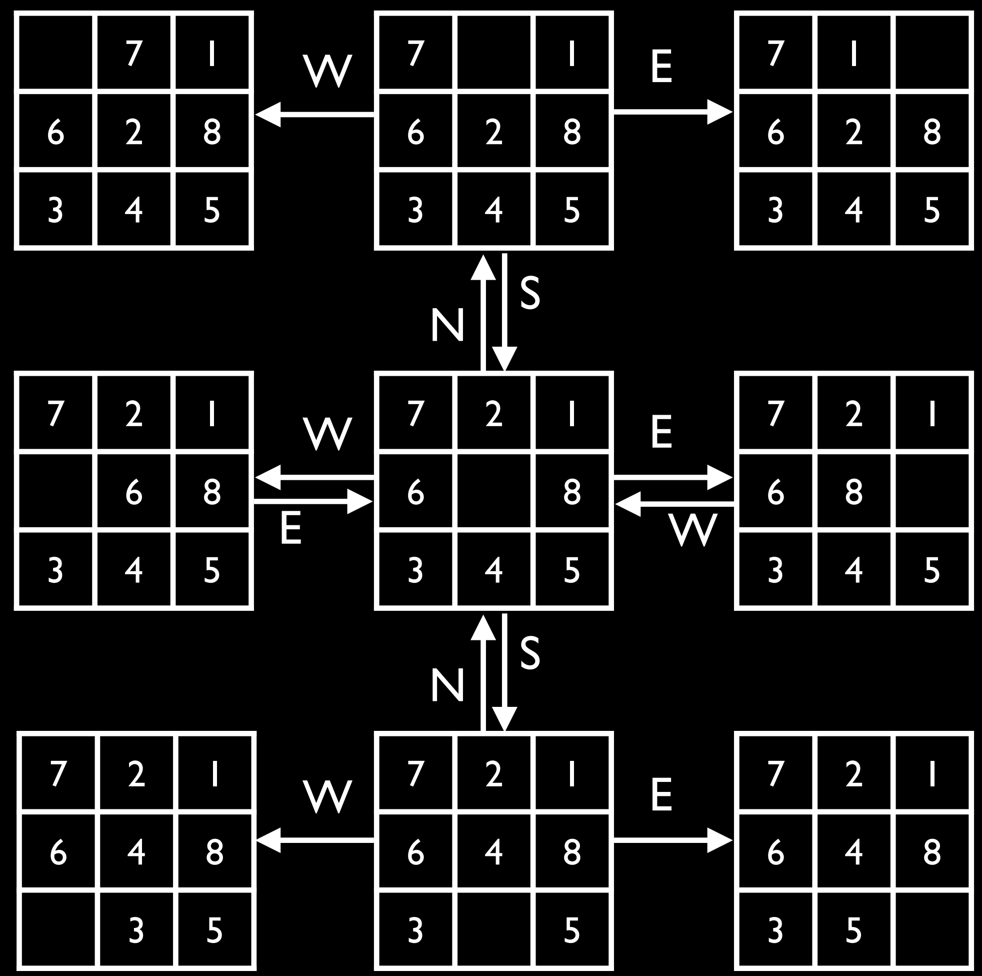

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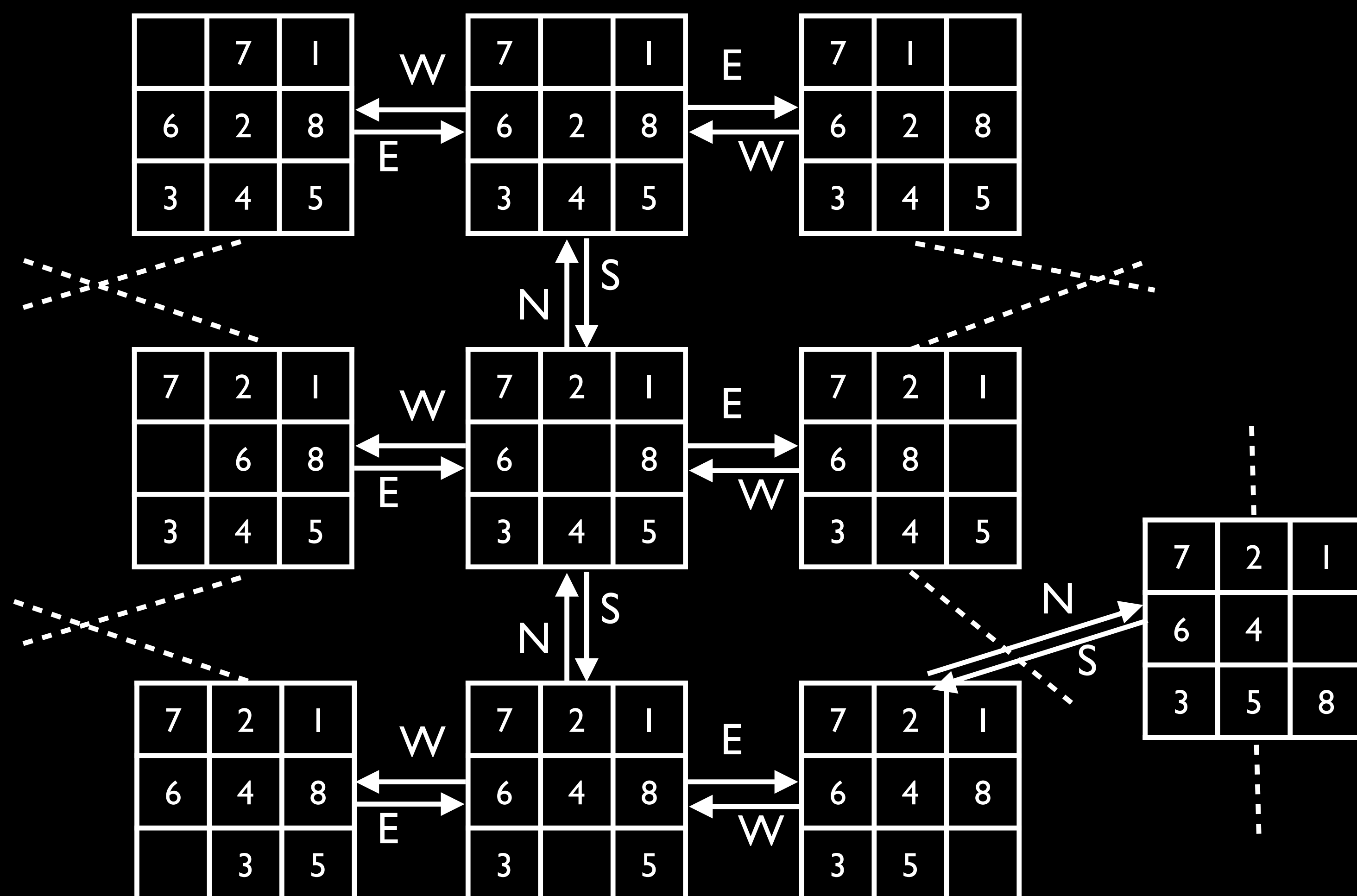

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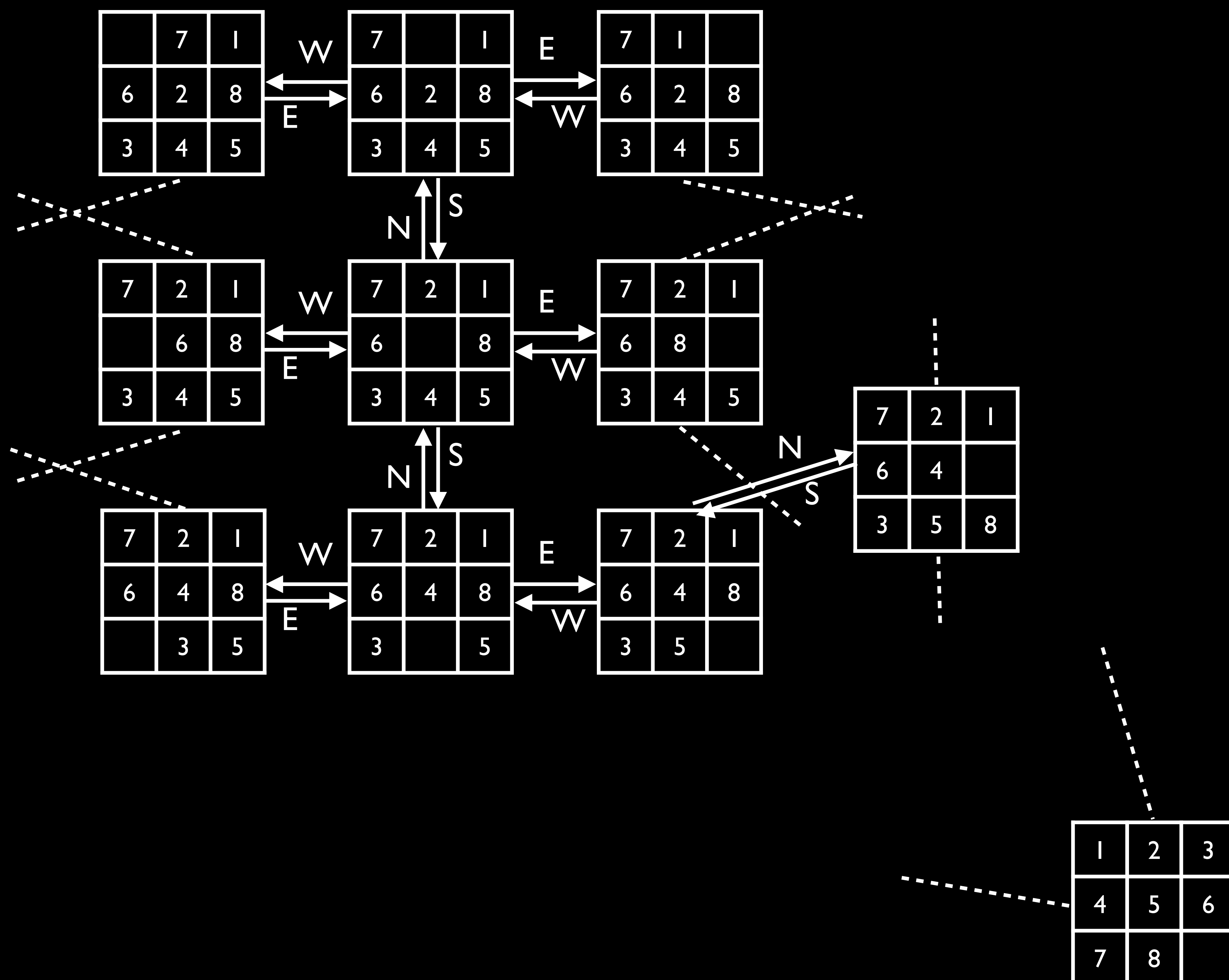
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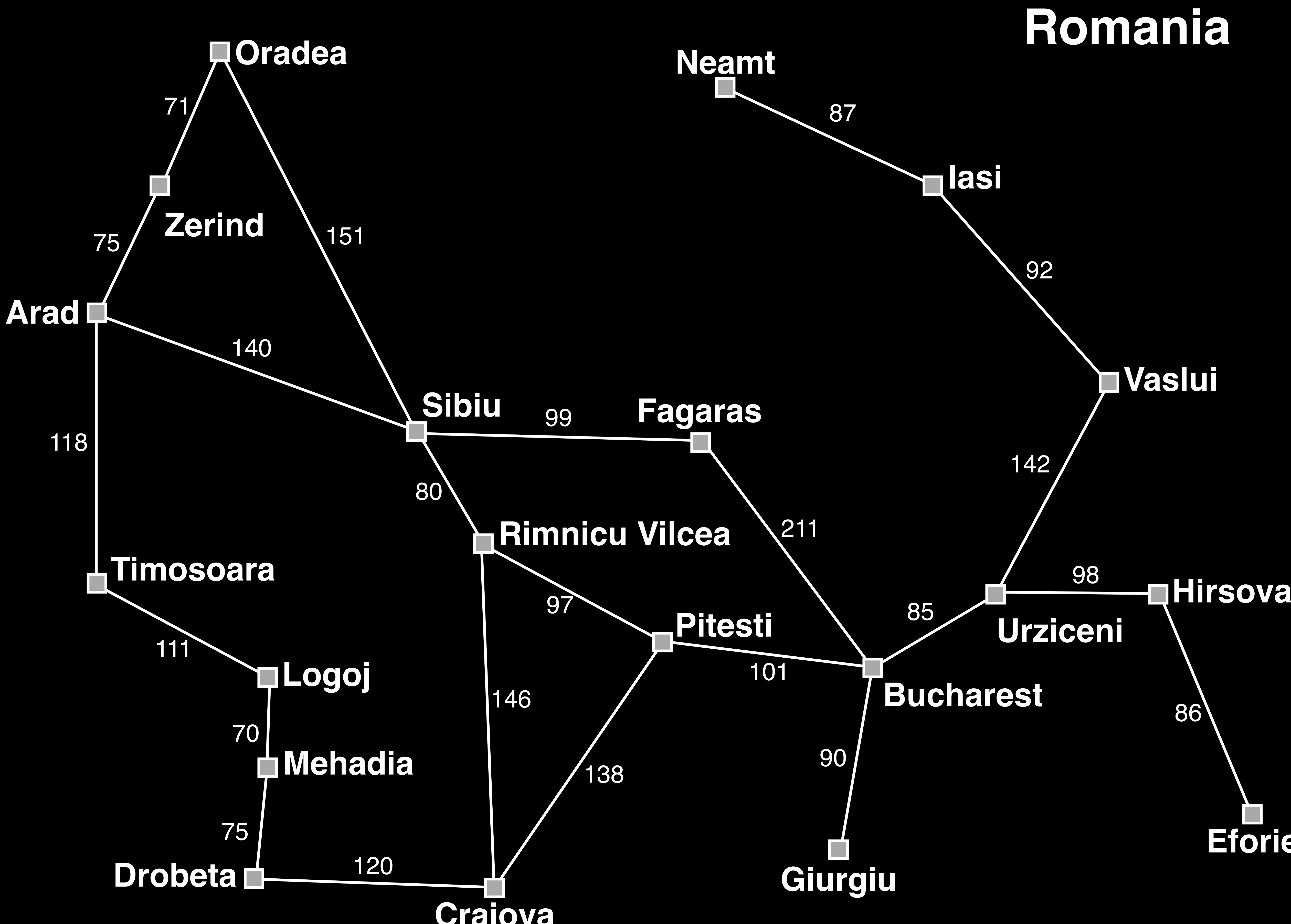
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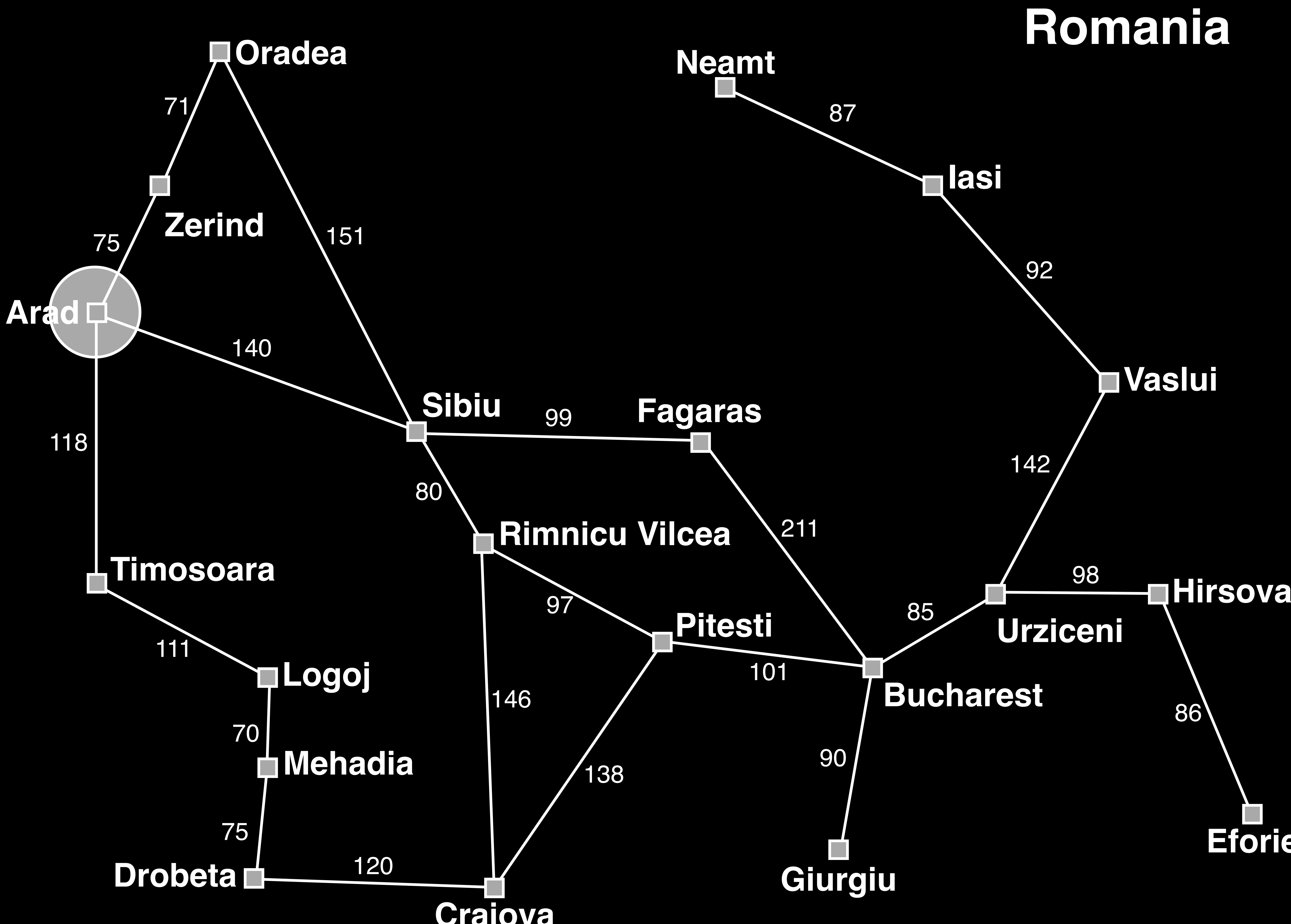

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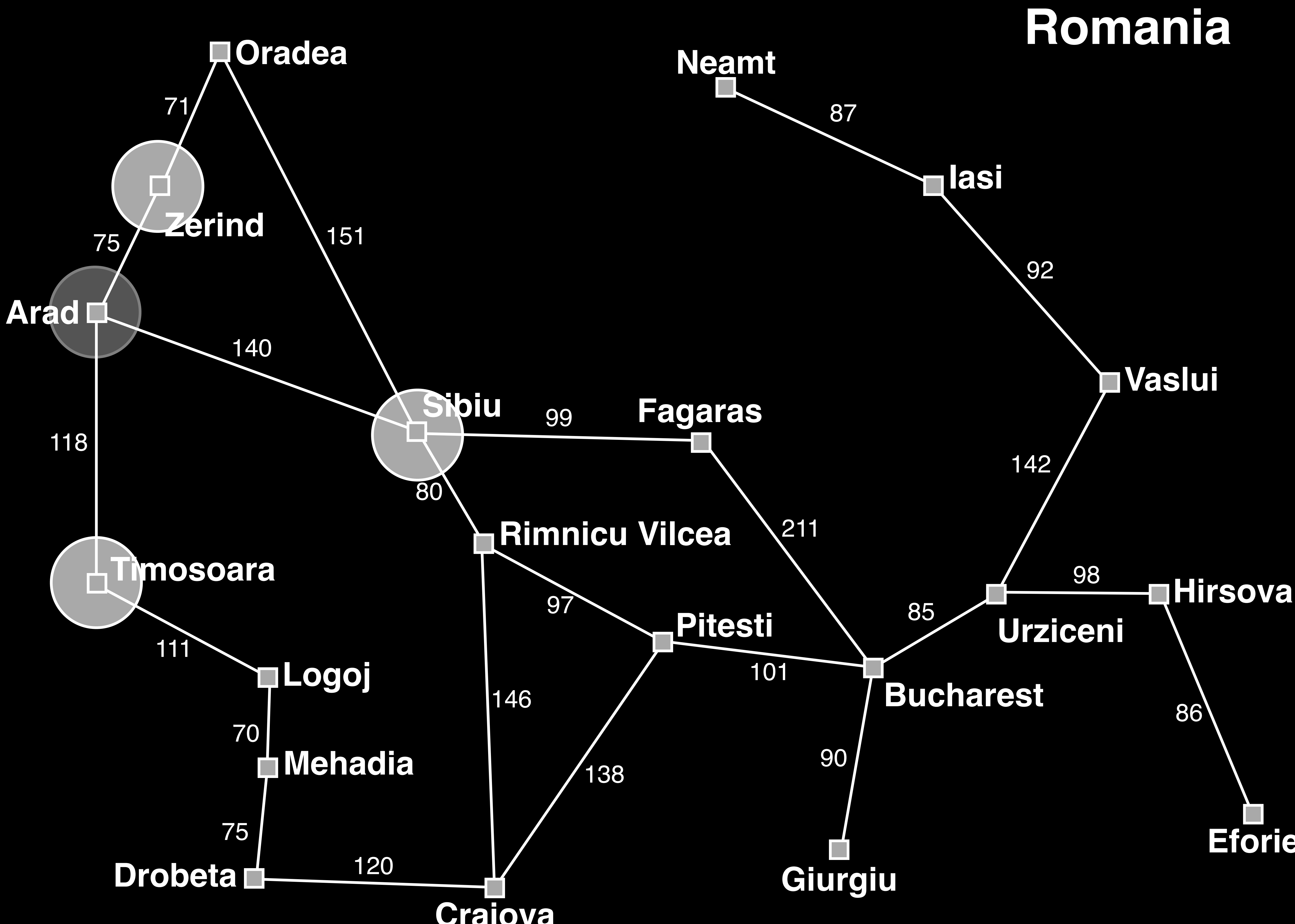
