Efficient Route Planning

SS 2011

Lecture 7, Friday July 1st, 2011
(Contraction Hierarchies again, implementation advice)

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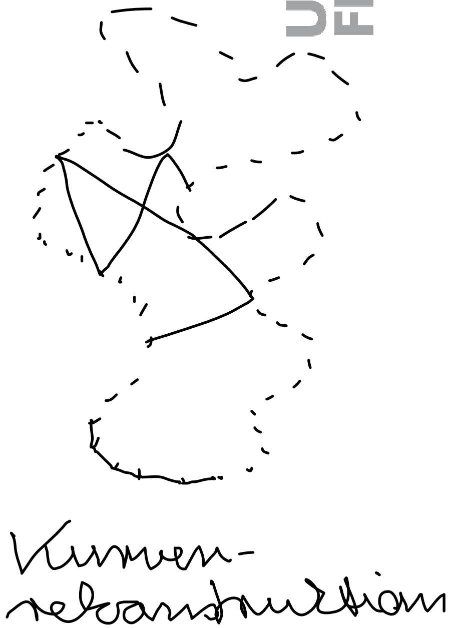
Overview of this lecture

- Previous stuff
  - Your web applications from Exercise Sheet #4
  - Don't be shy to give us feedback!
  - How will the exam look like?
- Contraction Hierarchies again
  - Recapitulation of the main parts of the algorithm
  - A non-trivial working example
  - All kinds of implementation advice
  - Please ask questions when something is not 100% clear!

  - No new exercise sheet, please finish the last one (#5) until Friday next week (July 8, 2 pm)



Feedback

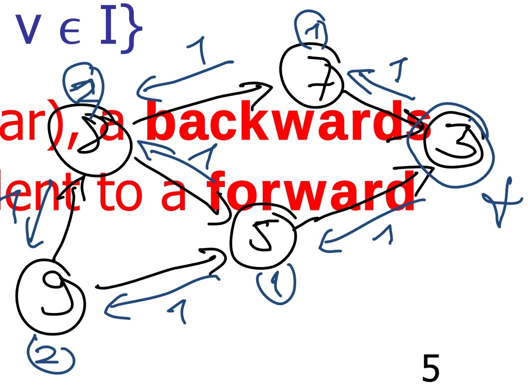
- Don't be shy to give us feedback
  - If you have any questions, ask!
  - If you think it's too much, say it!
  - Don't complain afterwards, complain before!

Exam

- The exam will be on Monday, August 15 at 2 pm
  - It will last (only) 90 minutes
  - There will be **4 tasks**, out of which you can select **3 tasks**
  - Three **kinds** of tasks are possible
    - Execute an algorithm from the lecture, or some variant of it, on a given example (on paper)
    - Write a small program to solve a variant of a problem we have seen in the lecture
    - Compute, reason about, or prove a non-trivial (but also not very difficult) property of an algorithm or data structure from the lecture, or some variant of it
  - See the Search Engines WS 2009/2010 exam for examples

