On Compact Representation and Robustness of Transfer Patterns in Public Transportation Routing

Master's Thesis

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Outline

Transfer Pattern Routing

Compact Representation of Transfer Patterns

Robustness of Transfer Patterns

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Transfer Pattern Routing

Transfer Patterns

- Example Freiburg $\rightarrow$ Munich

  [F, Karlsruhe, M], [F, Titisee, Ulm, M]

State-of-the-art routing algorithm (Hannah Bast et al. [1])

- Optimal transfer patterns
- Efficient direct connection queries

Modeling timetable data

- Time-expanded graph
- Realistic routing adds transfer buffer, walking (Robert Geisberger [2])
- Multi-variate cost model: time of travel, number of transfers
- Pareto-optimal paths by multi-label Dijkstra

Transfer Patterns

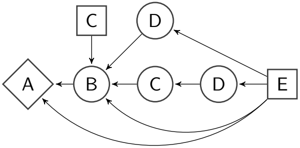
Computation and Storage

Perform a full Dijkstra for every station

- Backtrack optimal paths from each destination
- Transfers along paths yield patterns

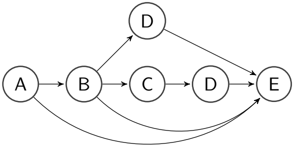
Store patterns as Directed Acyclic Graph

- Reversed, prefix-free
- One DAG per station
- Example for patterns 'ABC', 'AE', 'ABE', 'ABDE', 'ABCDE'



Transfer Patterns

Search



Query Graph

- Construction from patterns
- Arcs present direct connections

Efficient search

- Direct connection queries for arc relaxation
- List-intersection based algorithm

Pareto-optimal paths within a few ms

Transfer Pattern Routing

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Motivation

Size of the information

- Hardware requirements
- Access speed
- Future: increased number of patterns (multi-modal route planning)

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First Approach

Routing with first transfers

Idea

- Store only the first transfer instead of full patterns
- At search time, recursively construct query graph
- Example Freiburg → Munich

Problems

- Requires same precomputation...
- ...but discards most information
- Less informed, search space twice as large → slower
- Only small advantage in space

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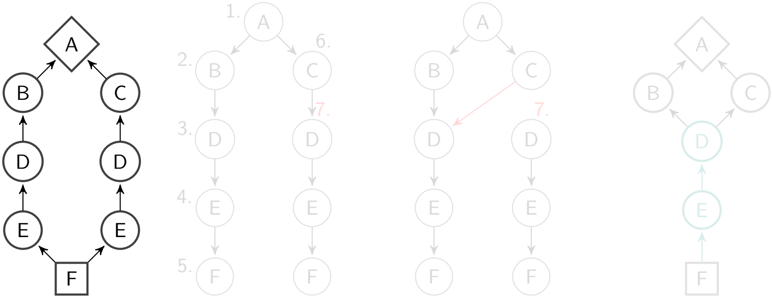
Removing Redundancy (1)

Equal suffixes

- DAG is prefix-free
- Detect and remove equal suffixes



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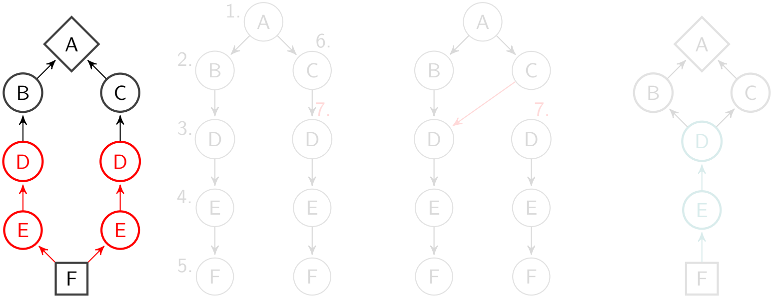

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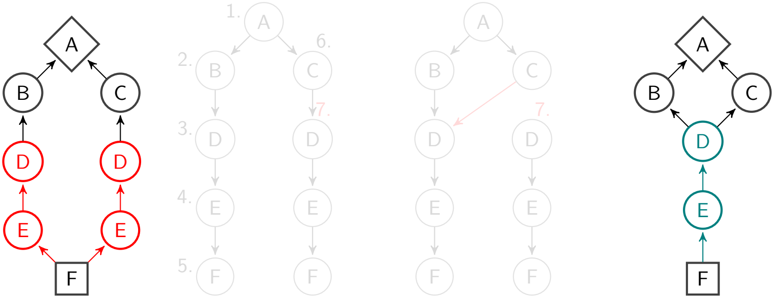

