# Dynamic
# Highway-Node Routing

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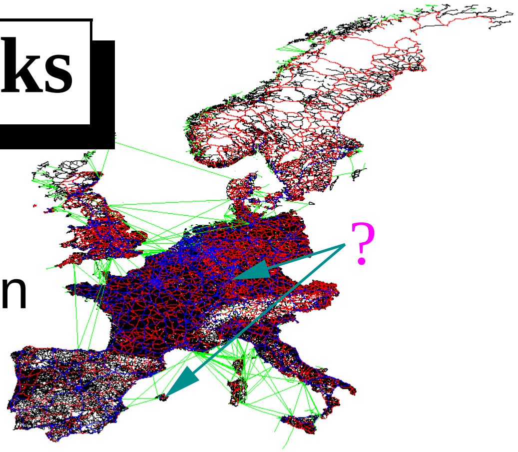
# Static Route Planning in Road Networks




**Task:** determine quickest route from source to target location

**Problem:** for large networks, simple algorithms are too slow

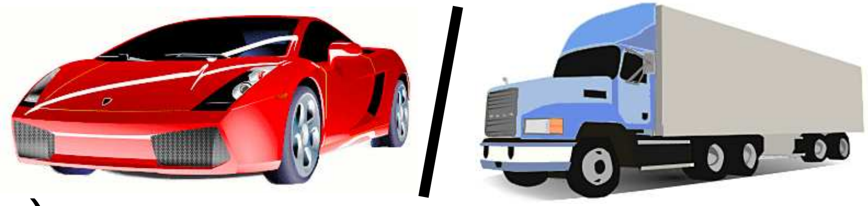
**Assumption:** road network does not change

**Conclusion:** use preprocessed data to accelerate source-target-queries

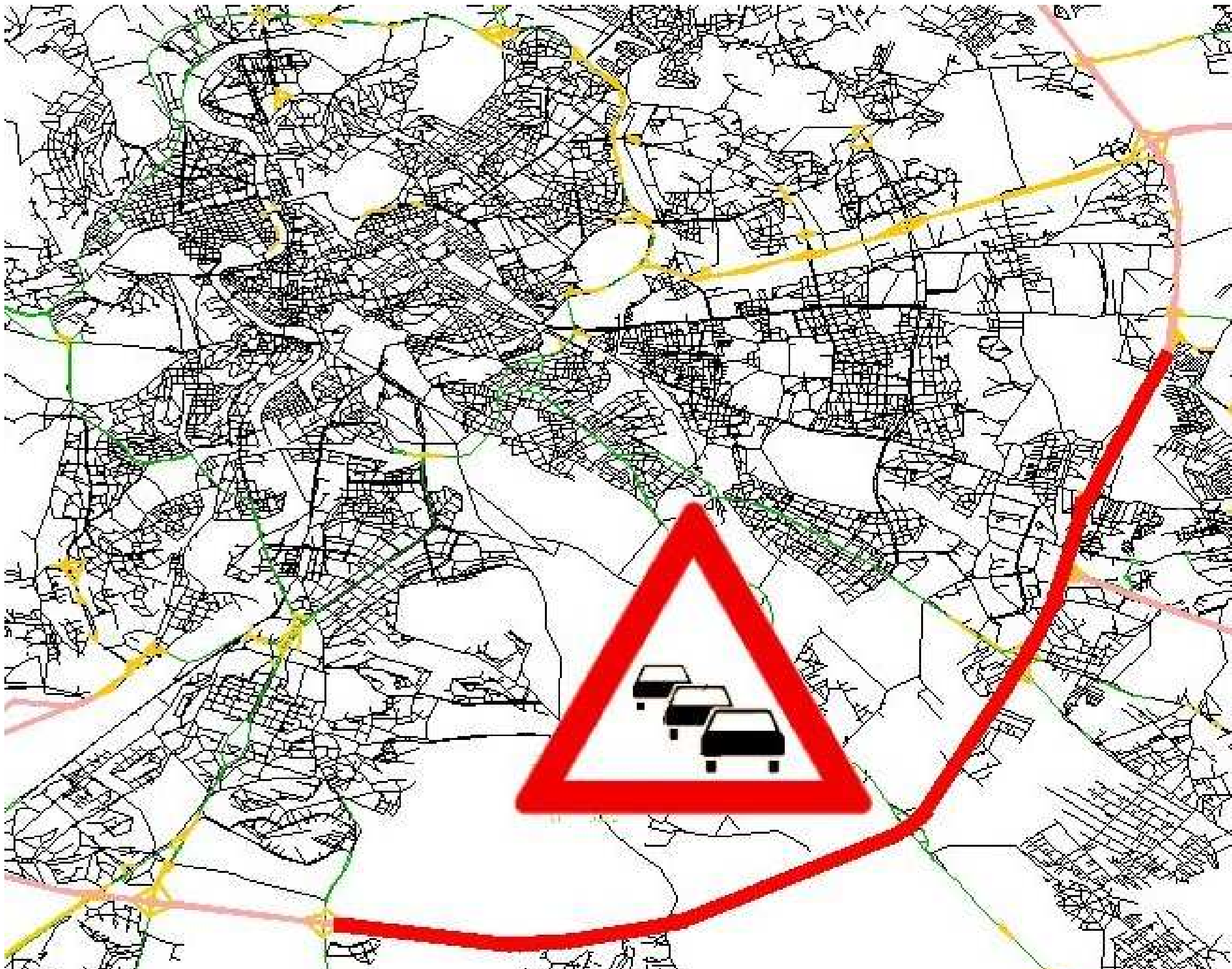
(research focus during the last years [⟶ invited talk])

