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dr hab. Jarosław Byrka
Institute of Computer Science
University of Wrocław

Review of the PhD thesis of Adam Karczmarz entitled "Data Structures and Dynamic Algorithms for Planar Graphs"

Thesis offers a study of efficient algorithms and data structures for dynamic planar graphs. In the studied graph model the set of vertices is constant but the set of edges changes over time. A natural challenge in this context is to quickly answer questions about selected properties of the current graph. The questions addressed in this thesis include connectivity (in both directed and undirected graphs) and shortest paths.

Generally, the studied setting is very well motivated by the existence of large real-world examples of networks that are both dynamic and often planar or close to planar. Naturally, these networks require maintenance and it is vital to quickly test properties like connectivity. Most of the results in this thesis address a partially dynamic scenario in which edges are only added (incremental connectivity model) or only deleted (decremental connectivity model). Although such a special case has more limited applicability, in my opinion a theoretical study of the complexity of the connectivity questions in a partially dynamic graph is also very important.

Technically, one may interpret the contribution as dedicated data structures to store selected information about the current graph. It is argued that previously known data structures were not sufficient. New, more refined structures and algorithms are proposed and analyzed.

Chapter 3. Maintaining a planar graph under contraction. Contractions are used as subroutines in many algorithms for static problems, such as the Karger's min cut algorithm. In such an application the algorithm maintains a dynamic auxiliary graph. Handling such an auxiliary graph is addressed in the thesis. A data structure offering a total linear time of updates and a constant time adjacency queries is proposed. It improves upon the previous constructions that required logarithmic update time. As a result algorithms for problems like decremental 2-edge-connectivity and finding unique perfect matching have been made faster.

Chapter 4. Decremental reachability in planar digraphs. The setting with a directed edges disappearing over time is studied. For single source reachability an algorithm explicitly maintaining reachable vertices with amortized polylogarithmic update time is proposed. For arbitrary nodes reachability (also called dynamic transitive closure) an algorithm with $\tilde{O}(\sqrt{n})$ query time and polylogarithmic update time is obtained.

The proposed algorithms are based on dividing the graph via separators of size $O(\sqrt{n})$, explicitly storing the transitive closure of the separator, and recursively maintaining connectivity information in the sub-instances.

Chapter 5. Shortest paths in dense distance graphs. Dense distance graphs are graphs where distances are defined via distance-cliques (complete graphs on subsets of vertices of the original graph). The author proposes an improved algorithm for computing shortest paths in dense distance graphs. Because this is a subroutine in a number of other algorithms including dynamic shortest paths in planar graphs, the obtained result implies the best known running time for a number of natural problems in planar graphs.

Overall evaluation. I am generally quite impressed with the technical quality of the results. All three parts of the thesis contain deep results improving state-of-the-art algorithms for natural problems. No surprise that the results were published at top computer science conferences. Although some of the results were obtained in a collaboration with other strong researchers, the list of publications also includes a single author SODA paper which is a certificate of the individual scientific capabilities of the candidate. I think the thesis could be used as an example of an outcome of a successful PhD project.

Quality of presentation. The thesis appears to be particularly well written. This applies to the general structure of the document as well as to the quality of the particular detailed arguments. I would like to note that I think it is a very good practice to include an open problems section at the end of the thesis.

Conclusion. I am very positive about the thesis. It contains a collection of consistent algorithmic results on natural dynamic planar connectivity problems. The publications at STOC, SODA, ICALP, ESA leave no doubt that these are top level results. I am fully convinced that the quality of the thesis is perfectly sufficient to award the PhD title. I would also like to suggest that the thesis can be considered for a distinction (pol. wyróżnienie).

Jarosław Byrka

dr hab. Jarosław Byrka