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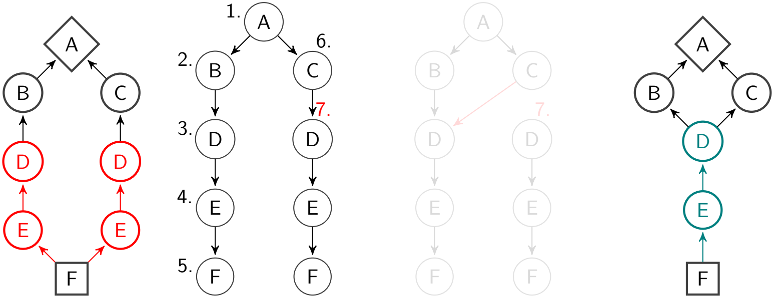

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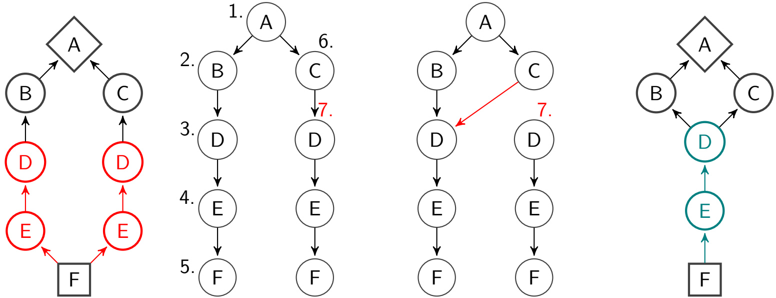


Removing Redundancy (2)

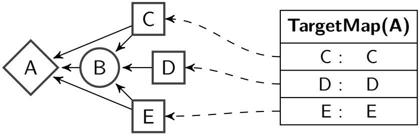
Entry points

Information of destination nodes

- Station id + successors

Destination map determines station id as well

- Merge destination nodes with equal successors



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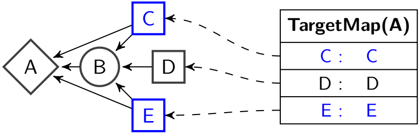

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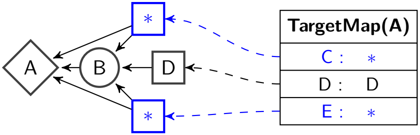

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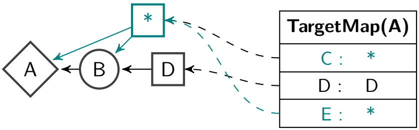


Removing Redundancy (3)

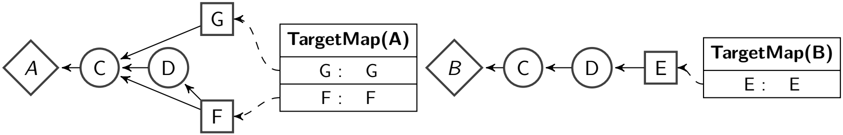
Joint Graph

Observation

- Information of the departure node is redundant
- Context determines station id

Let all patterns share a common root

- Joint DAG resolves redundancy between all DAGs
- Station id is assigned at query time
- Other techniques can be applied on top of that



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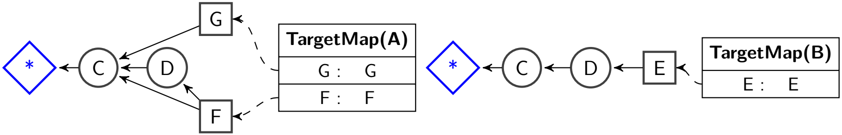

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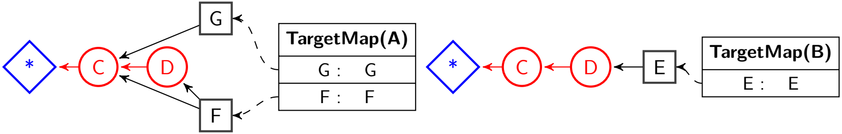

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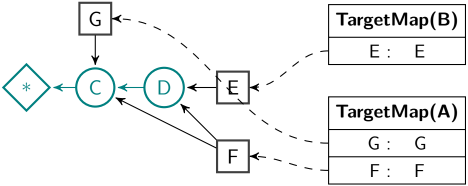

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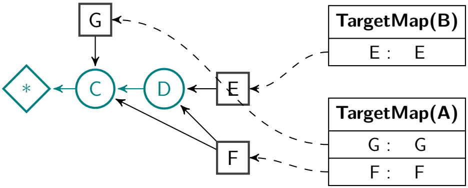

Results

Compact Representation

- Computed transfer patterns for Hawaii, Detroit, Toronto, NYC
- Measure size of 4 representations
- Example: Toronto at 1000m walking distance (162M patterns, 5.8 patterns per destination in average) [1]

