Karlsruhe Institute of Technology

Trip-Based Public Transit Routing

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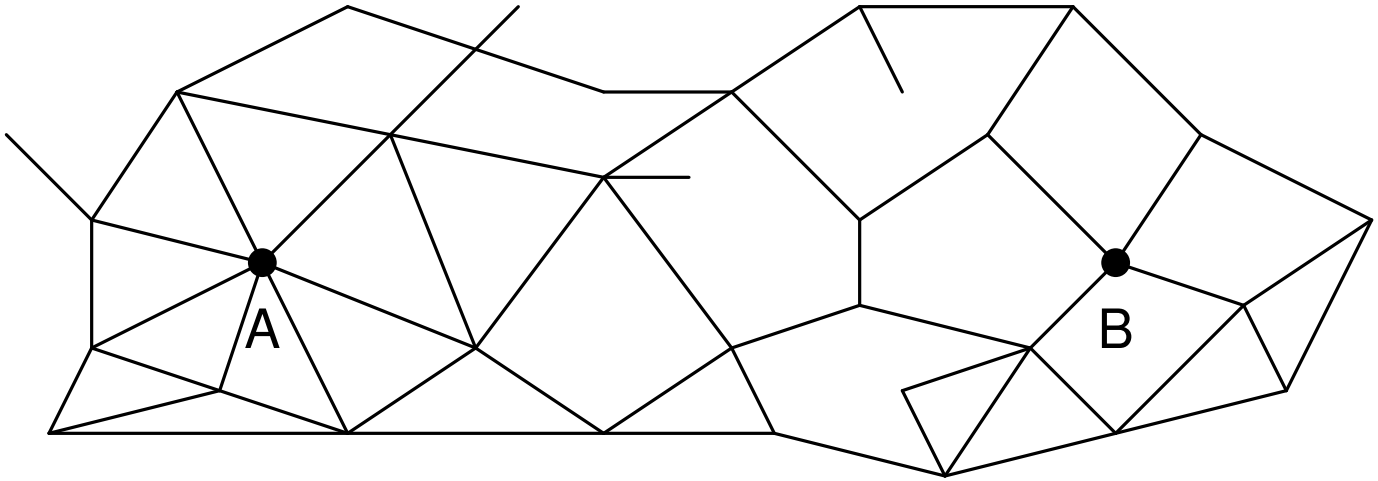
Agenda

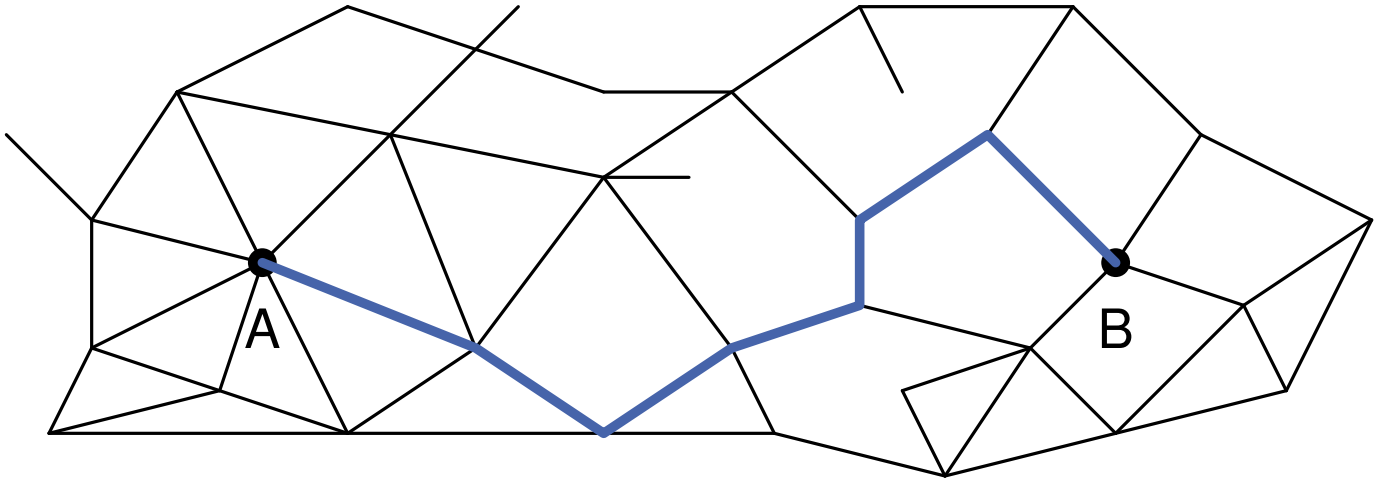
- Introduction
- Public Transit Routing
- Trip-Based Model and Algorithm
- Experiments
- Conclusion

Introduction
Routing 101

Introduction
Routing 101



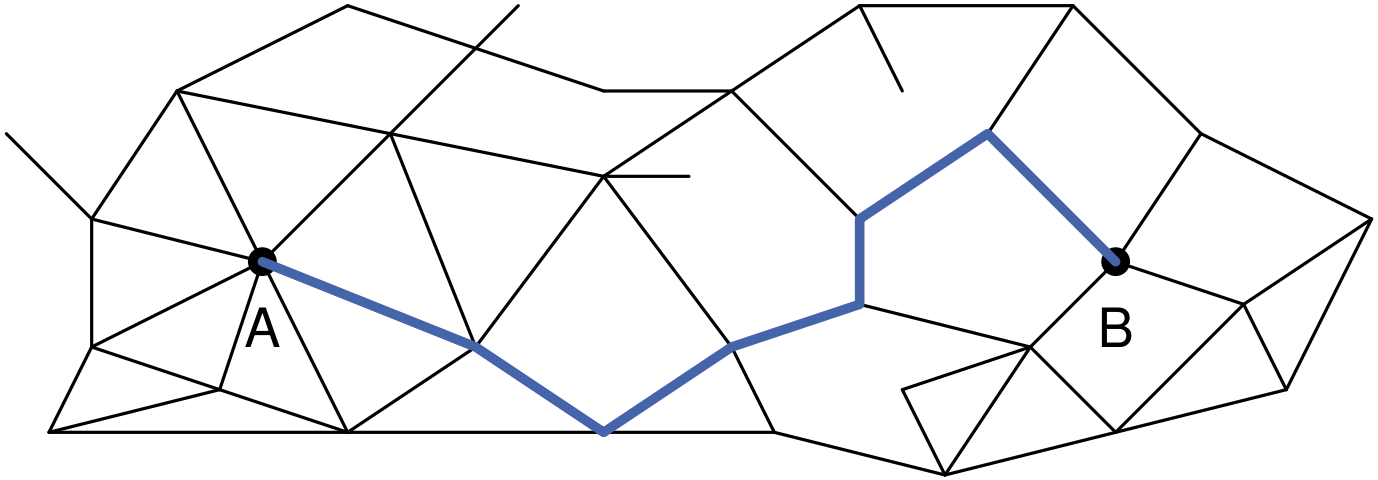
Introduction
Routing 101



Introduction
Routing 101


Goal-directed


Separator-based

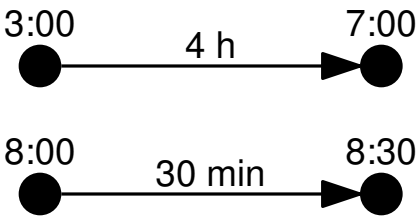



Hierarchical


Bounded-Hop

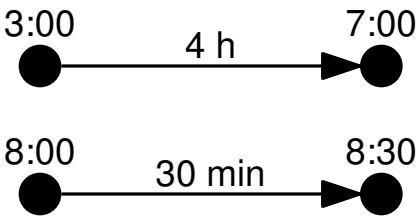
Introduction
Public Transit Routing

- Inherently time-dependent: Travel times depend on departure time

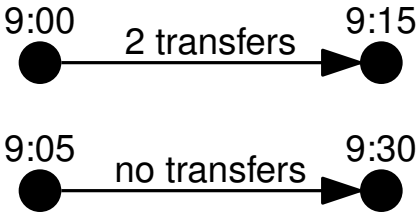


Introduction
Public Transit Routing

- Inherently time-dependent: Travel times depend on departure time



- Multiple natural problem variants
  - Earliest arrival queries
  - Profile (range) queries
  - Multi-criteria queries (e.g., number of transfers taken)



