Efficient Route Planning

SS 2011

Lecture 11, Friday July 29th, 2011
(Transfer Patterns, course evaluation)

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Overview of this lecture

- Organizational
  - Your results from Ex. Sheet #7 (Transit Networks, GTFS)
  - This is the **second to last** lecture
- Transfer patterns
  - A technique for fast routing on transit networks
  - We will also discuss why our previous methods have problems for transit networks
- Exercise sheet … the last one!
  - Fill out the evaluation form for this course → **10 points !**
  - Compute the number of transfer patterns between each pair of stations

Feedback from ES#7 (GTFS)

- Summary / excerpts
  - Verständnisprobleme mit der (optionalen) frequencies.txt
  - GTFS bothersome to parse
  - Implementation advice zum Netzwerk kam etwas spät
  - Neuer Rekord: 5-fach verschachtelte Schleife
  - Hin- und Rückrichtung sind zwei verschiedene "stations"
  - Wichtige Termine standen an. Unser Volk hungert.
  - Difficult to find the motivation
  - Zeitprobleme jetzt gegen Ende der Vorlesungszeit
  - Kein Unterschied zwischen Dijkstra und A*, warum?

Summary of our algorithms so far

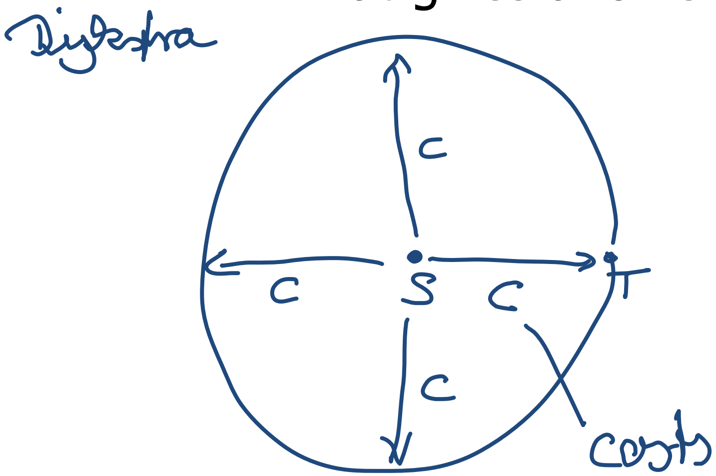
- For computing the shortest path from A to B
  - In the following list, Q = average query time, and P = precomputation time for the OSM network of BaWü
  - Times are only the order of magnitude, not exact, hence ~
  - Dijkstra's algorithm ... Q ~ 0.5 sec, P ~ 0
  - A* with the straightline heuristic ... Q ~ 0.2 sec, P ~ 0
  - A* with the landmark heuristic ... Q ~ 0.1 sec, P ~ 10 sec
  - Arc flags ... Q ~ 1 msec, P ~ 10 hours
  - Contraction Hierarchies ... Q ~ 1 msec, P ~ 1 min
  - Transit Node Routing ... Q ~ 10 – 100 µsec, P ~ 1 min
  - Performance on (time-expanded) transit networks?

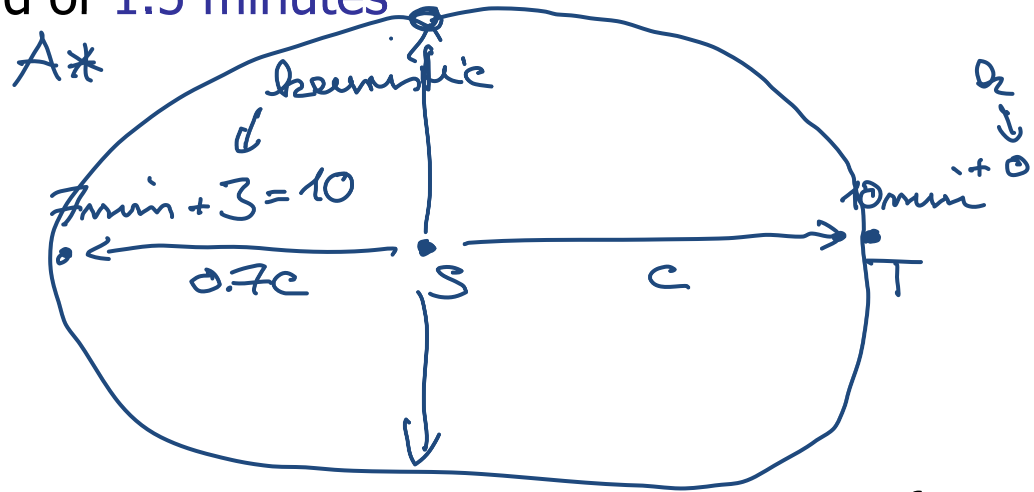
Dijkstra's algorithms

- Performance on time-expanded transit networks
  - One iteration takes ~ 1 µsec / node, as usual
  - But graphs are bigger, for example
    - New York area: ~ 50 000 stations, ~ 2 million nodes
  - When travel time from source to target is T, we settle evything that can be reached within time T, like with the Dijkstra for road networks
  - When T is large or ∞ we search the whole graph ... this happens more often than in road networks, reasons e.g.:
    - bad connectivity by bus / train
    - overnight connections

A* algorithm with straightline heuristic

- Performance on time-expanded transit networks
  - Experiment on the Wiki show hardly any improvement over Dijkstra's algorithm, why?
  - Consider Bus 10 from Bärenweg to Siegesdenkmal
  - Takes 10 minutes, straightline distance is ≈ 2.5 km
  - Let's say the maximum speed is 100 km/h (trains!)
  - That gives a lower bound of 1.5 minutes





A* algorithm with landmark heuristic

- Performance on time-expanded transit networks
  - Also not much improvement over Dijkstra, why?

