Efficient Route Planning

SS 2011

Lecture 9, Friday July 15th, 2011

(Transit Networks, GTFS)

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Overview of this lecture

- Organizational
  - Your feedback from Ex. Sheet #6 (transit node routing)
- Transit Networks
  - In the US, "transit" means "public transportation"
  - Transit node routing has nothing to do with this "transit"
  - We will see how to model a transit network
  - GTFS = General Transit Feed Specification
  - Do our algorithms so far work on transit networks?

  - Exercise Sheet #7: Parse a transit network from GTFS and run Dijkstra on it, and if possible, your other alg's too

Feedback on ES#6 (transit node routing)

- Summary / excerpts Stand 15.7 12:59
  - Noch beim Debuggen von contraction hierarchies
  - Gerade Endsemesterstress bei vielen

Coding standards

- Sind jetzt auch für Java ausgearbeitet
  - Siehe Link auf Ihrer Daphne-Seite

    https://daphne.informatik.uni-freiburg.de/svn/CodingStandards/
  - Sie finden dort
    - Eine README.deutsch.txt
    - Ein vollständiges Code-Beispiel für C++
    - Ein vollständiges Code-Beispiel für Java
    - Für eigene Projekte, einfach den entsprechenden Ordner kopieren und Code schreiben, sollte dann gehen

Transit Networks

- What kind of data have we got?
  - Stations (train stations, bus stops, etc.)
  - Lines (trains, buses, trams, etc.)
  - The schedule of these lines, that is, on which days do they serve which stations at which times
  - Since we want to compute shortest path queries also for transit networks (best way to get from A to B), we want to model them as (directed) graphs, too, just like road networks ... but how?