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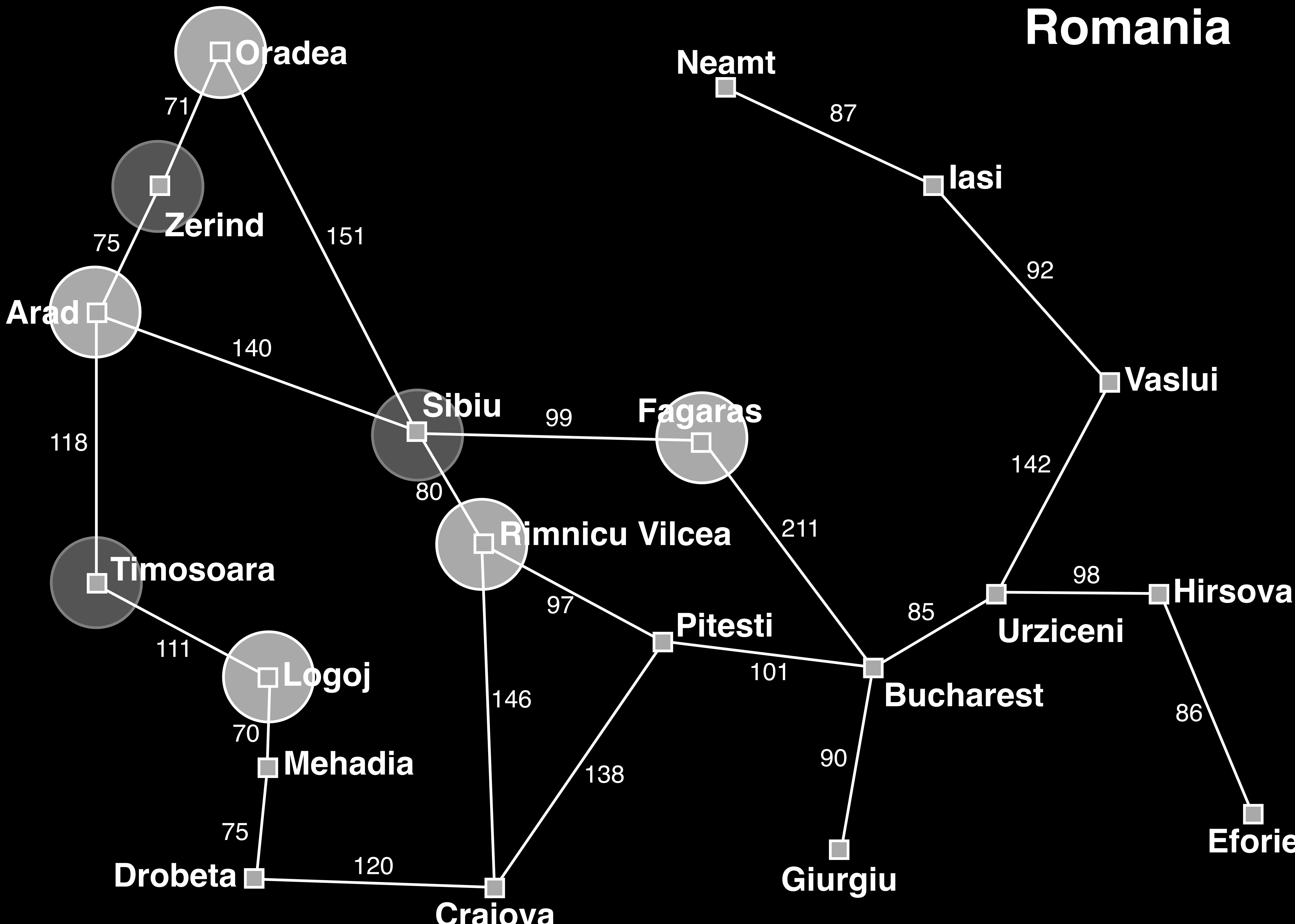

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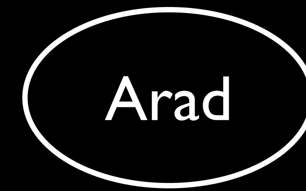
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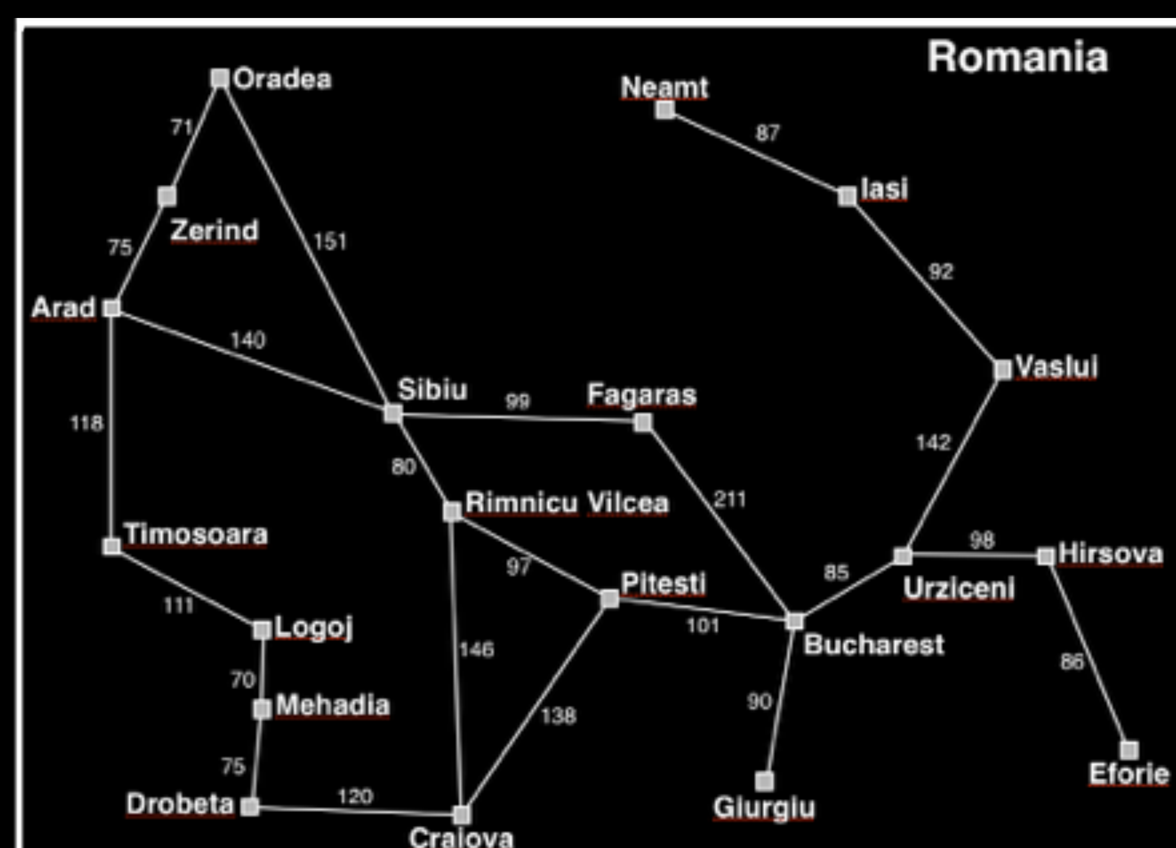
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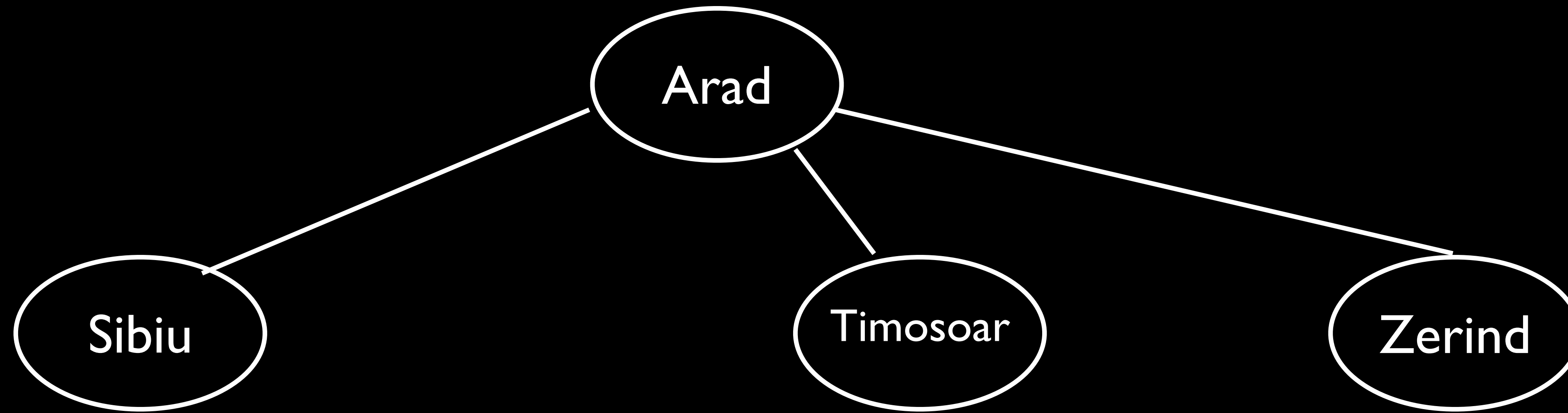
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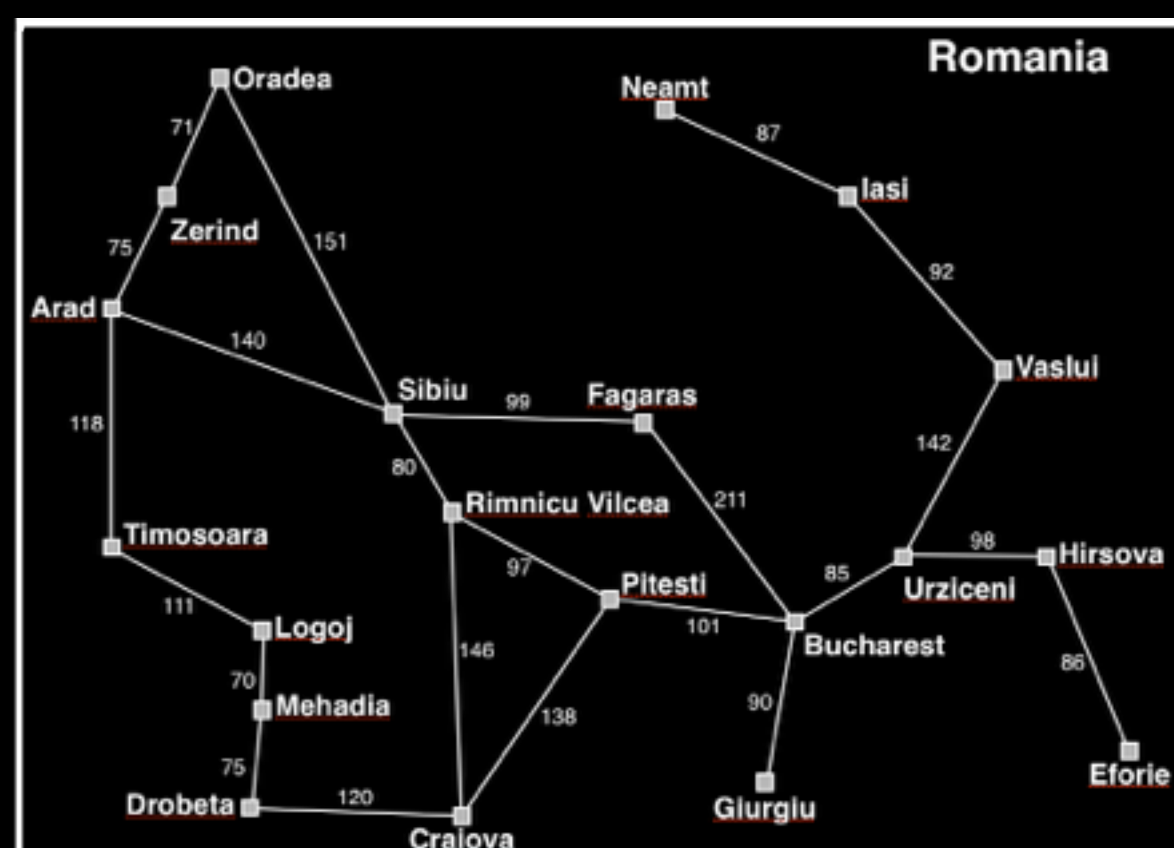