⇝ correctness relies on the above assumption

# Dynamic Scenarios



- change entire cost function
  (e.g., use different speed profile)



- change a few edge weights
  (e.g., due to a traffic jam)

# Constancy of Structure

## Weaker Assumption:

- structure of road network does not change

  (no new roads, road removal = set weight to ∞)

  ⇝ not a significant restriction

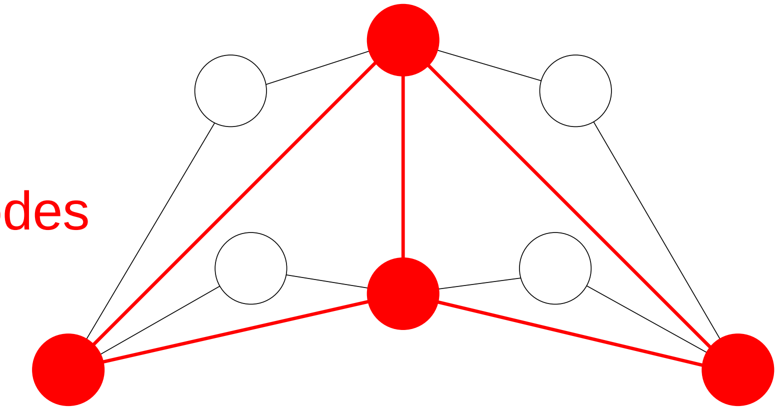
- classification of nodes by 'importance' might be slightly perturbed, but not completely changed

  (e.g., a sports car and a truck both prefer motorways)

  ⇝ performance of our approach relies on that

  (not the correctness)

# Outline



- **basic concepts:** overlay graphs, covering nodes

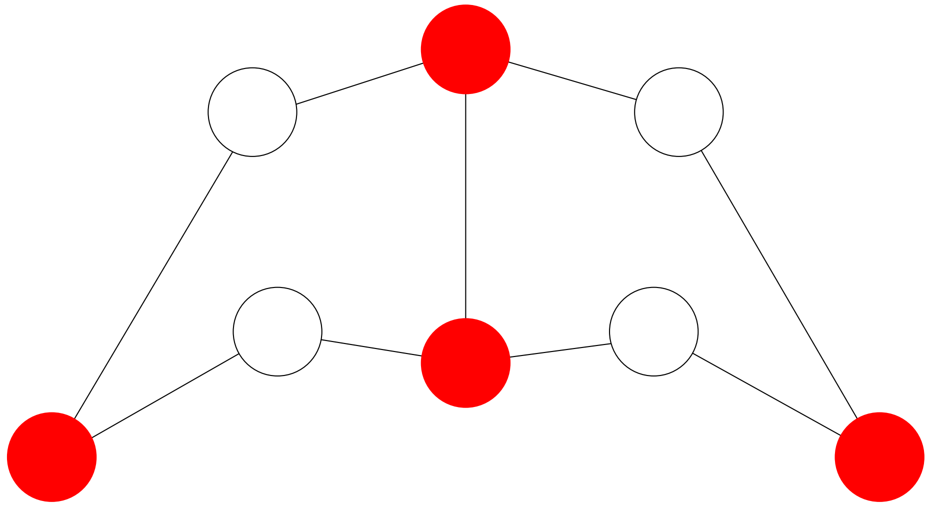
- lightweight, efficient **static approach**

- **dynamic version**

# Overlay Graph

[Holzer, Schulz, Wagner, Weihe, Zaroliagis 2000–2007]

- graph $G = (V, E)$ is given
- select node subset $S \subseteq V$



# Overlay Graph

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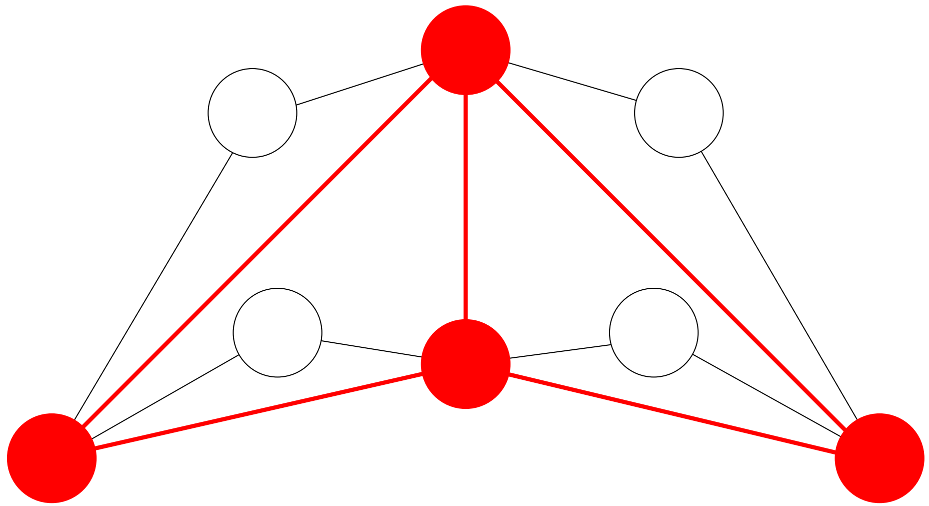