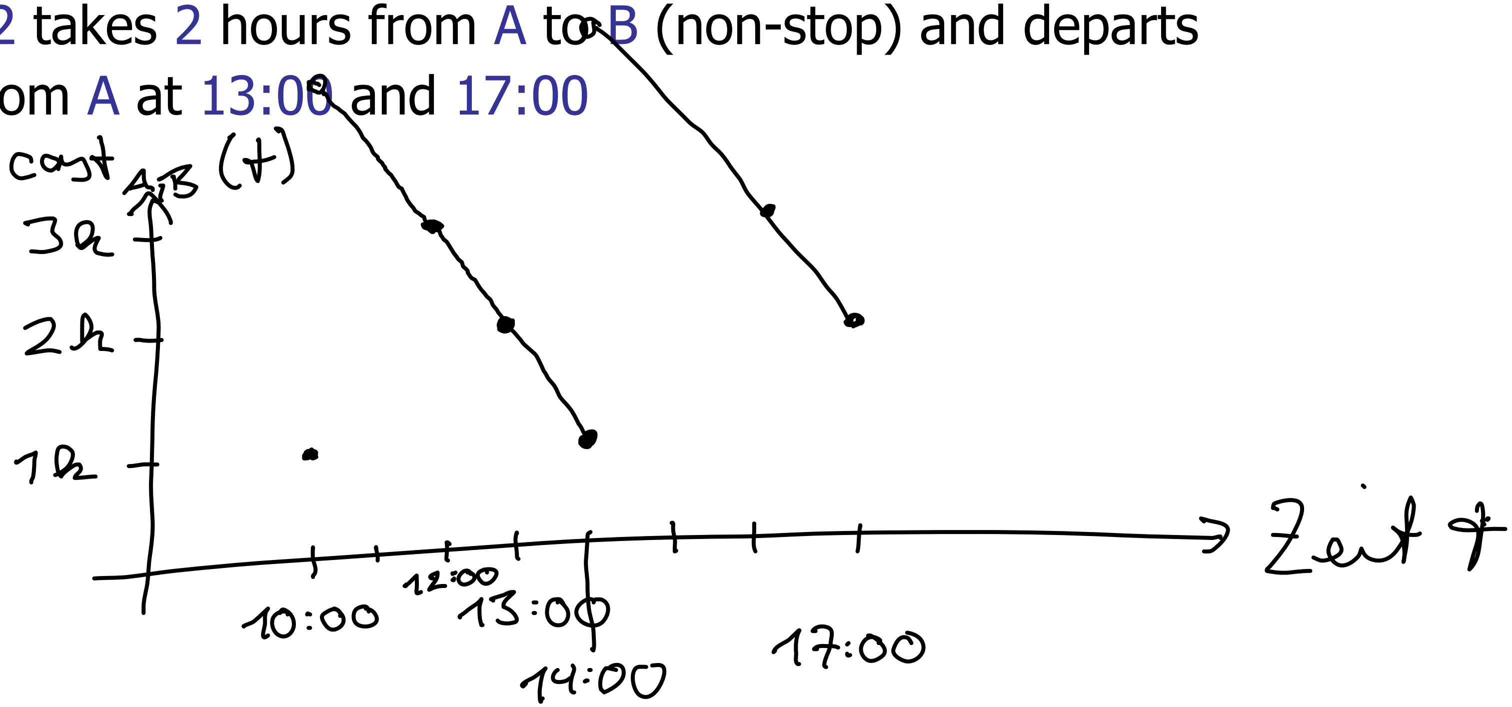
Time-dependent model 1/2

- The first thing that comes to mind
  - Each station is a **node**
  - There is an **arc** between two nodes u and v, if there is a vehicle (train, bus, tram, ...) going **non-stop** from u to v
  - However, that arc can only be used at certain times, and the time it takes to travel across the arc depends on the vehicle commuting at that time
  - We can model this via a cost function for each arc (u, v)

    $cost_{u,v}(t)$ = the time to get from u at time t ... to v

Time-dependent model 2/2

- Example
  - Stations A and B with two lines L1 and L2
  - L1 takes 1 hour from A to B (non-stop) and departs from A at 10:00, 14:00 and 18:00
  - L2 takes 2 hours from A to B (non-stop) and departs from A at 13:00 and 17:00