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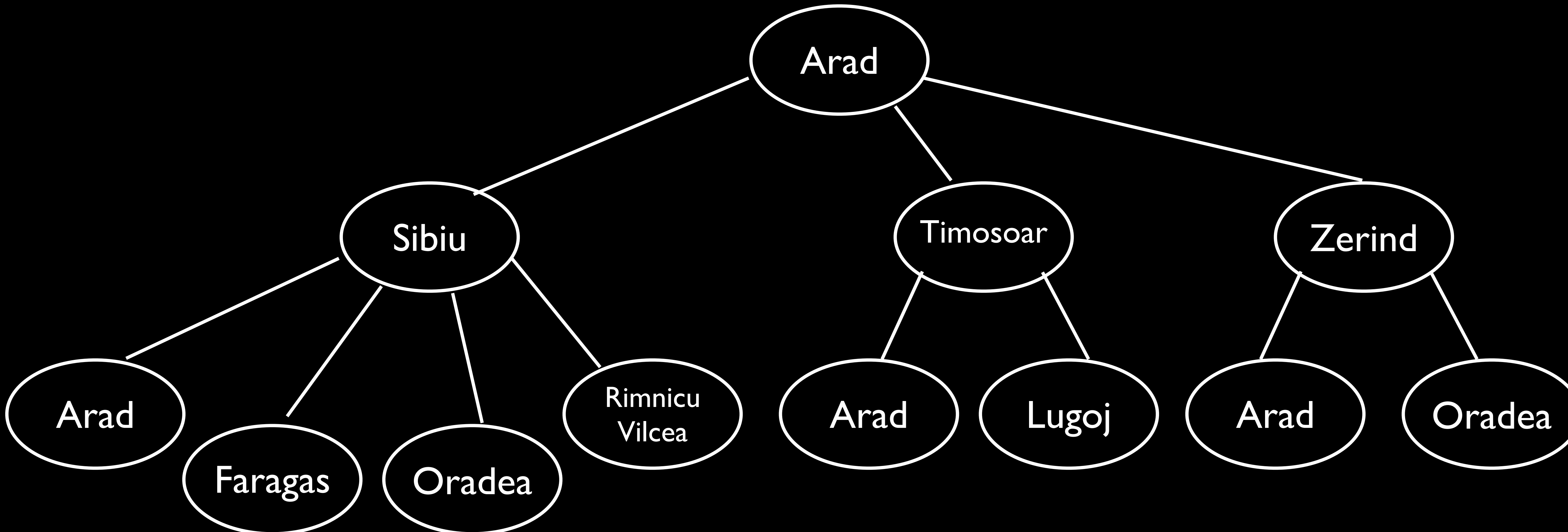
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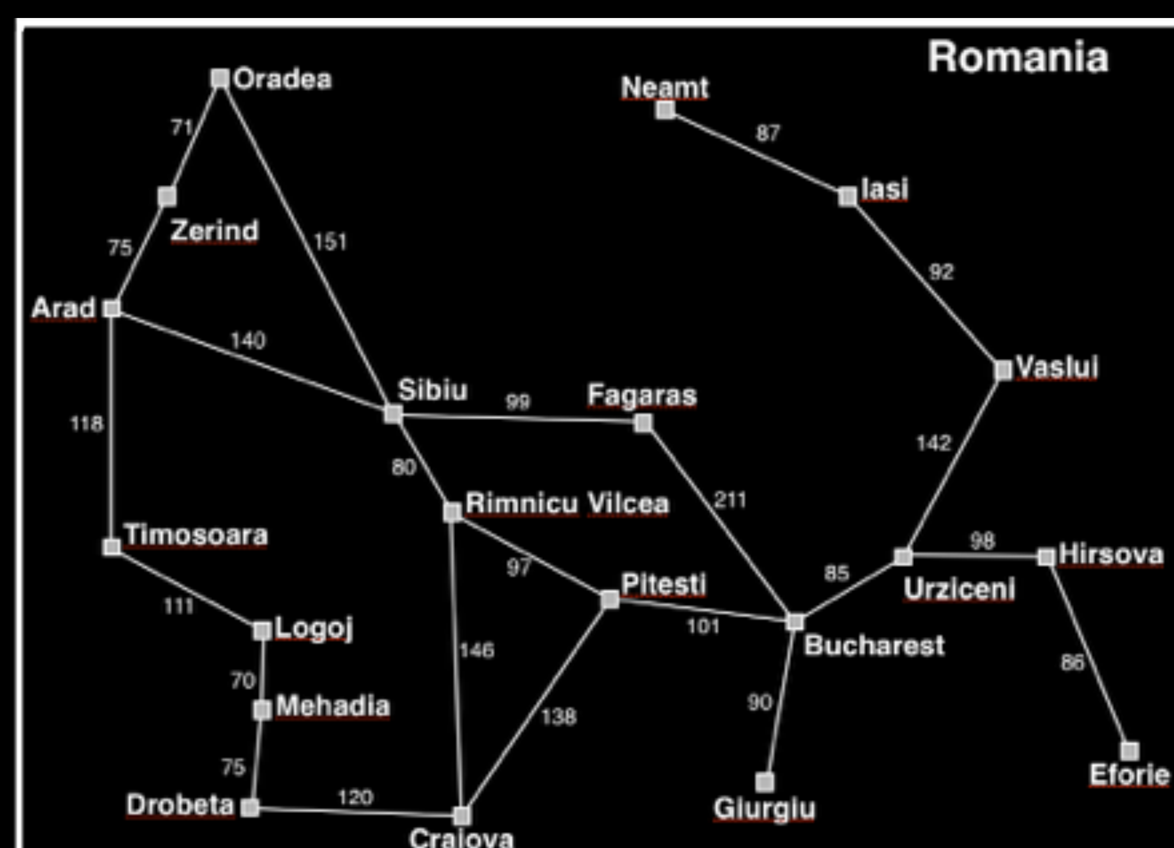
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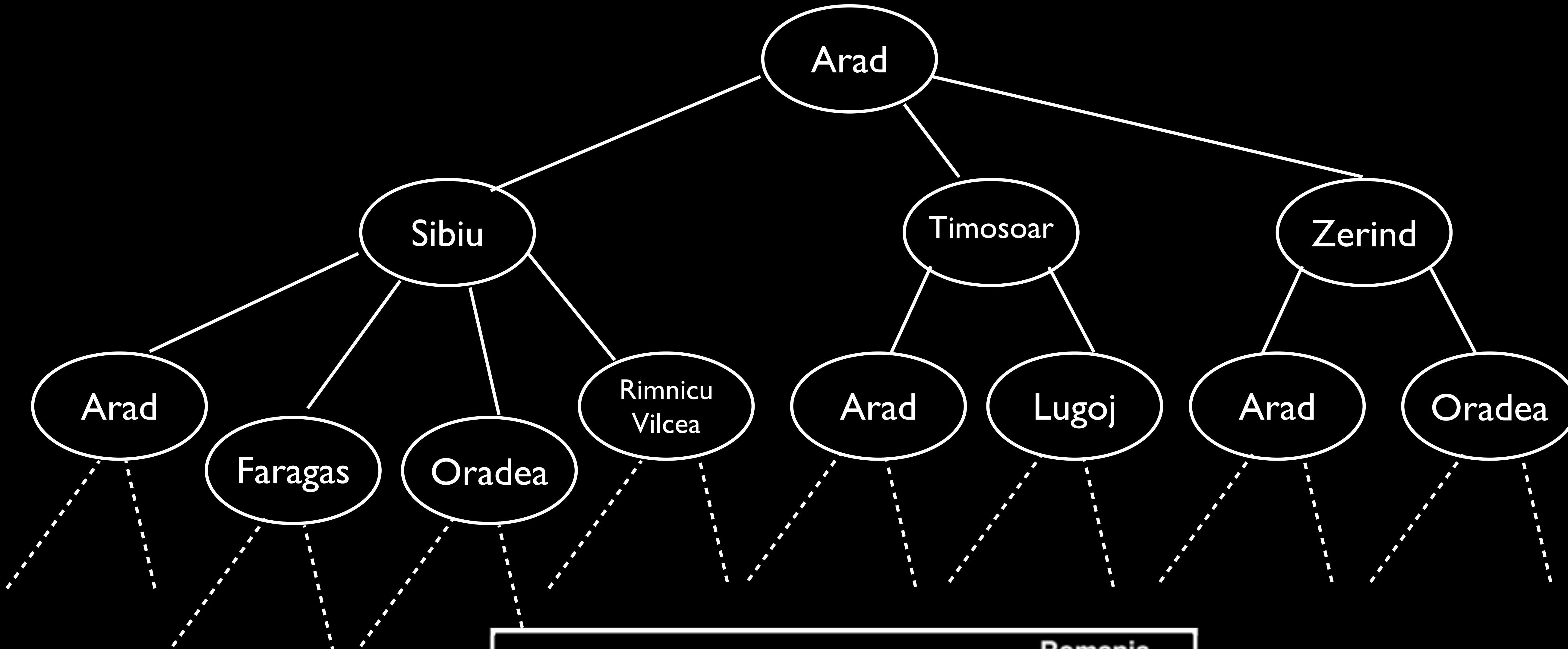
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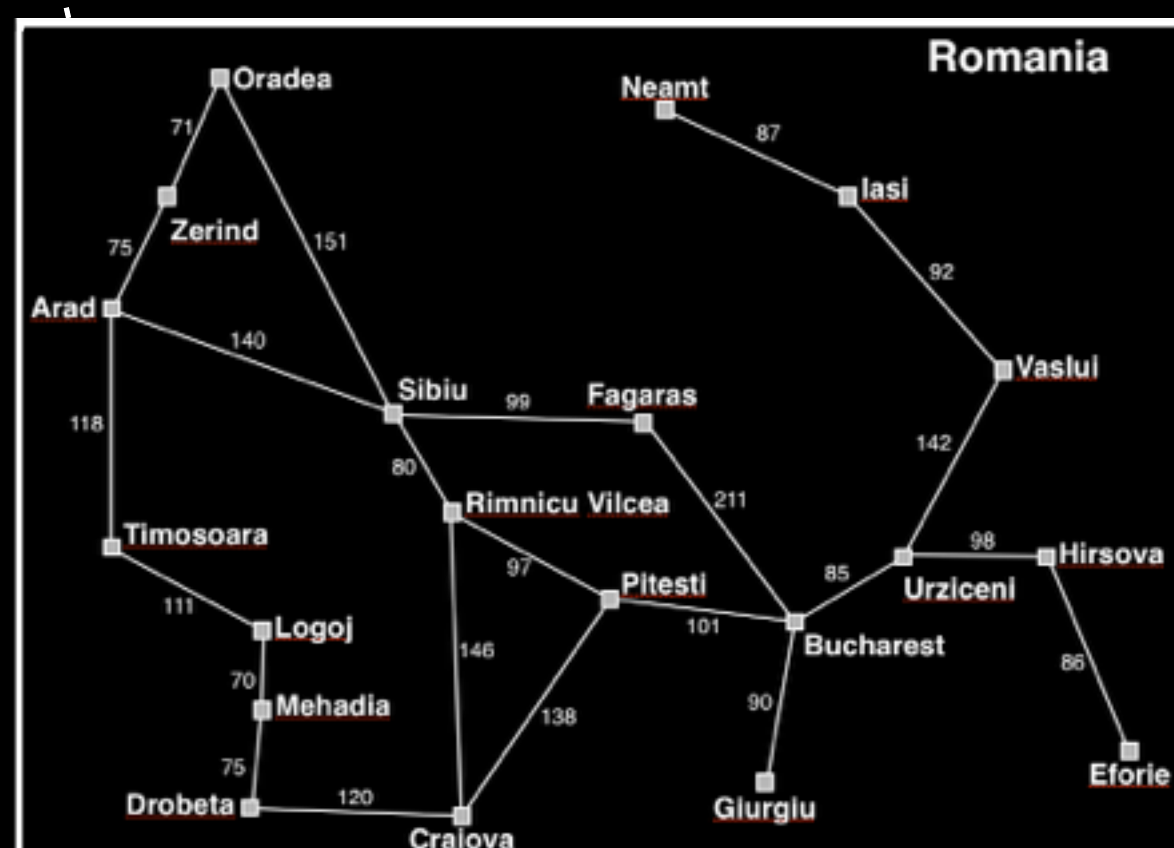
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Neamt
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Iasi
Zerind
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75
