Semester Report WS05/06

Name:	Heiko Schilling
Supervisor:	Prof. Dr. Rolf H. Möhring
Field of Research:	Combinatorial Optimization & Graph Algorithms
Topic	Constrained Route Assignment on Large Networks
PhD Student	associated member since July 2001

Field of Research and Results

Length-Bounded Cuts and Flows. We proofed various results concerning the complexity and approximability of length-bounded cut and flow problems. An L-length-bounded cut in a graph G with source s and sink t is a cut that destroys all s-t-paths of length at most L. An L-length-bounded flow is a flow in which only flow paths of length at most L are used. We showed that the minimum length-bounded cut problem in graphs with unit edge lengths is $\mathcal{NP}$-hard to approximate within a factor of at least 1.1377 for $L \geq 5$ in the case of node-cuts and for $L \geq 4$ in the case of edge-cuts. We also gave approximation algorithms of ratio $\min\{L, n/L\}$ in the node case and $\min\{L, n^2/L^2, \sqrt{m}\}$ in the edge case. Furthermore, we showed that the integrality gap of the LP relaxation can be at least $\Omega(\sqrt{n})$. We also discussed the maximum length-bounded flow problem. For series-parallel graphs with unit edge lengths and unit edge capacities, we showed a lower bound of $\Omega(\sqrt{n})$ on the integrality gap of the LP formulation. We also showed that edge- and path-flows are not polynomially equivalent for length-bounded flows. That means, even if the graph is outer-planar, there is no polynomial algorithm to transform an edge-flow which is known to correspond to a length-bounded path-flow into a length-bounded path-flow. We also analyzed the structure of optimal solutions and showed that there are instances where each maximum flow ships a large percentage of the flow along paths with a very small flow value. The fractionality of these maximum flows can be chosen arbitrarily small.

This is joint work with Georg Baier (Siemens AG), Thomas Erlebach (U Leicester), Alexander Hall (ETH Zürich), and Ekkehard Köhler (TU Berlin) and is submitted to the 33rd International Colloquium on Automata, Languages and Programming (ICALP 2006), see the preprint [BEH+06].

A Column Generation Approach for Routing and Scheduling Freight Trains. We work on a challenging combinatorial optimization problem drawn from the real world: Find routes and a schedule for a fleet of freight trains that operates in a multi-hub-spoke system. Our current approach uses a decomposition method and column generation.

This is joint work in progress with Alberto Ceselli (U Milano), Michael Gatto and Marc Nunkesser (ETH Zürich), and Marco Lübbecke (TU Berlin). I will give a talk about this work on this years conference on High Performance Scientific Computing. We plan a submission to the ESA 2006.

Weather-dependent Sea Routes for Ships. We work on the problem of computing routes for ships. Depending on the weather situation and the sea state we try to find a route that minimizes the fuel consumption of a ship. Additionally, parameters such as the rolling angle of a ship have to be kept below a given bound on the route to be computed. We distinguish two scenarios: the common routing and the disaster scenario. In the first case, there is a fixed point in time up to which the destination has to be reached. In the case of a ship disaster, we have to solve the problem of reaching the nearest refuge in the shortest possible time and coping with limited maneuvering capabilities. To solve the problem, we suggest a discretized network which models turning possibilities of ships on the sea. In this network, nodes are associated with costs. The costs vary with the turning angle and the following three parameters: wave height, wave period, wave direction. These parameters are time-dependent and can be derived from the weather forecast. Obviously, the forecast is less reliable when the point in time to which it refers is further away in the future. We work on routing algorithms for this dynamic network setting. The algorithms will be part of a weather and sea routing advice decision support system for ships.

This is joint work in progress with Alex Hall (ETH Zürich), Ekkehard Köhler, Anton Telle, and Carl-Uwe Böttner (TU Berlin). We plan a publication of the work later this year.