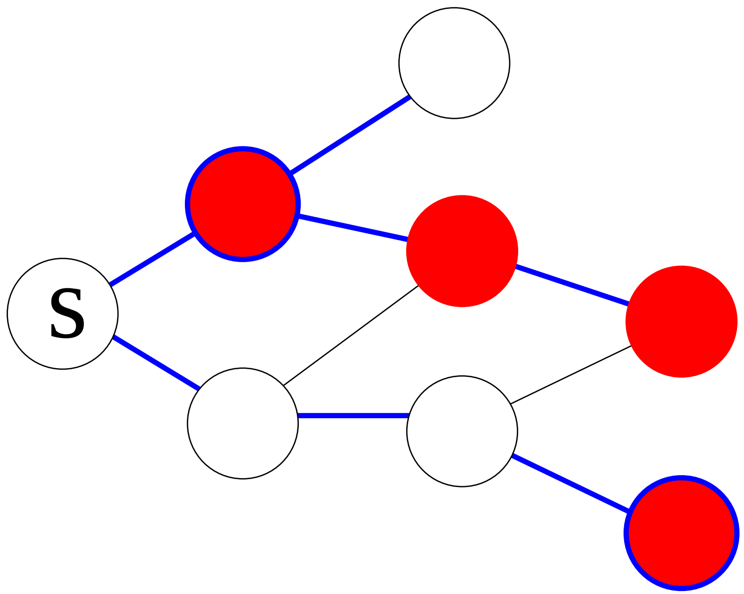
- overlay graph $G' := (S, E')$ where

$E' := \{(s,t) \in S \times S \mid$ no inner node of the shortest $s$-$t$-path belongs to $S\}$

# Covering Nodes

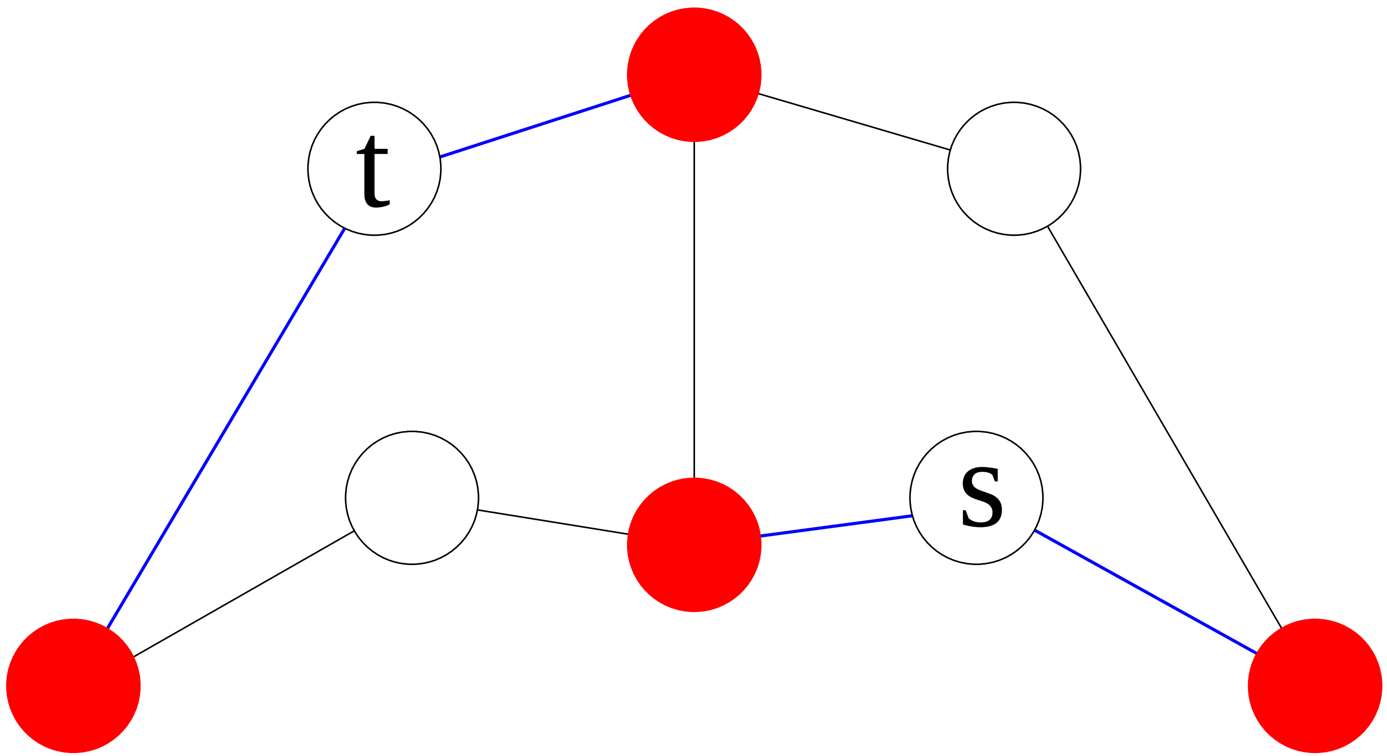
## Definitions:

- covered branch: contains a node from $S$
- covered tree: all branches covered
- covering nodes: on each branch, the node $u \in S$ closest to the root $s$