92
Arad
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Vaslui
Sibiu
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Fagaras
118
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Rimnicu Vilcea
211
142
Timosoara
98
Hirsova
97
Pitesti
85
Urziceni
111
Logoj
101
Bucharest
146
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Mehadia
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Eforie
Drobeta
120
Giurgiu
Craiova

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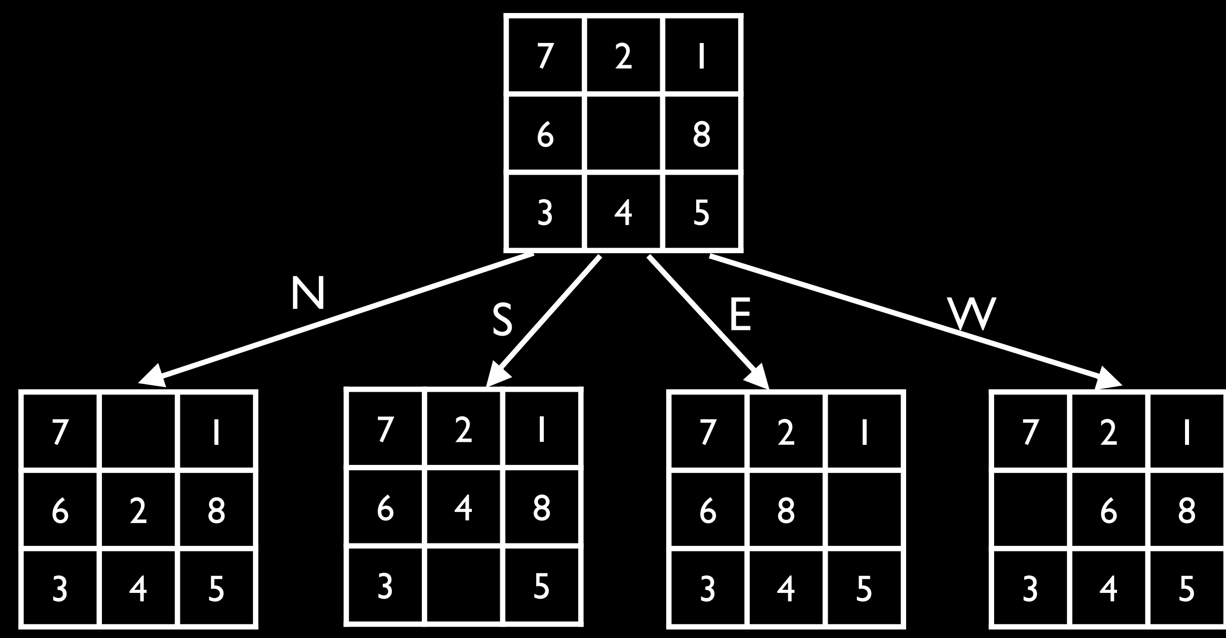
