UnLimited TRAnsfers for Multi-Modal Route Planning: An Efficient Solution

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INSTITUTE OF THEORETICAL INFORMATICS · ALGORITHMICS GROUP

Multi-Modal Route Planning

Goals:

- Journey planning for public transit
- Find **optimal** journeys
- Considered modes of transportation:
  - All timetable-based modes
    (trains, trams, buses, ...)

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But also:

- Allow secondary transfer mode
- Non-schedule-based
  (walking, bike, e-scooter, ...)

Problem Statement

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Given:

- Public transit network (timetable)

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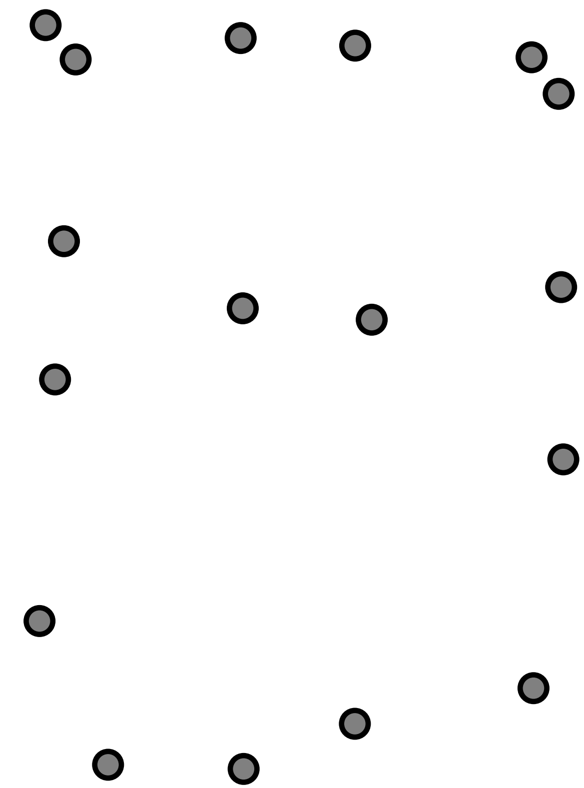

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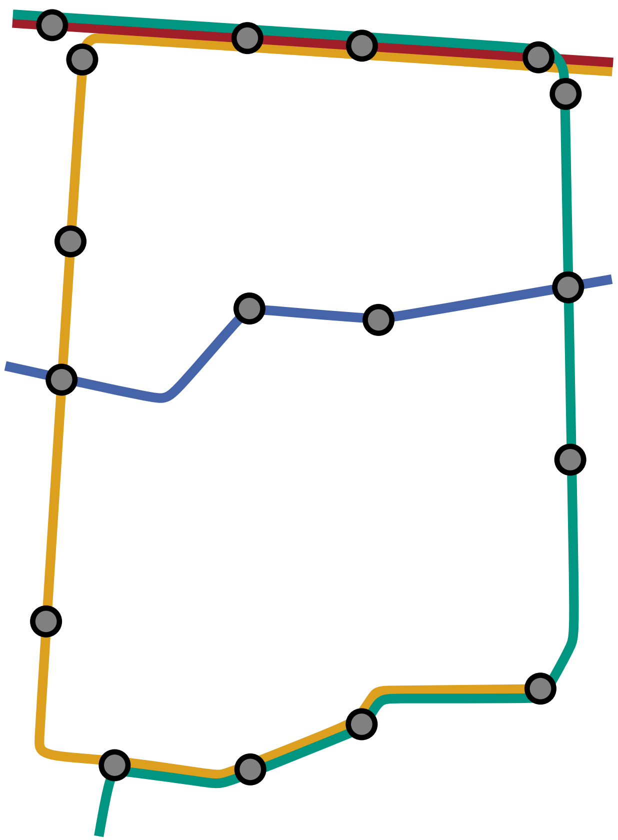

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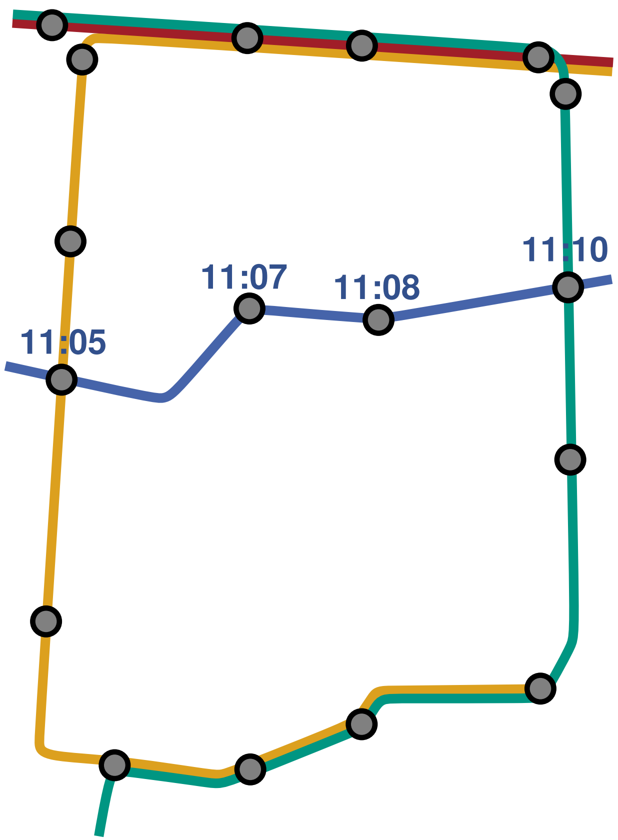

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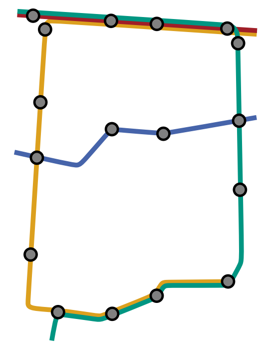

- Transfer graph (non-schedule-based)

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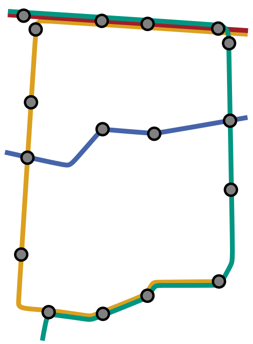

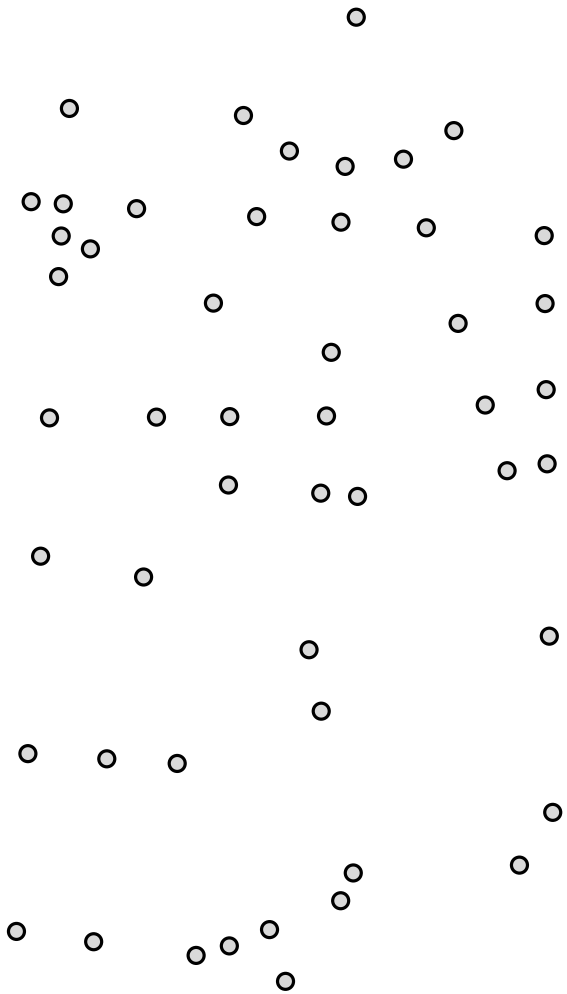

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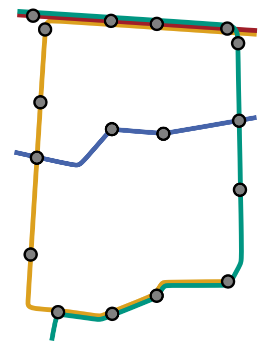

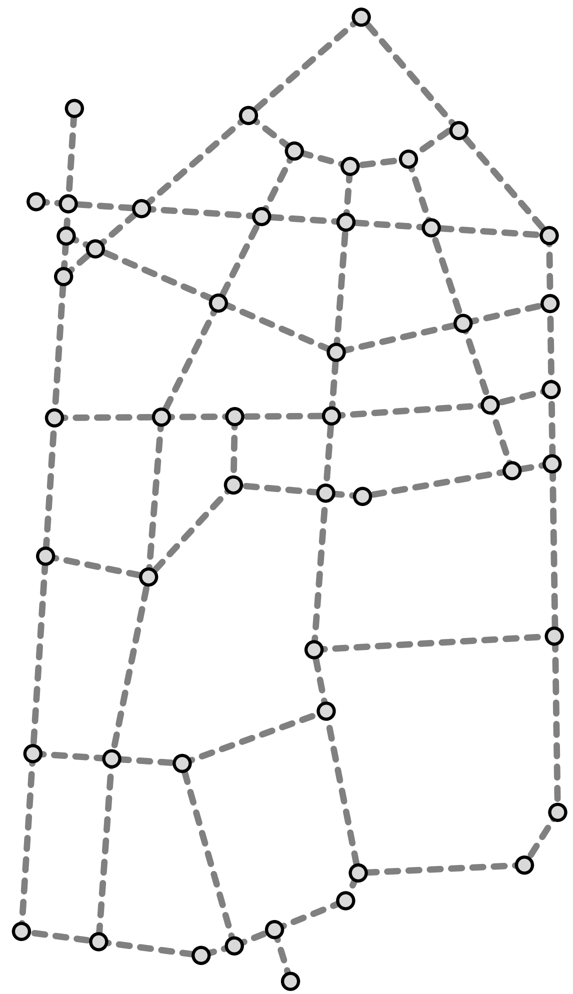

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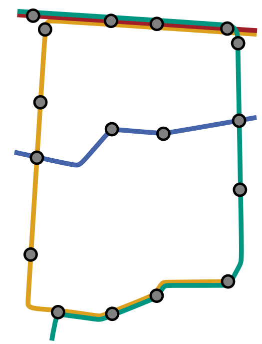

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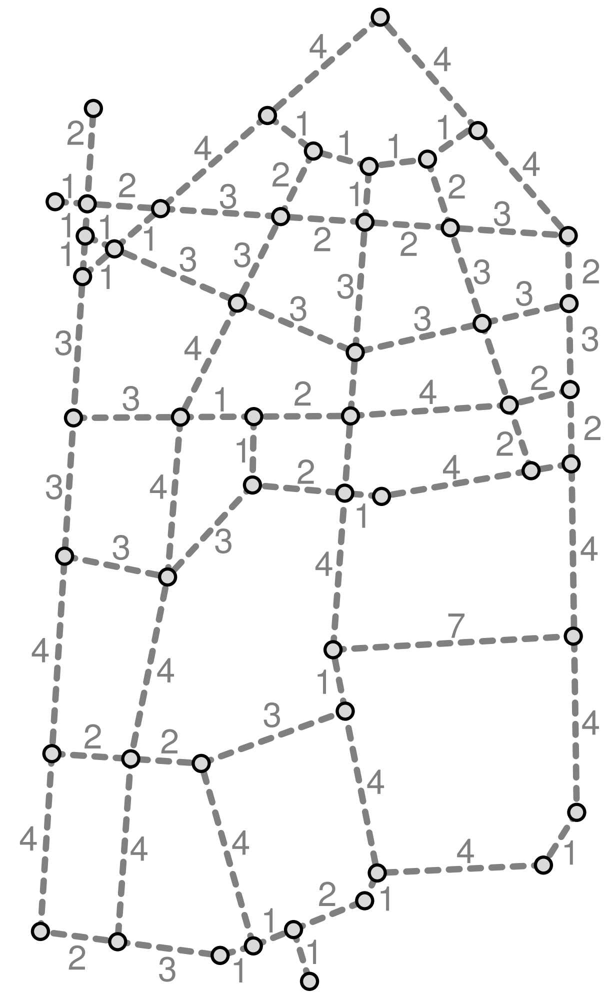

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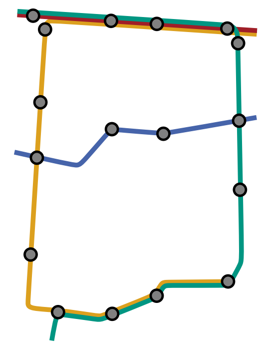

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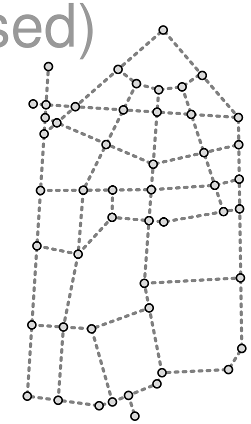