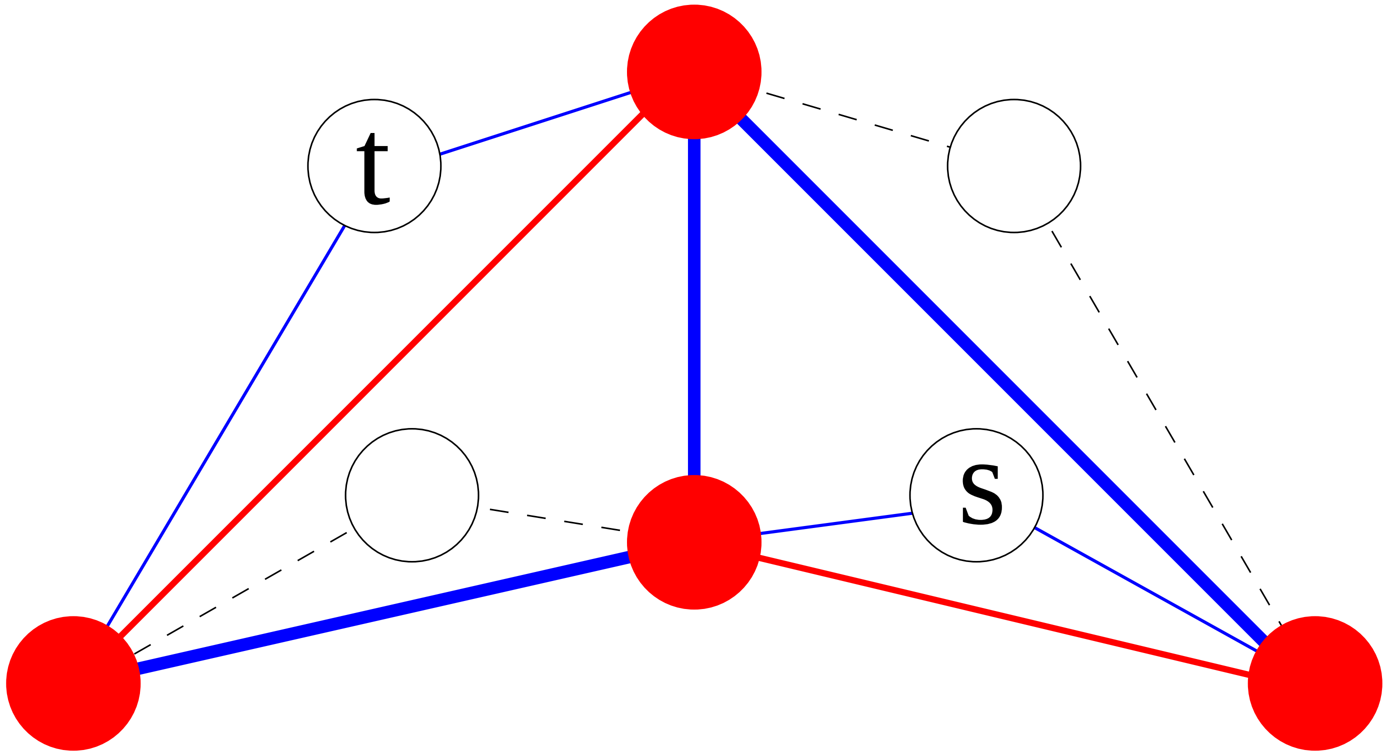
# Query

- bidirectional
- perform search in $G$ till search trees are covered by nodes in $S$



# Query

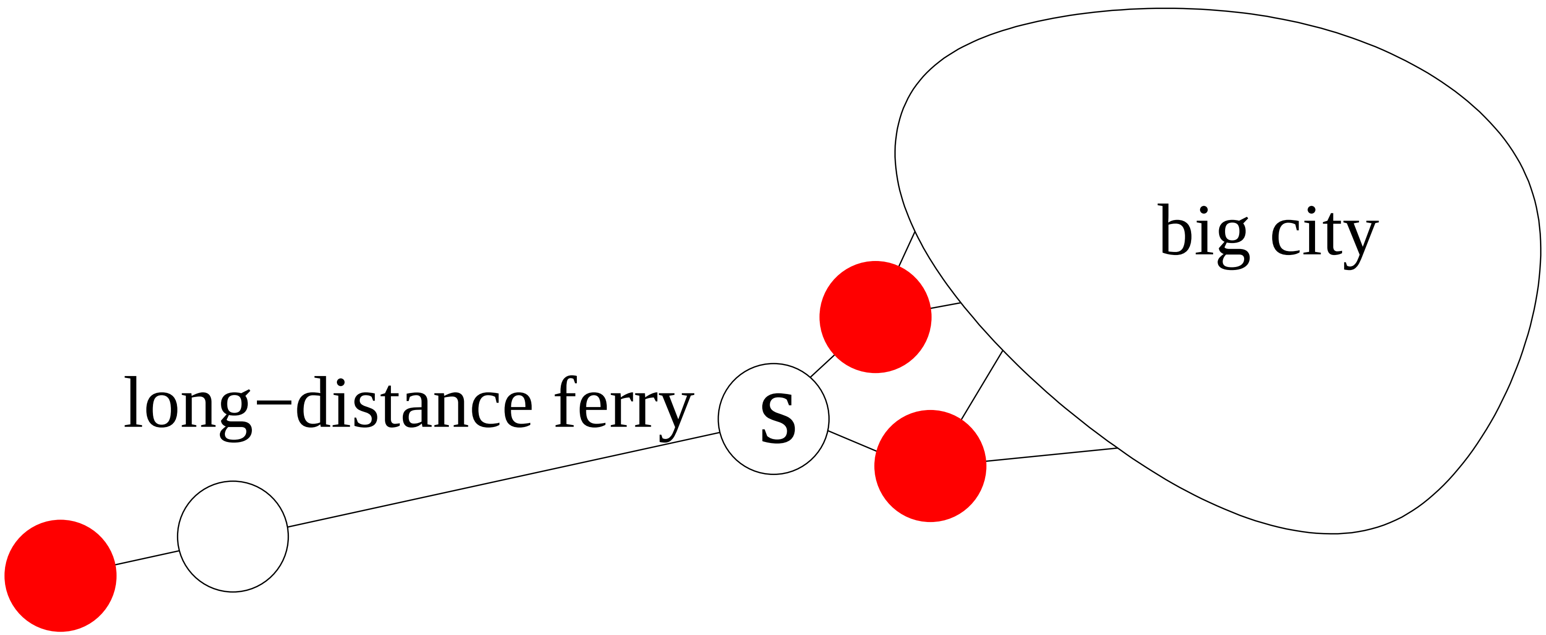
- bidirectional
- perform search in $G$ till search trees are covered by nodes in $S$
- continue search only in $G'$