Public Transit Routing

Terminology

Public Transit Routing

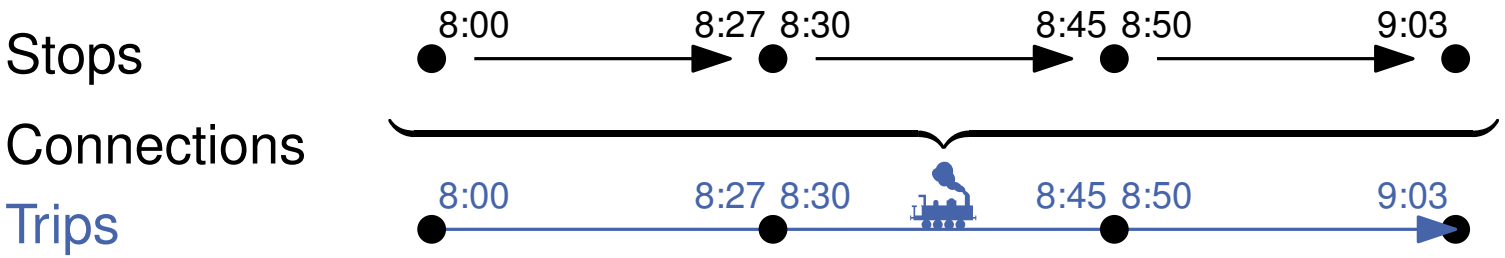
Terminology

Stops

Connections

Public Transit Routing

Terminology



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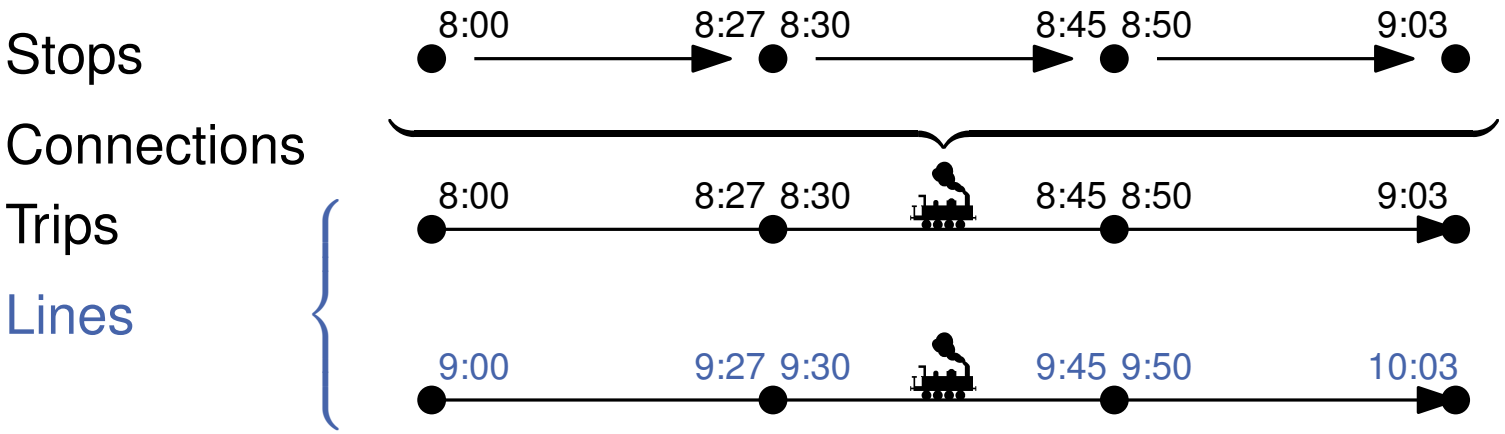

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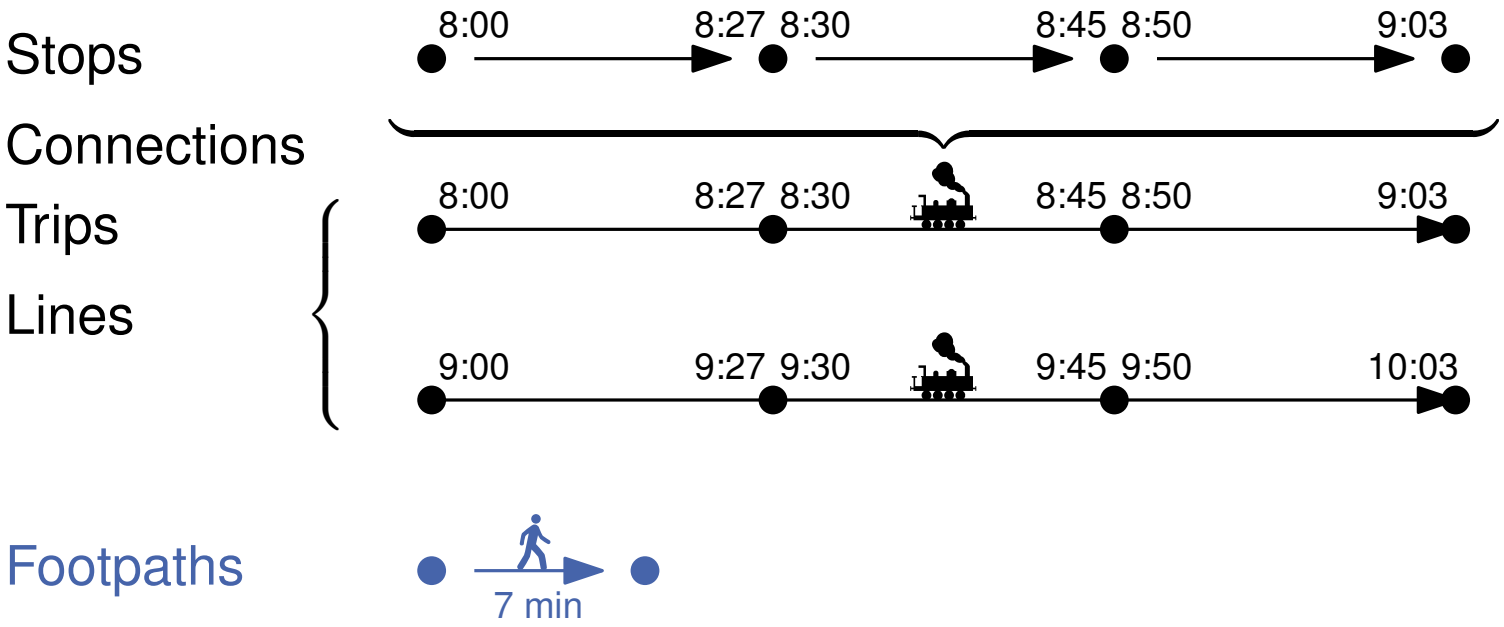

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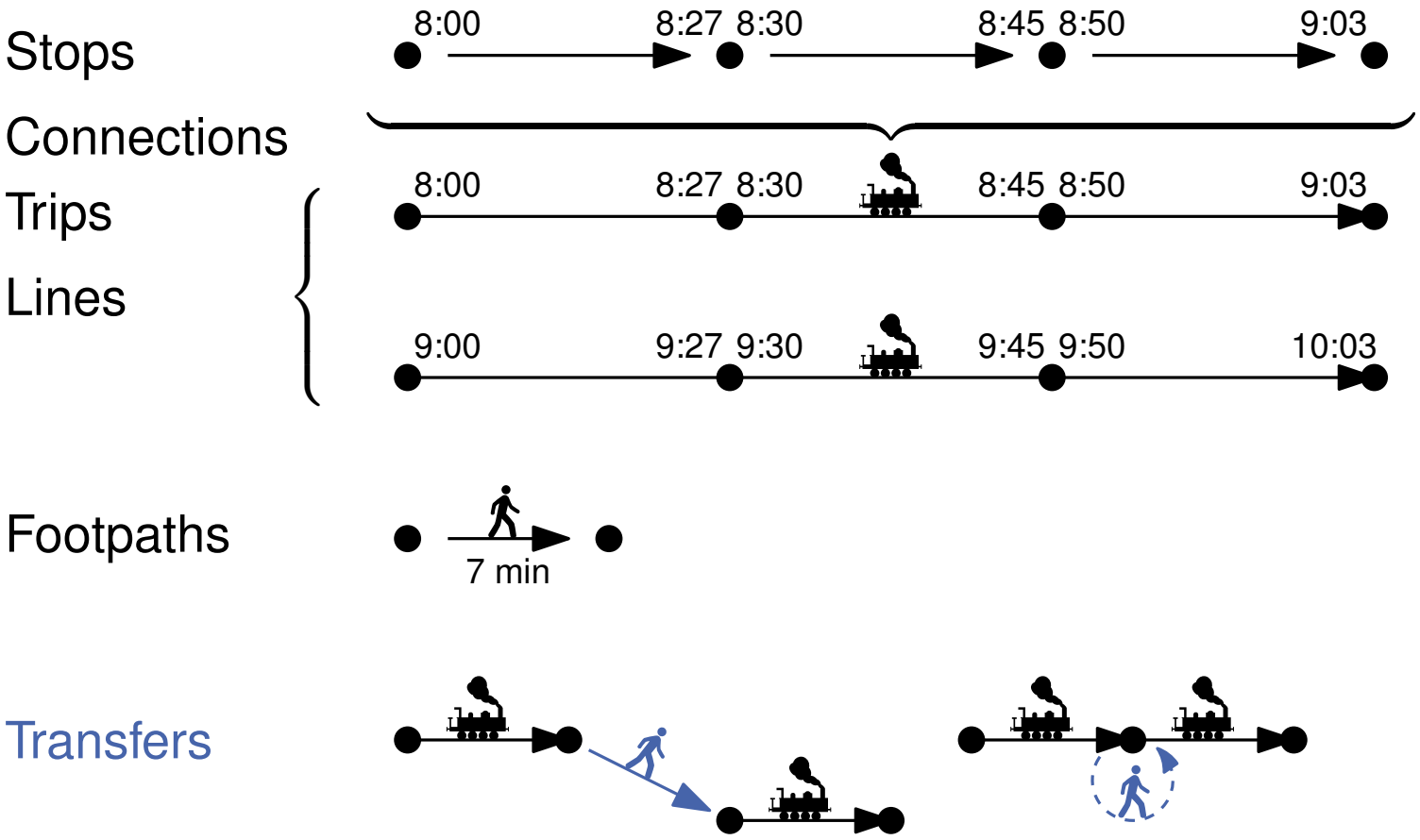

