Multimodal Dynamic Journey Planning

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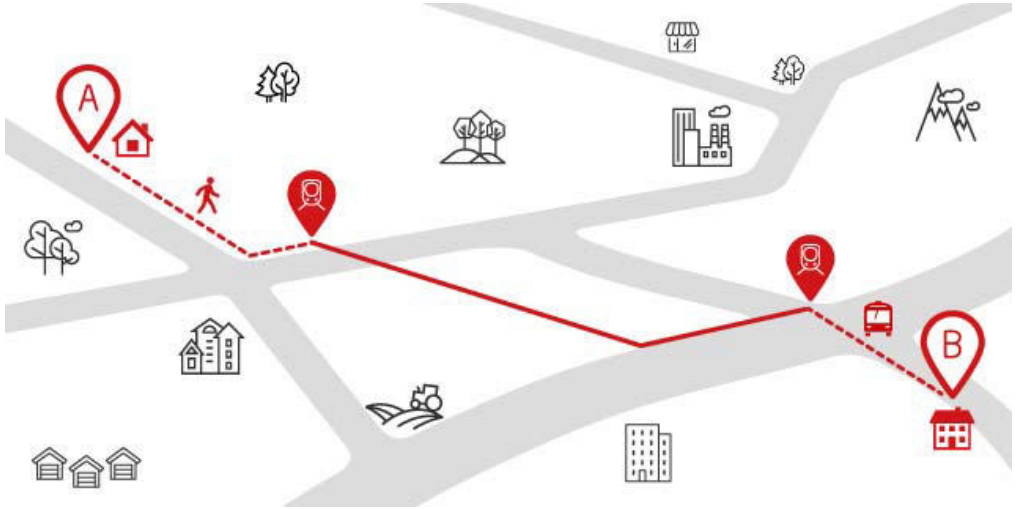
Journey Planning



Journey Planners

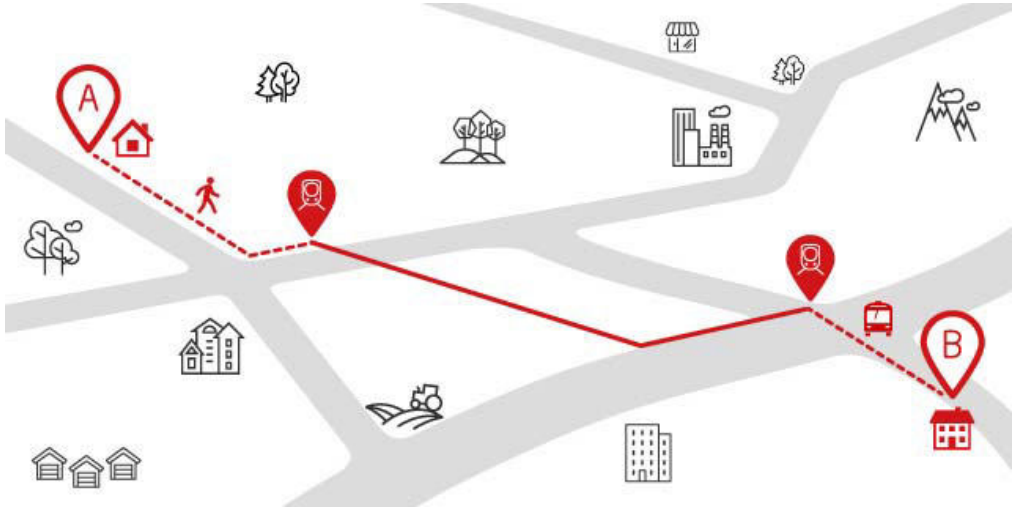
compute best journeys in public (scheduled-based) transport networks

Optimization problems (also in a multimodal setting)

- ***Earliest Arrival Problem (EAP)***: find the best journey from ***A*** to ***B*** that minimizes the arrival time at ***B***, when departing from ***A*** after time ***t***

- ***Minimum Number of Transfers Problem (MNTP)***: find the best journey from ***A*** to ***B*** that minimizes the number of vehicle transfers, when departing from ***A*** after time ***t***