# Covering Nodes

**Conservative Approach:**

- stop searching in $G$ when all branches are covered

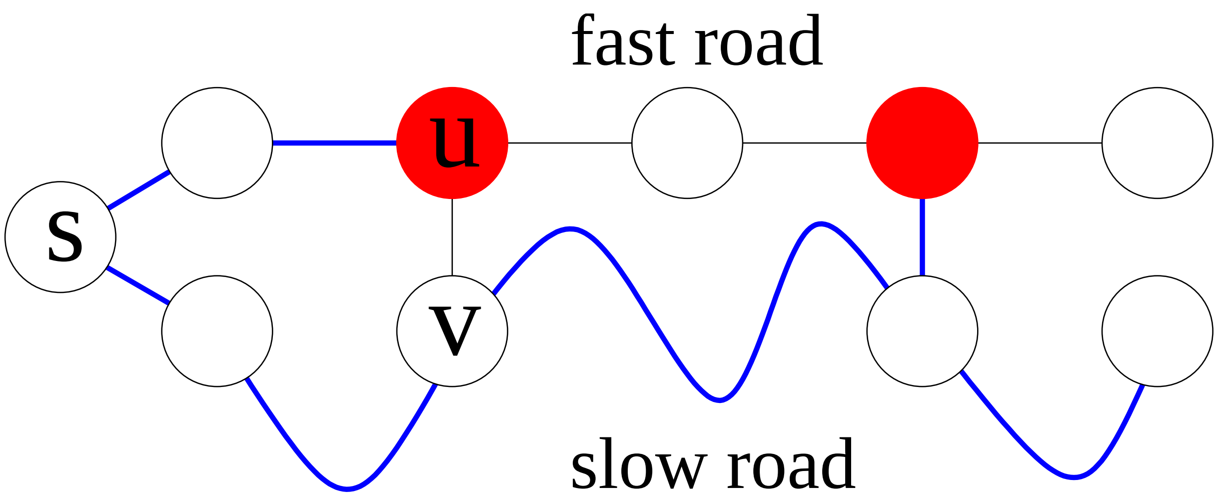



- can be very inefficient

# Covering Nodes

## Aggressive Approach:

- do not continue the search in $G$ on covered branches



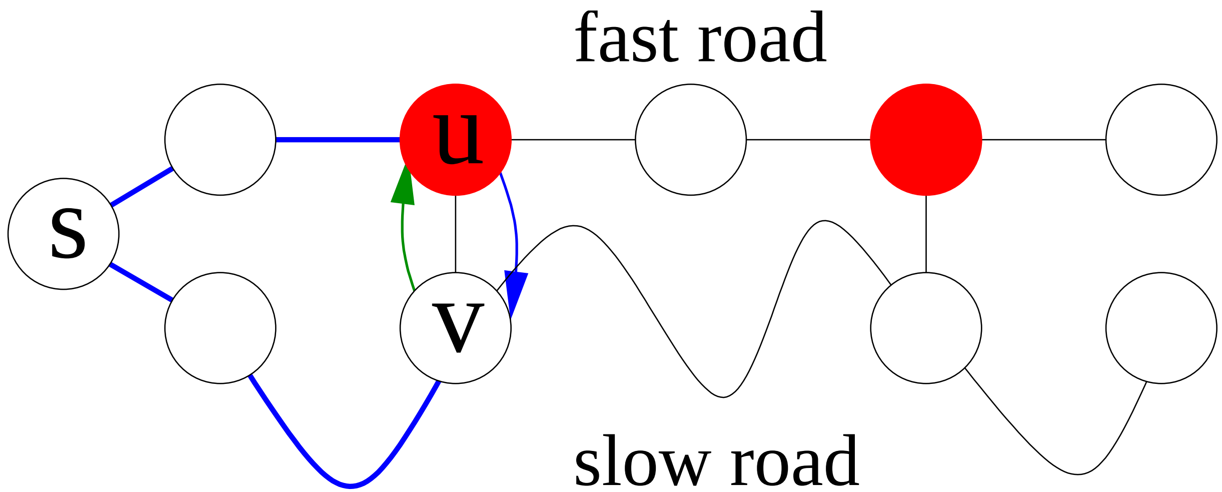

- can be very inefficient

# Covering Nodes

## Stall-on-Demand:

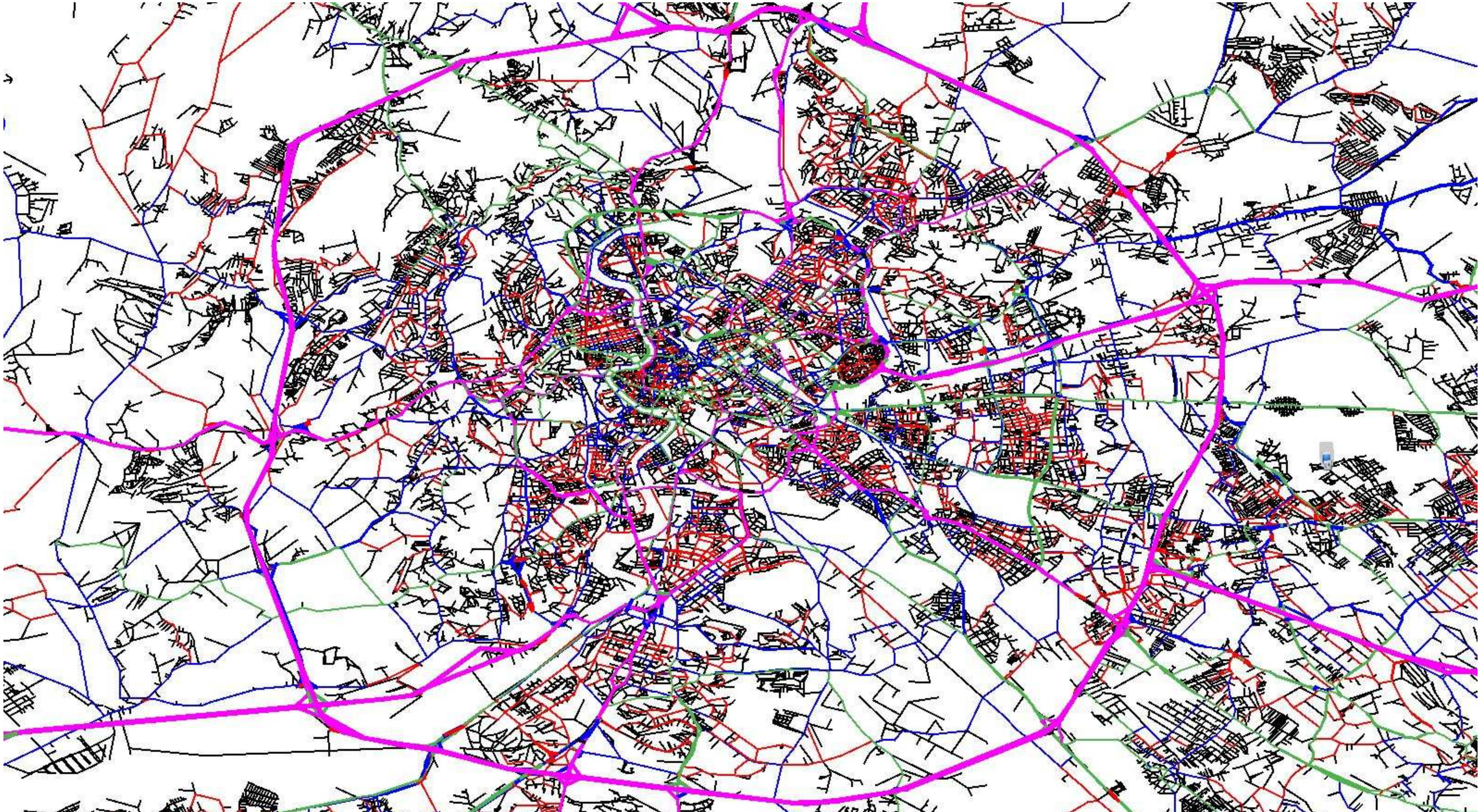
- do not continue the search in $G$ on covered branches
- a node $v$ can 'wake' a node $u$ on a covered branch
- $u$ can 'stall' $v$ (if $\delta(u) + w(u,v) < \delta(v)$)

  i.e., search is not continued from $v$



# Highway Hierarchies

- previous static route-planning approach [SS05–06]
- determines a hierarchical representation of nodes and edges



# Static Highway-Node Routing

- extend ideas from
  - multi-level overlay graphs [HolzerSchulzWagnerWeiheZaroliagis00–07]