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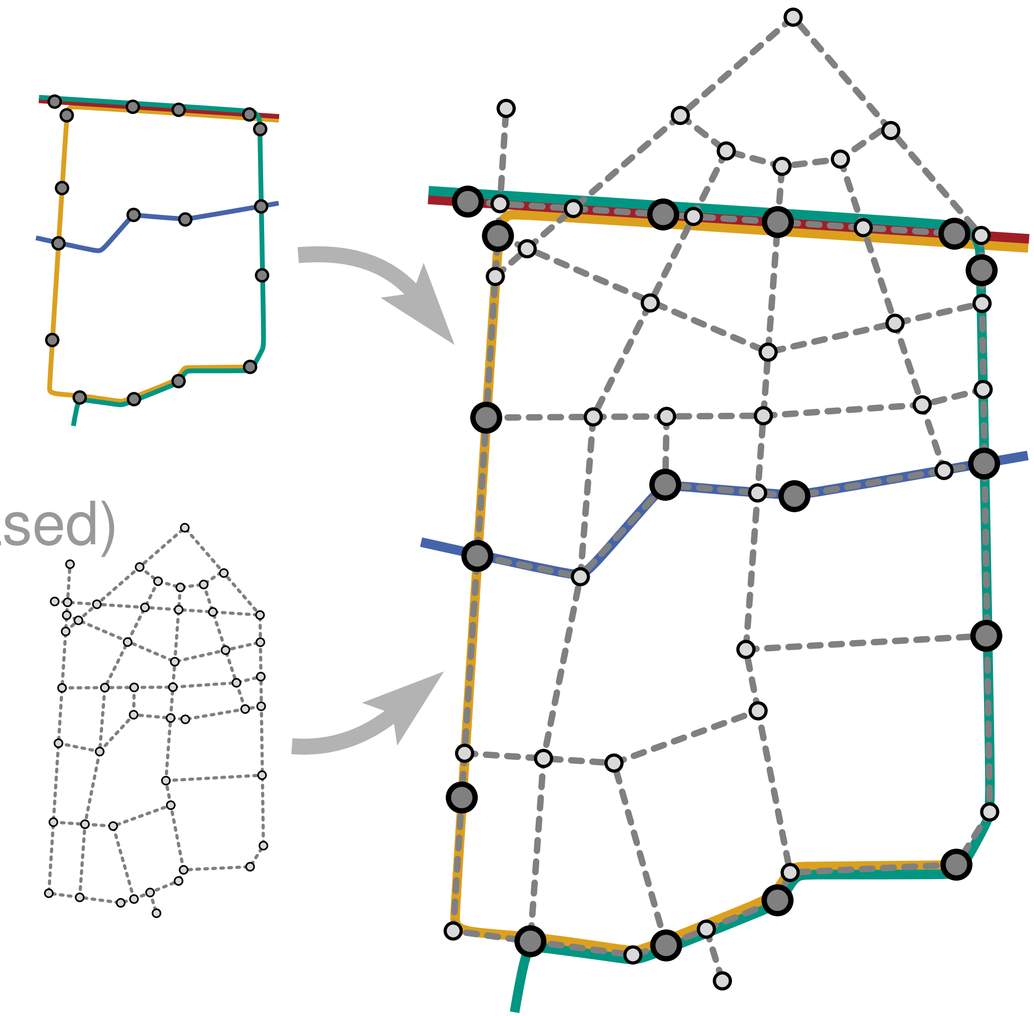

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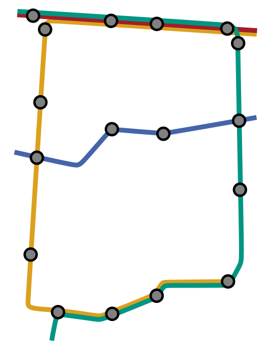

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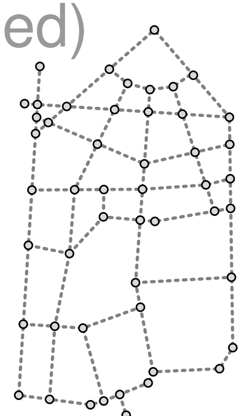

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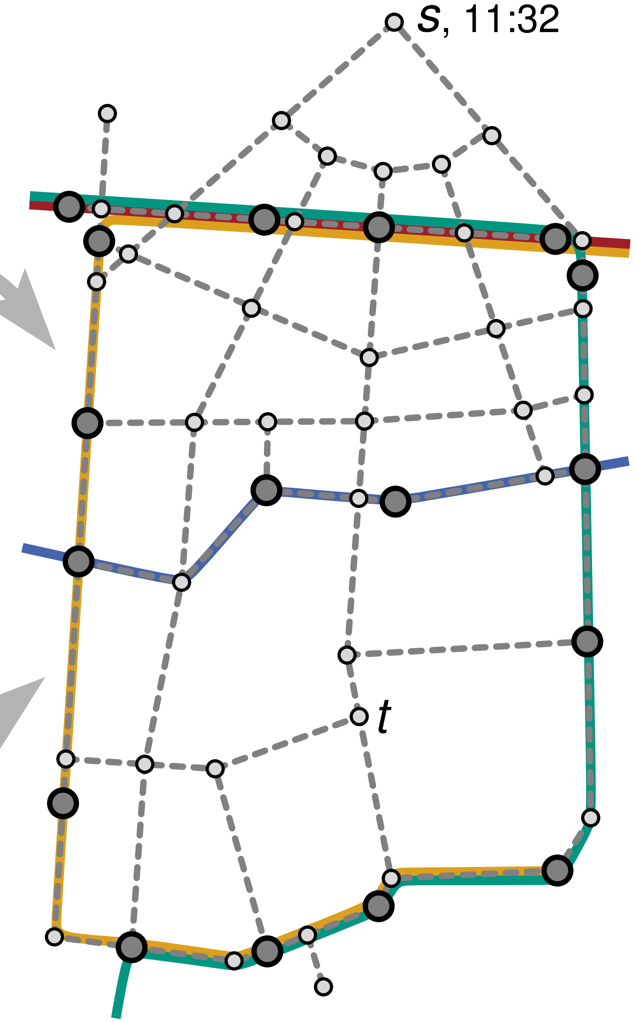

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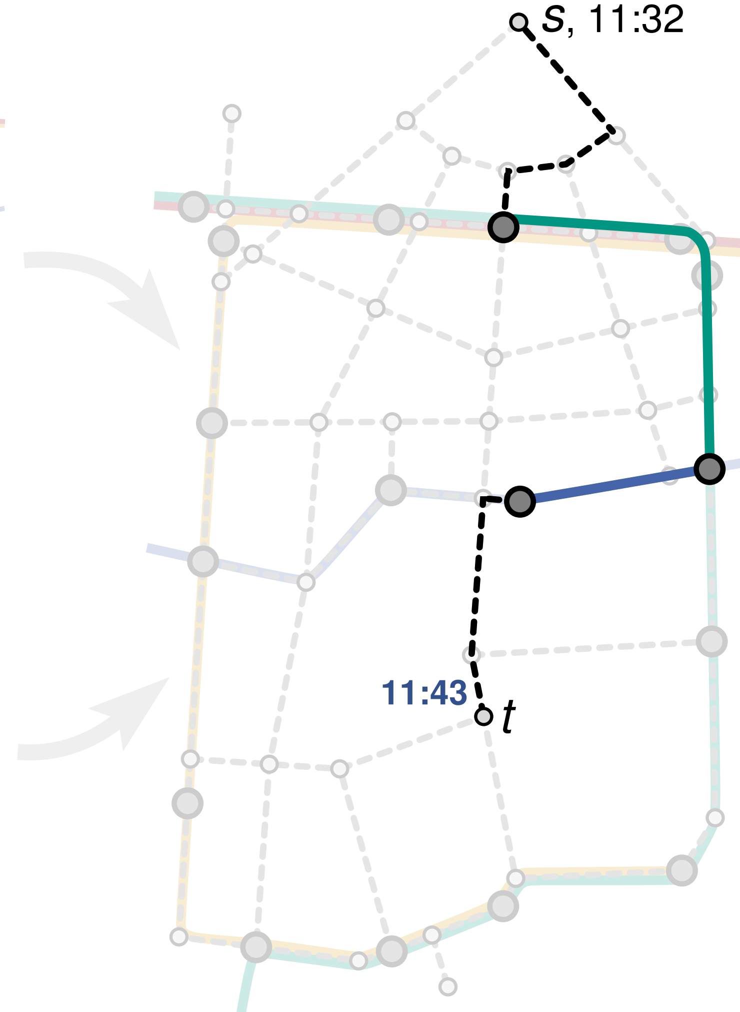

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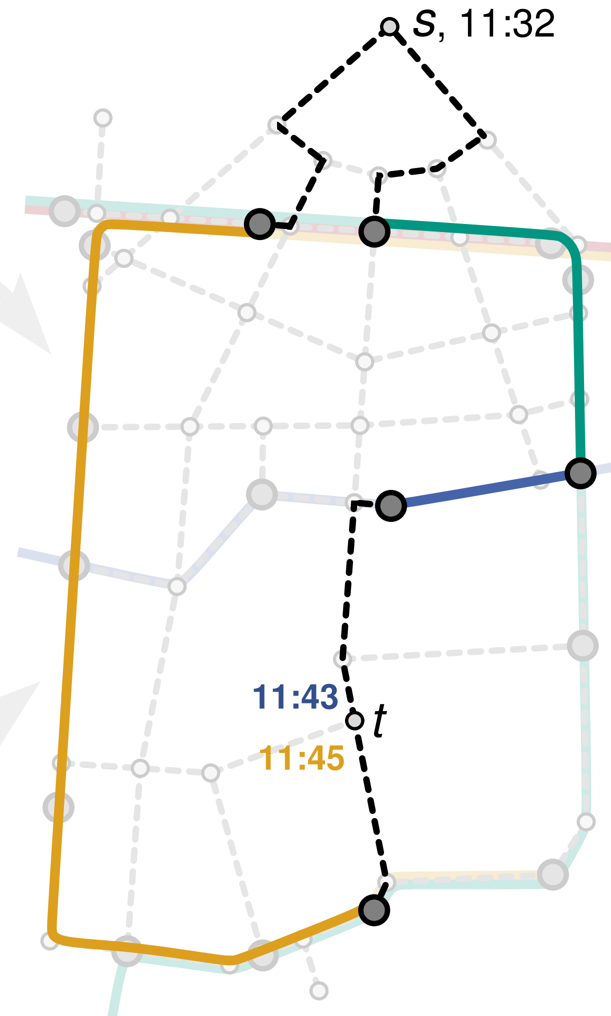

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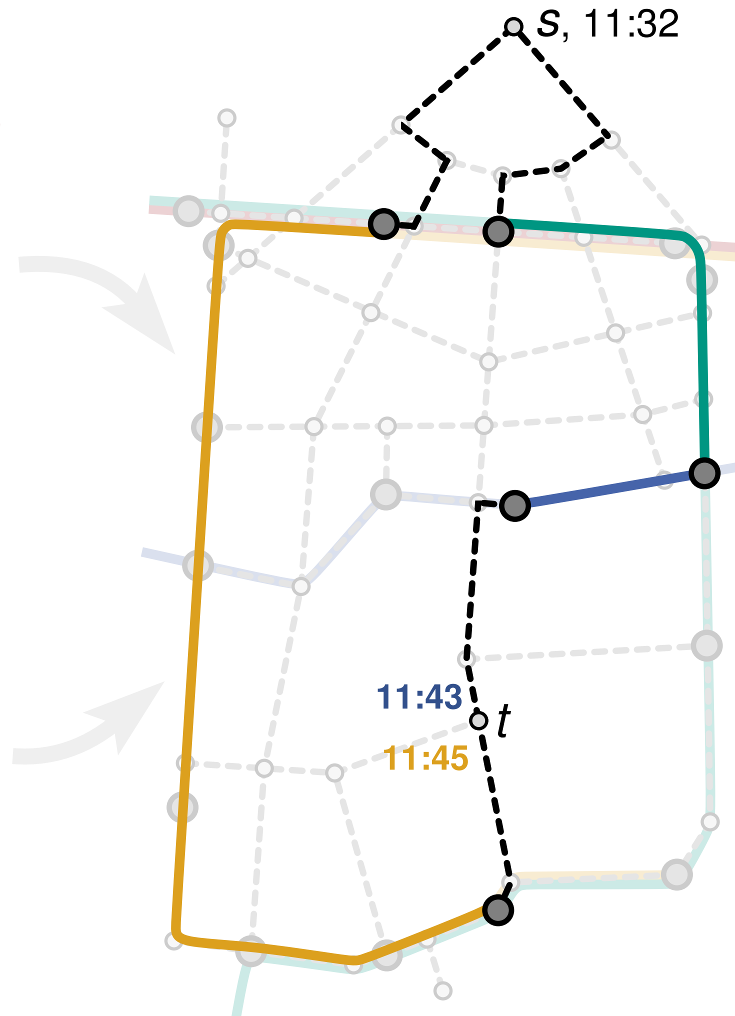

Objective:

- Find a Pareto-set of journeys w.r.t. **arrival time** and **number of trips**

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Related Work

Public Transit:

- Restricted transfers, only between a few stops
- Transitively closed transfer graph:
  - RAPTOR (Delling et al. '14), CSA (Dibbelt et al. '14), Trip-Based (Witt '16)
  - Only feasible for up to 15 minutes of walking
- Only evaluated with limited transfers:
  - Transfer Patterns (Bast et al. '16), Frequency-Based (Bast, Storandt '14)

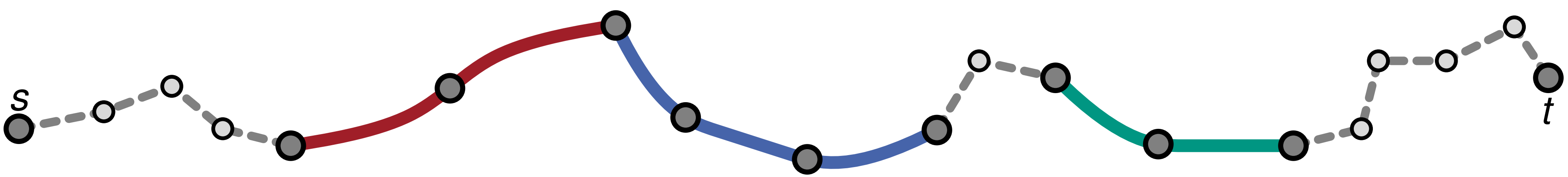
Multi-Modal:

- Interlace RAPTOR and Dijkstra: MCR (Delling et al '13)
- Has significant impact on travel times: (5% London – 40% Switzerland)
  - Profile-MCR (Wagner, Zündorf '17)
  - HLRaptor, HLCSA (Phan, Viennot '19)

Our Approach

Observation: (Sauer 2018)

- Long transfers are mostly useful at the source/target
- Transfers between two public transit routes are mostly short



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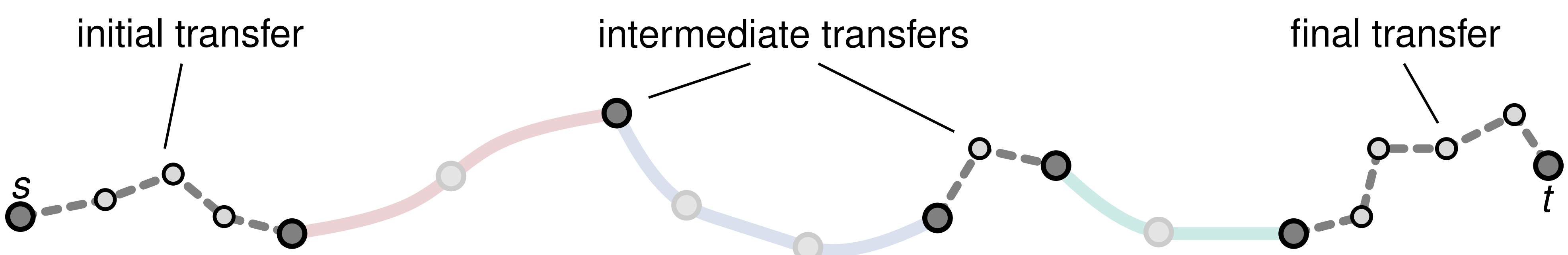
Idea:

- Process transfers differently based on their position in a journey
- We distinguish:
  - Initial transfers
  - Final transfers
  - Intermediate transfers



Our Approach – Transfer Handling

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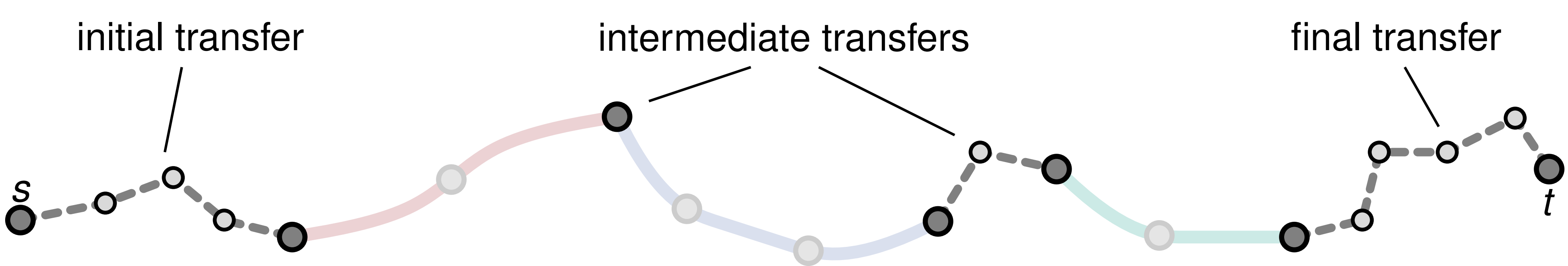
Initial/Final Transfers:

- – Frequent
- – Often long

Intermediate Transfers:

- + Rare
- + Mostly short



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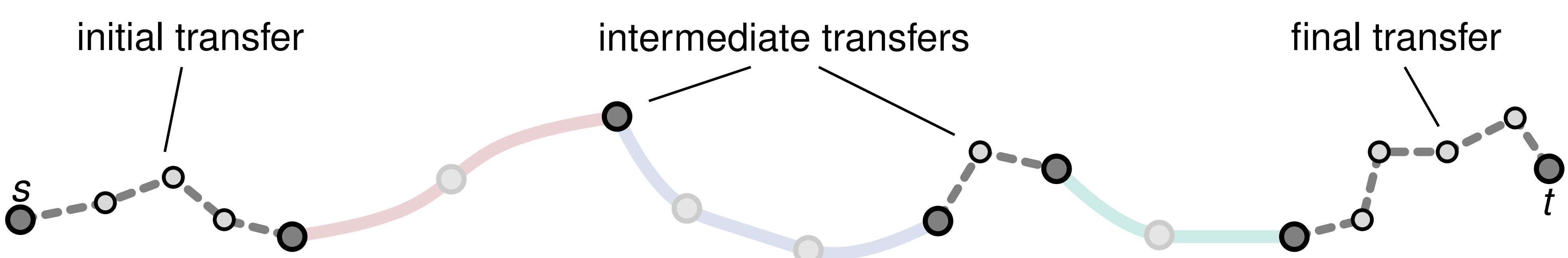

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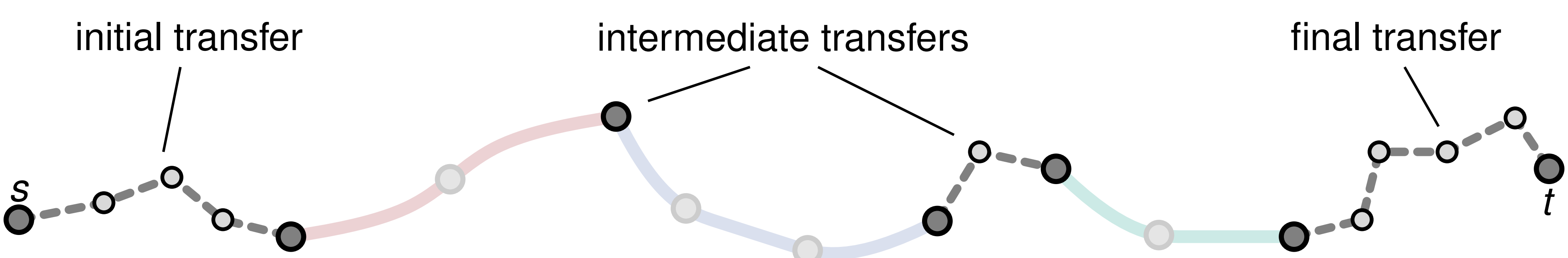
- Precompute **all** of them
- One-hop transfers during query



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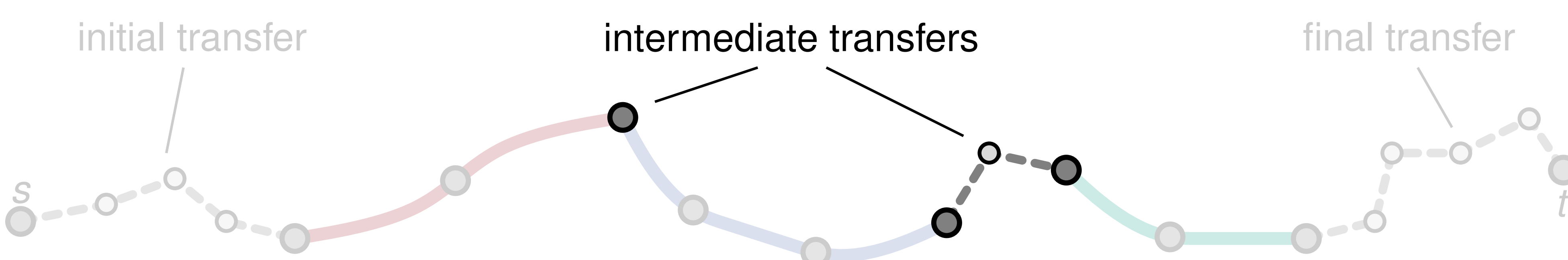

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First Idea:

- Enumerate all Pareto-optimal journeys
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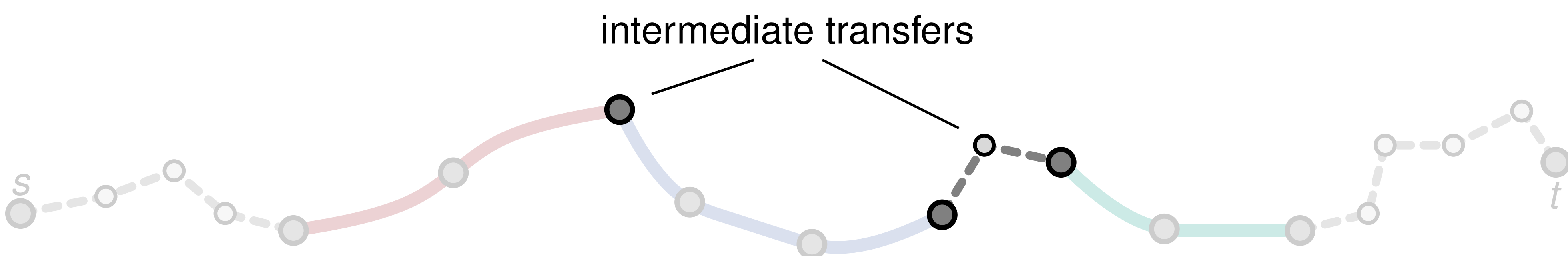

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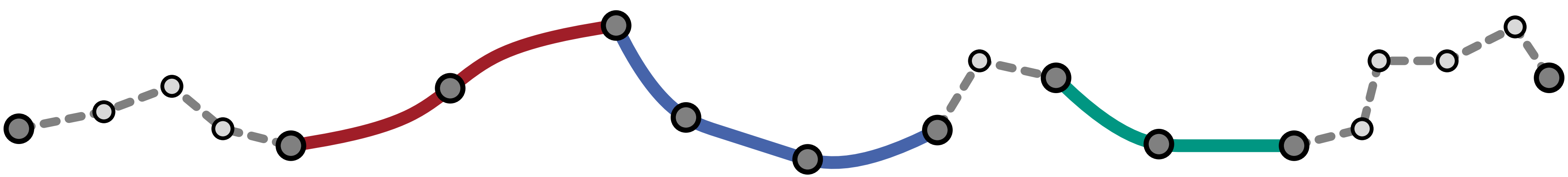

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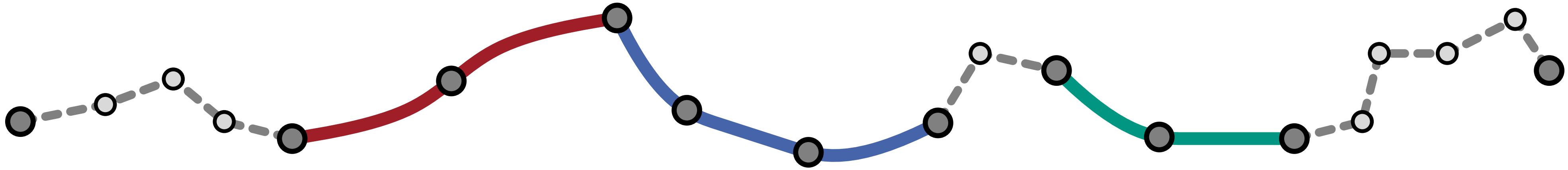
Improvements:

- Exploit the **subpath property**
- Enumerating journeys with exactly 2 trips is sufficient



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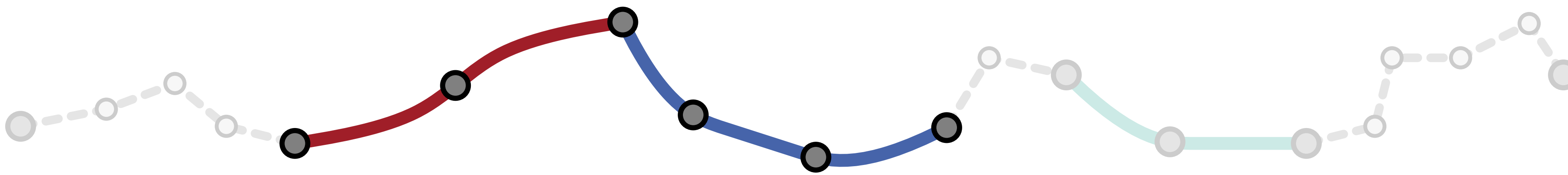

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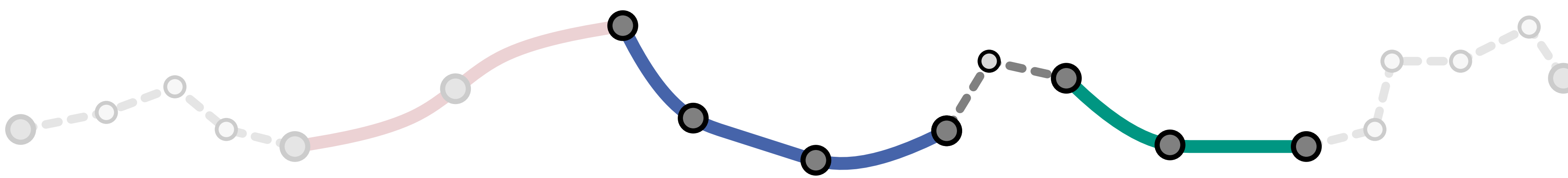