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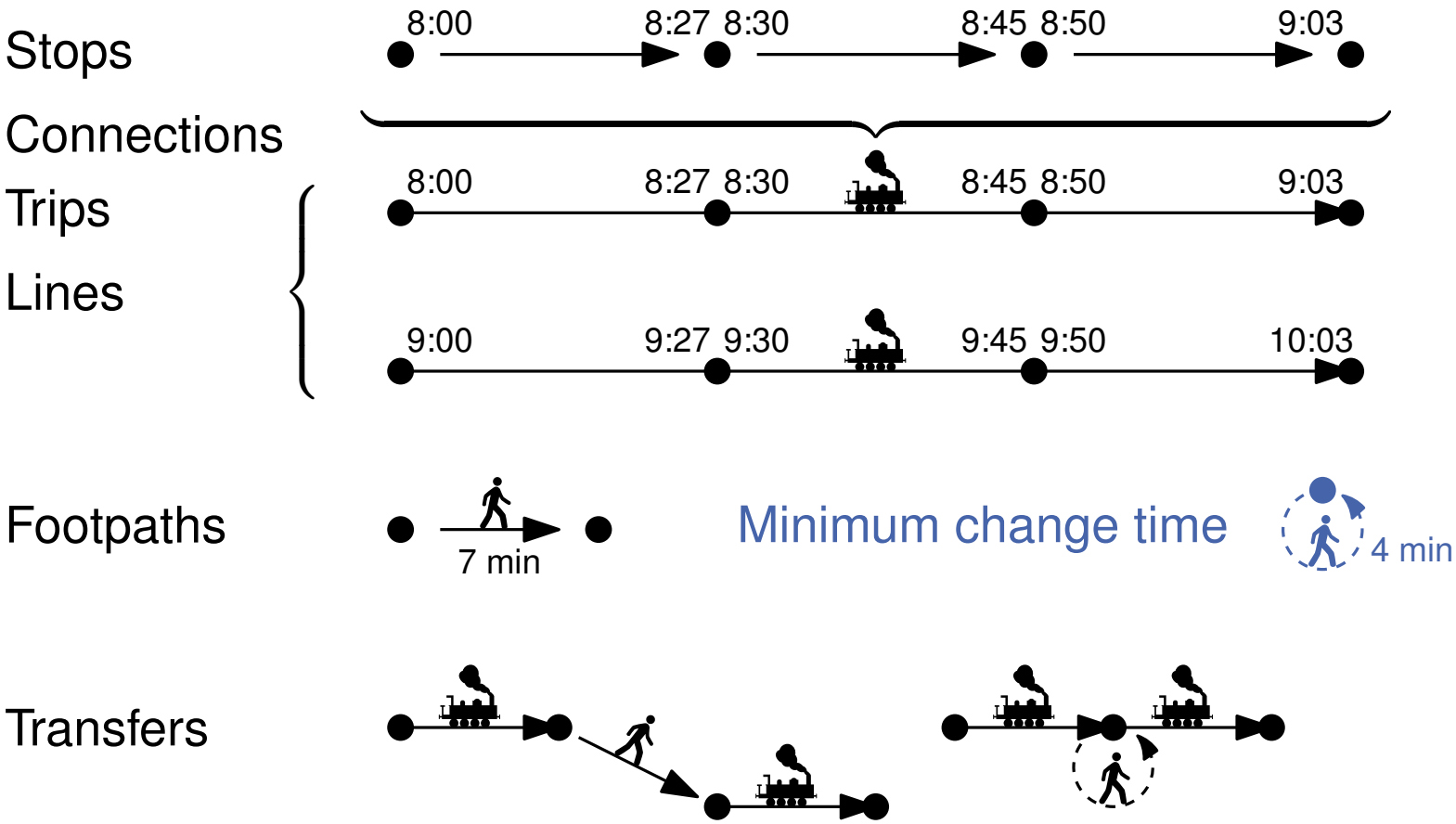

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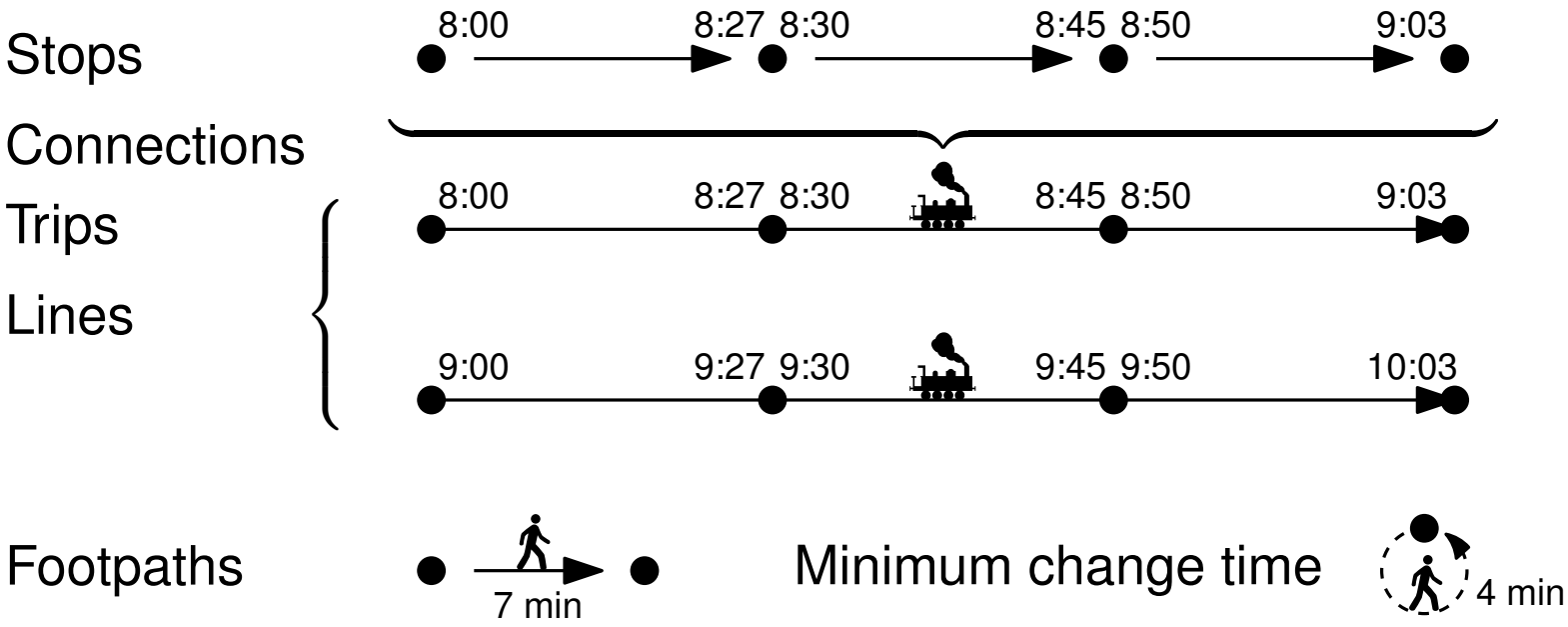
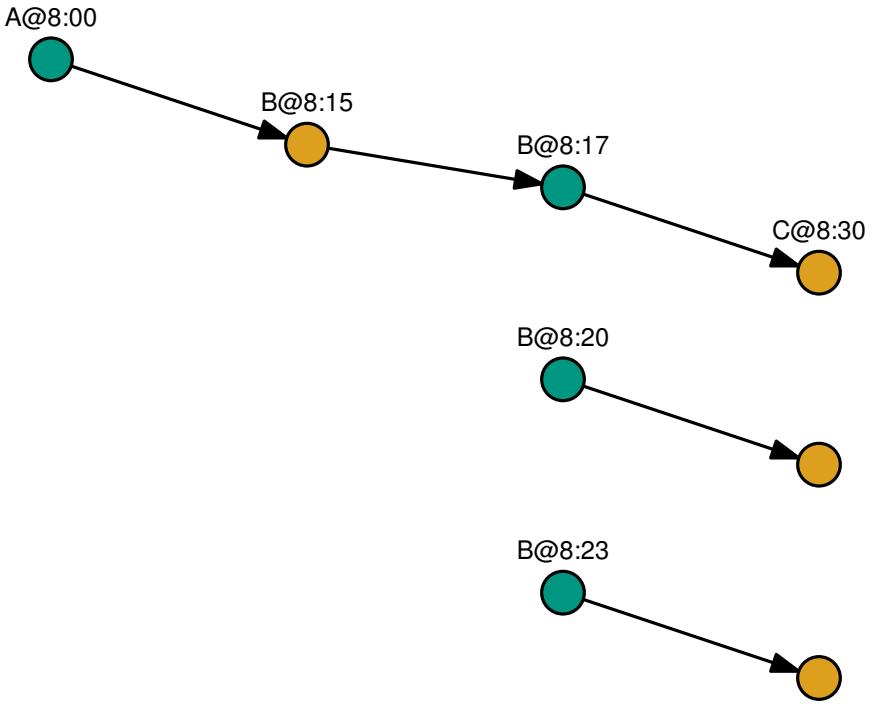