  - highway hierarchies [SS05–06]
  - transit node routing [BastFunkeMatijevicSS06–07]
- use highway hierarchies to classify nodes by ‘importance’

  i.e., select node sets $S_1 \supseteq S_2 \supseteq S_3 \ldots$

  (crucial distinction from previous separator-based approach)
- construct multi-level overlay graph
- perform query with stall-on-demand technique

# Static Highway-Node Routing

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- use highway hierarchies to classify nodes by 'importance'

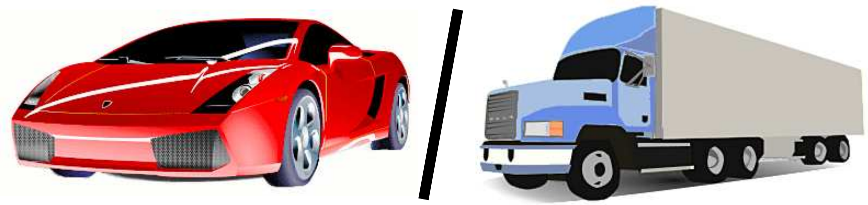
  i.e., select node sets $S_1 \supseteq S_2 \supseteq S_3 \ldots$ 16 min

  (crucial distinction from previous separator-based approach)
- construct multi-level overlay graph 3 min, 8 bytes/node
- perform query with stall-on-demand technique 1.1 ms

(experiments with a European road network with ≈ 18 million nodes)