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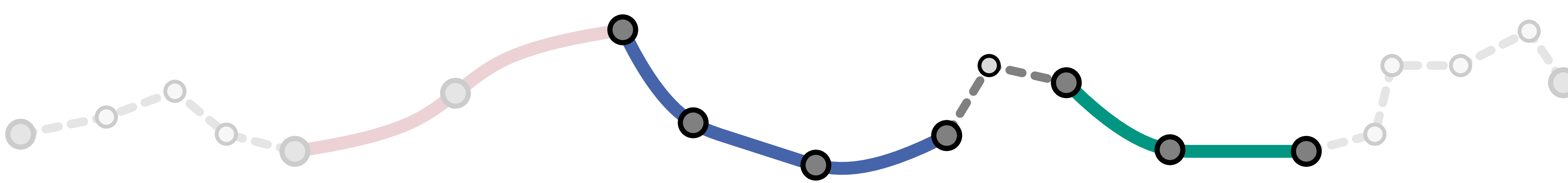
- Run range MCR from each stop restricted to two rounds



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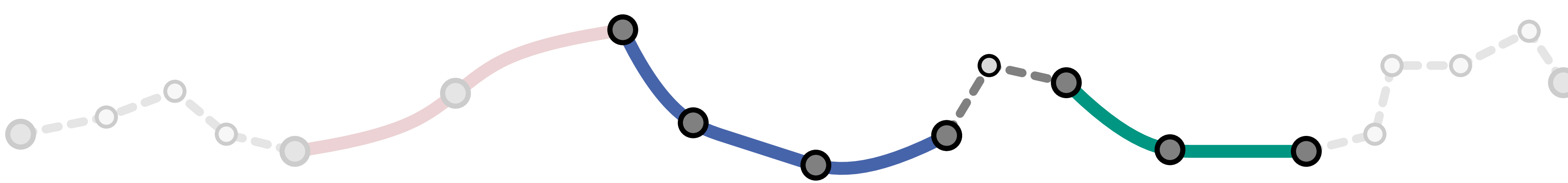

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Observation:

- Collecting all Pareto-optimal 2-trip journeys is superfluous
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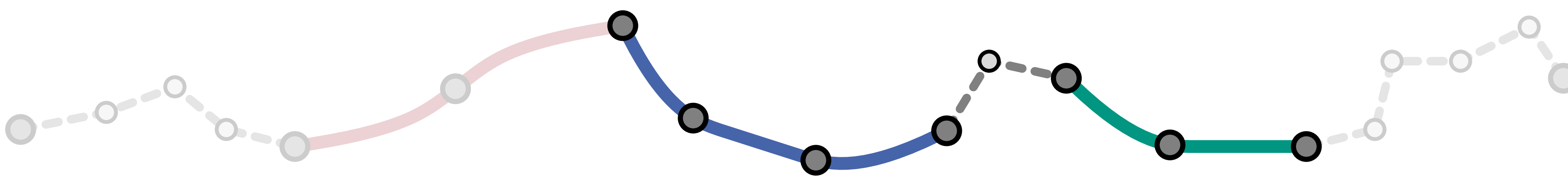

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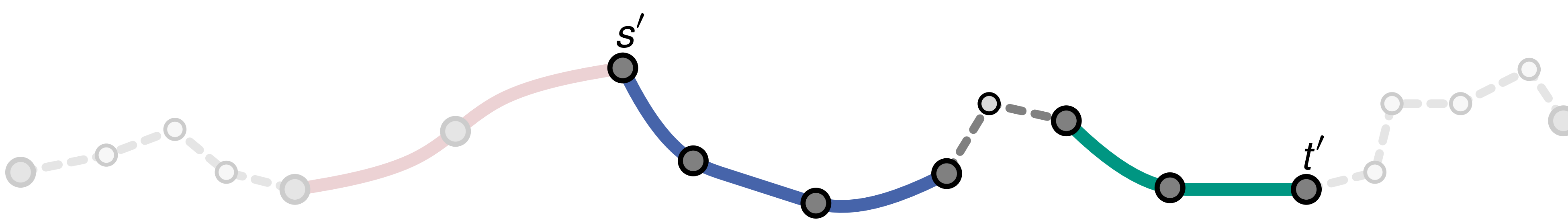

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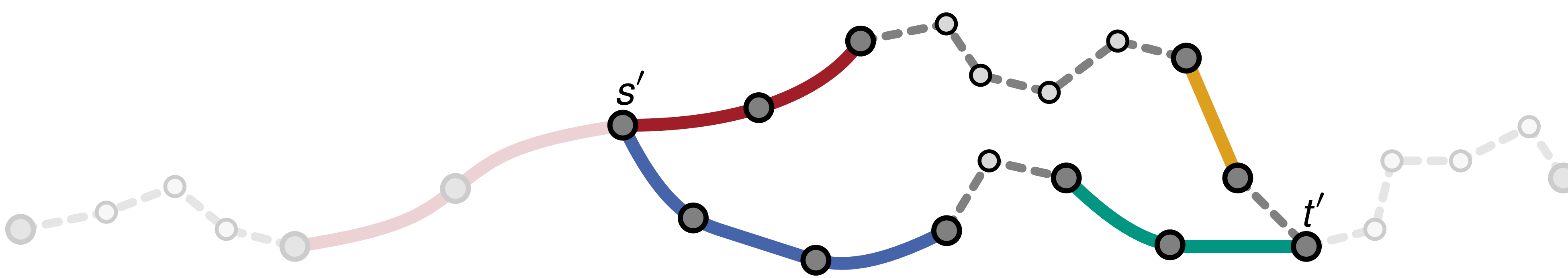

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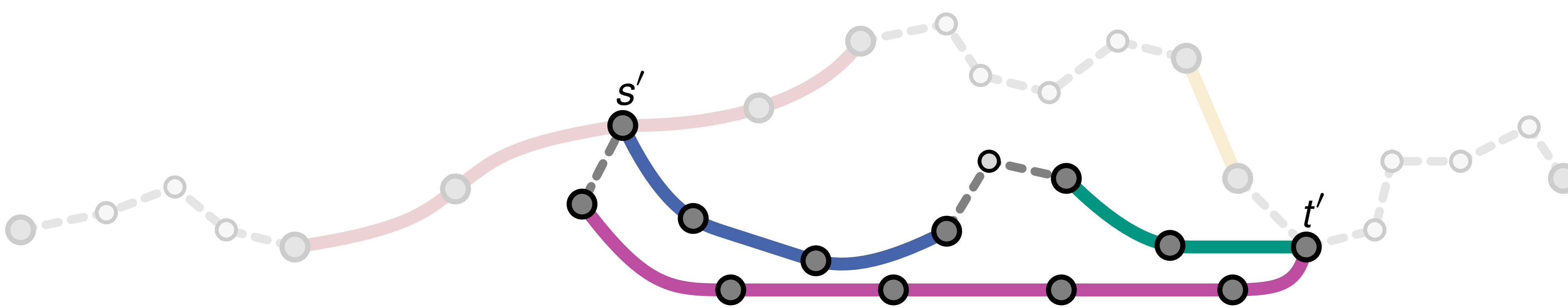

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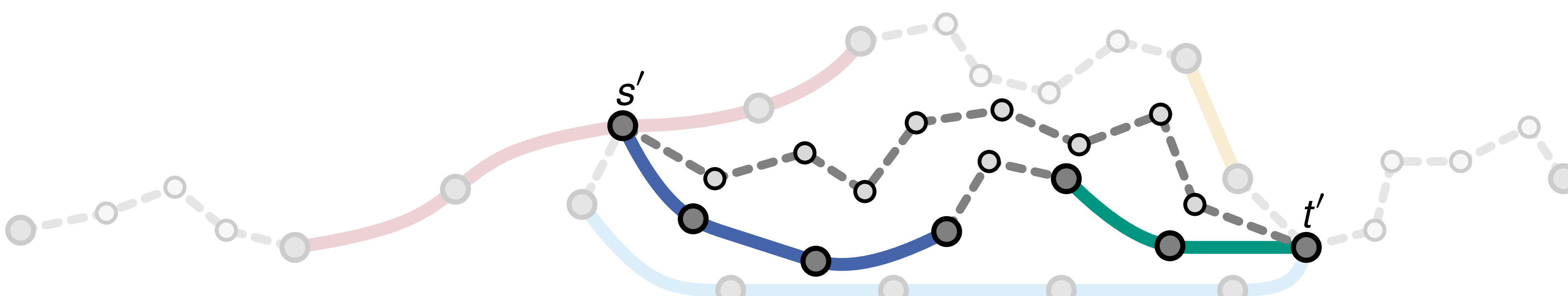

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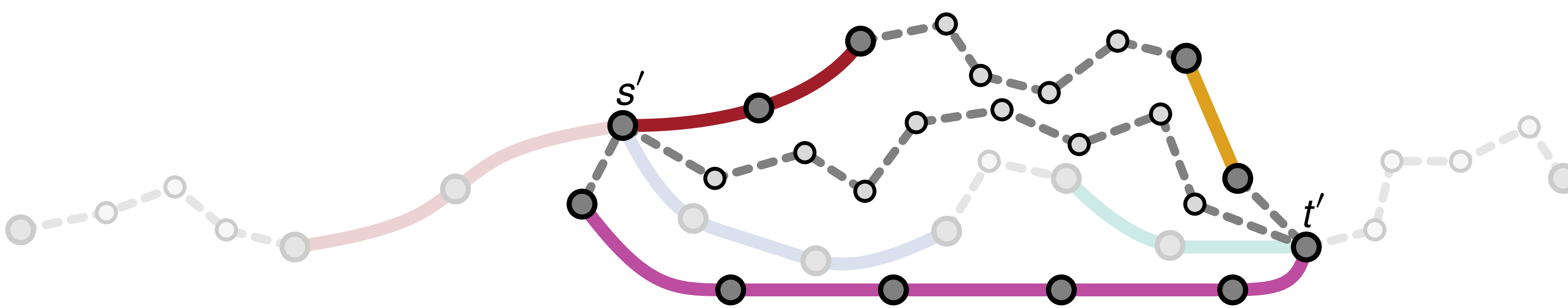
A Witness dominates a Candidate $\Leftrightarrow$ No shortcut needed



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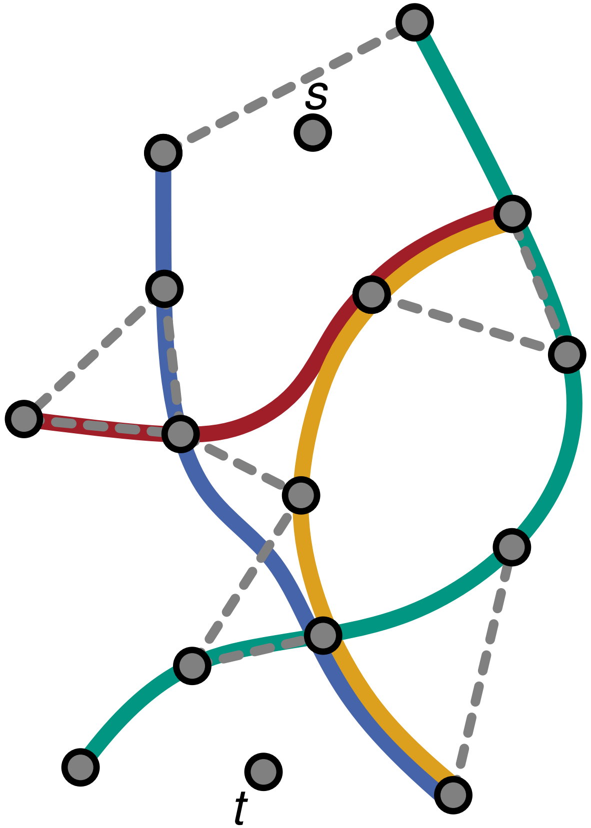

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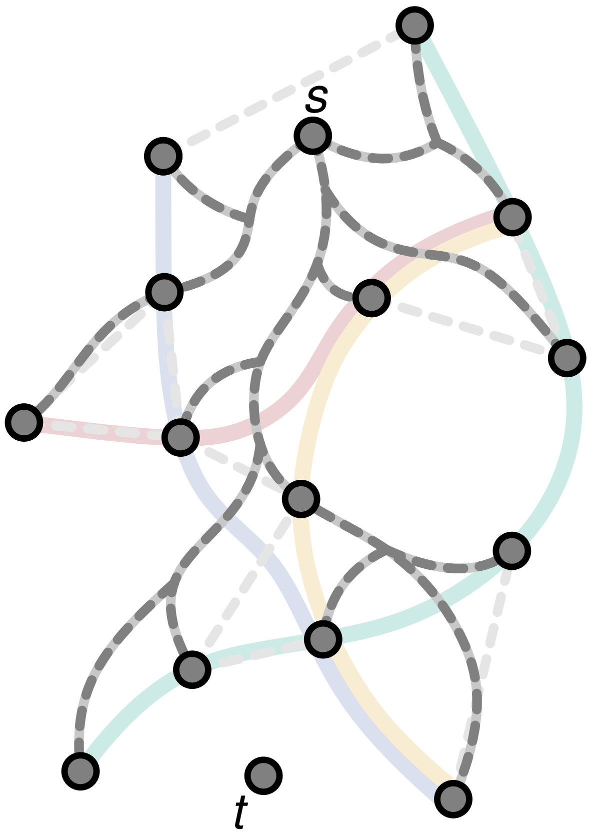