Public Transit Routing

Time-Expanded Model

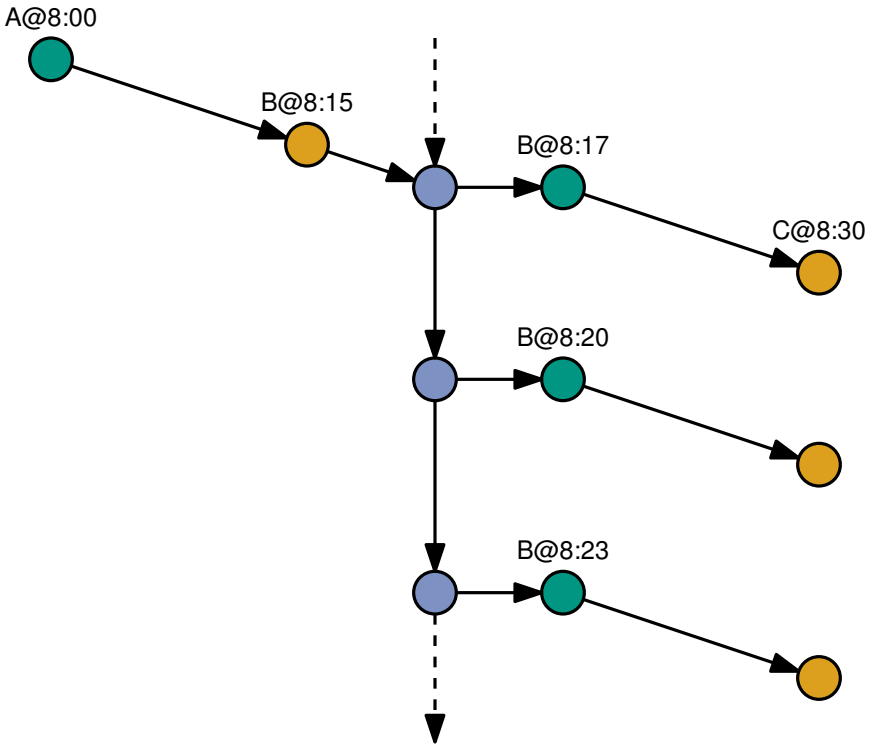
- One vertex per event



Public Transit Routing

Time-Expanded Model

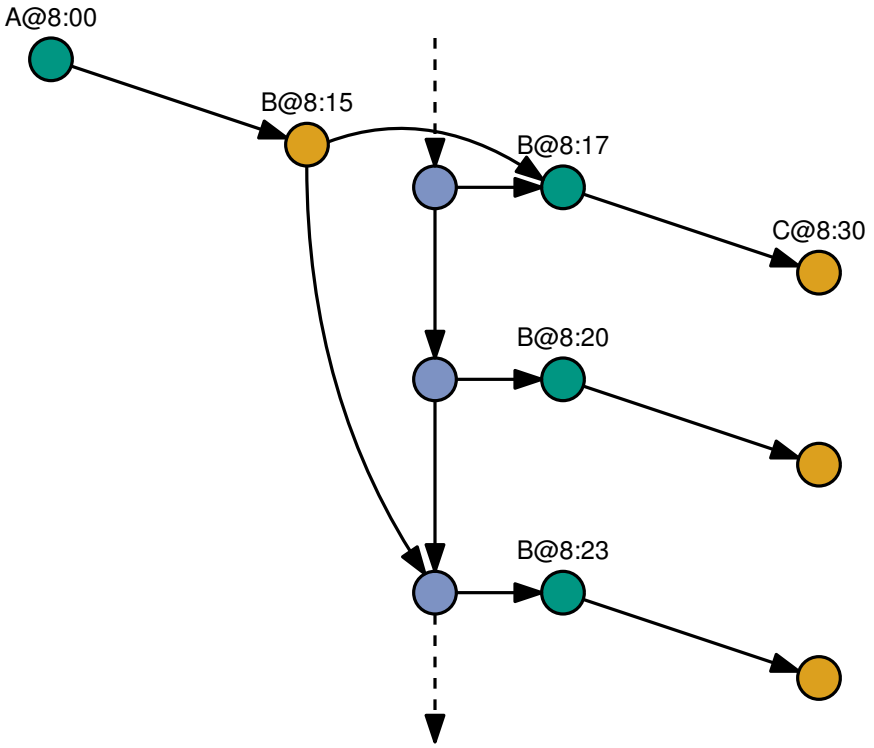
- One vertex per event
- Plus transfer vertices



Public Transit Routing

Time-Expanded Model

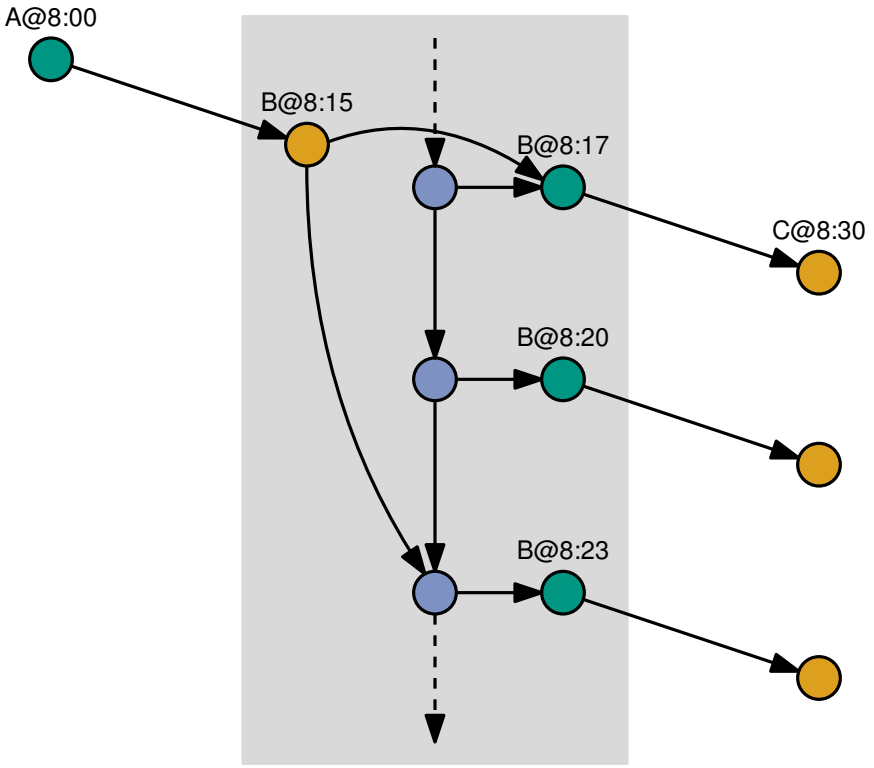
- One vertex per event
- Plus transfer vertices
- Transfer arcs obey minimum change times
- Extra arcs allow staying in vehicle



Public Transit Routing

Time-Expanded Model

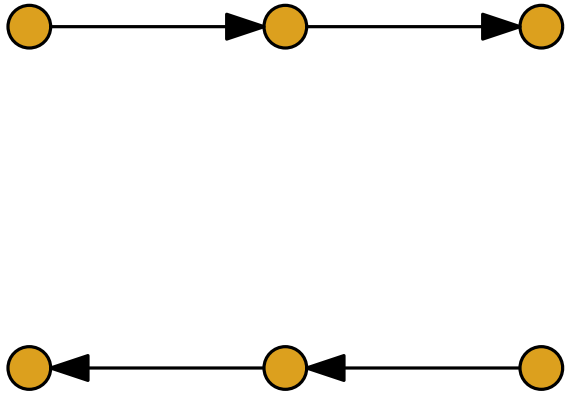
- One vertex per event
- Plus transfer vertices
- Transfer arcs obey minimum change times
- Extra arcs allow staying in vehicle
- Many vertices for each stop



Public Transit Routing

Time-Dependent Model

- One vertex per line at each stop



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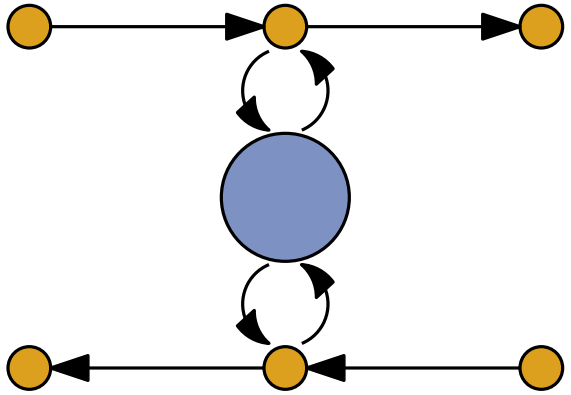
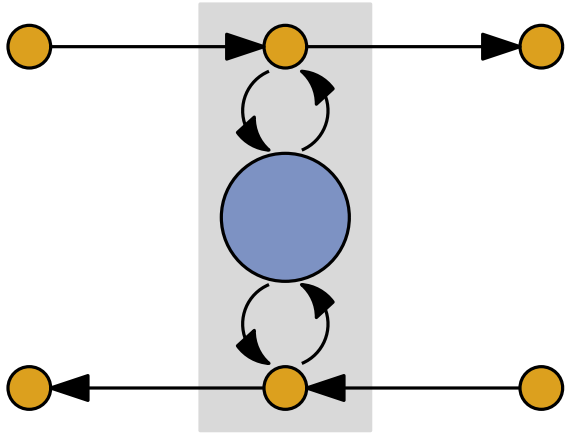


Public Transit Routing

Time-Dependent Model

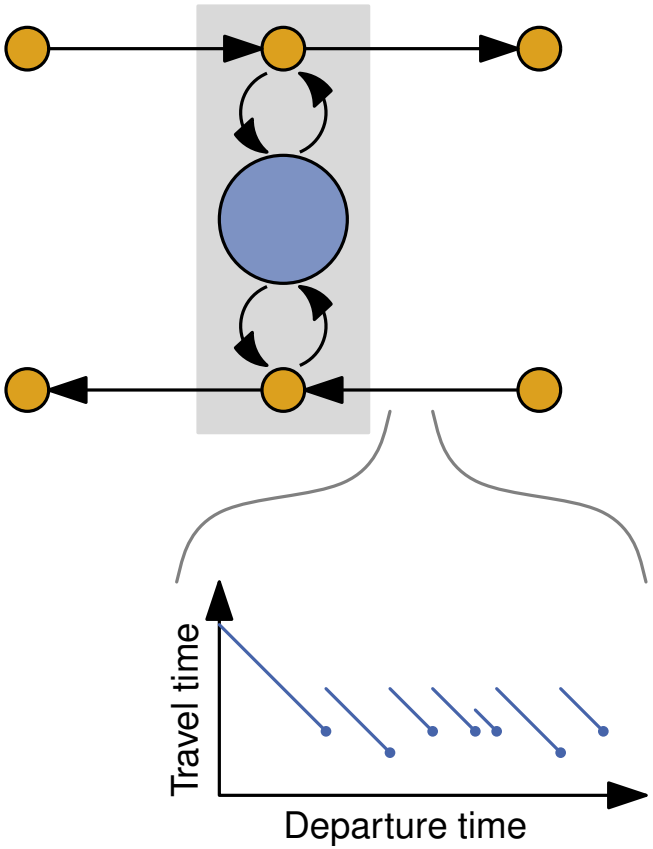
- One vertex per line at each stop
- Plus one transfer vertex per stop
- Fewer vertices and edges