# Dynamic Highway-Node Routing

**change entire cost function**



- keep the node sets $S_1 \supseteq S_2 \supseteq S_3 \ldots$
- recompute the overlay graphs

| speed profile | default | fast car | slow car | slow truck | distance |
|---|---|---|---|---|---|
| constr. [min] | 1:40 | 1:41 | 1:39 | 1:36 | 3:56 |
| query [ms] | 1.17 | 1.20 | 1.28 | 1.50 | 35.62 |
| #settled nodes | 1 414 | 1 444 | 1 507 | 1 667 | 7 057 |

# Dynamic Highway-Node Routing

**change a few edge weights**

- **server scenario:** if something changes,
  - update the preprocessed data structures
  - answer many subsequent queries very fast


- **mobile scenario:** if something changes,
  - it does not pay to update the data structures
  - perform single ‘prudent’ query that takes changed situation into account

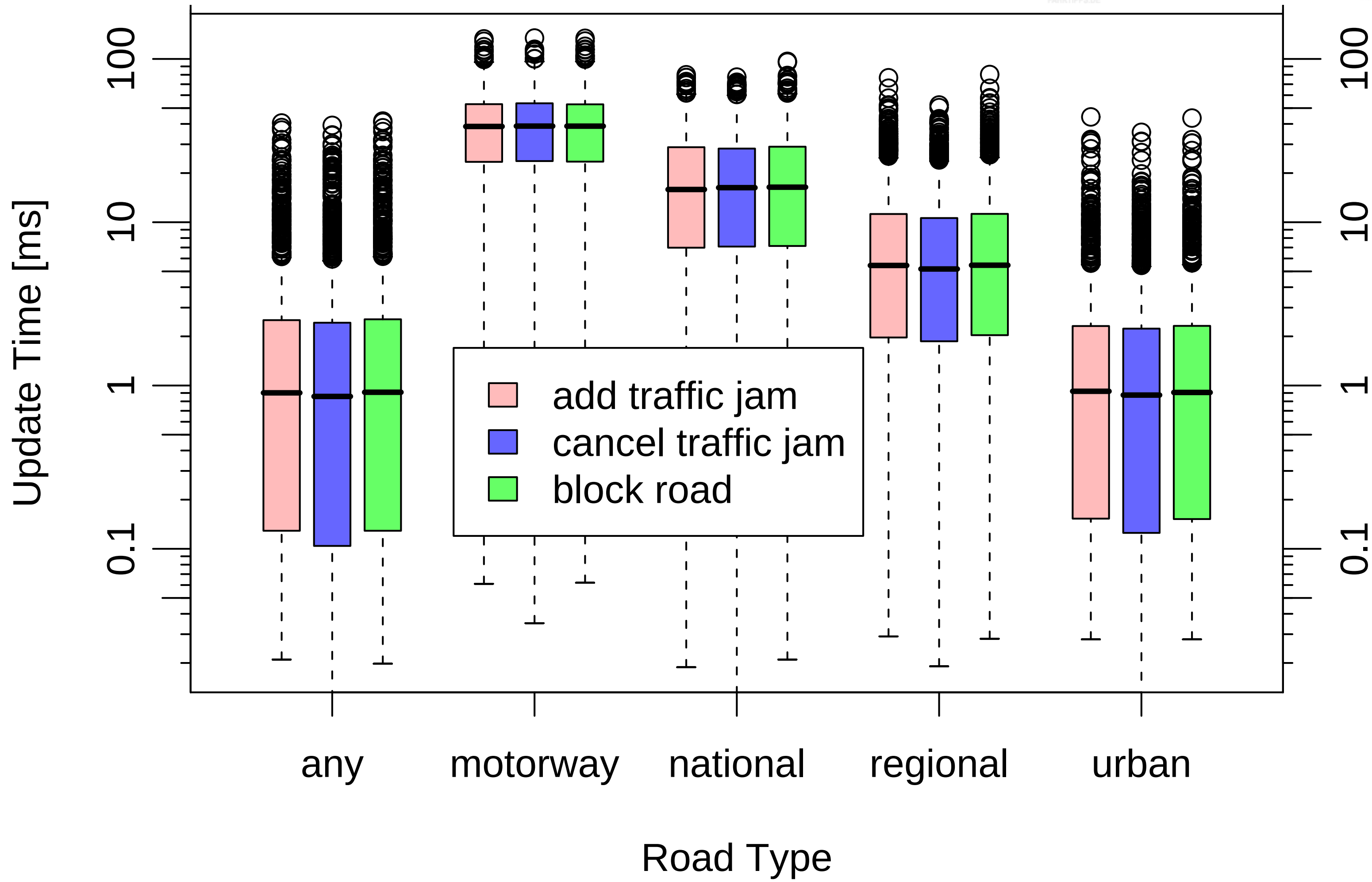
# Dynamic Highway-Node Routing

**change a few edge weights, server scenario**

- keep the node sets $S_1 \supseteq S_2 \supseteq S_3 \ldots$
- recompute only possibly affected parts of the overlay graphs
  - the computation of the level-$\ell$ overlay graph consists of $|S_\ell|$ local searches to determine the respective covering nodes
  - if the initial local search from $v \in S_\ell$ has not touched a now modified edge $(u, x)$, that local search need not be repeated
  - we manage sets $A_u^\ell = \{v \in S_\ell \mid v\text{'s level-}\ell\text{ preprocessing might be affected when an edge } (u,x) \text{ changes}\}$