Journey Planning



Journey Planners

compute best journeys in public (scheduled-based) transport networks

Optimization problems (also in a multimodal setting)

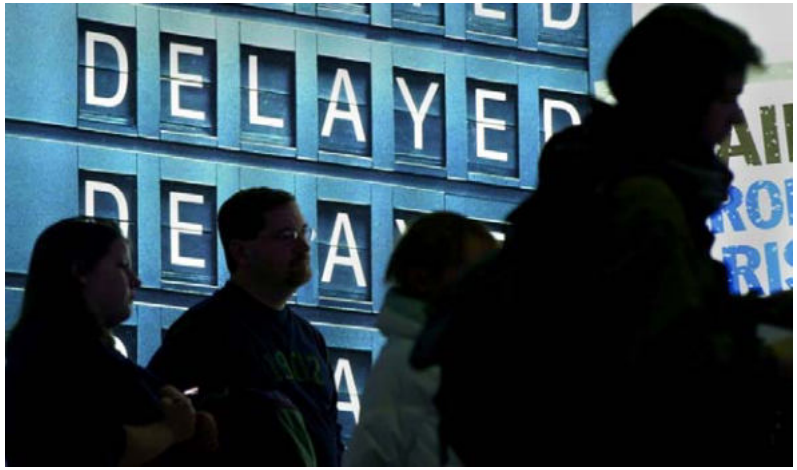
- ***Multicretiria Problem (MP)***: find the optimal Pareto set of journeys from ***A*** to ***B*** minimizing the EA and MNT criteria

- ***Profile query Problem (PP)***: find the set of the earliest arrival journeys from ***A*** to ***B***, departing from ***A*** within a given departure time interval $I=[t_1,t_2]$

Journey Planning

Challenges in scheduled-based journey planning:

- Inherent time-dependent component & **transfer time among vehicles**: **complex modeling**
- Accommodate **multimodality**:
  - Scheduled-based transport across multiple modes (eg train, bus, tram)
  - Unrestricted/Restricted (wrt departing time) traveling (walking, EVs)
- Accommodate **delays** of scheduled vehicles so that timetable information is correctly and efficiently updated
- **High query demand**: real-time answering (also in mobile devices)



State-of-the-Art

- **Journey Planning (public transport)**
  - **Array-based approaches**
    - RAPTOR [Dibbelt et al 2012]
    - Connection Scan Algorithm [Dibbelt et al 2013]
    - Public Transit Labeling [Dibbelt et al 2015]
    - Trip-based public transit routing [Witt 2015]
  - **Graph-based approaches**
    - Time-expanded (TE) realistic model [Pyrga et al 2004 & 2008]
    - Reduced TE (TE-Red) [Pyrga et al 2008; Cionini et al 2014 & 2017]

- **Dynamic (unimodal) journey planning**
  - Dynamic TE-Red [Cionini et al 2014 & 2017]
  - Dynamic Timetable Model (DTM) [Cionini et al 2014 & 2017]

- **Multimodal Journey Planning**
  - McRAPTOR [Delling at el 2013; Dibbelt 2016]