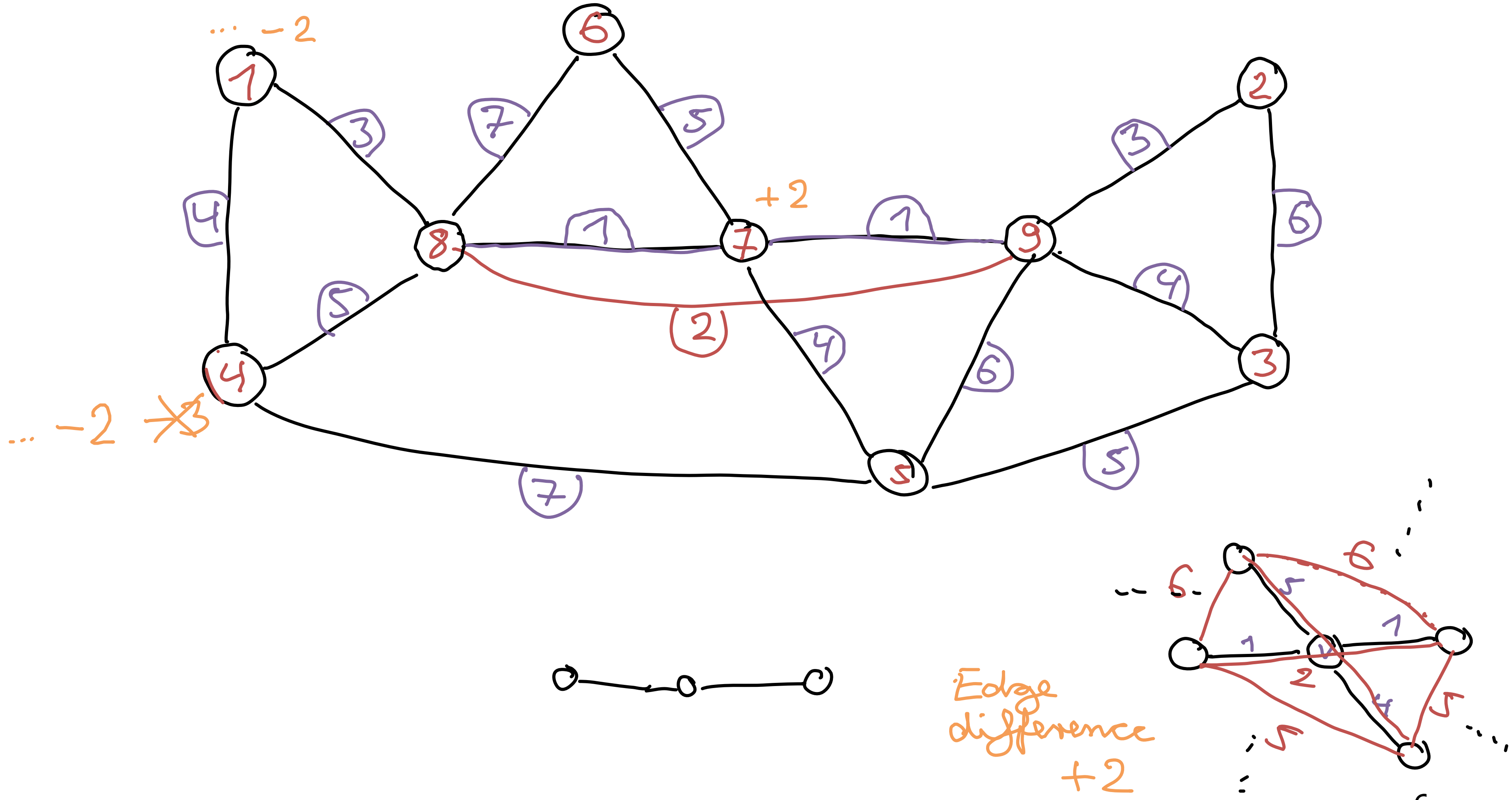
Contraction Hierarchies — Reprise

- Query algorithm, for given source s and target t
  - Do a full Dijkstra computation from s **forwards**, considering only arcs (u, v) with u < v
    - we call G↑ = (V, {(u, v) : u < v}) the **upward graph**
  - Do a full Dijkstra computation from t **backwards**, considering only arcs (u, v) with u > v
    - we call G↓ = (V, {(u, v): u > v}) the **downward graph**
  - Let I be the set of nodes settled in both Dijkstras
  - Take dist(s, t) = min {dist(s, v) + dist(v, t) : v ϵ I}
  - NOTE: for **symmetric** graphs (like ours so far), a **backwards search in the downward graph** is equivalent to a **forward search in the upward graph**