# Dynamic Highway-Node Routing

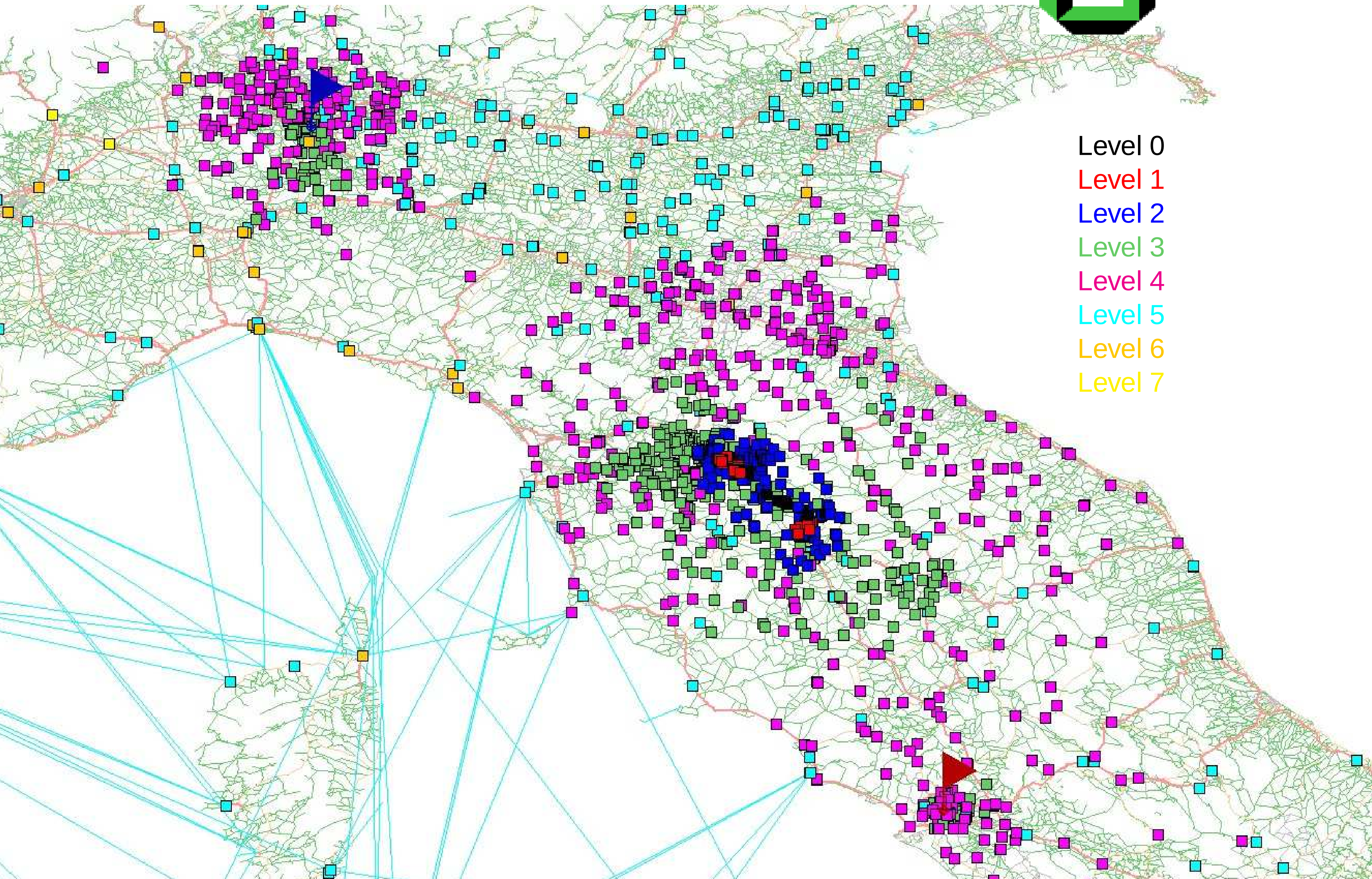
**change a few edge weights, server scenario**



# Dynamic Highway-Node Routing

**change a few edge weights, mobile scenario**

- keep the node sets $S_1 \supseteq S_2 \supseteq S_3 \ldots$
- keep the overlay graphs
- use the sets $A_u^\ell$ to determine for each node $u$ a reliable level $r(u)$
- during a query, at node $u$
  - do not use edges that have been created in some level $> r(u)$
  - instead, downgrade the search to level $r(u)$


Level 0
Level 1
Level 2
Level 3
Level 4
Level 5
Level 6
Level 7

# Dynamic Highway-Node Routing

**change a few edge weights, mobile scenario**

| \|change set\| (motorway edges) | affected queries | #settled nodes absolute | #settled nodes relative | query time [ms] |
|---|---|---|---|---|
| 1 | 0.6 % | 2 347 | (1.7) | 2.3 |
| 10 | 6.3 % | 8 294 | (5.9) | 9.1 |
| 100 | 41.3 % | 43 042 | (30.4) | 47.5 |
| 1 000 | 82.6 % | 200 465 | (141.8) | 243.9 |

# Summary

- **efficient static approach**
  - fast preprocessing $<$ 20 min
  - fast queries 1 ms
  - outstandingly low memory requirements 2 bytes/node $\rightsquigarrow$ 1.6 ms
- **can handle practically relevant dynamic scenarios**
  - change entire cost function typically < 2 minutes
  - change a few edge weights
    - $*$ update data structures 2 – 40 ms per changed edge

    OR
    - $*$ perform prudent query e.g., 48 ms if 100 motorway edges changed

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numbers refer to the Western European road network with 18 million nodes

# Future Work

- make it even faster / less space-consuming
- find simpler / better ways to determine the node sets $S_1 \supseteq S_2 \supseteq S_3 \ldots$
- adapt to many-to-many queries
- deal with time-dependent scenarios

  (where edge weights depend on the time of day)