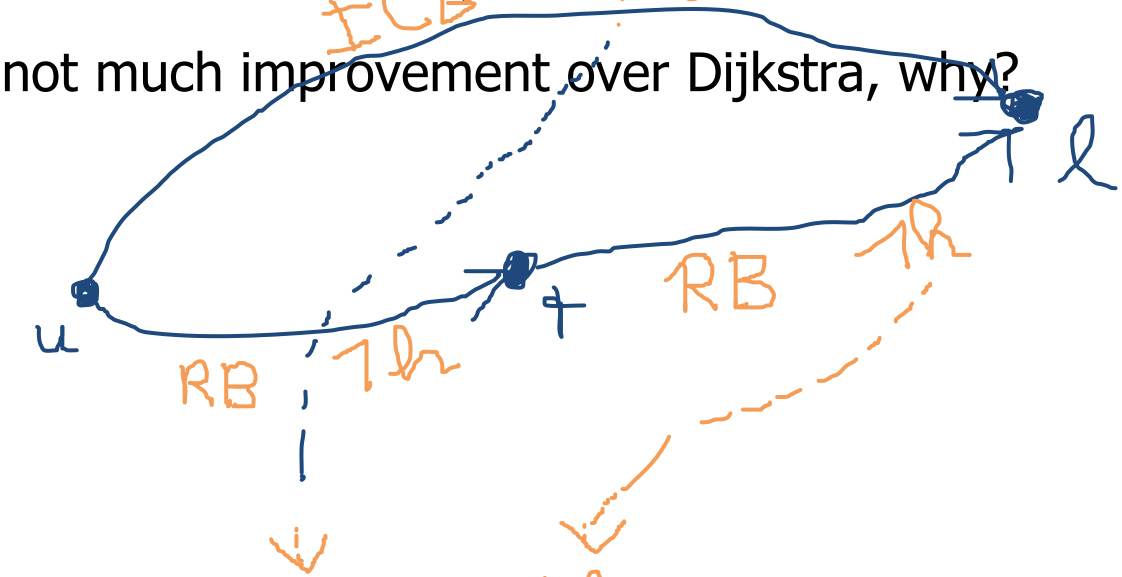
WRONG!

$$h(u) = d(s,l) - d(u,l)$$

Schwacher Zusammenhang zwischen geometrischer Entfernung und Länge (Zeit) eines kürzesten Weges.

A* algorithm with landmark heuristic

- Performance on time-expanded transit networks
  - Also not much improvement over Dijkstra, why?



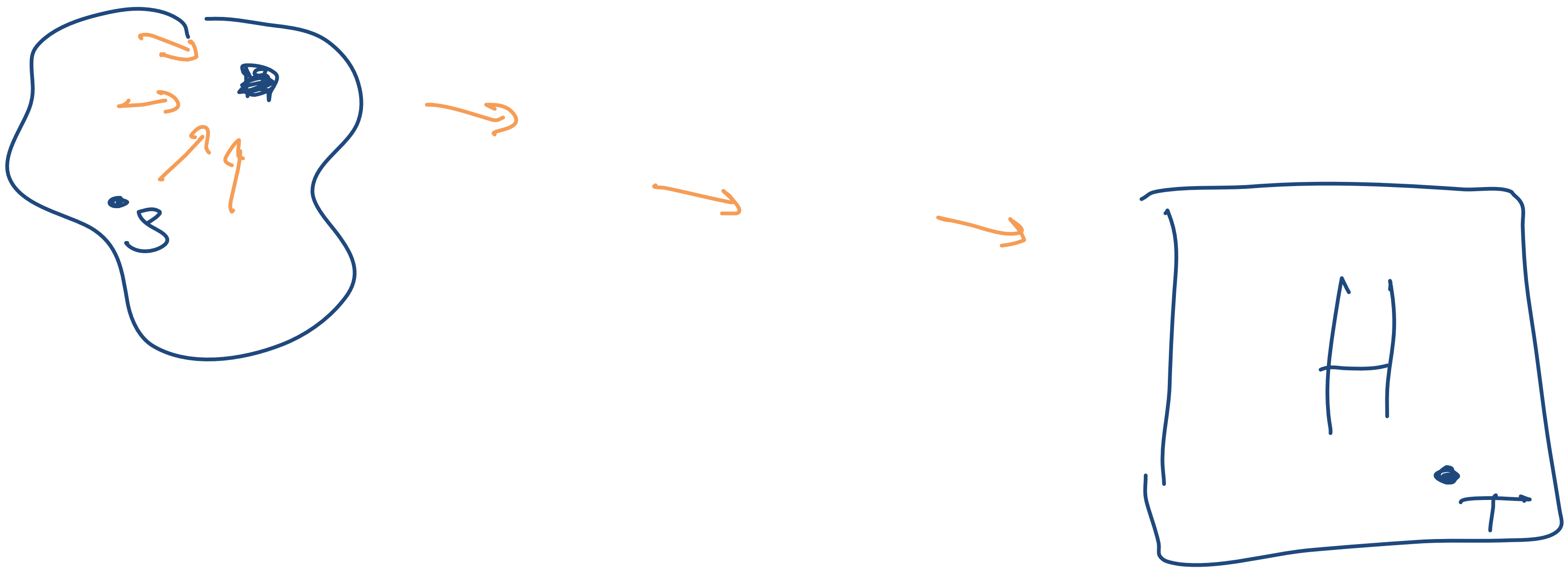
$0h = 1h - 1h$

$h(u) = d(u, l) - d(t, l)$

Schwacher Zusammenhang zwischen geometrischer Entfernung und Länge (Zeit) eines kürzesten Weges.