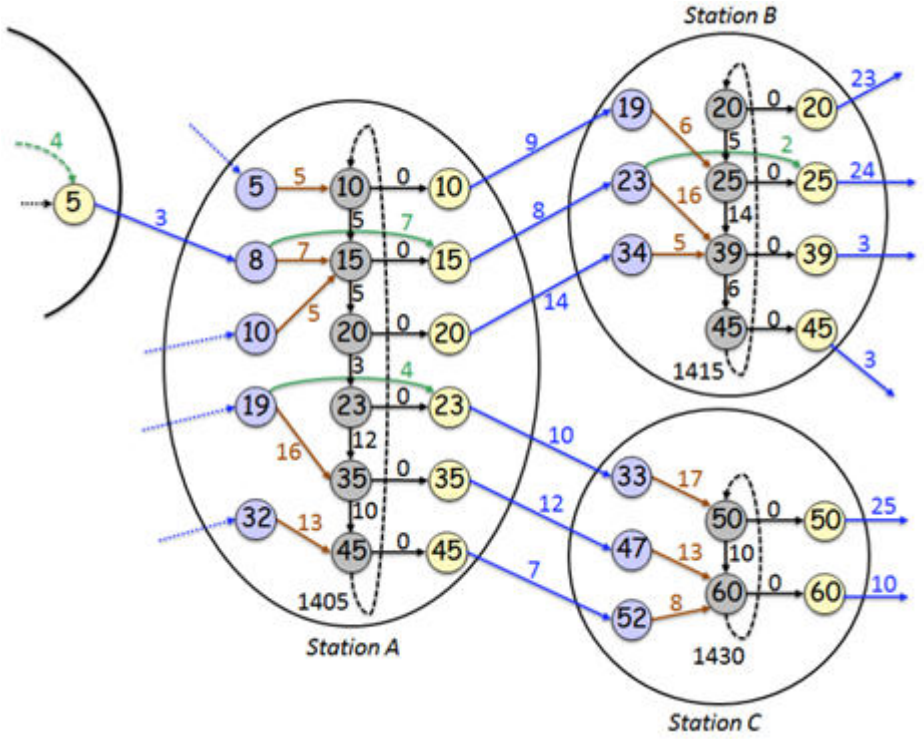
  - ***Questions***
    - *Can **graph-based** approaches be competitive to SotA ?*
    - ***Dynamization** ?*

Main Contributions

- **Multimodal Dynamic Journey Planner**
  - New model: ***Multimodal DTM*** (extension of Dynamic Timetable Model)
  - Efficient **core engine** for real-time response and update requirements
  - Comparative experimental study in large metropolitan networks (London, Berlin)
    - **Multimodal EAP, multicriteria & profile queries:** competitive (with SotA) even in the case of unlimited/limited walking or Evs
    - Limited Walking Query: < 16 msec
    - **Update:** < 0.17 msec

Time-Expanded Realistic Model

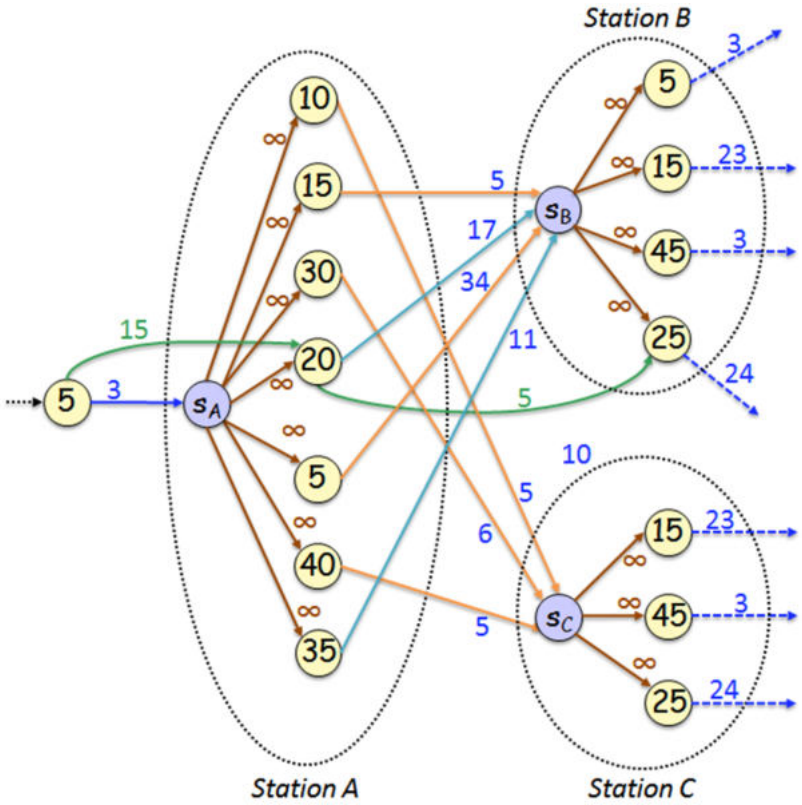
[Pyrga, Schulz, Wagner & Z, 2004 & 2008]