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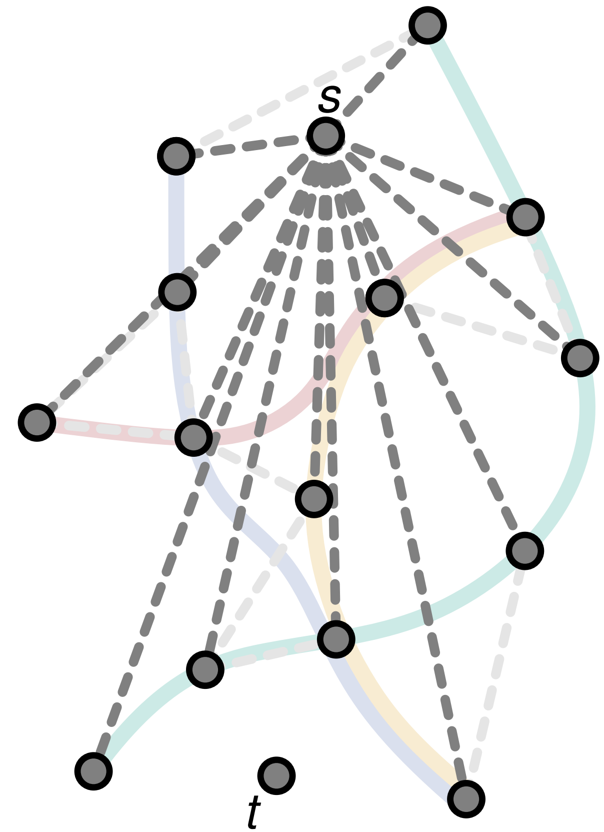

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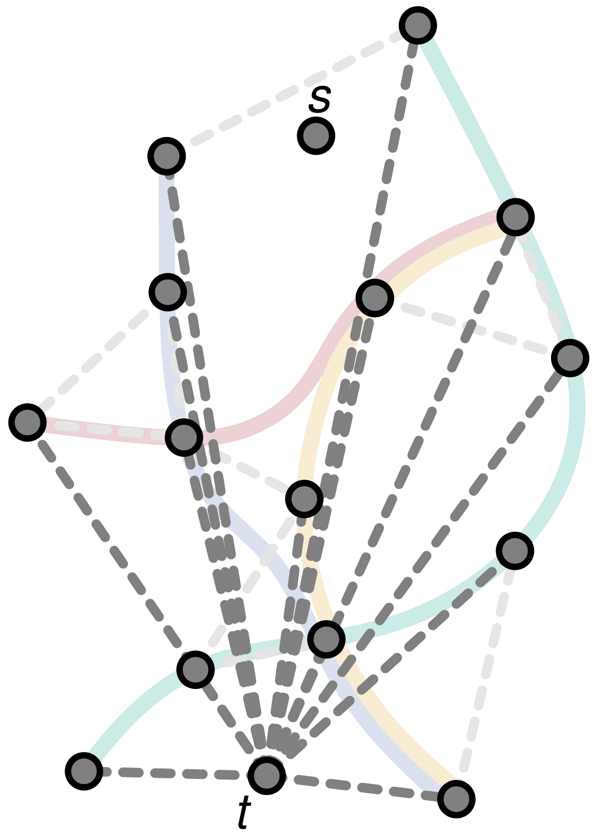

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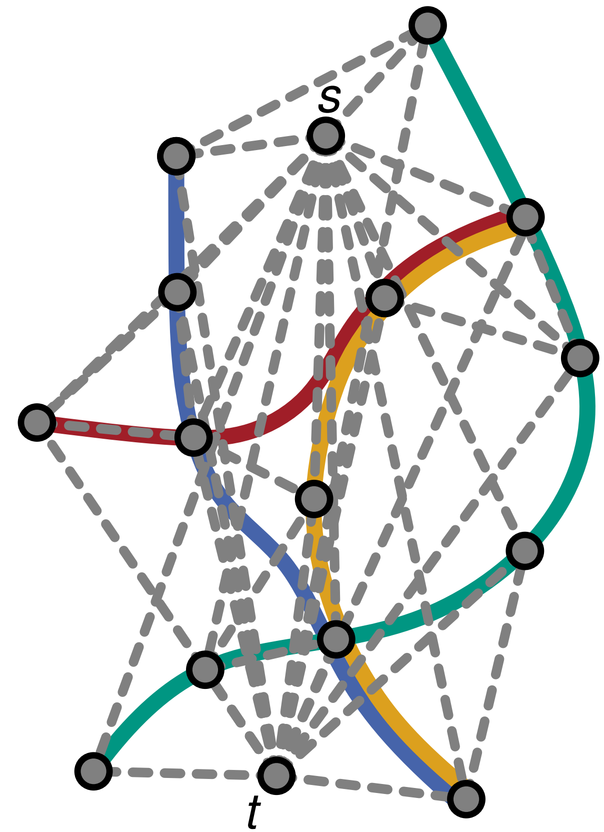
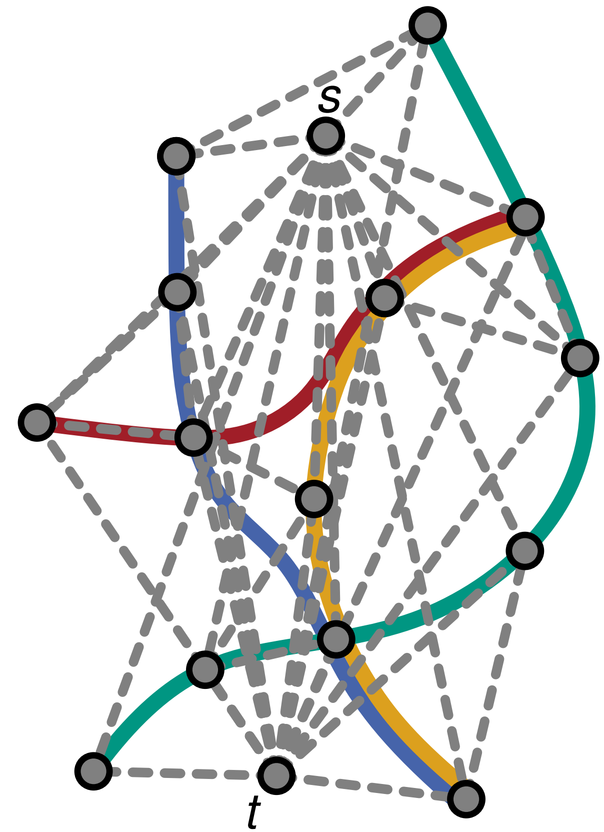


ULTRA Query Algorithms

Query Algorithm Outline:

- Build a temporary transfer graph *G* including:
  - Preprocessed shortcuts
  - Initial transfers
  - Final transfers
- Run any query algorithm on: (Timetable, *G*)
- Use one-to-many query for initial/final transfers
  - One = source/target
  - Many = public transit stops
  - Fast implementation: Bucket-CH



Observations:

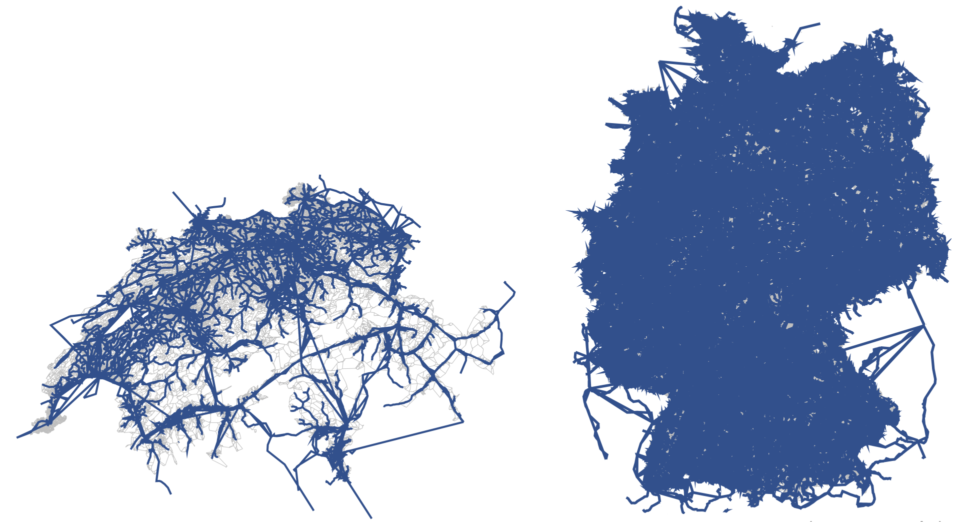
- Approach is independent of the used public transit query algorithm
- Knowing the algorithm can enable direct integration

Experimental Evaluation

Karlsruhe Institute of Technology

Instances:

- Timetables comprising two days
  - Switzerland (GTFS feed)
  - Germany (from DB)
- OpenStreetMap transfer graphs
  - Streets and pedestrian zones
  - Speed limits
- Transitive graphs for comparison
  - Limited maximum distance
  - Avg. degree ≈ 100



(not to scale)

Network	Switzerland	Germany
Stops	25 426	244 055
Routes	13 934	231 089
Trips	369 534	2 387 297
Stop events	4 740 929	48 495 169
Vertices	604 167	6 872 105
Full edges	1 847 140	21 372 360
Transitive edges	4 687 016	22 645 480

Experimental Evaluation – Preprocessing

Karlsruhe Institute of Technology

Setup:

- Switzerland with different speeds for the transfer graph
- In parallel on a machine with 16 cores

Result:

- Parallel speed-ups for walking as transfer mode (4.5 km/h)

Number of threads	1	2	4	8	16
Preprocessing time [mm:ss]	2:00:56	58:03	31:11	17:29	10:12
Speed-up factor	1	2.08	3.88	6.92	11.85

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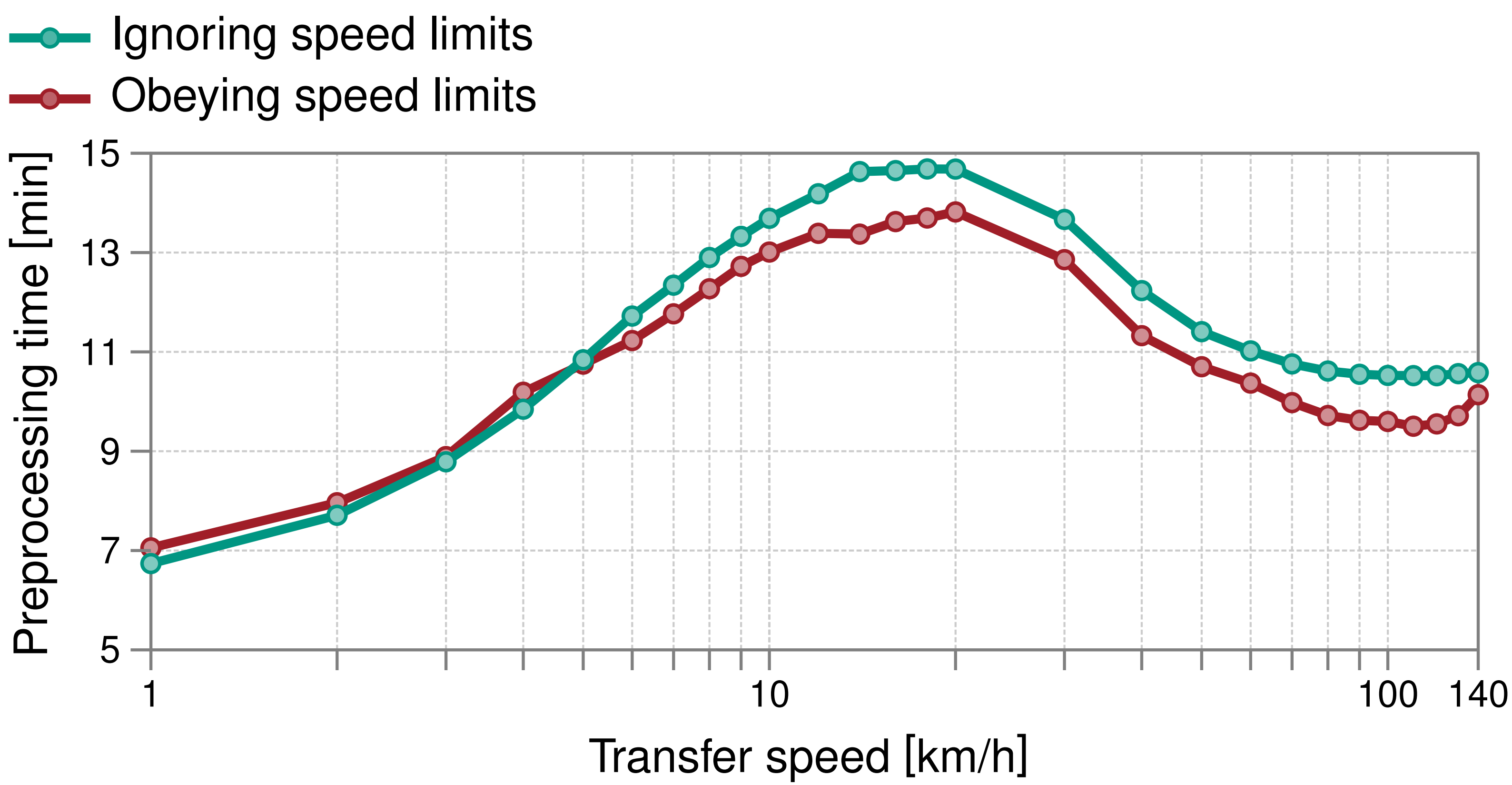