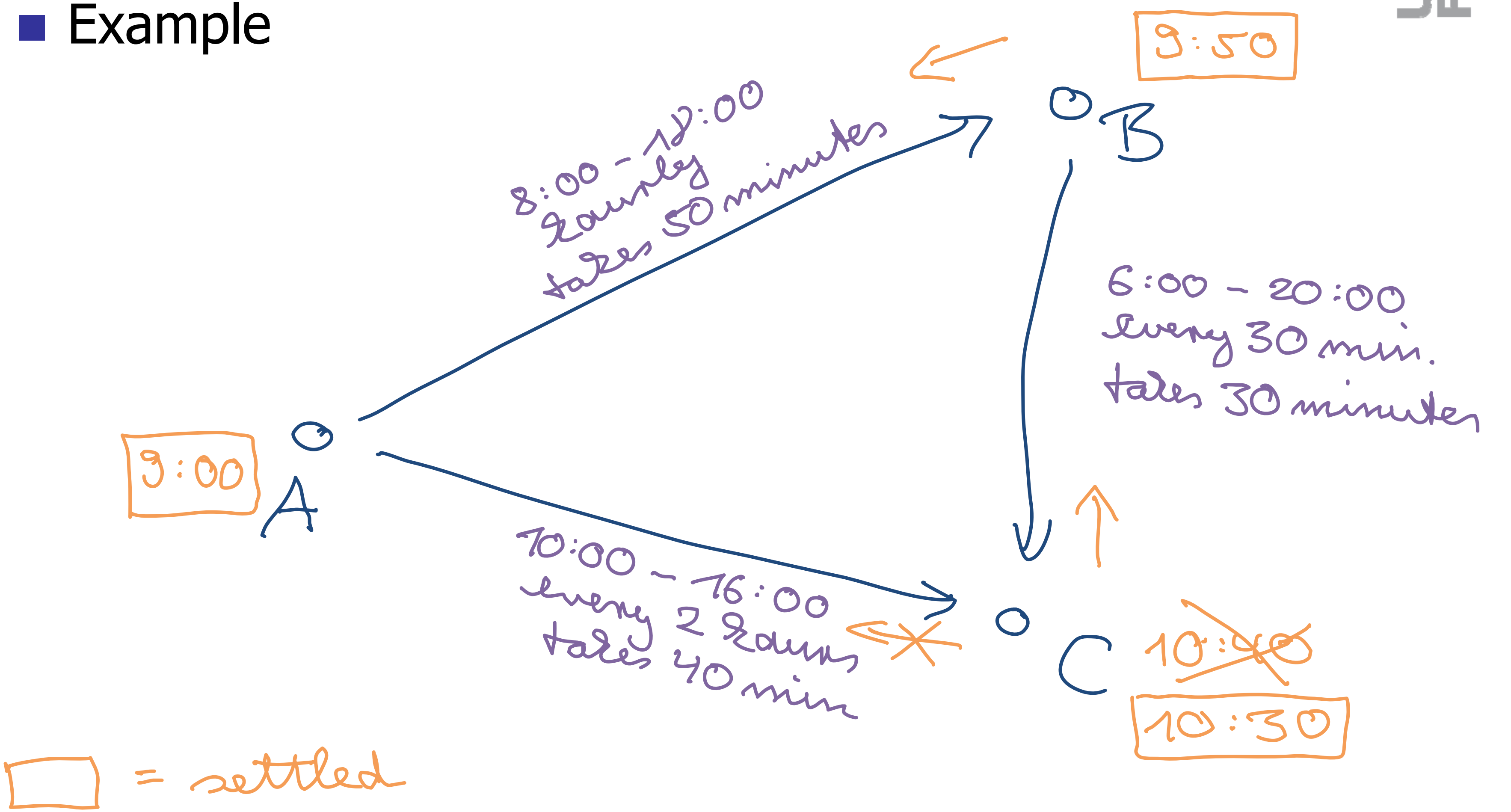


Time-dependent Dijkstra 1/2

- How to compute shortest paths on such a graph?
  - A simple variant of Dijkstra's algorithm does it
  - Tentative distances at the nodes are now **times of day**
    - We will store **absolute** times (like 10:20) and call them t[u] for node u, but we could also store times relative to the start time (like 40 minutes)
  - Start with t[s] = start time and all other t[u] = ∞
  - When relaxing an arc (u, v) we compute $c = c_{u,v}(t[u])$ and take t[v] = t[u] + c if that improves on the previous t[v]
  - As for ordinary Dijkstra process the node u with the smallest t[u] next, and stop when this is the target node

