Semester Report WS04/05 and SS05

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Field of Research:	Combinatorial Optimization & Graph Algorithms
Topic	Routing Problems on Large Networks
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Field of Research and Results

Dynamic flow models. On this years Workshop on Algorithm Engineering and Experiments (ALENEX '05) we presented our paper on "Flows over Time: Towards a more Realistic and Computationally Tractable Model" [HS05]. In the paper we introduced a novel model for "flows over time" which captures the behavior of cars traveling through a road network better than previous models. In our model the transit time of a unit of flow through an arc a is dependent on the flow rate at any point on that arc a. Therefore we call this model "Rate-dependent Flow Model". We showed that computing an optimal solution in the new model is NP-hard and presented an LP-based algorithm which we evaluated with several experiments on real world data of road networks and generated requests. Among other things we compared the quality of the solutions with solutions generated by an FPTAS for a related but considerably less realistic model.

Accelerated shortest path algorithms. On this years Workshop on Efficient and Experimental Algorithms (WEA '05) we presented our paper on "Acceleration of Shortest Path and Constrained Shortest Path Computation" [KMS05]. We focused on two methods based on Dijkstra's algorithm for shortest path computations and two methods based on a generalized version of Dijkstra for constrained shortest paths. The methods are compared with other acceleration techniques, most of them published only recently. We also looked at appropriate combinations of different methods to find further improvements.

For shortest path computations we investigated hierarchical multiway-separator and arc-flag approaches. The hierarchical multiway-separator approach divides the graph into regions along a multiway-separator and gathers information to improve the search for shortest paths that stretch over several regions. We presented a new multiway-separator heuristic which improves

the hierarchical separator approach. The arc-flag approach divides the graph into regions and gathers information on whether an arc is on a shortest path into a given region. Both methods yield significant speed-ups of the plain Dijkstra's algorithm. The arc flag method combined with an appropriate partition and a bi-directed search achieves an average speed-up of up to 1,400 on large networks. This combination narrows down the search space of Dijkstra's algorithm to almost the size of the corresponding shortest path for long distance shortest path queries.

For the constrained shortest path problem we showed that goal-directed and bi-directed acceleration methods can be used both individually and in combination. The goal-directed search achieves the best speed-up factor of 110 for the constrained problem.

Also at the WEA '05 we presented our paper on "Partitioning Graphs to Speed Up Dijkstra's Algorithm" [MSS$^+$05]. In the paper, we considered Dijkstra's algorithm for the point-to-point shortest path problem in large and sparse graphs with a given layout. In [KMS05], a method has been presented that uses a partitioning of the graph to perform a preprocessing which allows to speed-up Dijkstra's algorithm considerably.

We presented an experimental study that evaluates which partitioning methods are suited for this approach. In particular, we examined partitioning algorithms from computational geometry and compared their impact on the speed-up of the shortest-path algorithm. Using a suited partitioning algorithm speed-up factors of 500 and more were achieved.

Furthermore, we presented an extension of this speed-up technique to multiple levels of partitionings. With this multi-level variant, the same speed-up factors can be achieved with smaller space requirements. It can therefore be seen as a compression of the precomputed data that conserves the correctness of the computed shortest paths.

Length-bounded s-t-cuts . During my guest visit at the group of Prof. Erlebach we continued working on the length-bounded s-t-cut problem.

We call a subset C_E or C_V of the edge set E or node set V of a graph $G = (V, E)$ a *length-bounded s-t-edge-cut* or *-node-cut* with respect to some length bound L if the nodes s and t have distance greater than L in $G' = (V, E \setminus C_E)$ or $G' = (V \setminus C_V, E')$. Here edges or inner nodes reps. of s-t-paths are being counted.

We show that it is $\mathcal{APX}$-hard to compute a length-bounded s-t-cut with

a length bound between 4 and $|V| - const$, both for an edge- and a node-cut. Here were able to show that computing a length-bounded s-t-cut smaller than $\frac{7}{6}$ of the optimal length-bounded s-t-cut value in polynomial time is not possible unless $\mathcal{P} = \mathcal{NP}$. Furthermore we found an approximation algorithm which computes a length-bounded s-t-cut of size no bigger than $\sqrt{|V|}$ times the optimal length-bounded s-t-cut value. For bounded treewidth graphs it is possible to compute a length-bounded s-t-cut in $O(L^{k^2} n^2)$ time, where k is the treewidth of graph G.