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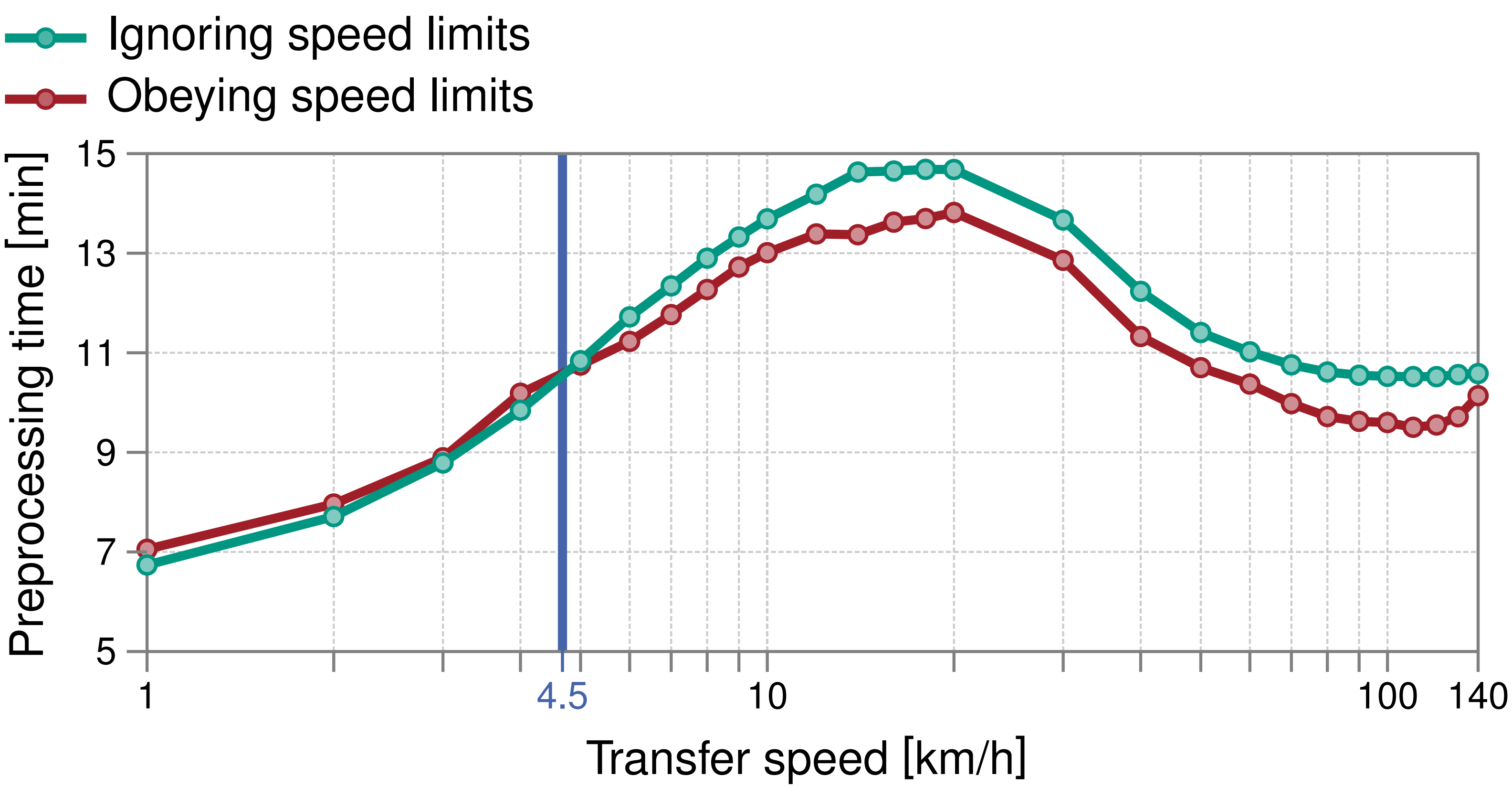

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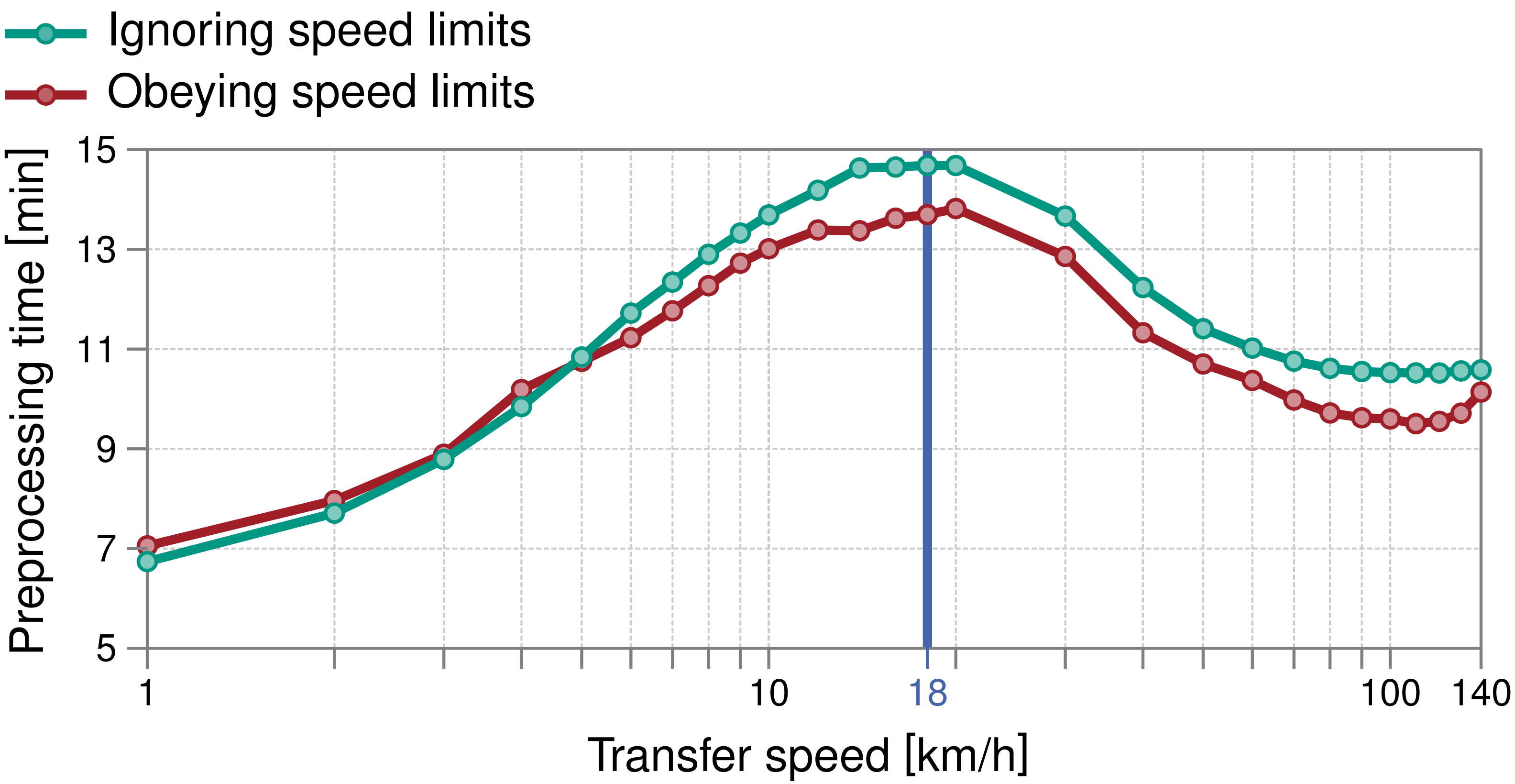

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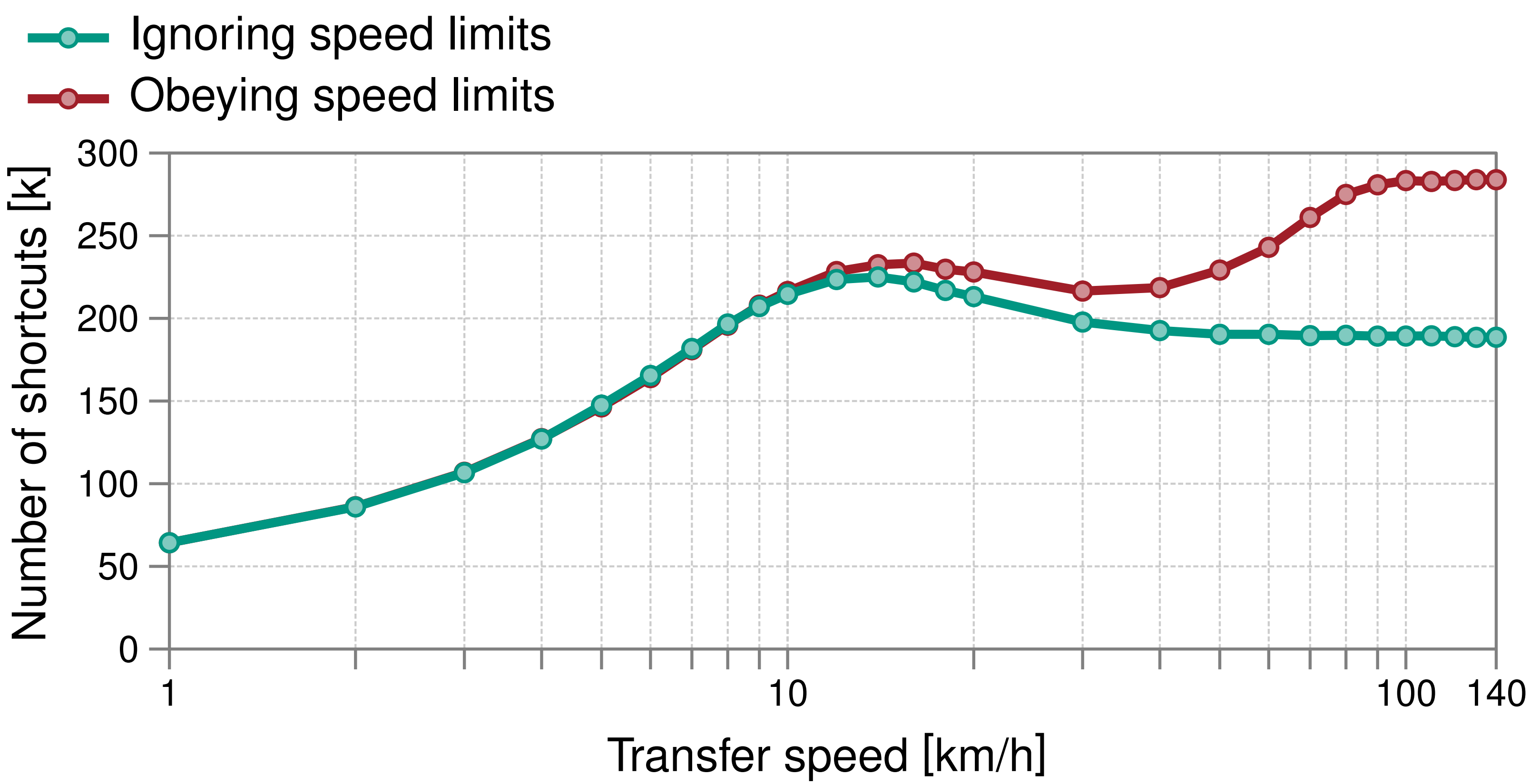

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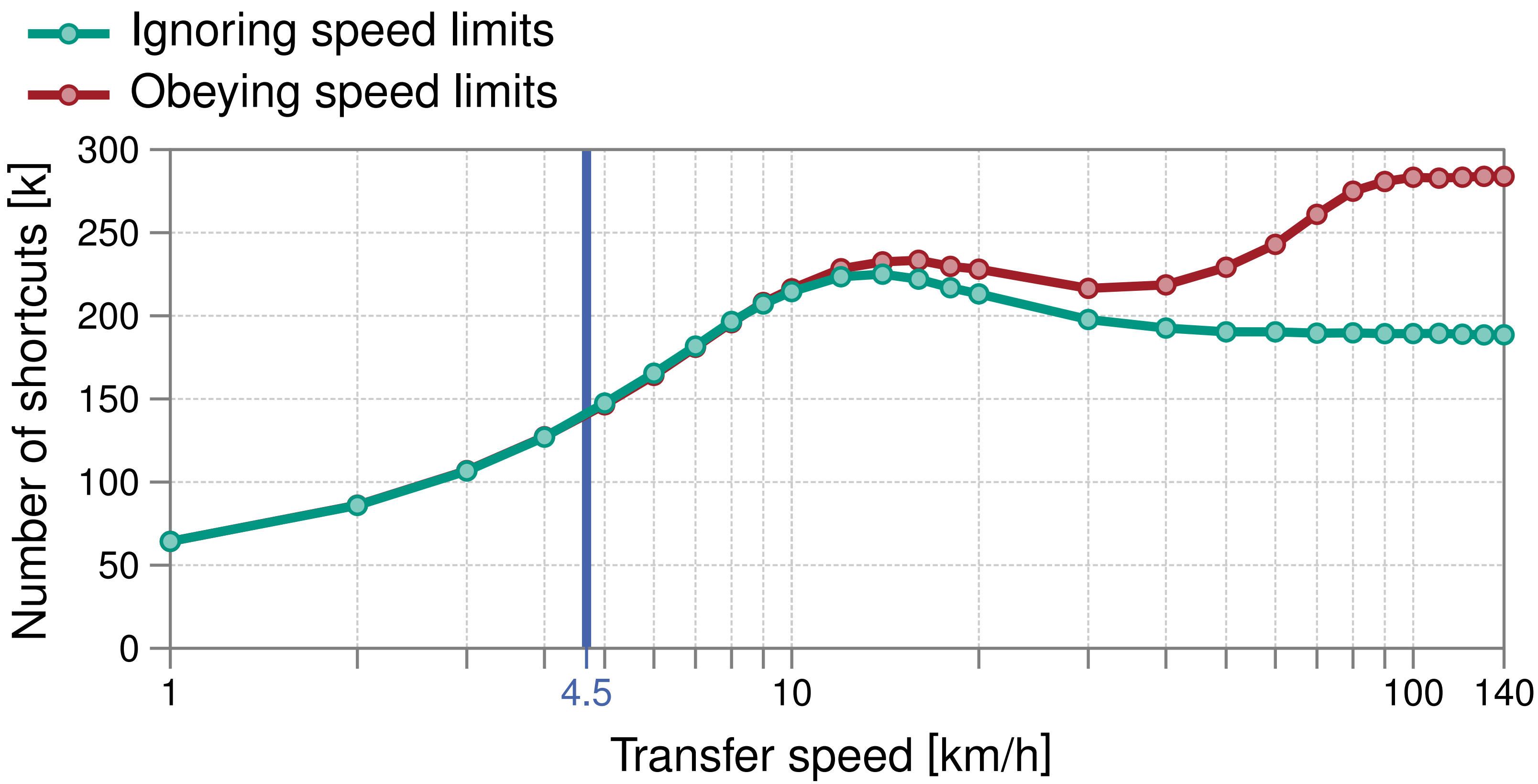