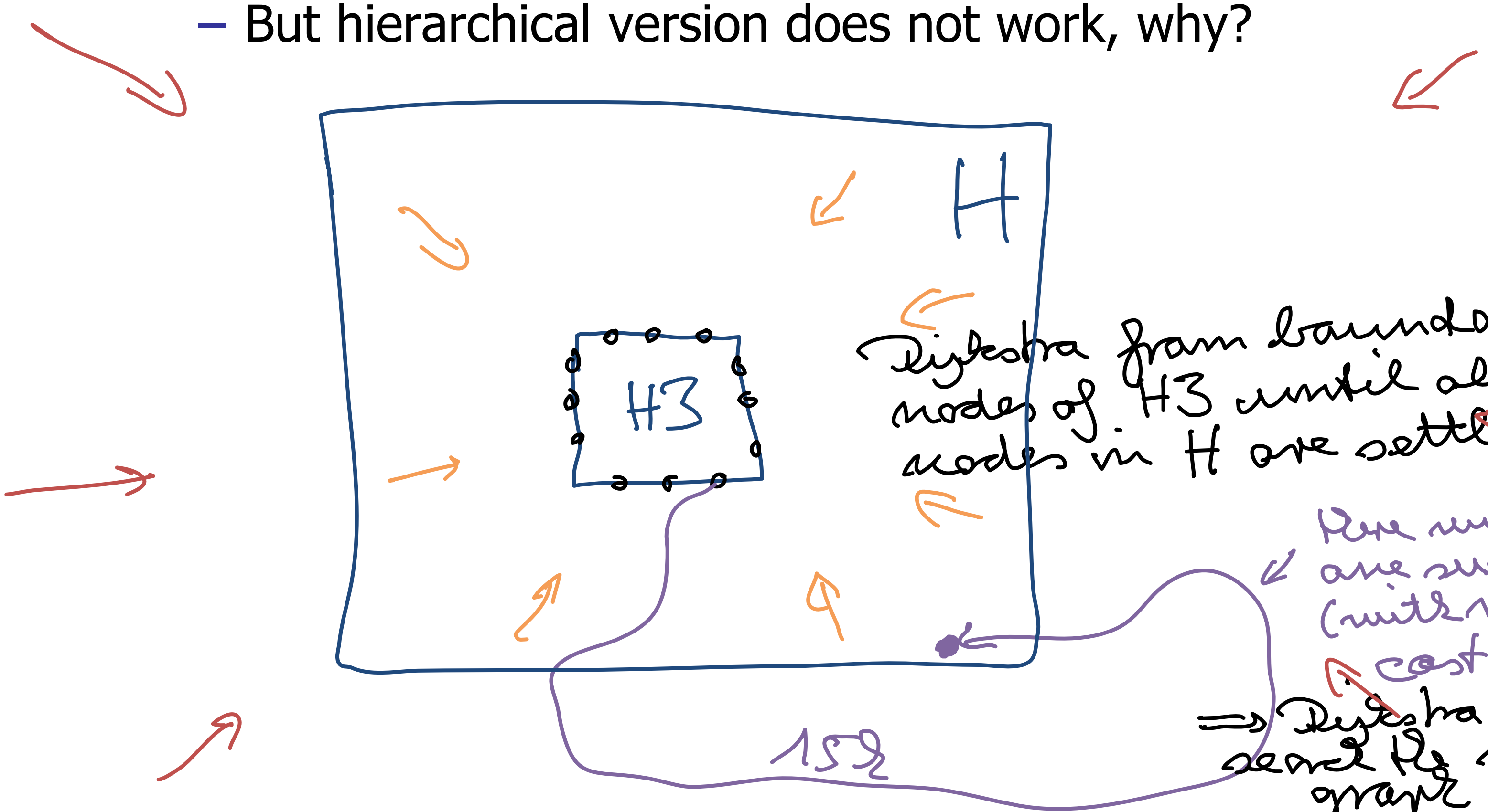
Arc flags 1/2

- Performance on time-expanded transit networks
  - Goal direction works well, good query times, why?



Arc flags 2/2

- Performance on time-expanded transit networks
  - But precomputation cost (for the much larger transit graph is enormous) → calls for hierarchical version
  - But hierarchical version does not work, why?



Dijkstra from boundary nodes of H3 until all nodes in H are settled

There will be one such path (with very high cost).

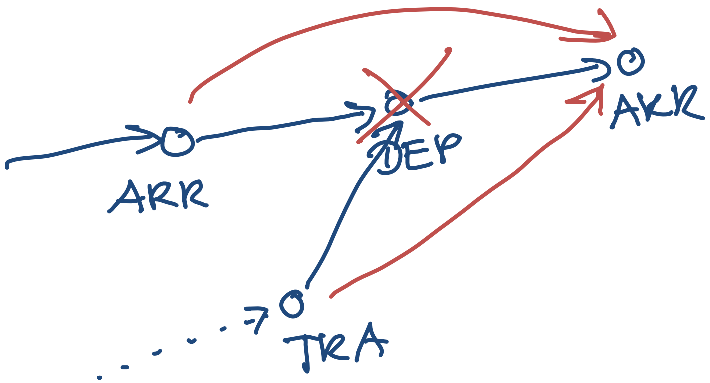
⇒ Dijkstra will search the whole graph.