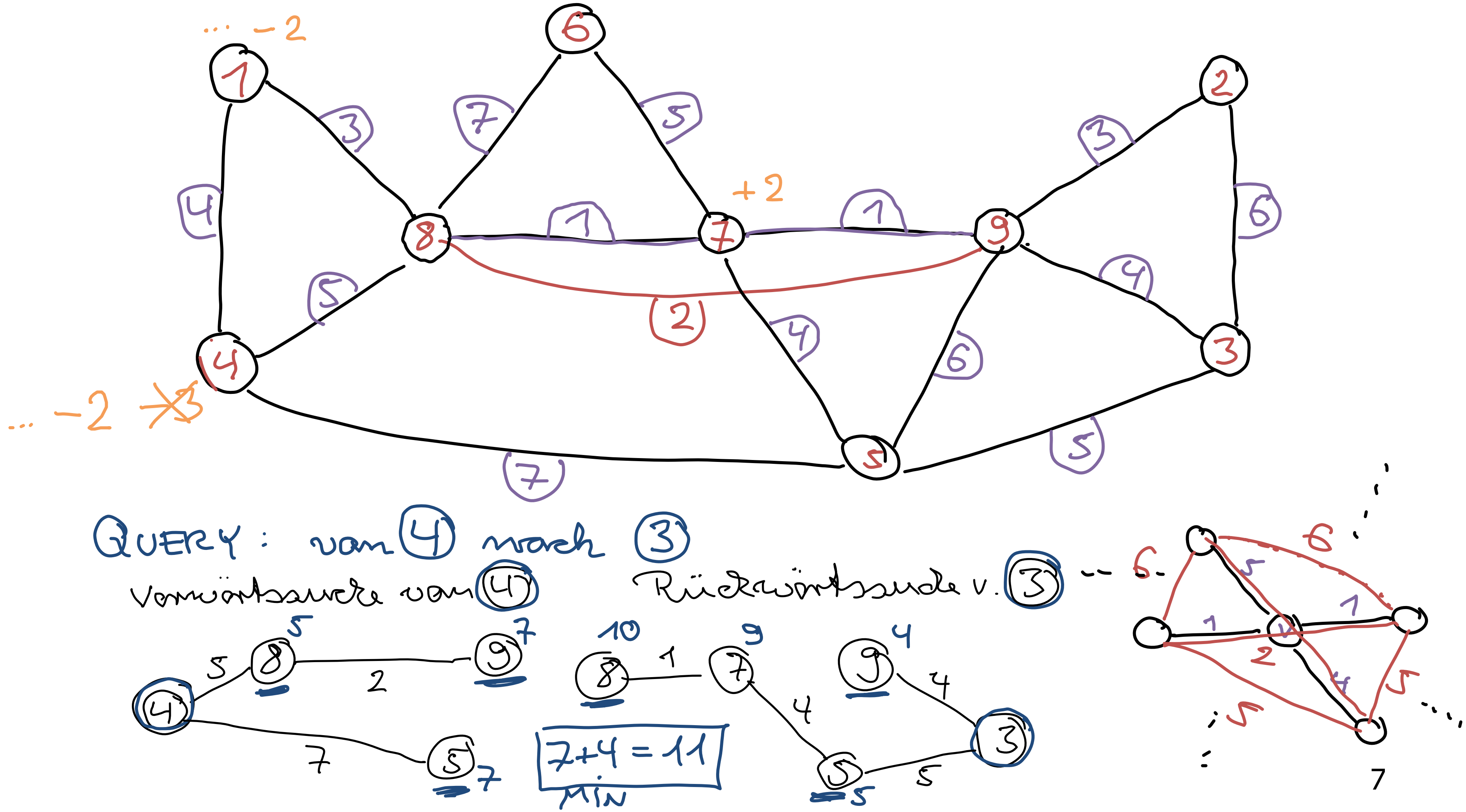
Contraction Hierarchies — Example 1/2

- The **full** pre-processing for a small graph



Contraction Hierarchies — Example 2/2

- A query on the fully pre-processed graph



Implementation Advice 1

- Disclaimer:
  - The following is just advice
  - You don't have to do it that way
  - It's a good and clean way to do things, however
    - based on quite some experience
    - with writing code in general
    - and with writing code for route planners in particular

Implementation Advice 2

- The canonical classes to have (so far)
  - class RoadNetwork
  - class RoutePlanningAlgorithm
  - class Dijkstra : public RoutePlanningAlgorithm
  - class Landmarks : public RoutePlanningAlgorithm
  - class ArcFlags : public RoutePlanningAlgorithm
  - class ContractionHierarchies : public RoutePlanningAlgorithm
  - class RoutePlanner
  - Let's have a look at my code ...

Implementation Advice 3

- The RoadNetwork class (or however you call it)
  - A good and simple implementation is with

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

  - Have a DebugString method or something like that for writing the whole graph to a human-readable strins
  - Have a method for addings nodes and arcs
  - Or even better: a method for parsing a graph from a string in the same format as output by DebugString
  - That will be a great asset in testing and debugging
  - Let's have a look at my code ...

Implementation Advice 4a

- Dijkstra's algorithm and its **many** variants
  - Have a separate Dijkstra class with member variables like

    _estimatedCostsToTarget (for A*, landmarks, ...)