Public Transit Routing

Time-Dependent Model

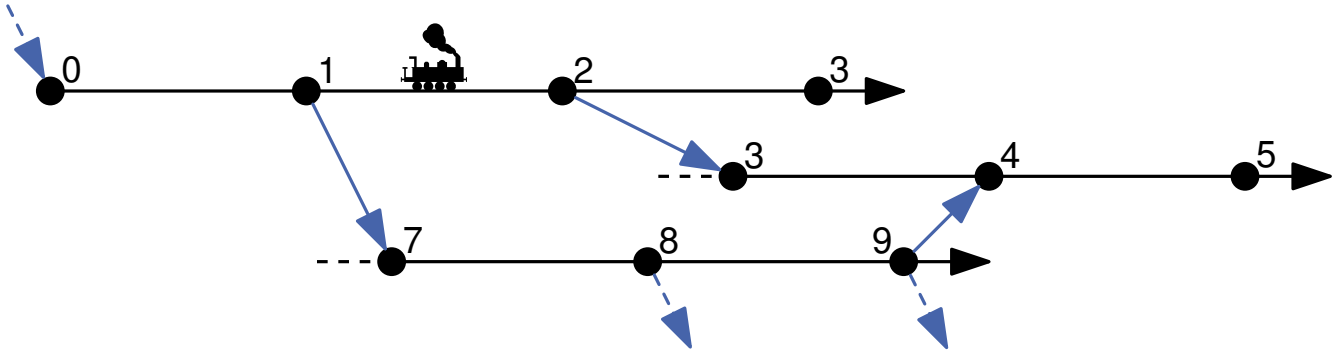
- One vertex per line at each stop
- Plus one transfer vertex per stop
- Fewer vertices and edges
- Edge weights replaced by functions



Trip-Based Routing

Motivation

- Move emphasis from stops to trips
- Model transfers between trips explicitly



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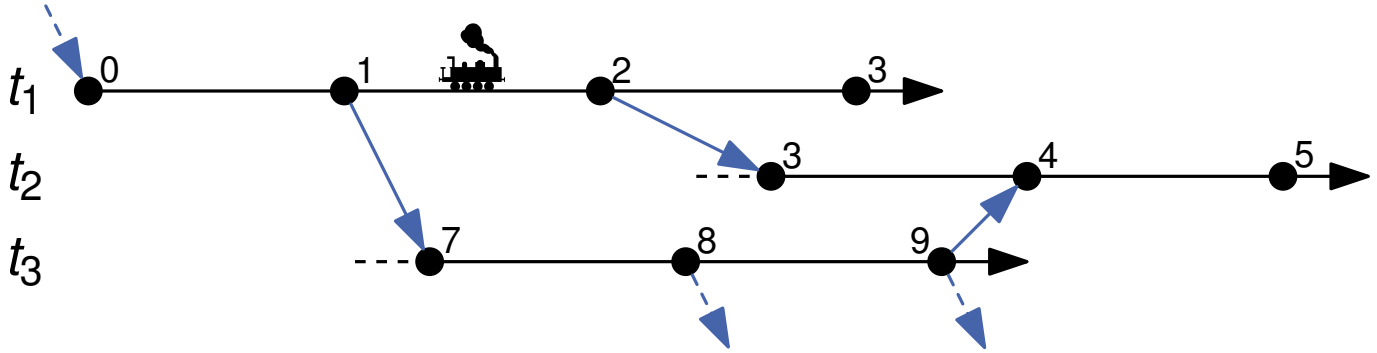
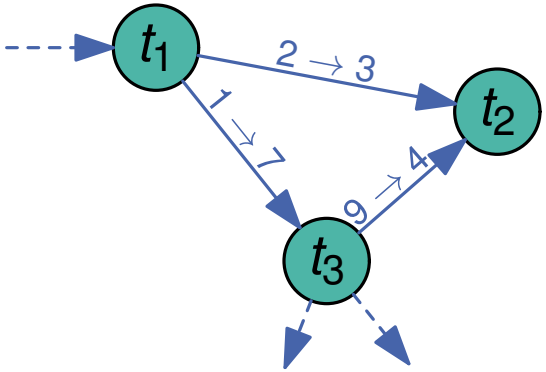


- Query is similar to breadth-first search
- Levels correspond to number of transfers



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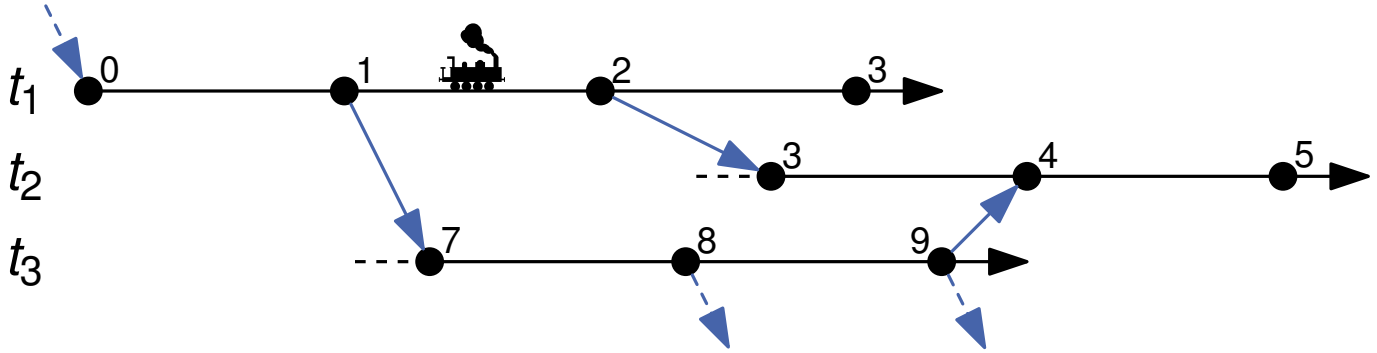
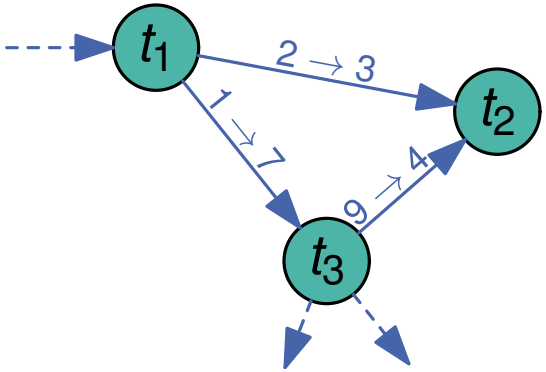


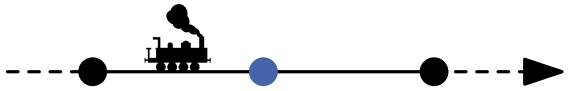
- Query is similar to breadth-first search
- Levels correspond to number of transfers
- Footpaths etc. are handled during preprocessing



Trip-Based Routing

Preprocessing

- Compute transfers between trips



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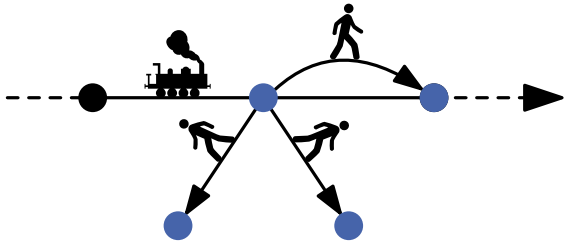

Trip-Based Routing

Preprocessing

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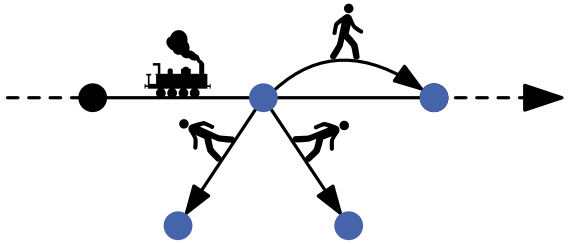

- For each line, find the first reachable trip
  $(\text{arrival time} + \text{footpath length} \leq \text{departure time})$

Trip-Based Routing

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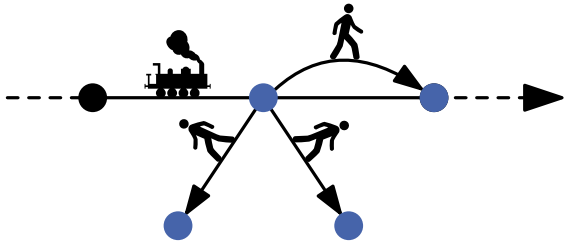
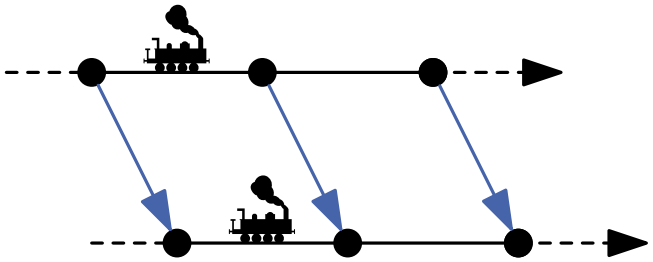