Time-dependent Dijkstra 2/2

- Example

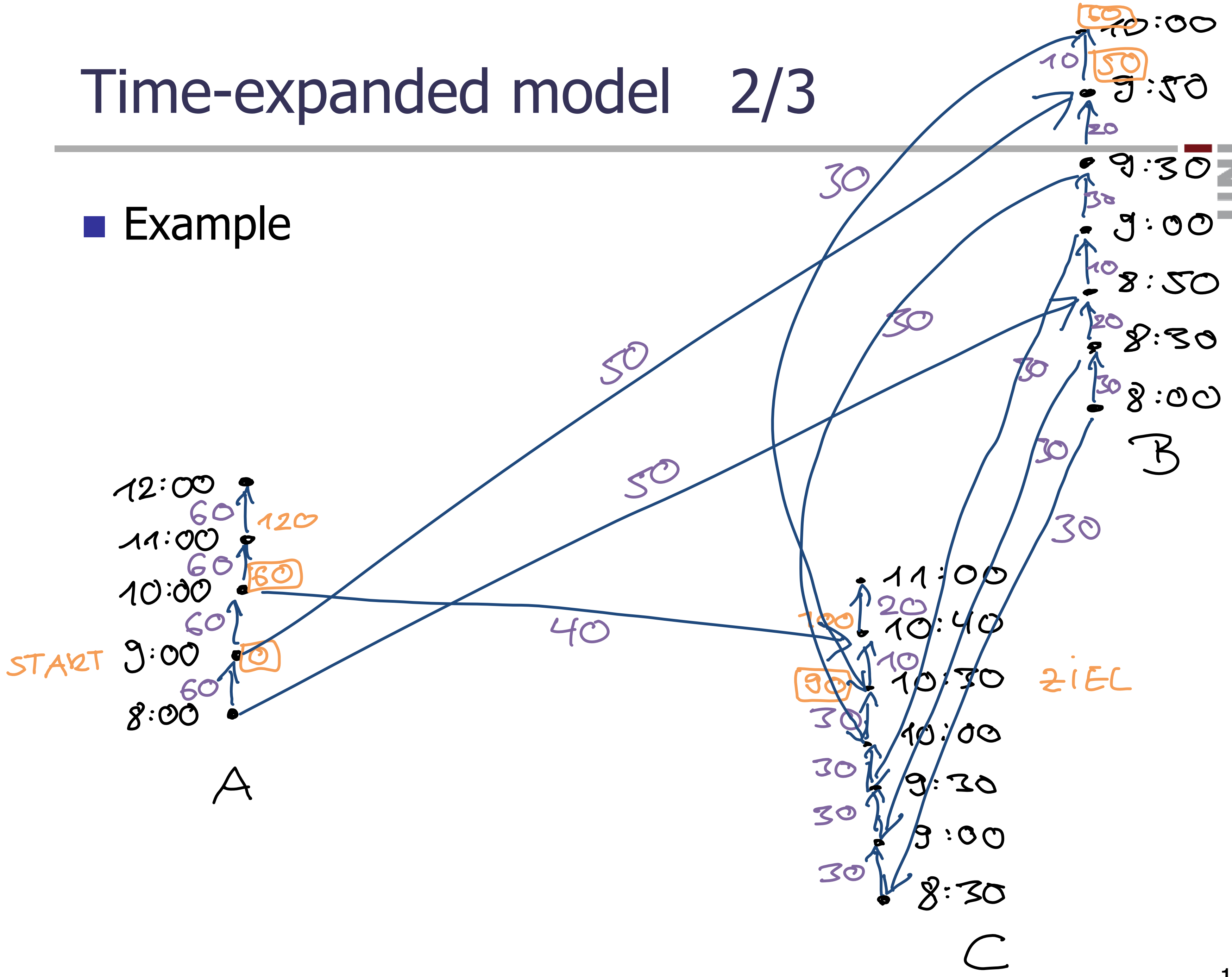


Time-expanded model 1/3

- A node = a particular time at a particular station
  - Only at times, where something (= an arrival or a departure) is happening
  - For example, Freiburg Hbf @ 13:57
  - There is an arc between two nodes A@t1 and B@t2 if there is a vehicle departing from A at time t1 and arriving at B at time t2, without stops inbetween
  - The cost of the arc is simply the travel time t2 – t1
  - There is also an arc from A@t1 to that node A@t2 with the smallest t2 > t1 ... we call these **waiting** arcs

Time-expanded model 2/3

- Example



Time-expanded model 3/3

- How do we compute shortest paths in this model?
  - It's an ordinary directed graph with non-negative arc costs, so we can use ordinary Dijkstra
  - Only problem: we do not have a target node, we only have a target station
  - Solution: Run Dijsktra until anyone node from the target station is settled (which will be the first one reached)

Time-expanded vs. time-dependent

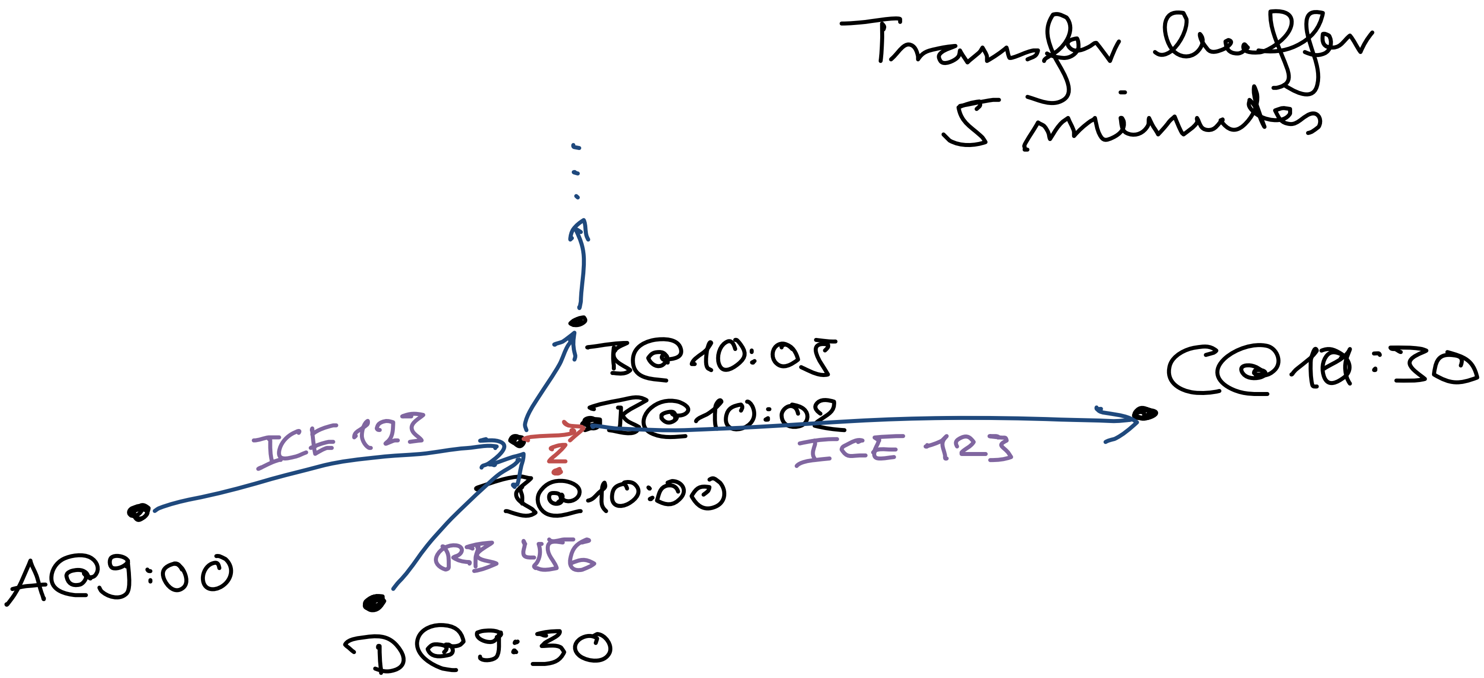
- So far, not much difference
  - Given a query A@t → B, consider the sequence of arcs relaxed by a (time-dependent) Dijkstra on the time-dependent graph
  - The Dijkstra on the time-expanded graph relaxes the same arcs in the same order, **plus** some additional waiting arcs to some additional nodes and the arcs leaving from these nodes
  - Intuitively, the time-dependent Dijkstra considers waiting and normal arcs in one (time-dependent) arc
  - The big advantage of the time-expanded model is that we have an ordinary directed graph and can thus use all our previous algorithms on it

