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Review of Dr. Bartłomiej Bosek's Habilitation Thesis

Thank you for giving me an opportunity to provide an evaluation of Dr. Bartłomiej Bosek's research accomplishments, in connection to his candidacy for habilitation. I find that his research record meets the criteria for habilitation, and the rest of this letter provides a detailed justification for this assessment.

At the outset, I'd like to mention that I have not had any personal or professional interaction in the past with Dr. Bosek. While we work in related fields, our research paths never crossed, and we generally work on different problems. My evaluation is based solely on the review of his publication record and the information packet that was provided to me.

Dr. Bosek's main research interests involve various combinatorial covering and packing problems, mostly graph coloring, poset chain partitioning, and bipartite matching. While these may look rather disparate to an untrained eye, these problems are in fact closely related, either via various reductions or primal-dual relationships. The three problems I just mentioned play central role in combinatorial optimization and have been extensively studied since mid 1900s, and some even earlier. Dr. Bosek's work contains a number of significant scientific advances that include solutions to some important problems involving posets, colorings and matchings, and contribute to our improving our understanding of their combinatorial and algorithmic properties.

There has been renewed interest in the two last decades in these problems, especially in their online, incremental or dynamic variants, which can be used to model certain types of computational problems arising in modern technologies. Matchings, for example, that in the past have been used to model a variety of assignment problems arising in practical domains, in areas ranging from management and transportation to chemistry and networking, now are increasingly used to model dynamic assignment or resource allocation problems in server allocations or in online advertising. Thus, while Dr. Bosek's work is strictly theoretical and may not be directly applicable, it is still relevant to today's technology.

Below I highlight and comment on three themes of his work that form the core of his habilitation thesis.

Bipartite matchings. Dr. Bosek has written several papers on dynamic algorithms for maximum bipartite matchings, where the graph can change over time and the objective, in general, is to maintain a large bipartite matching. There is a number of variants of this problem in the literature, depending on the type of graph updates, and on the allowed modifications of the matching. Dr. Bosek has focussed on the model where nodes in one partition (clients) arrive over time, together with their edges to the other partition (servers) which is fixed, and the objective is to maintain an assignment of clients to servers that forms a maximum matching, while minimizing the total number of client reassignments. In his paper *" Online bipartite matching in offline time"* (FOCS 2014) he developed an algorithm that reassigns each client only $O(\sqrt{n})$ times, leading to an algorithm with running time $O(\sqrt{n}m)$. I find this result to be quite remarkable. The reason is that it matches the overall best running time of the now-classic algorithm by Hopcroft and Karp for the static model, even though the Hopcroft-Karp algorithm only computes one overall matching, while the algorithm of Dr. Bosek actually computes n maximum matchings along the way, one for each time step. The maximum-matching problem for bipartite graphs is among the most studied problems in combinatorial optimization, so it is very suprising that one can still discover new properties and algorithms in this area, especially of such fundamental nature. He has two other papers on the topic that deal with the algorithm that uses shortest augmenting paths, where he determined a tight bound of $O(n \log n)$ for trees, which constitutes a major step in resolving the open problem by Chaudhuri *et al.* asking whether this bound holds for arbitrary graphs.

Graph coloring. Graph coloring is another funamental and widely studied problem in combinatorial optimization. It's actually a large collection of problems that address different classes of graphs or hypergraphs and different combinatorial or algorithmic aspects. One intriguing variant, studied by Dr. Bosek, is called *majority coloring*, and it asks for the minimum number of colors needed to color a digraph in such a way that at least half of out-neighbors of each vertex have different colors than this vertex. I was actually not familiar with this concept until reading Dr. Bosek's research statement, but I found it very natural and I'm suprised it has not attracted more attention. The idea here, as I understand it, is to relax the standard requirement in graph coloring, by allowing a certain fraction of neighbors to have the same color as the vertex, so, as a result, constant number of colors will be sufficient for the whole graph. (For undirected graphs it is not hard to show that each graph is majority 2-colorable. For directed graphs, the problem seems much harder.) It is easy to construct majority 4-colorings and show that 3 colors are necessary for arbitrary digraphs. The conjecture by Kreutzer *et al.* is that 3 colors are in fact sufficient. In his paper *"Majority choosability of digraphs"* (Eletr. J. of Combinatorics, 2017), Dr. Bosek strengthened the upper bound of 4 by proving that majority colorings exist even if we require the color for each vertex to be chosen from its assigned list of 4 colors. This also implies that 3 colors are sufficient *if* we relax the coloring requirement, allowing up to a 2/3rd fraction of out-neighbors to have the same color as the vertex. These results that represent significant progress towards resolving the conjecture by Kreutzer *et al.*