Publications

[HS05] A. Hall and H. Schilling. Flows over time: Towards a more realistic and computationally tractable model. In *Proceedings of the 7th Workshop on Algorithm Engineering and Experiments (ALENEX '05)*. SIAM, 2005.

[KMS05] E. Köhler, R. H. Möhring, and H. Schilling. Acceleration of shortest path and constrained shortest path computation. In S. E. Nikoletseas, editor, *WEA '05: 4th International Workshop on Efficient and Experimental Algorithms*, volume 3503 of *Lecture Notes in Computer Science*, pages 126–138, Heidelberg, 2005. Springer.

[MSS+05] R. H. Möhring, H. Schilling, B. Schütz, D. Wagner, and T. Willhalm. Partitioning graphs to speed up Dijkstra's algorithm. In S. E. Nikoletseas, editor, *WEA '05: 4th International Workshop on Efficient and Experimental Algorithms*, volume 3503 of *Lecture Notes in Computer Science*, pages 189–202, Heidelberg, 2005. Springer. invited for the Special Issue of the ACM Journal of Experimental Algorithmics (JEA)

Talks

- *Monday Colloquia of the CGC Graduate Program.*
- "Partitioning Graphs to Speed Up Dijkstra's Algorithm", *4th International Workshop on Efficient and Experimental Algorithms (WEA)*, Santorini, Greece, May 10, 2005.

- "Acceleration of Shortest Path and Constrained Shortest Path Computation", *4th International Workshop on Efficient and Experimental Algorithms (WEA)*, Santorini, Greece, May 10, 2005.
- "Shortest Path Computation - An Overview", *Oberseminar at the TU Berlin*, Berlin, May 03, 2005.
- "Efficient Algorithms for Path-Based and Dynamic Flow Problems in Large Networks", *DFG Jahres-Kolloquium*, Karlsruhe, March 12, 2005.
- "Flows over Time: Towards a more Realistic and Computationally Tractable Model", *Monday Lecture of the DFG Graduate Program CGC*, Berlin, February 7, 2005.
- "Flows over Time: Towards a more Realistic and Computationally Tractable Model", *Oberseminar at the TU Berlin*, Berlin, December 16, 2004.
- "Flexible Implementation von Graphenalgorithmen mittels generischer Techniken in C++", *DFG Workshop "Flows in large networks"*, Dortmund, November 02, 2004.

Conferences, Workshops & Schools

- Summer School on Shortest Paths - Between Algorithms and Optimization (PATH05), Kopenhagen, Denmark, July 04–08, 2005.
- Eleventh Conference on Integer Programming and Combinatorial Optimization (IPCO), Berlin, June 08–10, 2005.
- IPCO XI Summer School, Berlin, June 06–07, 2005.
- Workshop on Optimization Software of the "DFG Research Center Matheon: Mathematics for key technologies", Berlin, June 01, 2005.
- The 20th International Conference on Theory and Practice of Software Development (TAPSOFT05), Berlin, February 17–18, 2005.
- ACM-SIAM Symposium on Discrete Algorithms (SODA05), Vancouver, Canada, January 23–25, 2005.
- The Seventh Workshop on Algorithm Engineering and Experiments (ALENEX05), Vancouver, Canada, January 23–25, 2005.

Guest visit

- Guest visit at the group of Prof. Erlebach, University of Leicester from June 14–24 (supported by DFG project SPP 1126).

Collaborations

- Michael Balmer, ETH Zürich
- Thomas Erlebach, University of Leicester
- Alex Hall, ETH Zürich
- Kai Nagel, TU Berlin
- Dorothea Wagner, University of Karlsruhe
- Thomas Willhalm, University of Karlsruhe

Miscellaneous

- Supervising two tutors at the DFG project "Efficient Algorithms for Path-Based and Dynamic Flow Problems in Large Networks".
- Supervising students at the Seminar "Algorithmische Diskrete Mathematik", TU Berlin, 2005.
- Support of implementation work of several students working on their diploma thesis in the COGA group, Prof. Möhring.
- Wrote report and application for extension of the DFG project "Efficient Algorithms for Path-Based and Dynamic Flow Problems in Large Networks" (SPP 1126).
- Reorganization of the design and content management of our COGA group web pages.
- Weekly meetings of the COGA group, Prof. Möhring.