6		8
3	4	5



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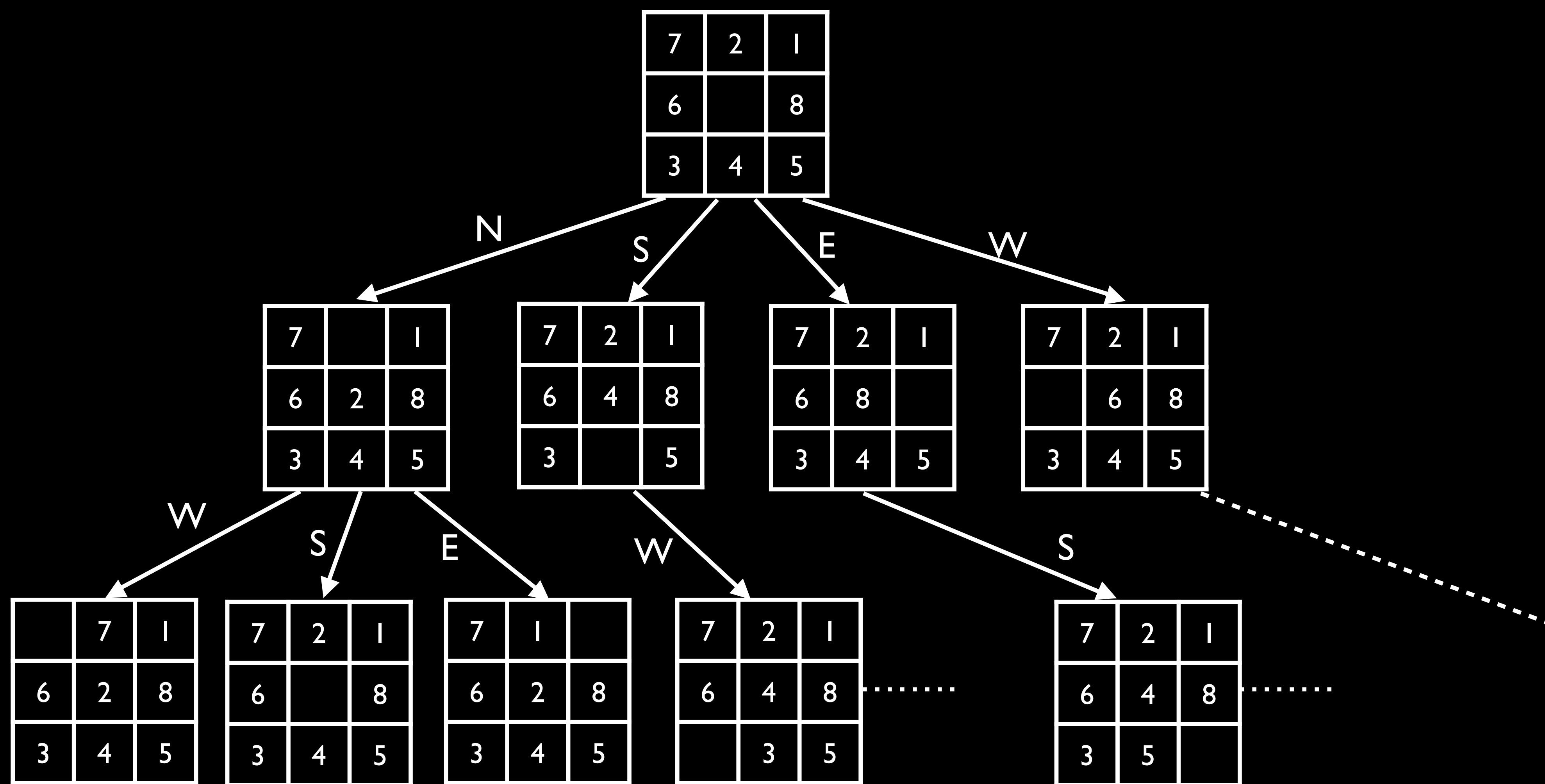
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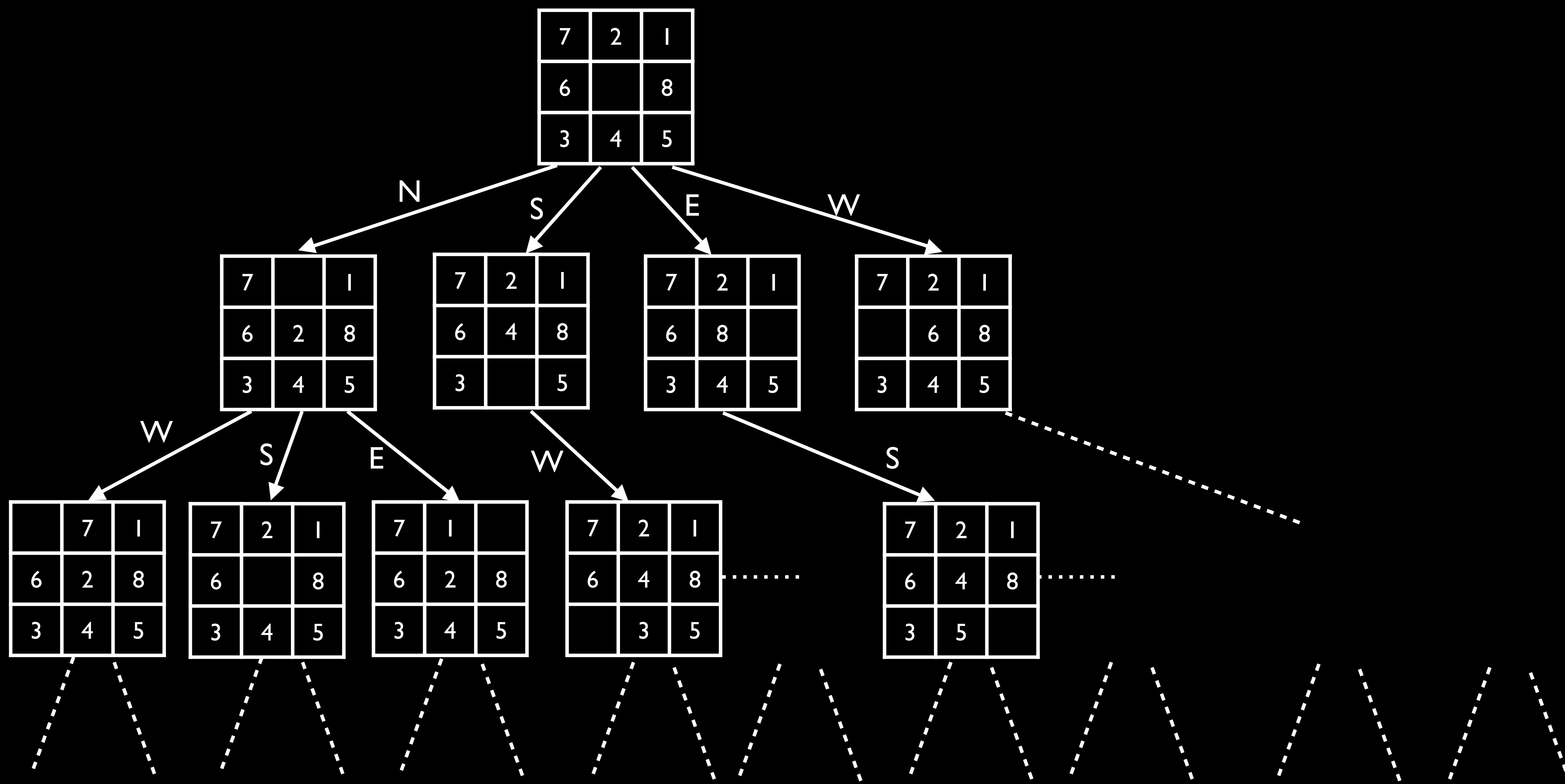
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6 8
3 4 5
7 1
6 2 8
3 4 5
7 2 1
6 4 8
3 5
7 2 1
6 4 8
3 5

State-Space Search

- Start with initial state
- Generate successor states by applying applicable actions
- Until you find a goal state

```
Solution treeSearch(Problem p) {