Advanced modelling issues

- For example, what about ...
  - Transfer buffers
    - We need a minimal amount of time to transfer between two vehicles → next slide
  - Service days
    - Different schedules on different weekdays, holidays, etc. → later slide
  - Multi-criteria cost functions
    - Maybe we can get from A@t to B in 3 hours with 0 transfers, or in 2 hours with 2 transfers
    - Which one is better depends on user preference, so we should compute both → next lecture

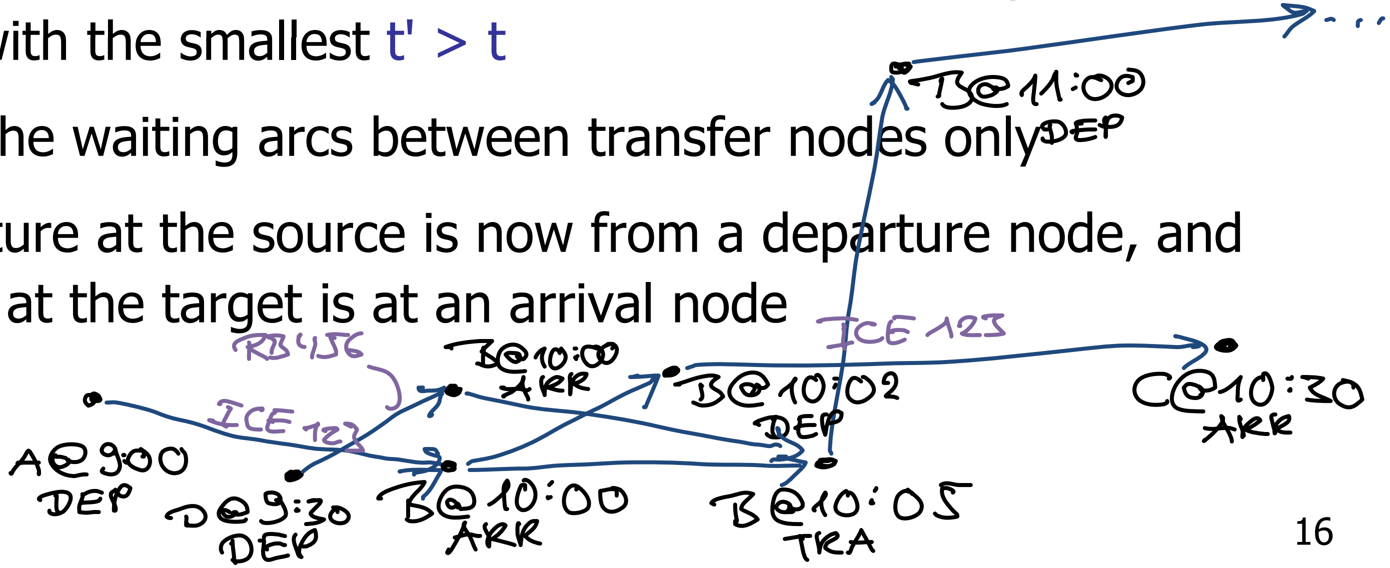
Transfer buffers 1/5

- Time-expanded model
  - This is non-trivial, because we need to distinguish between staying on a vehicle at a station (which must not require any transfer time) and changing the vehicle, for example:



Transfer buffers 2/5

- Time-expanded model, solution
  - Split up each node from before into an **arrival node** and a **departure node**, and add an arc between the two (we can also model layover time that way now)
  - For each arrival node A@t, add a **transfer node** A@t' and an arc from A@t to A@t', where t' – t is the transfer buffer
  - For each transfer node A@t, add an arc to the departure node A@t' with the smallest t' > t
  - Have the waiting arcs between transfer nodes only
  - Departure at the source is now from a departure node, and arrival at the target is at an arrival node



Transfer buffers 3/5

- Time-dependent model, solution 1
  - We also have to distinguish here between staying on a vehicle and changing the vehicle at a station
  - It looks like we can do this by simply remembering for each node, along with the tentative arrival time t[u], the id ℓ of the vehicle with which we arrive at u
  - Then we can build the transfer buffer into the cost function

    $\mathrm{cost}_{u,v}(t, \ell)$ = time to reach v, if we are at u at time t sitting in vehicle ℓ
  - Unfortunately, Dijkstra's algorithm will not always correctly compute the shortest path anymore then

Transfer buffers 4/5

- Time-dependent model, problem

Transfer buffers 5/5

- Time-dependent model, solution 2
  - Have separate arrival and departure nodes, too
  - One arrival and one departure node per line suffices
  - But still, we no longer only have one node per station
- Time-dependent model, solution 3
  - When we can arrive at a station at two different times t1 and t2 with different vehicles, and |t2 – t1| is ≤ the transfer buffer, pursue both possibilities
  - Then we need to do a multi-label Dijkstra (Dijkstra maintaining several shortest paths to the same node), see next lecture

GTFS

- General Transit Feed Specification
  - Standard format established by Google in 2005
  - Here is a nice story about it: http://tinyurl.com/6yczek2
  - See the references to the GTFS specification
  - Relatively complex, because there are so many pecularities, special cases, etc. for transit networks
  - For a simple graph model, it is easy though

GTFS

- Basic concepts
  - stop = what we call a station
    - e.g. Freiburg Hbf or Bertoldsbrunnen
  - trip = journey of a particular vehicle at a particular time
    - e.g. the journey of Bus 11 from Munzinger Straße at 9:28 to Paduaalle at 10:11
  - route = trips that have a common description
    - e.g. all journeys of Bus 11 over the day
  - service days = days of the week when a trip is available
    - e.g. on weekdays (Mo-Fr) or on the weekend (Sa-Su)

GTFS

- The files we need for exercise sheet #7
  - stop_times.txt : the actual schedule information, what eventually becomes the arcs in the transit graph
  - frequencies.txt : some lines repeat in exactly the same way over the same day, then you have the schedule only once in stop_times.txt, and the periodicity here
  - calendar.txt : service day patterns, and which days of the week belong to it
  - trips.txt : tells us which trips commute on which service days (via the patterns from calendar.txt)
  - All files are in CSV format = a table with one record per line, columns separated by a comma, headings in first line

Implementation Advice 1/7

- Write a class CsvParser
  - With a method readNextLine() that reads the next line from the file and makes the columns available via another method getItem(int i)
  - You find my CsvParser.h and CsvParserTest.cpp in the course SVN under folder lectures
  - Note: for efficiency reasons, I let my getItem method return a const char* which points to part of an internal string object containing the last line read

    It's slightly easier if you just return an std::string, but then you get one or two additional copies / allocations

Implementation Advice 2/7

- Graph class
  - If you have a graph class with members

    ```
    vector<Node> _nodes;
    vector<vector<Arc> > _adjacencyLists;
    ```

    you can use that for the (time-expanded) transit network as well
  - That way, you can run your algorithms with little or no modifications on the transit network as well
  - You might want to add some additional info to the Node class (like the station to which a node belongs) and to the Arc class (like the name of the GTFS route)