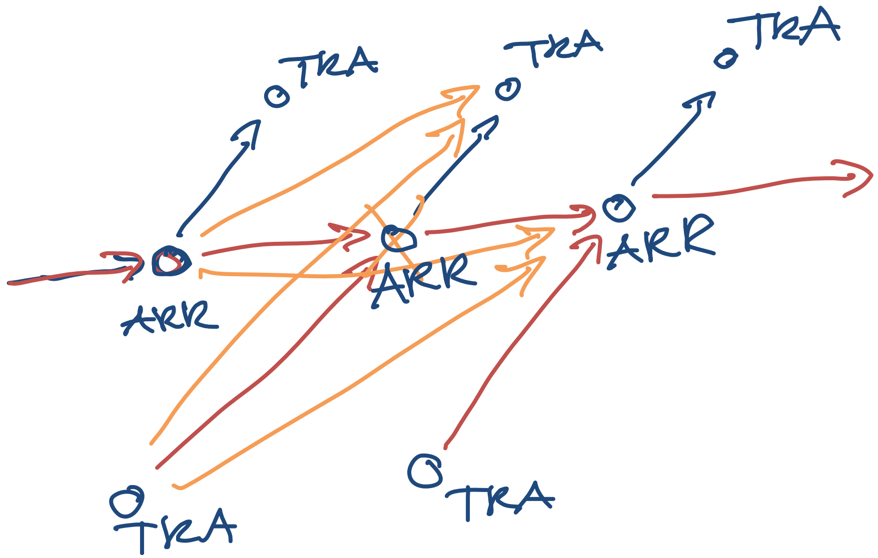
Transit-node routing

- Performance on time-expanded transit networks
  - We can also find small sets of transit / access nodes
  - But how do we compute them efficiently?
  - Also, local queries are not necessarily cheap in transit networks → the "15 hours to the next village problem"

Contraction Hierarchies 1/5

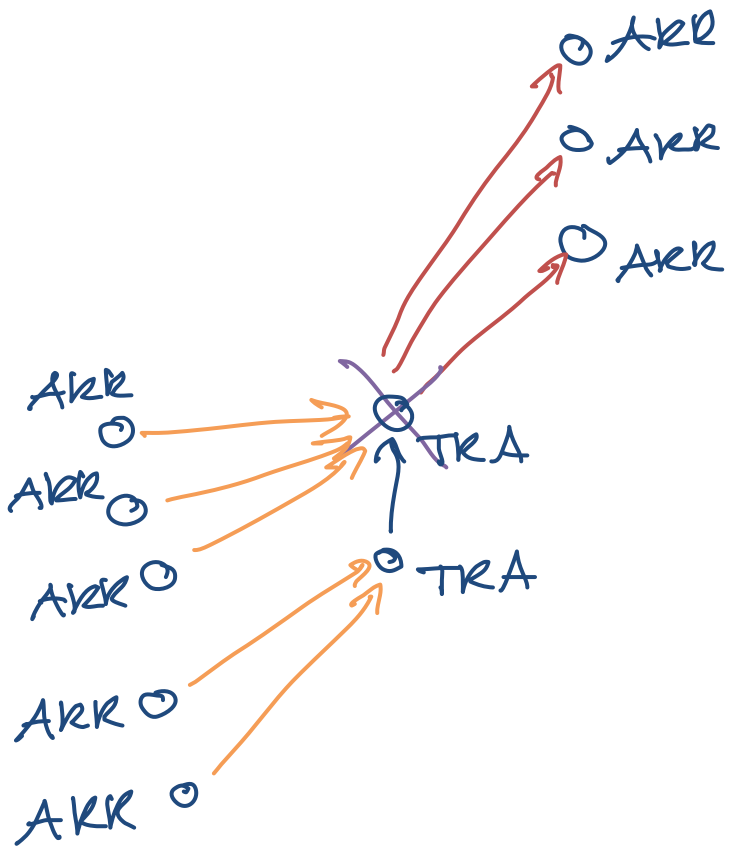
- Performance on time-expanded transit networks
  - Certain nodes can be contracted very well
  - We have already seen that the departure nodes can be contracted trivially, and this even saves us arcs
  - It seems like arrival nodes can also be contracted without loss





Contraction Hierarchies 2/5

- Performance on time-expanded transit networks
  - When we start to contract transfer nodes, the degree explodes:

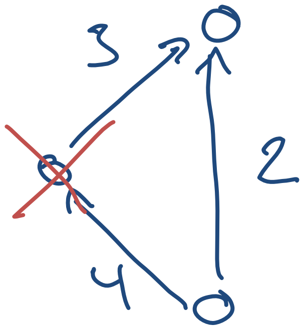


$3 \times 3 + 2 \times 3 = 15$

Contraction Hierarchies 3/5

- Performance on time-expanded transit networks
  - Here is one surprising explanation why we need to add so many arcs in transit networks but not in road networks
  - Note that in transit networks (with cost = travel time), whenever we contract a node (with in and out degree > 0), we always need to add **all** the potentially necessary shortcuts
  - In road networks this is not the case, why this difference?