Toronto@1000m: 162.0M, 5.8

	TP	TP^c	*jDAG*	$jDAG^c$
# internal nodes	24.2M	20.6M	3.2M	3.0M
# destination nodes	27.9M	11.7M	27.9M	7.2M
# arcs	186.2M	110.0M	165.2M	78.3M
Memory size (Byte)	1.6G	1.1G	1.3G	659.8M
Byte/pattern	9.8	6.5	7.8	4.1

[1] TP^c: techniques 1 + 2, *jDAG*: technique 3, $jDAG^c$: 1 + 2 + 3

Results

Compact Representation

Evaluation (general)

- Removing equal suffixes saves 10–20% internal nodes
- Merging destination nodes removes 50–80% nodes and a lot of arcs
- Joint DAG shrinks the internal structures by factor $\sim$8
- Approaches combine very well
- Destination maps become dominant part of the data

Transfer Pattern Routing

Compact Representation of Transfer Patterns

Robustness of Transfer Patterns

Motivation

Transfer patterns vs. real-time updates

Time-consuming precomputation

- Computation of transfer patterns in $O(N^2)$
- Heuristics: important stations, limits
- Still very long

Realistic applications

- Frequent updates: delay
  - Traffic jam, strike, cow on the track, ...
- Can the patterns still guarantee optimal responses?

Motivation

Transfer patterns vs. real-time updates

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Delay model

Scenarios

- Delay fixed percentage of trips
- Random, exponentially distributed offset
- After random insertion stop

Scenario	Share of trips and average delay
Low	25% : 5 min
Medium	25% : 15 min
High	25% : 50 min
Switzerland	10% : 5 min, 3% : 15 min, 1% : 50 min
Germany	20% : 5 min, 10% : 15 min, 5% : 50 min
India	40% : 5 min, 40% : 15 min, 20% : 50 min

Experimental setup

- Compute transfer patterns
- Update network
- Answer random location queries
  - Original transfer pattern, updated direct connection data
  - Dijkstra on updated network
- Compare and classify responses

Class	Difference d to optimal path costs c^*
OPTIMAL	$d = 0$
ALMOST OPTIMAL A	$d \leq 5\text{min} \wedge \frac{d}{c^*} \leq 5\%$
ALMOST OPTIMAL B	$d \leq 10\text{min} \wedge \frac{d}{c^*} \leq 10\%$
FAILING	otherwise

Results

Robustness

Example: 50,000 successful queries on Toronto

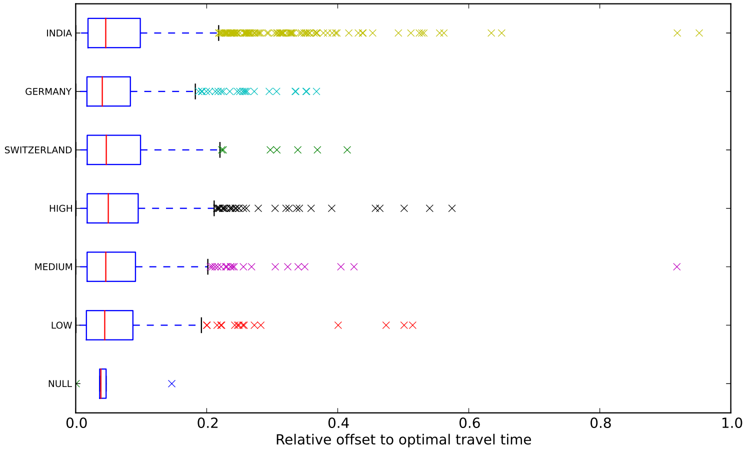
- Classification of responses

	optimal	almost a	almost b	failing
Null	99.98%	0.00%	0.00%	0.00%
Low	99.73%	0.12%	0.04%	0.08%
Medium	99.59%	0.20%	0.06%	0.13%
High	99.49%	0.27%	0.07%	0.16%
Switzerland	99.82%	0.09%	0.02%	0.05%
Germany	99.54%	0.22%	0.06%	0.16%
India	97.85%	1.12%	0.31%	0.70%

Results

Robustness

- Suboptimal responses: time of travel



Results

Robustness

Evaluation (general)

- Never more than 5% suboptimal queries
- Majority of suboptimal responses is almost optimal
- Even under worst scenario INDIA
- But: A few critical outliers

Summary

Compact Representation

Contribution

- Understanding sources of redundancy
- Several techniques reducing data size, maintain accessibility
- Store twice as many patterns in the same memory

Future work

- Dominant destination maps
  - Joint destination maps
  - Invest in hub selection strategies
- Space-efficient implementation

Summary

Robustness

Contribution

- Indication for robustness
- Even for extreme scenarios
- Quality guarantee for transfer pattern routing

Future work

- Acquire and test with real data
- Dependency from precomputation parameters
- How to improve robustness?

Bibliography

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