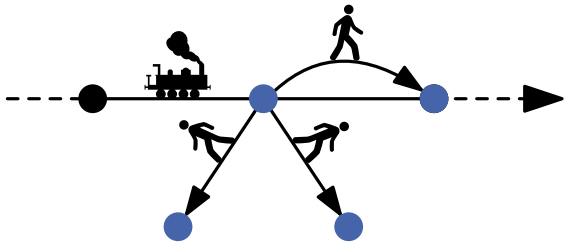
- For each line, find the first reachable trip
  $(\text{arrival time} + \text{footpath length} \leq \text{departure time})$
- Huge number of transfers, not all of which are useful



Parallel trips

Trip-Based Routing

Preprocessing



- Compute transfers between trips
- For each line, find the first reachable trip
  (arrival time + footpath length $\leq$ departure time)
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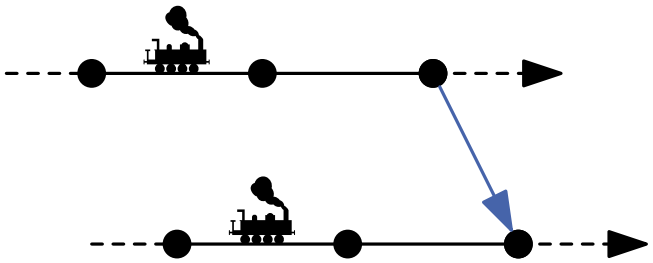

Parallel trips

Trip-Based Routing

Preprocessing

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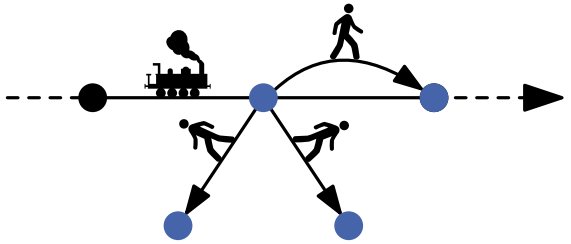

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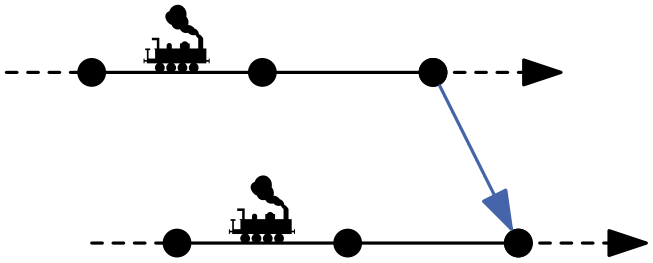
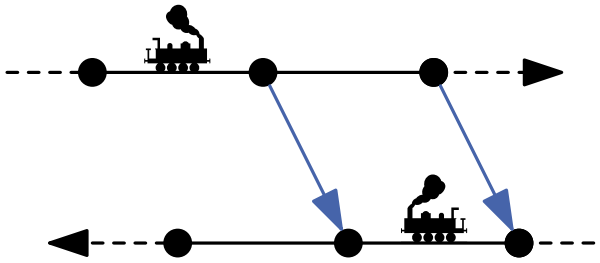


Parallel trips

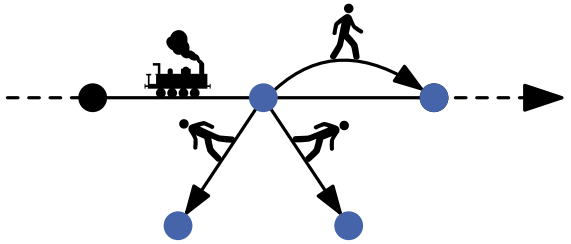


U-turns

Trip-Based Routing

Preprocessing

- Compute transfers between trips



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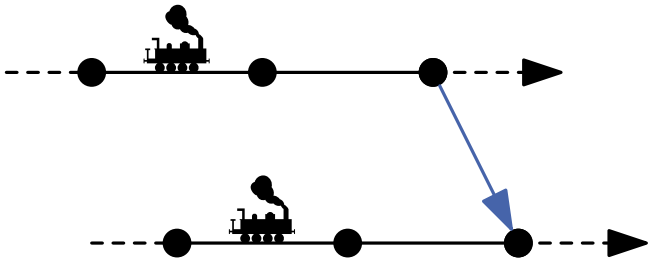

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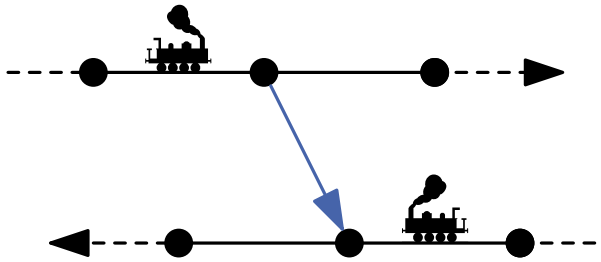


U-turns

Trip-Based Routing

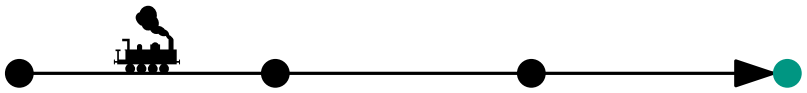
Preprocessing

- Reduce number of transfers by eliminating redundant ones

Trip-Based Routing

Preprocessing

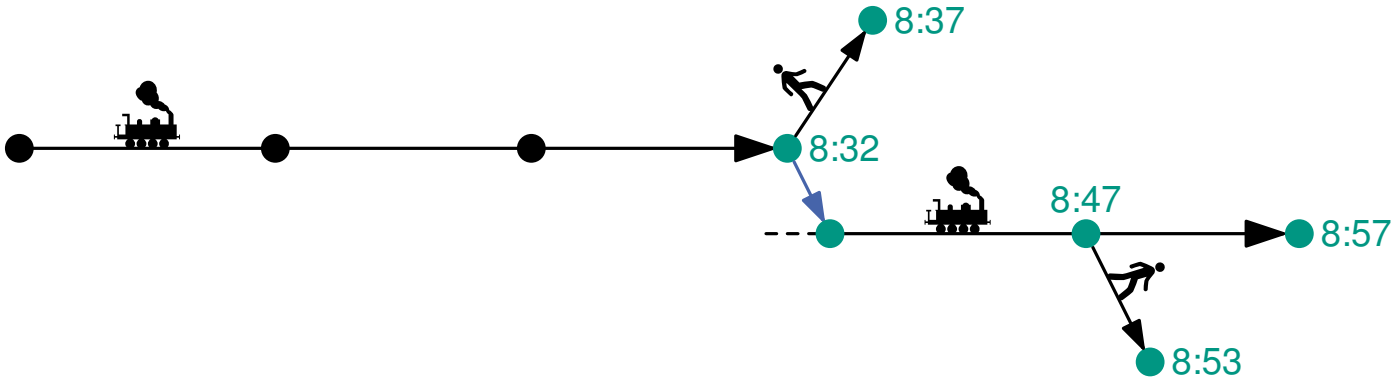
- Reduce number of transfers by eliminating redundant ones
- Process trips backwards



Trip-Based Routing

Preprocessing

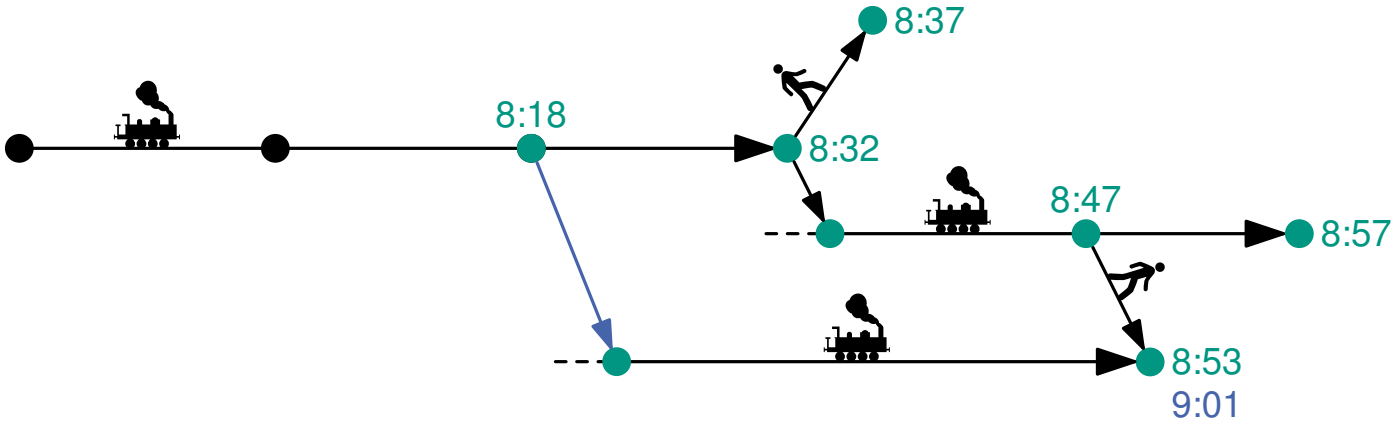
- Reduce number of transfers by eliminating redundant ones
- Process trips backwards
- Keep track of which stops can be reached at what time