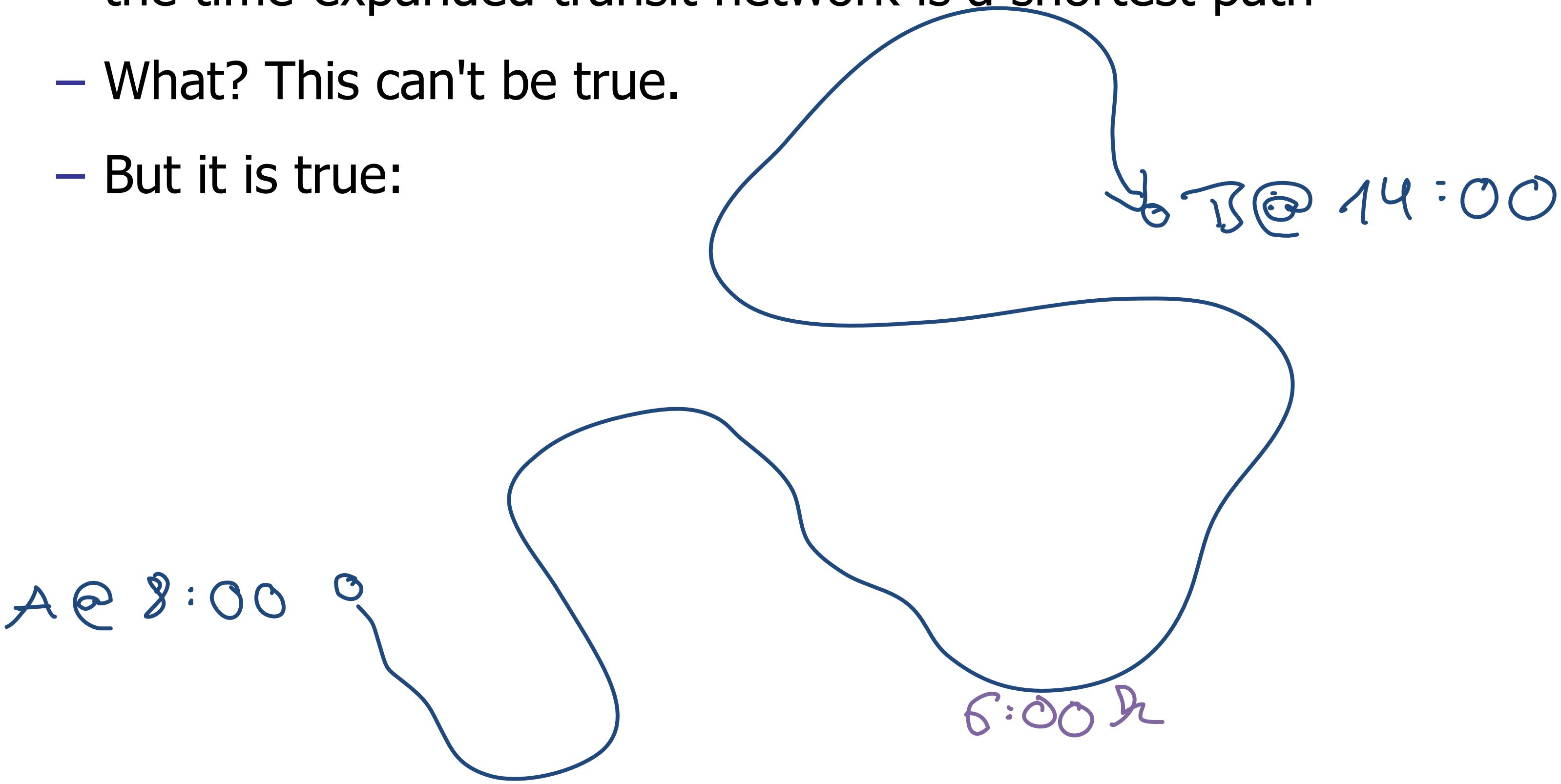
Road network



no need to add shortcut

Contraction Hierarchies 4/5

- Performance on time-expanded transit networks
  - The reason is that (when cost = travel time), **every** path in the time-expanded transit network is a shortest path
  - What? This can't be true.
  - But it is true:



Contraction Hierarchies 5/5

S

T

- Performance on time-expanded transit networks
  - For multi-criteria costs the situation becomes even worse
  - We have seen that in that case, a part P' of a shortest path from A to B might be a non-optimal path itself, and this P' can be arbitrarily far away from A and B
  - How are we supposed to figure out that we need P' (when contracting a node on P') with local Dijkstra computations
    - this is at the heart of contraction hierarchies

Faster

TS EXPRESS

Summary until here

- None of our algorithms so far
  - ... that is: Dijkstra, A* with the straightline heuristic, A* with the landmark heuristic, arc flags, contraction hierarchies, and transit node routing
  - ... is practical for large transit networks
  - And matters seem to become hopeless when realistic features like transfer buffers and multi-criteria cost function come into play
  - And fully-realistic models pose even more challenges:

    service days, vehicle restrictions, finding a suitable source and target station, walking between stations, ...