    _nodesToBeIgnored (for arc flags, contr. hierar., ...)

    _nodesToBeSettled (for contraction hierarchies, ...)

    _costUpperBound (for contraction hiearchies, ...)
  - Have setters for these member variables
  - Have a **single** implementation of computeShortestPath
    - containing various if statements that are executed conditional on the values of the above member variables

Implementation Advice 4b

- Dijkstra's algorithm and its **many** variants
  - Similarly, return anything else but the cost via member variables like

    size_t _numNodesSettled

    size_t _numArcsRelaxed

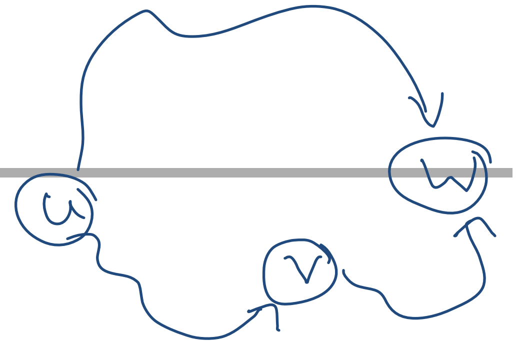
    vector<Arc> _arcsOnShortestPath
  - That avoids having a computeShortestPath method with an exorbitant number of arguments (or a complex result object, which is only partly used by most applications)
  - Let's have a look at my code

Implementation Advice 5

- Have a separate class ContractionHierarchies
  - Which has a RoadNetwork as a member variable
  - Better **not** to have CH-specific information (like the node ordering or which nodes are contracted already) in the RoadNetwork class, but as member variables in the ContractionHiearchies class

    vector<int> _orderingNumbers;
    vector<bool> _nodesContractedMarks;
  - Otherwise your RoadNetwork class (or your Node and Arc class) will get cluttered up with information from all kinds of difference algorithms
  - Let's have a look at my (preliminary) class ...

Implementation Advice 6



- How to contract a node v
  - For each pair of u and w with arcs (u, v) and (v, w), we need to figure out whether dist(u, w) in the graph **with** v is **strictly** better than the dist(u, w) in the graph **without** v
  - Compute d_{uv} = dist(u, v) in the graph **with** v
    - will be fast because $d_{uv} \leq$ cost of the arc (u, v)
  - Compute d_{vw}= dist(v, w) in the graph **with** v
    - will be fast because $d_{vw} \leq$ cost of the arc (v, w)
  - Then compute a lower bound d'_{uw} on dist(u, w) in the graph **without** v, stopping the search after cost $d_{uv} + d_{vw}$
    - without such a bound, this search could take **very** long

Implementation Advice 7

- How to contract a node v, optimizations
  - Do the shortest path computations for all pairs (u, w) simultaneously, in two parts
  - Do a single Dijkstra from u until all neighbours are settled
  - Do a single Dijkstra from each neighbour of v until all the other neighbours are settled (in the graph without v)
  - Use something like the _nodesToBeSettled explained earlier
  - Note: we might add slightly more shortcuts that way, because shortcuts introduced due to one pair (u, w) can now no longer influence the computation for another pair (u', w')
    - I don't think this is a big issue in practice though

Implementation Advice 8

- How to ignore nodes in a Dijkstra search
  - Use a vector<bool> with a mark for each node

    (more efficient than a hash map!)
  - In the Dijkstra class have one member variable which is a pointer to such a vector<bool>, as explained before
  - That way, you do not need to clutter up the Dijkstra class with information / code that is very algorithm-specific ... like arc flags or contracted nodes

Implementation Advice 9

- Augmenting the graph
  - Pay attention when you add an arc by just appending it to one of the elements from your vector<vector<Arc>>
  - It could happen that you already have an arc (u, w) with cost c1, and a contraction will add a shortcut (u, w) with cost c2 < c1
  - It depends on your implementation of Dijkstra, whether two arcs between the same pair of nodes is a problem or not, but be aware of the issue
  - To be on the safe side, search the adjacency list before you add a new arc, and just update the cost, if the arc is already there

Implementation Advice 10

- How to compute the edge difference
  - You can also use the method contractNode for that
  - Again, use member variables to change the calling mode and return result values

    bool _computeEdgeDifferenceOnly

    int _lastEdgeDifferenceComputed