- Node **blue**/**grey**/**yellow** ≡ arrival/transfer/departure
- Arc **blue**/**green**/**black** ≡ connection/arrival-departure/transfer-x
- C : connections; n = # nodes; m = # arcs;
- **Space**: $O(|C|)$ $(n = 3|C|; 4|C| \le m \le 5|C|)$

Dynamic Timetable Model (DTM)

[Cionini, D'Angelo, Emidio, Frigioni, Giannakopoulou, Paraskevopoulos & Z, 2014 & 2017]

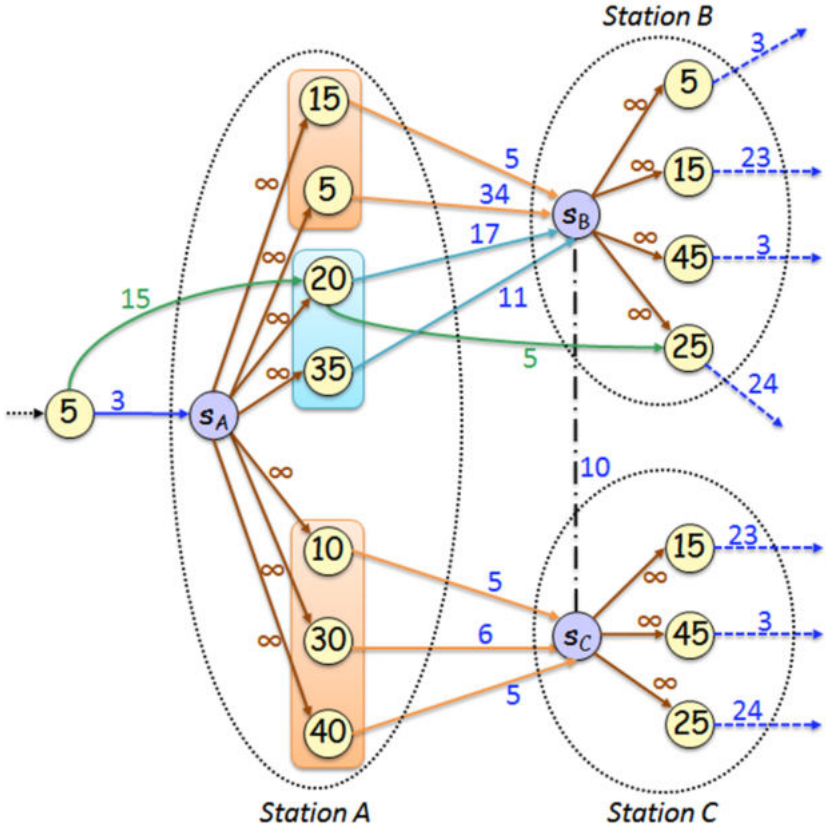


- node **blue**/**yellow** ≡ **switch**/**departure**
- arc **brown**/**green**/**other** ≡ **switch**/**vehicle**/**connection**
- **Space**: $O(|C|)$ $(n = |B|+|C|;\ m \le 3|C|)$

  B: stations; ***C***: connections; n = # nodes; m = # arcs;

- The departure nodes are ordered by **increasing arrival time at the next station**

New: Multimodal DTM



- node **blue**/**yellow** ≡ **switch**/**departure** (ordered by arrival time)
- arc **brown**/**green**/**other** ≡ **switch**/**vehicle**/**connection**
- connection arc **dotted** /**solid** ≡ **unrestricted-departure** / **restricted-departure**
- **grouping blue** / **orange** ≡ **train** / **bus** travelling
- **Space**: $O(|C|)$ $(n = |B| + |C|;\ m \leq 3|C|)$

- **Grouping of Departure nodes**
  - Γ_1 **(primary):** departure nodes with the same **head switch node**
  - Γ_2 **(secondary** grouping within Γ_1): departure nodes of the same **transport mode**
  - **Departure nodes within** Γ_2 are ordered by **increasing arrival time at the next station**

Multimodal DTM – Query

Unicriteria Query Algorithm (modified Dijkstra)