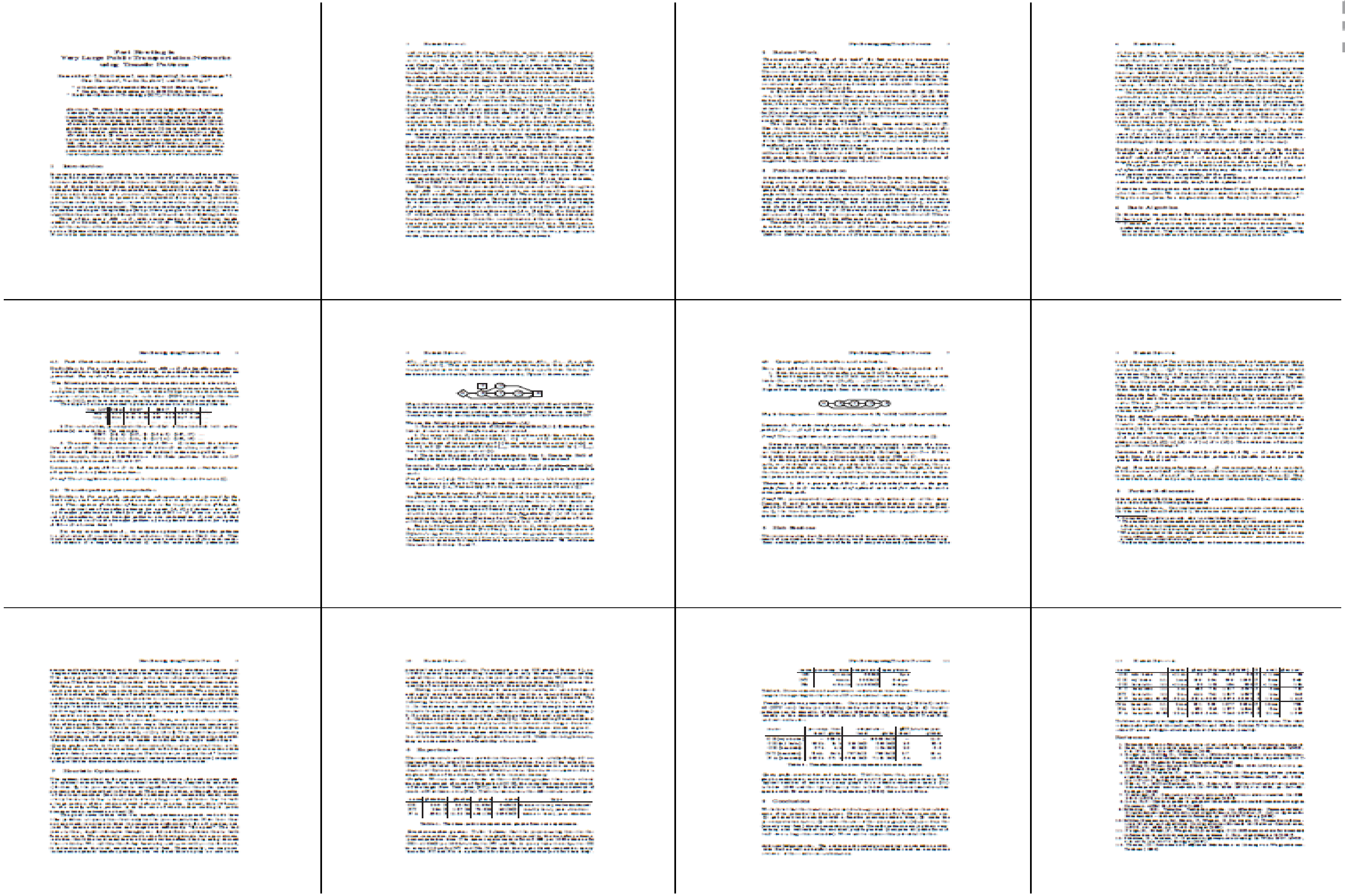
Transfer Patterns 1/3

- An algorithm designed for transit networks
  - Trying to exploit what is special about transit networks
  - But what could this be? So far we have only seen things which are harder on transit networks than on road networks
  - Here is one thing special about transit networks:

    transfers

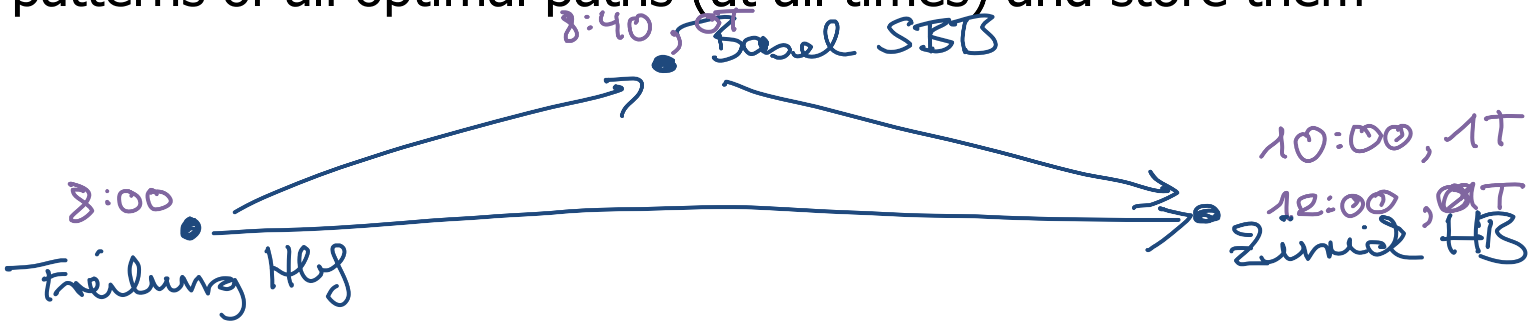
  - Even when you take a very long trip, the number of transfers is almost always a very small number
  - And more than that, for a given source and destination, there is only a very limited number of "**patterns**" where it makes sense to transfer

Transfer Patterns 2/3



Transfer Patterns 3/3

- The basic idea on one slide
  - The **transfer pattern** of a path = the sequence of stations on the path where one boards, transfers, or alights
  - Idea: for each pair of stations, precompute all transfer patterns of all optimal paths (at all times) and store them



  - Then, at query time, do a time-dependent Dijkstra computation on this so-called **query graph**, where each arc evaluation is again a shortest path query, but restricted to **no transfers**
  - Such **direct-connection** queries are easy to compute fast

Direct-Connection Queries

- One table per "line", let's call this one L17

Stations:	S154	S97	S987	S111	...	
Time from start:	0min	7min	12min	21min	...	
Start times:	8:15	9:15	10:15	11:20	12:20	...