Chain partitions of posets. Another topic where Dr. Bosek has made significant contributions is chain partitioning of posets. Here the goal is to partition a poset into the smallest number of chains. This question was extensively studied in the online scenario, where the vertices of the poset arrive one at a time and the algorithm must irrevocably assign each vertex to a chain right after its arrival. The natural approach is called First-Fit: insert each vertex into the first chain where it fits. Until recently, the performance of First-Fit has not been well understood; in particular little has been known about the relationship between the number of chains used by First-Fit and the width w of the poset: for some posets, even with $w = 2$, a linear number of chains is needed, while for other classes of posets First-Fit produces partitions with few chains. In particular, Joret and Milans asked for a characterization (in terms of forbidden sub-posets) of posets for which First-Fit produces a partition with a number of chains bounded by a function of width w. Addressing this question, in his paper *"First-fit coloring of incomparability graphs"* (SIAM. J. Discr. Math. 2013), Dr. Bosek provided an elegant (and, to me, quite surprising in its simplicity) characterization of such posets in terms of forbidden width-2 posets, showing (roughly) that forbidding any width-2 poset is sufficient to have this property.

A related question is whether there is *any* online algorithm that produces chain partitioning of any poset into a number of chains bounded by some function of its width w. The work of Kierstead, who proved that partitions with $O(5^w)$ chains can be found online, raised the question whether polynomially chains can be achieved. This is still open. Dr. Bosek has written a number of papers in this topic, culminating in his recent and yet-unpublished paper *"Online partitioning of width w posets into $w^{O(\log\log w)}$ chains"*. As the title says, the paper shows an upper bound of $w^{O(\log\log w)}$. This is very significant progress towards finding a solution to this problem and, to my knowledge, is currently the best upper bound in the literature.

Other results. Besides the work highlighted above, Dr. Bosek has worked on a number of other problems in combinatorial optimization: majority coloring game, additive colorings, online dimension, and other. I see that all these papers appeared in very respected venues in discrete mathematics, so, while I was not able to review them carefully, it is safe to assume they are of equally high quality as the results discussed earlier.

Overall publication record. Since his doctorate Dr. Bosek has maintained a steady — if not increasing — publication rate. (I counted 24 papers in this period in dblp.org. This includes 4 journal papers in 2018, and already 2 in 2019.) Most of these papers are in highly respected journals, including *Discrete Mathematics*, *Discrete Applied Mathematics*, *Order*, and *SIAM Journal on Discrete Mathematics*. He also has two papers that appeared in FOCS (Foundations of Computer Science), one of the most prestigious and competitive conferences in theoretical computer science. This is a strong record of research activity, certainly compatible with this advancement.

Conclusion. As documented in his dossier, Dr. Bosek has a well-established, focussed, and productive research program in the area of combinatorial optimization, specializing mostly in online optimization problems involving graph coloring, chain covering of posets, and bipartite matchings. He works on problems that are technically challenging, well motivated, of interest to other researchers, and where there is potential to produce significant impact. I consider this to be an important aspect of his work and a strong argument in favor of the habilitation. His published writings exhibit depth and breadth of knowledge, creativity and maturity – that is, all the qualities required for a successful career as an independent researcher. In conclusion, I find that Dr. Bosek's research record meets the requirements for habilitation, and I strongly recommend that this habilitation be awarded.

If you need any more information, please feel free to call me at +1-951-315-4439, or contact me by email at `marek@cs.ucr.edu`.

Sincerely,

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