- **Start** at s_S at departure station S.
- **Stop** when s_T at arrival station T is settled.
- **If** switch node settled **then** ***set switch arc weights:***
  departure event reachable in current time period
  ≡ dep. time > current time + transfer time
- **Skip** unselected transportation means
  and past departures

Multicriteria Query Algorithm (modified multicriteria Dijkstra)

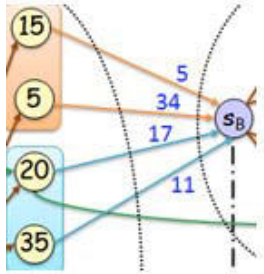
- Criteria: EA & MNT
- Transfer weight: 1 for all switch edges;
  0, otherwise

Restriction: Non-dominating EA & MNT journeys with arrival time < $P \cdot A_{min}$

A_{min}: minimum arrival time, P: threshold

Heuristic Improvements

- Pruning (EAX)
- Exploiting station topology
- ALT



Earliest Arrival Index (EAX)

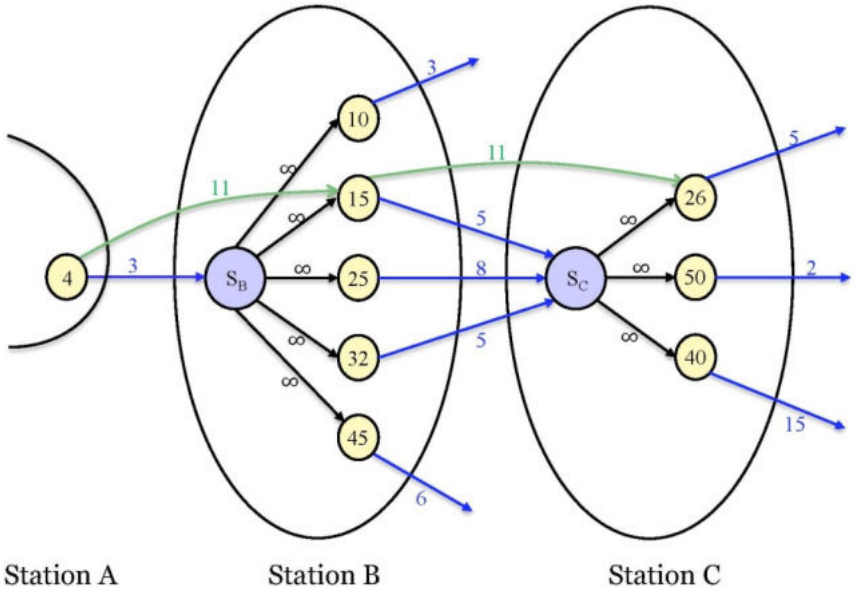
Partially encodes the departure time ordering (efficient search on valid non-past routes) and the arrival time ordering (efficient search on optimal routes)

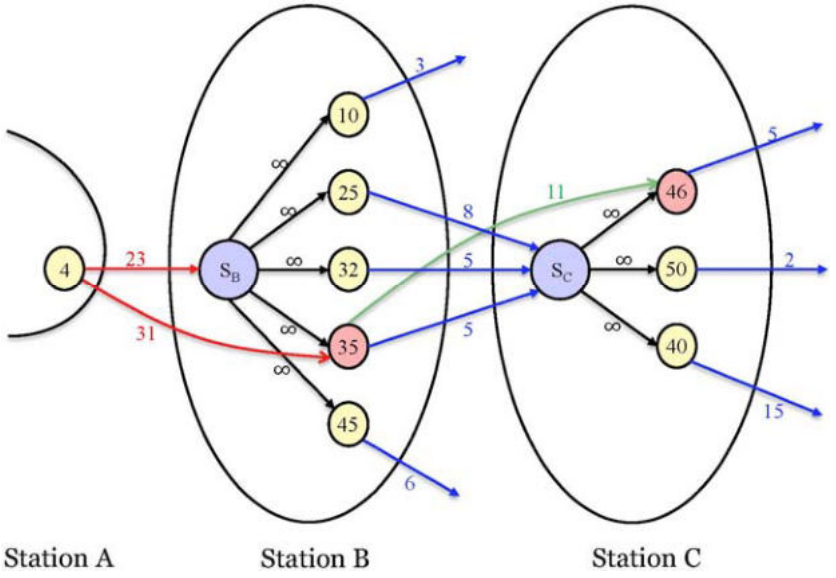
For each consecutive pair (d_i, d_{i+1}) in EAX: d_{i+1} has greater departure and arrival time than d_i.