  Set<Node> frontier = new Set<Node>(p.getInitialState());

  while (true) {
    if (frontier.isEmpty()) {
      return null;
    }
    Node node = frontier.selectOne();
    if (p.isGoalState(node.getState())) {
      return n.getSolution();
    }

    for (Node n : node.expand()) {

        frontier.add(n);

    }
  }
}
```

```
Solution graphSearch(Problem p) {
  Set<Node> frontier = new Set<Node>(p.getInitialState());
  Set<Node> explored = new Set<Node>();
  while (true) {
    if (frontier.isEmpty()) {
      return null;
    }
    Node node = frontier.selectOne();
    if (p.isGoalState(node.getState())) {
      return n.getSolution();
    }
    explored.add(node);
    for (Node n : node.expand()) {
      if (!explored.contains(n)) {
        frontier.add(n);
      }
    }
  }
}
```

Summary

- General-purpose algorithm for solving any problem that can be represented using states and actions that transition between them
- State-space search framework will allow us to explore and compare alternatives

```
Solution graphSearch(Problem p) {
  Set<Node> frontier = new Set<Node>(p.getInitialState());
  Set<Node> explored = new Set<Node>();
  while (true) {
    if (frontier.isEmpty()) {
      return null;
    }
    Node node = frontier.selectOne();
    if (p.isGoalState(node.getState())) {
      return n.getSolution();
    }
    explored.add(node);
    for (Node n : node.expand()) {
      if (!explored.contains(n)) {
        frontier.add(n);
      }
    }
  }
}
```

Next Class

Your Homework this Weekend:
Read Chapters 2 and 3