- Lines per station (with positions in the respective line table)

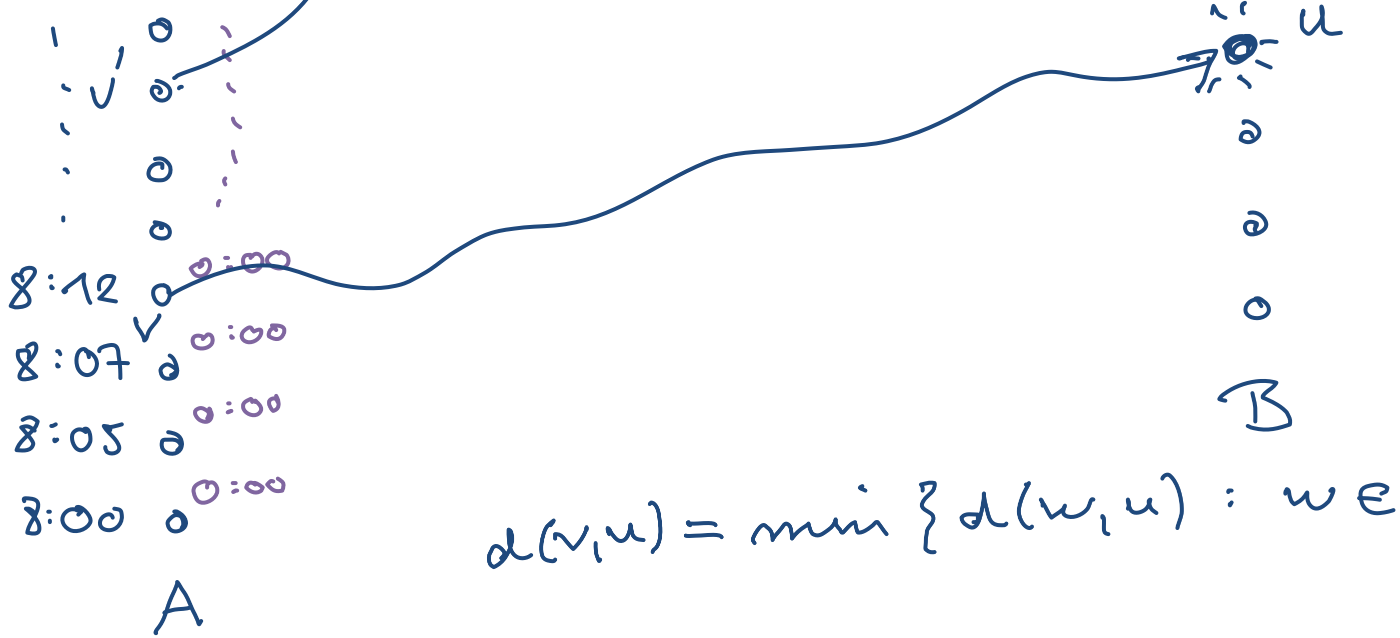
  Station S97: (L8, 4) (L17, 2) (L34, 5) (L87, 17) ...

  Station S111: (L9, 1) (L13, 5) (L17, 4) (L55, 16) ...

- Example query from S97 @ 10:20 to S111
  - Intersect the lists of the two stations : (L17, 2 → 4) ...
  - Find time from start to S97 and to S111 : 7min and 21min
  - Find first start time after 10:20 – 7min : 10:15 → **depart 10:22**
  - Compute arrival time at S111 : 10:15 + 21min → **arrive 10:36**