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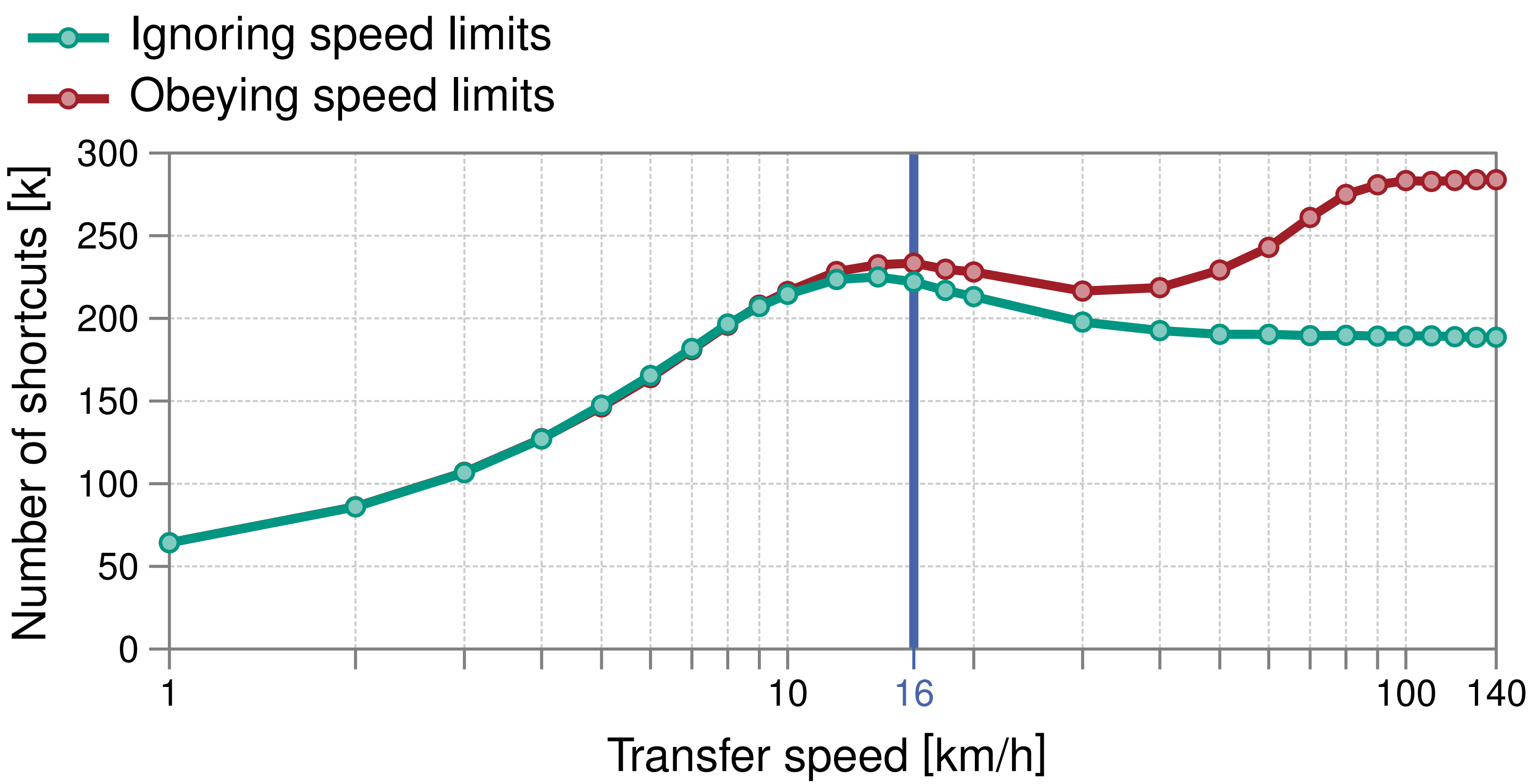

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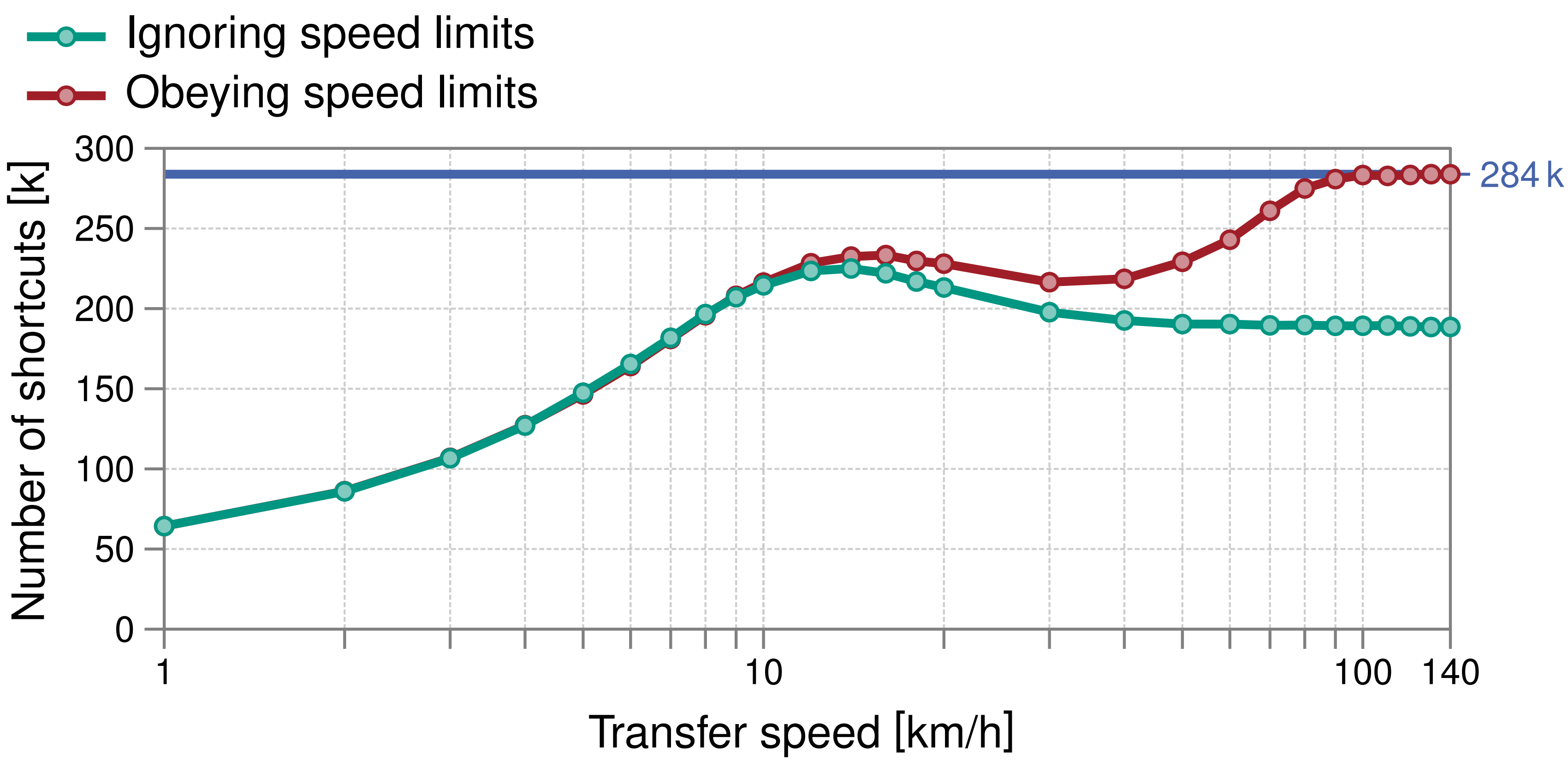

Experimental Evaluation – Preprocessing

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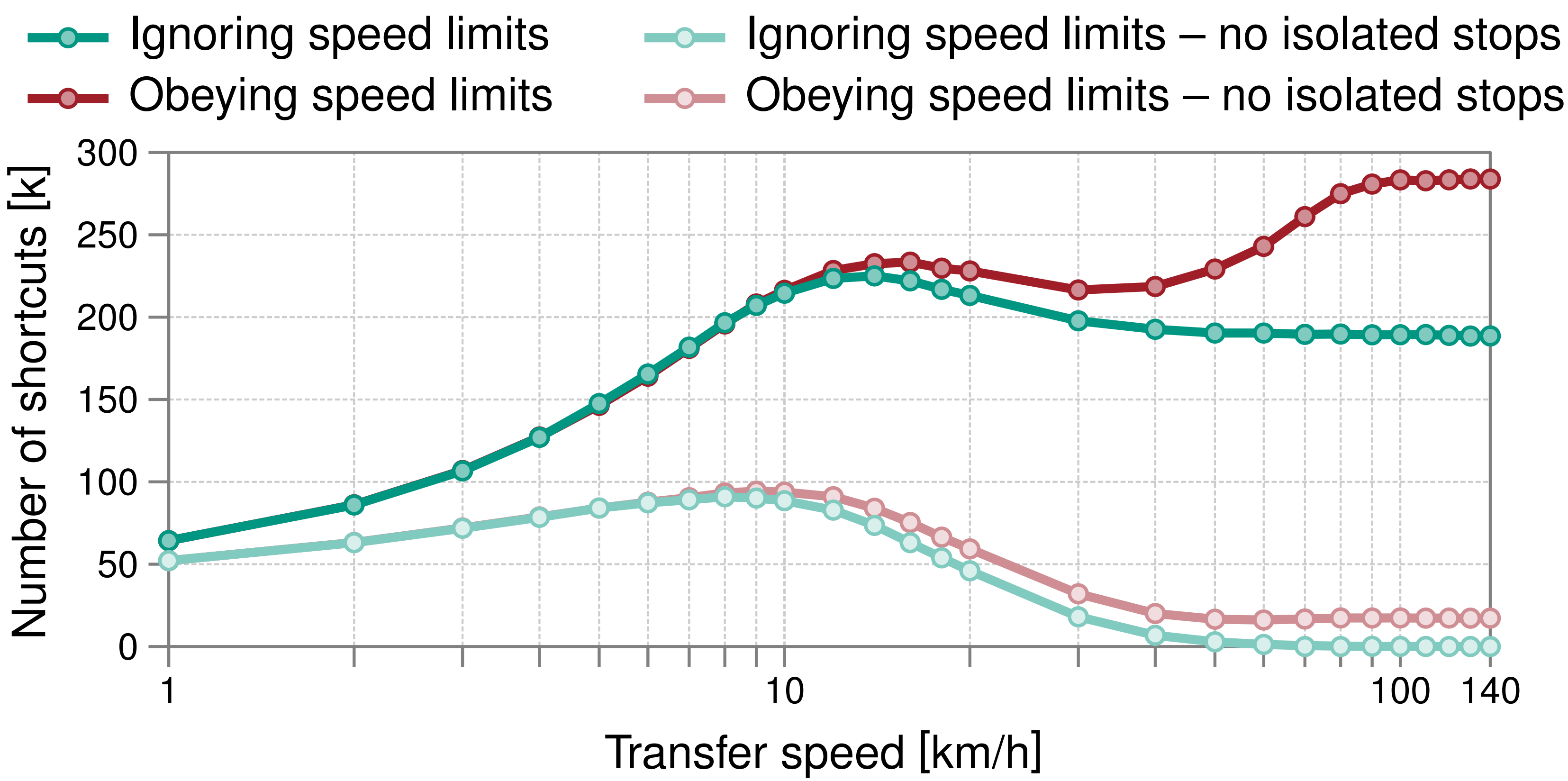
Setup:

- Switzerland with different speeds for the transfer graph
- Isolated stops / imperfect data was filtered out

Result:



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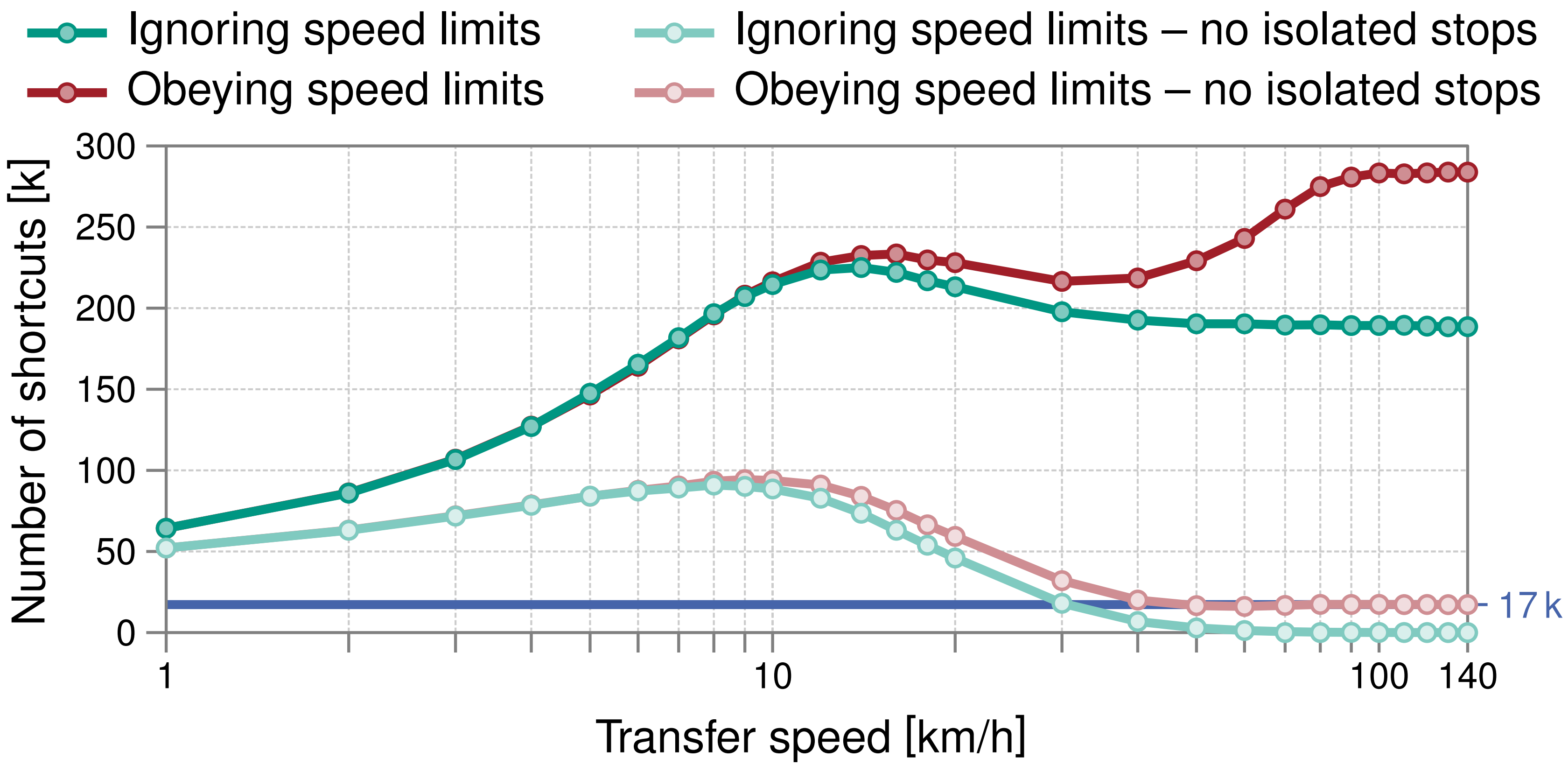

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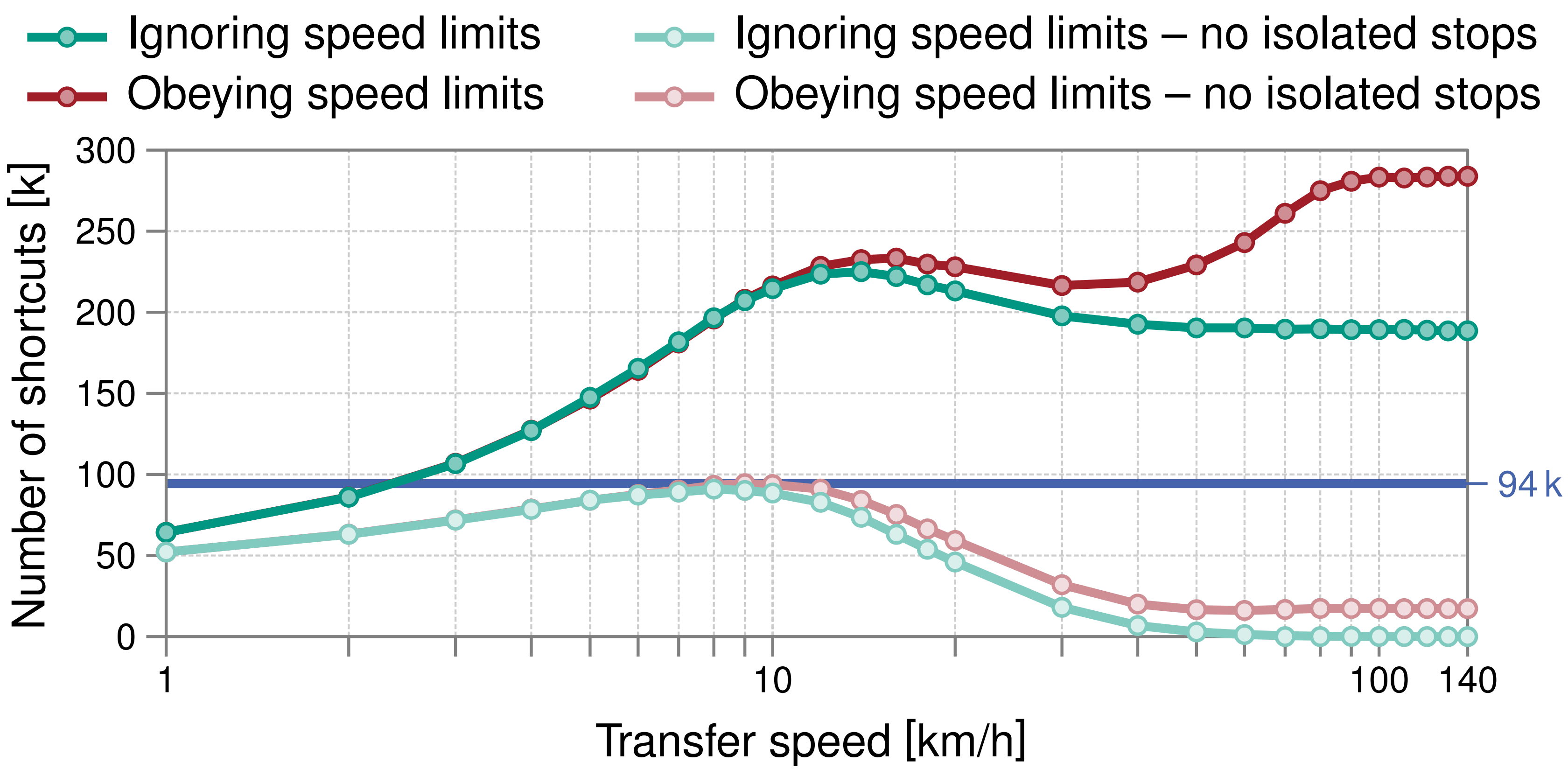

Experimental Evaluation – ULTRA-CSA

Karlsruhe Institute of Technology

Setup:

- CSA-based queries, optimizing only arrival time
- MCSA interleaves CSA with Dijkstra's algorithm
- Query type for CSA*: stop-to-stop
- Query type for MCSA, ULTRA-CSA: vertex-to-vertex

Network	Algorithm	Scans [k]		Time [ms]		
		Connections	Edges	Init.	Scan	Total
Switzerland (4.5 km/h)	CSA*	124.7	1 294	0.1	6.0	6.2
	MCSA	85.3	244	9.9	9.0	18.8
	ULTRA-CSA	84.7	80	1.3	4.2	5.6
Germany (4.5 km/h)	CSA*	2 564.0	6 269	1.7	145.8	147.5
	MCSA	1 527.8	3 182	148.2	185.9	334.1
	ULTRA-CSA	1 523.4	933	23.3	119.7	143.0

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Experimental Evaluation – ULTRA-RAPTOR

Karlsruhe Institute of Technology

Setup:

- RAPTOR-based queries, optimizing arrival time and number of trips
- MR-∞ is MCR with unlimited walking
- Query type for RAPTOR*: stop-to-stop
- Query type for MR-∞, ULTRA-RAPTOR: vertex-to-vertex

Network	Algorithm	Scans [k]		Time [ms]				
		Routes	Edges	Init.	Collect	Scan	Relax	Total
Switzerland (4.5 km/h)	RAPTOR*	27.2	3 527	0.0	3.7	6.4	7.8	18.4
	MR-∞	34.9	769	11.6	5.9	8.2	12.3	39.3
	ULTRA-RAPTOR	37.7	148	1.6	4.9	7.9	1.9	16.7
Germany (4.5 km/h)	RAPTOR*	480.4	25 798	0.0	166.9	178.0	85.1	436.5
	MR-∞	555.8	12 571	191.1	250.7	202.2	272.2	944.1
	ULTRA-RAPTOR	610.6	2 224	26.8	204.5	202.9	37.0	477.8

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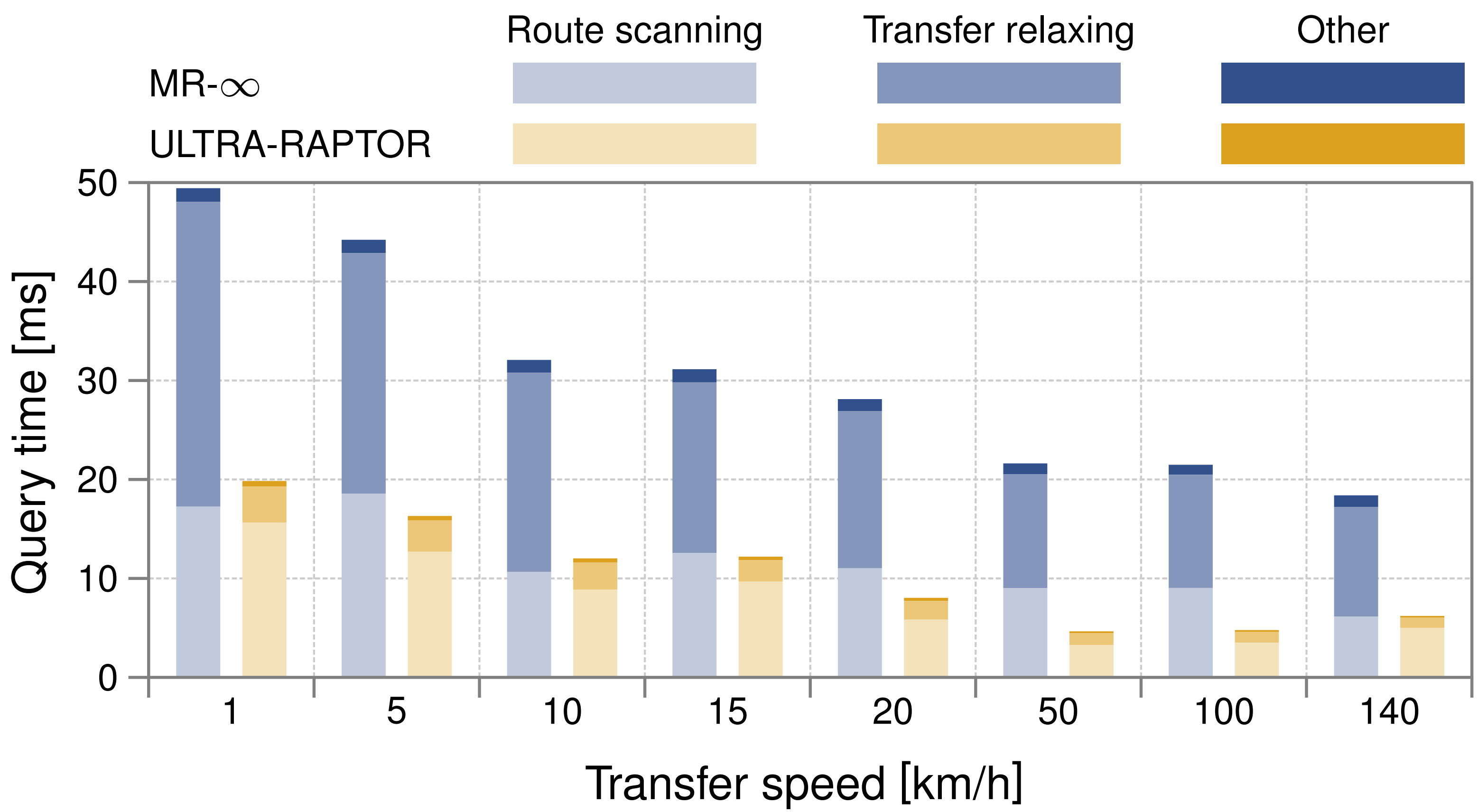

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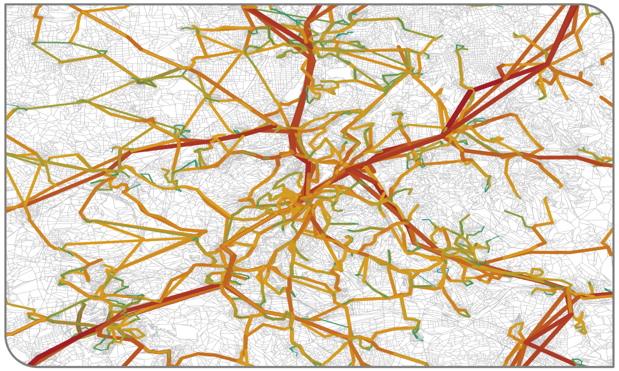
Ongoing and Future Work

Extending the ULTRA Preprocessing:

- Compute shortcuts for more criteria (price, transfer distance, ...)
- Accelerate the preprocessing phase
- Consider complicated transfer scenarios (bike sharing stations)

Utilizing the ULTRA Shortcuts:

- Multi-modal public transit traffic assignments
- Other query algorithms (Trip-Based, ...)
- One-to-many queries



Thank you for your attention

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