Molecular Dynamics and Efficient Hierarchical Algorithms. An interesting application of our results on hierarchical and shortest path algorithms is in the area of bio molecular conformations: Life processes consist of a wide network of physiological elementary processes, which present themselves on molecular level as interrelations between bio molecules. A certain

effectiveness is based on the so-called *molecular recognition*: A messenger molecule (key) commits itself to an active center of a goal molecule (lock), whereby a specific biological function of the goal molecule is activated or restrained. The synthesis of highly specific medicines exists now in the production of an artificial key. The substantial problem here is that the molecule keys which can be used do not only vibrate easily around a middle form, but change sometimes even into a completely different form. These different forms are called *conformations*. A molecule represents thus at the same time many ductile keys. The goal of this collaboration is to find bunches of paths used with high probability by the molecule to get from one conformation to another.

This is joint work in progress with Rolf H. Möhring (TU Berlin), Philip Metzner, and Christoph Schütte (Matheon & FU Berlin).

Partitioning Graphs to Speed-Up Dijkstra's Algorithm. We studied an acceleration method for point-to-point shortest path computations in large and sparse directed graphs with given nonnegative arc weights, see [MSS+06]. I reported on this work in previous reports. This is joint work with Rolf H. Möhring (TU Berlin) and Birk Schütz, Dorothea Wagner and Thomas Willhalm (U Karlsruhe). The paper has been invited to a special issue of the ACM Journal on Experimental Algorithmics. We submitted the final, camera ready version this year in January.

Publications

[BEH+06] Georg Baier, Thomas Erlebach, Alexander Hall, Ekkehard Köhler, and Heiko Schilling. Length-bounded cuts and flows. Technical Report 005-2006, TU Berlin, February 2006.

[MSS+06] Rolf H. Möhring, Heiko Schilling, Birk Schütz, Dorothea Wagner, and Thomas Willhalm. Partitioning graphs to speed up dijkstra's algorithm. In Journal of Experimental Algorithmics (JEA). 2006.

Conferences, Workshops & Schools

- Conference on High Performance Scientific Computing, Hanoi, Vietnam, March 6–10, 2006.

- DFG Miniworkshop "Distributed Algorithms for Flows on Large Networks", TU Braunschweig, February 23–24, 2006.
- Block Course: Combinatorial Optimization at Work, ZIB, Berlin, October 04–15, 2005.
- European Conference on Combinatorics, Graph Theory and Applications (EuroComb), TU Berlin, September 05–09, 2005.

Guest visits

- Guest visit at the group of Prof. Widmayer, ETH Zürich, July 17–31, 2005 (supported by DFG project SPP 1126).
- Guest visit at the group of Prof. Gasieniec, University of Liverpool, February 12–18, 2006.

Collaborations

- Michael Balmer, ETH Zürich
- Carl-Uwe Böttner, TU Berlin
- Alberto Ceselli, Universitá degli Studi di Milano
- Thomas Erlebach, University of Leicester
- Alex Hall, Marc Nunkesser and Michael Gatto, Group of Prof Widmayer, ETH Zürich
- Kai Nagel, TU Berlin
- Christoph Schütte and Philip Metzner, Matheon & FU Berlin
- Dorothea Wagner and Thomas Willhalm, University of Karlsruhe (TH)

Miscellaneous

- Member of the Organizing Committees of the EuroComb Conference 2005 and the Dies Mathematicus 2005 at the TU Berlin.

- Supervising two students with their diploma thesis: Torben Edelhoff "Traffic control - Optimization and Simulation" and Anton Telle "Weather-dependent Sea Routes for Ships".
- Supervising two tutors at the DFG project "Efficient Algorithms for Path-Based and Dynamic Flow Problems in Large Networks".
- Supervising a student at the Seminar "Graph- and Networkalgorithms", TU Berlin, 2006.
- Support of implementation work of several students working on their diploma thesis in the COGA group, Prof. Möhring.
- Monday Colloquia of the CGC Graduate Program.
- Weekly meetings of the COGA group, Prof. Möhring.