Transfer patterns precomputation 1/4

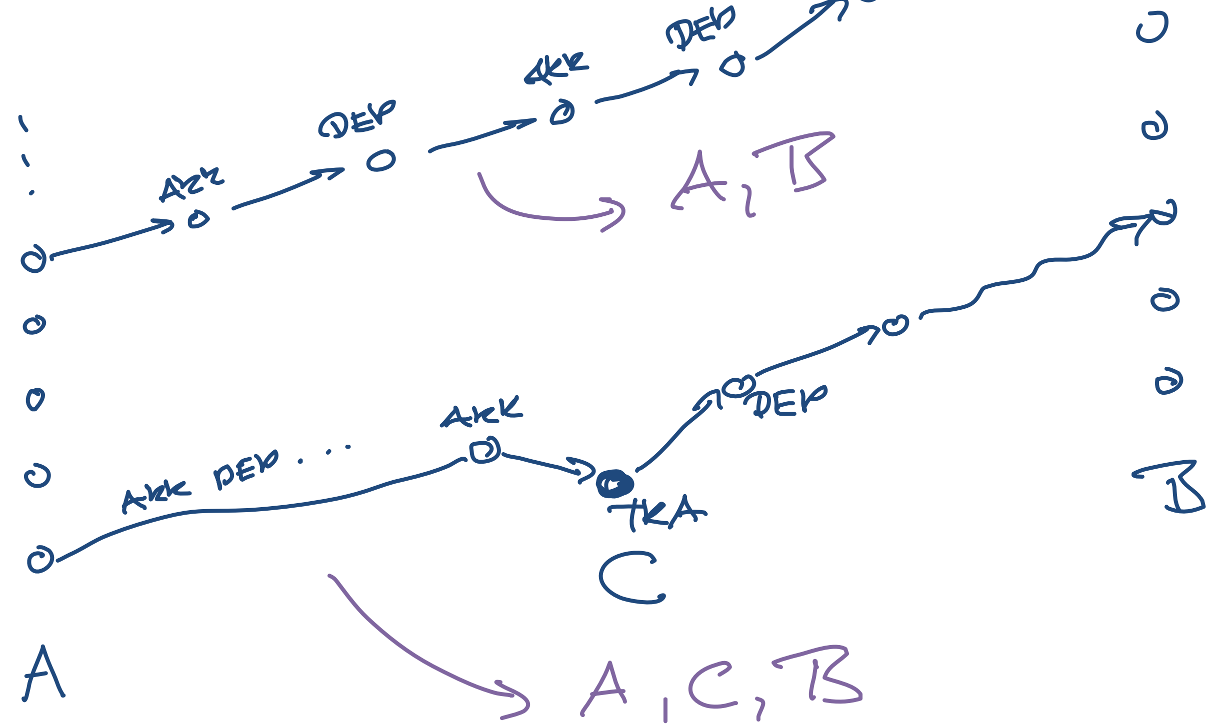
- Can be done via a Set-Dijkstra search
  - For each station A, do a Dijkstra starting from **all nodes** at that station (all with cost = travel time zero)
  - For each other node u in the graph, this will give us the path from the latest node at A so that u can still be reached



$$d(v,u) = \min\{d(w,u) : w \in A\}$$

Transfer patterns precomputation 2/4

- Now we have all optimal paths at all times
  - To obtain the transfer patterns for a station pair (A, B), simply trace back, in the Dijkstra search from A, the paths from all nodes in B and keep track of the transfers

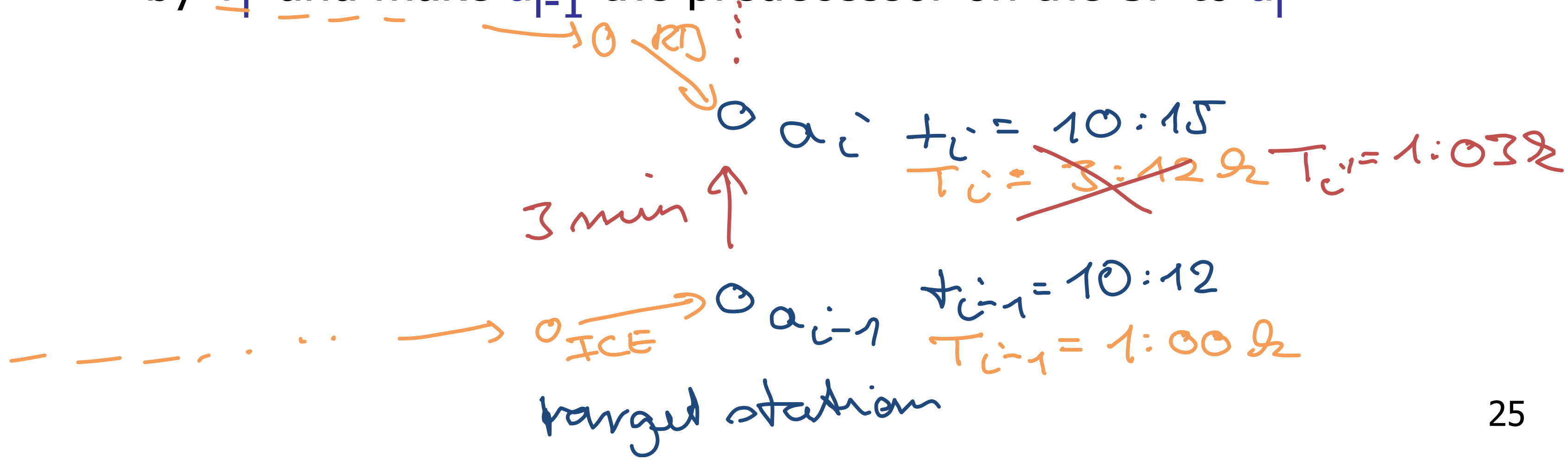


Transfer patterns precomputation 3/4

- Beware of non-optimal paths to arrival nodes
  - Note that there are no arcs between the arrival nodes at the target station
  - They would harm the Dijkstra search (because they would allow us to switch between lines when we shouldn't)
  - But after the Dijkstra search is done, we need them to discard non-optimal paths

Transfer patterns precomputation 4/4

- Arrival-loop algorithm for a target station B
  - Order the arrival nodes by time $t_1 \leq t_2 \leq t_3 \leq \ldots$ and call the corresponding arrival nodes $a_1, a_2, a_3, \ldots$
  - Do the following in the order of increasing time
  - Let T_{i-1} and T_i be the travel time of the shortest path to ai-1 and ai, respectively
  - If $T_i' := T_{i-1} + (t_i - t_{i-1}) \leq T_i$, replace the travel time at a_i by T_i' and make a_{i-1} the predecessor on the SP to a_i



References

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- Transfer Patterns

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