Trip-Based Routing

Preprocessing

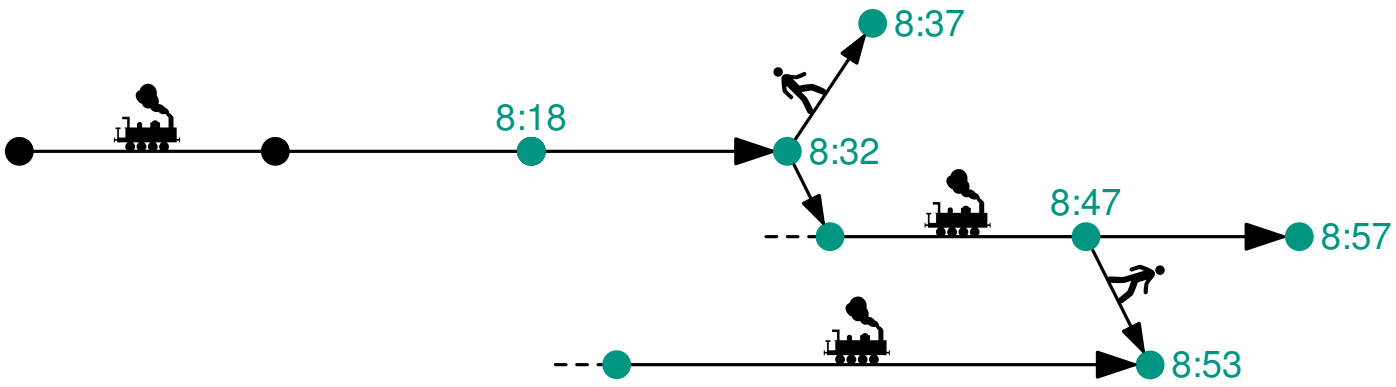
- Reduce number of transfers by eliminating redundant ones
- Process trips backwards
- Keep track of which stops can be reached at what time
- Evaluate transfers by checking if they improve arrival times



Trip-Based Routing

Preprocessing

- Reduce number of transfers by eliminating redundant ones
- Process trips backwards
- Keep track of which stops can be reached at what time
- Evaluate transfers by checking if they improve arrival times
- Removes up to 90% of original transfers



Trip-Based Routing

Query

- Input: Source stop, target stop, departure time

Trip-Based Routing

Query

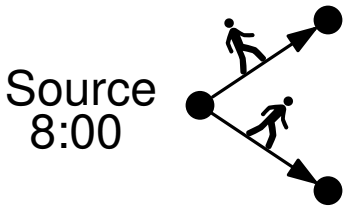
- Input: Source stop, target stop, departure time
- Identify trips reachable from the source

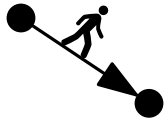
dep.	line	trip	index
8:00	2	15	8
8:03	4	56	0
8:07	11	456	31
9:00	110	3256	6

Trip-Based Routing

Query

- Input: Source stop, target stop, departure time
- Identify trips reachable from the source
- Identify lines reaching the target





dep.	line	trip	index
8:00	2	15	8
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8:07	11	456	31
9:00	110	3256	6

line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

Trip-Based Routing

Query

- Queue trips and mark as reached

Queue		
# tr.	trip	range
0	15	8–12
0	56	0–14
0	456	31–78
0	3256	6–45

Reached	
...	
15	8
16	8
17	8
...	
56	0
57	0
...	
456	31
457	31
...	
3256	6
...	

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8:00	2	15	8
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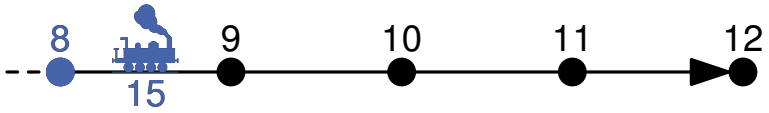
Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue



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line	index	footpath
3	8	—
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Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue
- Examine transfers

Queue		
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0	56	0–14
0	456	31–78
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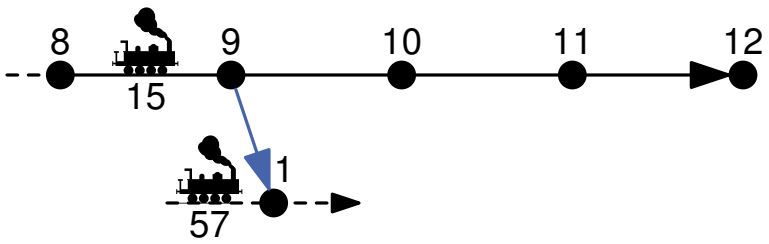


line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

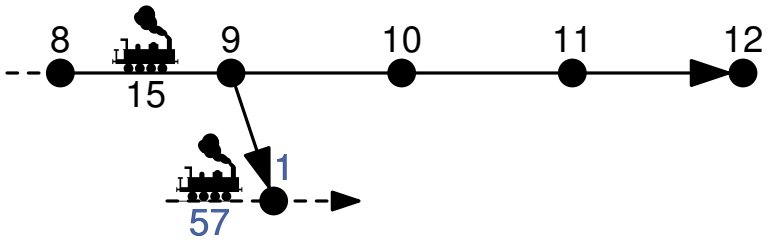
Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue
- Examine transfers
  - Compare against label

Queue		
# tr.	trip	range
0	15	8–12
0	56	0–14
0	456	31–78
0	3256	6–45

Reached	
...	
15	8
16	8
17	8
...	
56	0
57	0
...	
456	31
457	31
...	
3256	6
...	



line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

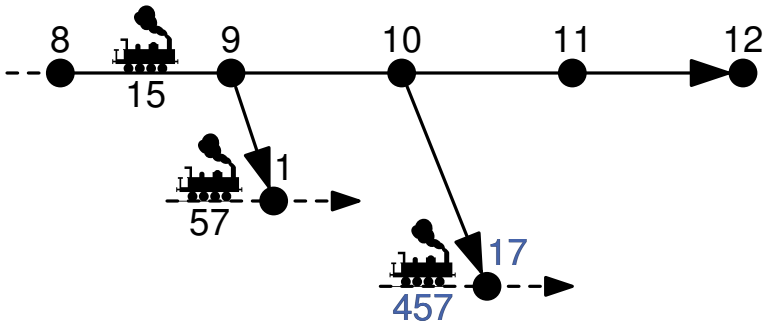
Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue
- Examine transfers
  - Compare against label

Queue		
# tr.	trip	range
0	15	8–12
0	56	0–14
0	456	31–78
0	3256	6–45

Reached	
...	
15	8
16	8
17	8
...	
56	0
57	0
...	
456	31
457	31
...	
3256	6
...	

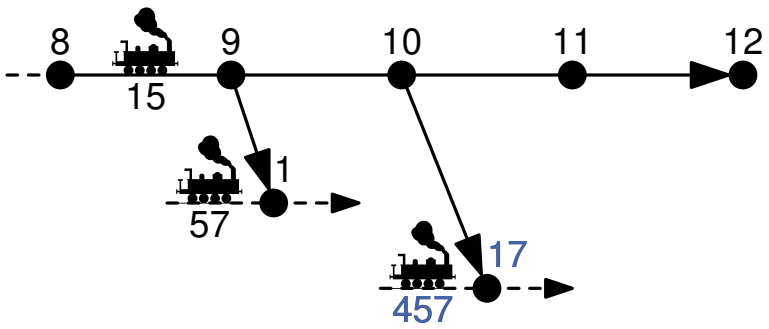


line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue
- Examine transfers
  - Compare against label
  - Queue newly reached trips



Queue		
# tr.	trip	range
0	15	8–12
0	56	0–14
0	456	31–78
0	3256	6–45
1	457	17–31

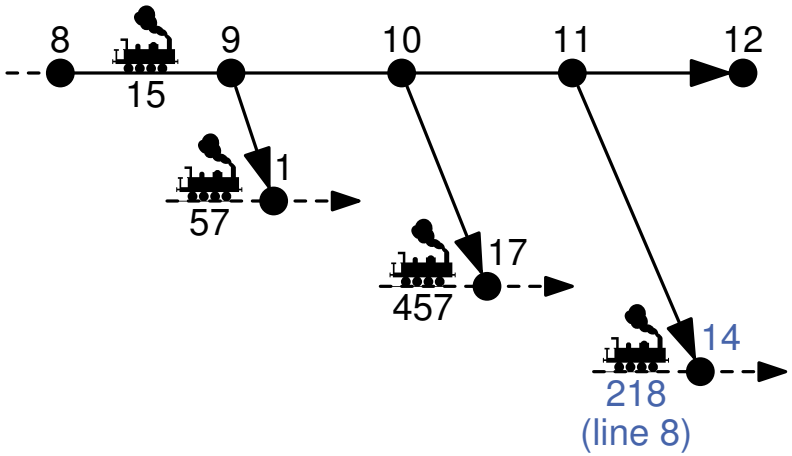
Reached	
...	
15	8
16	8
17	8
...	
56	0
57	0
...	
456	31
457	17
458	17
...	
3256	6
...	

line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue
- Examine transfers
  - Compare against label
  - Queue newly reached trips
  - Output a journey if target is reached



Queue		
# tr.	trip	range
0	15	8–12
0	56	0–14
0	456	31–78
0	3256	6–45
1	457	17–31
1	218	14–23