depNode	depTime	arrTime
d15	15	20
d20	20	37
d35	35	46

e.g. if arrival/starting time is 25 (> 20)
⟹ search for valid and optimal paths after d20

Multimodal DTM – Update





∀Affected station

- **Update**
  - Arc weights of arrival-departure arcs
  - Time associated with departure nodes
  - Repair the node arrival-time ordering within the affected groups

- **Delay**: 20 mins
- **Red** : updated arc weights, time associated with affected departure nodes
- Topology does **NOT** change

MDTM – Experimental Setup

			TE		TE (red)		DTM		MDTM	
City	Stations	Conn.	|V|	|E|	|V|	|E|	|V|	|E|	|V|	|E|
Berlin	12,838	4,322,549	12,967,647	21,612,745	8,645,098	17,024,138	4,335,387	12,701,695	4,335,387	12,708,568
London	20,843	14,064,967	42,194,901	70,324,835	28,129,934	55,758,468	14,085,810	41,837,355	14,085,810	41,856,048

	Berlin	London
Bus	76%	98%
Train	15%	2%
Tram	9%	

	Berlin		London	
	|V|	|E|	|V|	|E|
road		39		60
pedestrian L-Walk		2,381		37,226
pedestrian U-Walk	932,108	1,059,556	1,520,056	1,653,052

CPU: Intel Quad-core i5-2500K 3.30GHz

RAM: 32GB

Data: GTFS (Public transport timetables)

OSM (road and pedestrian networks)

- **Driving-paths**: free flow speed travelling between stops via shared EVs.

  10 EV-stations, driving travel-time $\leq$ 1h

- **Foot-paths**: walking speed 1m/s

  ❑ **Limited walking (L-Walk):** Walk paths between stops with travel time ≤ 10 mins

  ❑ **Unlimited walking (U-Walk):** The full pedestrian network is embedded and each switch node is connected with the nearest pedestrian node

MDTM – Experimental Evaluation

	Algorithm	MC	Travel Modes				Query [ms]	
			Public Transit	Walk	EV/Car	Cycle	L-Walk	U-Walk
Berlin	TE-QH-ALT [1]		●				6.28	
	DTM-QH-ALT [1]		●				11.66	
	MDTM-QH-ALT		●				5.71	
	MDTM-QH-ALT		●	●	●		8.15	103.46
London	TE-QH-ALT [1]		●				5.09	
	DTM-QH-ALT [1]		●				9.81	
	MDTM-QH-ALT		●				4.01	
	MDTM-QH-ALT		●	●	●		6.02	107.93
	McMDTM-QH-ALT-1.0	●	●	●	●		6.22	215.27
	McMDTM-QH-ALT-1.2	●	●	●	●		**15.40**	**360.56**
	MCR-ht [2]	●	●			●		361.23
	MR-∞-t10 [2]	●	●			●	21.47	
	PfMDTM-QH-ALT [2h]		●	●	●			2,150.2
	PfMDTM-QH-ALT [24h]		●	●	●			29,365.4

[1] [Cionini et al, 2014 & 2017], [2] [Dellling et al, 2013 & 2016]

Red: new algorithms
10K earliest arrival queries

MDTM – Experimental Evaluation

	Algorithm	Update [µs]
Berlin	TE-UH	249.3
	DTM-U	85.7
	MDTM-U	**87.2**
London	TE-UH	484.6
	DTM-U	148.1
	MDTM-U	**163.1**

random [1, 360] mins delays in 10K
randomly chosen elementary connections

Conclusion & Future Work

Multimodal Dynamic Journey Planner

- Real-time query responses for single and multicriteria queries
- Accommodation of walking and EV scenarios
- Accommodation of delays

Future work

- Investigate further realistic settings
- Mobile app

Thank You. Questions ?