Implementation Advice 3/7

- Parse the GTFS files in this order and way
  - First parse calendar.txt and remember (in a hash set) those service ids which contain the given weekday
  - Then parse trips.txt and remember (in a hash set) those trip ids with a valid (= remembered) service id
  - Then parse stops.txt and store (in a hash map) the names and coordinates by stop id
  - Then parse frequencies.txt and store by trip id
  - Then parse stop_times.txt and for each block of lines in the file with the same trip id, add the corresponding nodes and arcs to your graph

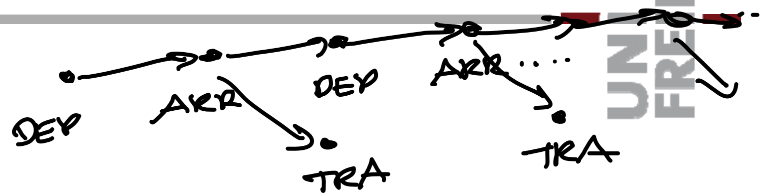
Implementation Advice 4/7

- Blocks with same trip id in stop_times.txt
  - For the last step, it is very convenient to have all lines with the same trip id together in one block, and within this block have them sorted by stop_sequence
  - You can easily achieve this with a command-line sort

    sort –t, -k1,1r –k5,5n stop_times.txt > new_file.txt
  - If you have frequency information for the trip id of a line from stop_times.txt, repeat accordingly, for example:

Implementation Advice 5/7

- Arrival, departure, transfer nodes



  – Create all nodes already while processing stop_times.txt

  – And also the arcs from arrival to departure nodes and vice versa, and from arrival nodes to transfer nodes

  – While processing stop_times.txt, maintain (in a hash map) for each station the list of nodes of that station, their time, and their type (arrival, departure, transfer)

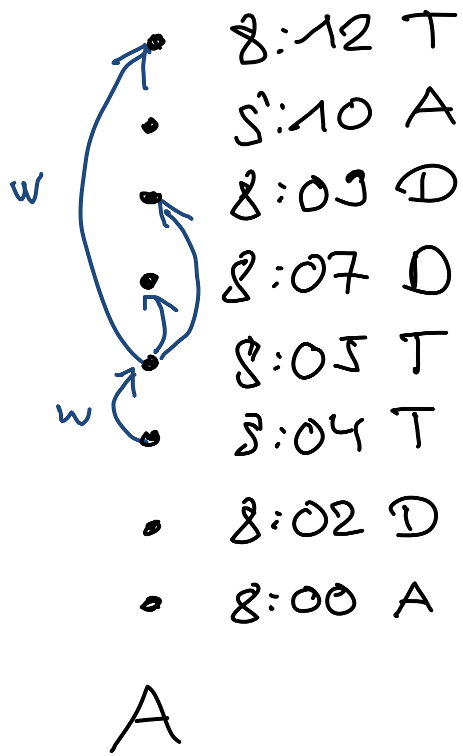
  – After processing stop_times.txt, for each station do:

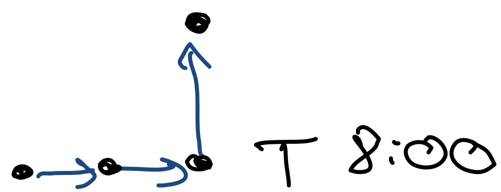
    Sort the nodes by time; then it is easy to add the missing arcs **from** the transfer nodes (waiting arcs to the next transfer node, and boarding arcs to the next departure node)

    - Beware: several nodes with exactly the same time

Implementation Advice 6/7

- Arcs **from** transfer nodes, example





Implementation Advice 7/7

- Tricks to save some arcs
  - We can trivially **contract** all departure nodes
  - This replaces pairs of a boarding and a traveling arc by a single arc ... and actually **descrease** the total number of arcs in the graph, for example:

Road vs. Transit Networks

- Assume the time-expanded model
  - Then we can all our algorithms so far also for transit networks
  - But will the speed-up over ordinary Dijsktra be the same?

References

- Transit network models

  Timetable information: Models and Algorithms

  Müller-Hannemann, Schulz, Wagner, Zaroliagis, ATMOS 2007

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- Road Networks vs. Transit Networks

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  Hannah Bast, Efficient Algorithms 2009, LNCS 5760

  http://www.springerlink.com/content/y46257m66372x730/

- GTFS
  - http://code.google.com/transit/spec/transit_feed_specification.html