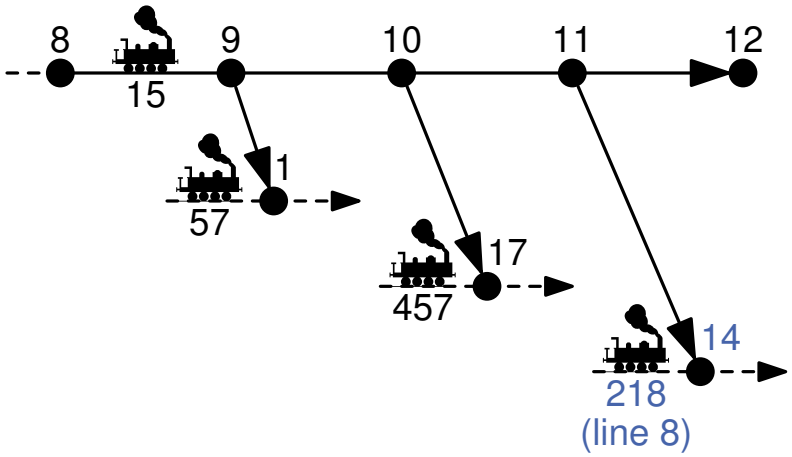
Reached	
...	
15	8
16	8
17	8
...	
56	0
57	0
...	
218	14
...	
456	31
457	17
458	17
...	
3256	6
...	

line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue
- Examine transfers
  - Compare against label
  - Queue newly reached trips
  - Output a journey if target is reached



Queue		
# tr.	trip	range
0	15	8–12
0	56	0–14
0	456	31–78
0	3256	6–45
1	457	17–31
1	218	14–23

Reached	
...	
15	8
16	8
17	8
...	
56	0
57	0
...	
218	14
...	
456	31
457	17
458	17
...	
3256	6
...	

line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

$$\text{arrival\_time}(218, 17) = 9{:}24 \implies \text{Arrival at 9:28 after 1 transfer}$$

Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue
- Examine transfers
  - Compare against label
  - Queue newly reached trips
  - Output a journey if target is reached
- Continue until queue is empty

Queue		
# tr.	trip	range
0	15	8–12
0	56	0–14
0	456	31–78
0	3256	6–45
1	457	17–31
1	218	14–23

Reached	
...	
15	8
16	8
17	8
...	
56	0
57	0
...	
218	14
...	
456	31
457	17
458	17
...	
3256	6
...	

line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

Arrival at 9:28 after 1 transfer

Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue
- Examine transfers
  - Compare against label
  - Queue newly reached trips
  - Output a journey if target is reached
- Continue until queue is empty
- Skip trips that cannot improve the currently best arrival time

$\text{departure\_time}(1302, 8) = 9{:}32 > 9{:}28$

Queue		
# tr.	trip	range
1	1302	8–45
1	2871	3–11
2	512	0–19
2	1523	19–88
2	43	13–15
2	44	4–53

Reached	
...	
15	8
16	8
17	8
...	
56	0
57	0
...	
218	14
...	
456	31
457	17
458	17
...	
3256	6
...	

line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

Arrival at 9:28 after 1 transfer

Trip-Based Routing

Query

- Queue trips and mark as reached
- Process queue
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  - Compare against label
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Queue		
# tr.	trip	range
1	2871	3–11
2	512	0–19
2	1523	19–88
2	43	13–15
2	44	4–53

Reached	
...	
15	8
16	8
17	8
...	
56	0
57	0
...	
218	14
...	
456	31
457	17
458	17
...	
3256	6
...	

line	index	footpath
3	8	—
8	17	4 min
27	3	4 min

Arrival at 9:28 after 1 transfer

Experiments

Instances

	London	Germany
Stops	20 764	249 724
Trips	129 263	2 389 253
Connections	4 991 130	46 116 453
Footpaths	45 624	100 470
Lines (Routes)	2 161	232 644
Transfers (full)	121 339 213	1 826 424 894
Transfers (reduced)	19 502 791	186 296 771
Space consumption	115.5 MiB	1 140.9 MiB

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	London	Germany
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Space consumption	115.5 MiB	1 140.9 MiB

Transfer	Preprocessing Times*	
Computation	3 s	37 s
Reduction	27 s	183 s
Total	30 s	220 s

* Dual 8-core Intel Xeon E5-2650 v2, 2.6 GHz, 128 GB DDR3-1600, 20MB L3, 16 threads

Experiments

Comparison

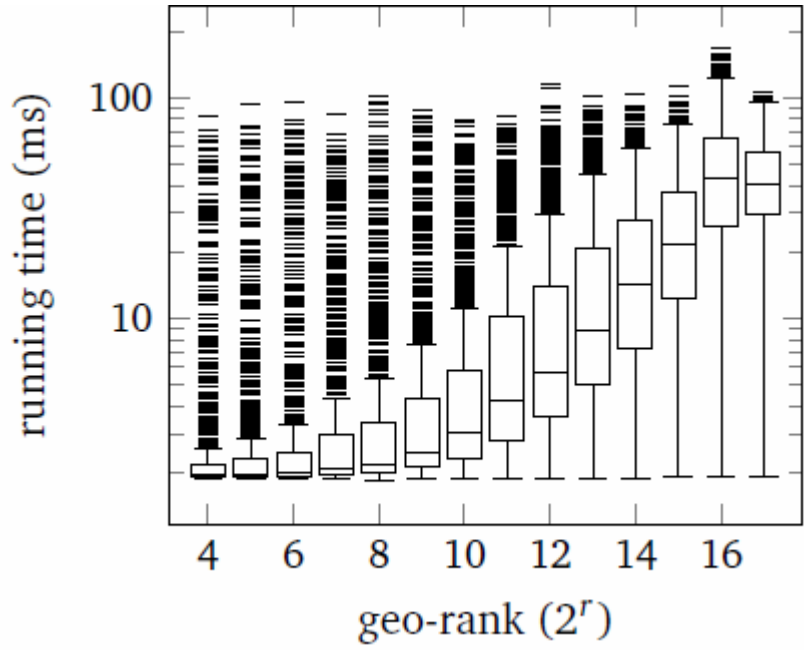
algorithm	instance	stops ($\cdot 10^3$)	conn. ($\cdot 10^6$)	transfers	profile	prep. (h)	query (ms)
Trip-Based	London	20.8	5.0	●	○	< 0.1	1.2
Transfer Patterns	Madrid	4.6	4.8	●	○	185.0	3.1
Public Transit Labeling	London	20.8	5.1	●	○	49.3	0.03
RAPTOR	London	20.8	5.1	●	○	—	5.4
Connection Scan	London	20.8	4.9	○	○	—	1.8
Contraction Hierarchies	Europe (LD)	30.5	1.7	○	○	< 0.1	0.3
Trip-Based	Germany	249.7	46.1	●	○	< 0.1	40.8
Transfer Patterns	Germany	248.4	13.9	●	○	372.0	0.3
Connection Scan	Germany	252.4	46.2	○	○	—	298.6
Accelerated Conn. Scan	Germany	252.4	46.2	○	○	0.2	8.7
Trip-Based	London	20.8	5.0	●	●	< 0.1	70.0
Transfer Patterns	Madrid	4.6	4.8	●	●	185.0	3.1
rRAPTOR	London	20.8	5.1	●	●	—	922.0
Connection Scan	London	20.8	4.9	●	●	—	466.0
Trip-Based	Germany	249.7	46.1	●	●	< 0.1	301.7
Transfer Patterns	Germany	248.4	13.9	●	●	372.0	5.0
Accelerated Conn. Scan	Germany	252.4	46.2	○	●	0.2	171.0

Dual 8-core Intel Xeon E5-2650 v2, 2.6 GHz, 128 GB DDR3-1600, 20MB L3

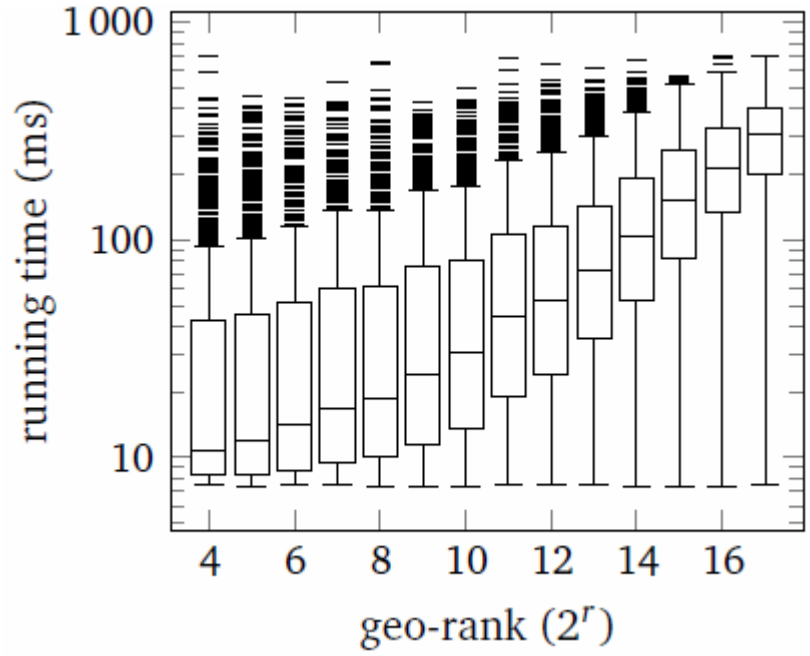
Experiments

Running times by distance

Earliest Arrival Query



Profile Query



Conclusion

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- Focused on trips and transfers between them
- Fine-grained modeling
- Competitive performance

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- Exploit periodicity (preprocessing and storage)
- Allow more criteria (financial cost, walking distance, . . .)

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- Technical Report at http://arxiv.org/abs/1504.07149