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Opponent Review of the Habilitation Thesis by Hans Raj Tiwary

The present habilitation thesis describes the contributions of the applicant around the concept of *extension complexity* of a polytope. The thesis (amounting to roughly 100 pages) is designed to be a commentary for ten research papers that have been co-authored by the applicant, and that appear in the appendix.

My idea of a commentary would be that (among the technical material), it provides a high-level overview about the field, and — in case of a habilitation thesis — also of the author's contributions. I'm not at all a friend of overadvertising one's own contributions, but here, I find the overview and advertising aspects clearly underrepresented.

As a non-expert in the field, let me describe my reading experience: after reading through the introduction, I had an idea about the concepts that are being discussed in the thesis, but not about their interconnections, or their significance. Most notably, the concept of an extended formulation would deserve some deeper treatment on a high level. As the autor writes, it is indeed obvious that a small extended formulation is generally useful for combinatorial optimization. But at that point, some illustrating results along these lines would have helped. For example, is there a problem for which the first (simple) polynomial-time algorithm was found through a small extended formulation?

It was also hard for me to buy the story that a "proof" of P=NP by Swart has sparked significant research. In fact, Yannakakis already mentioned in his paper defeating Swart's approach that there are several other motivations

to study extended formulations. None of them appear in the introduction to this thesis.

Concerning advertisement, the applicant has been involved in solving the major open problem of determining the extension complexity of the TSP polytope, 20 years after this question was posed by Yannakakis. The paper in the appendix clearly says so, but in the introduction to the present thesis, this fact can almost be overlooked.

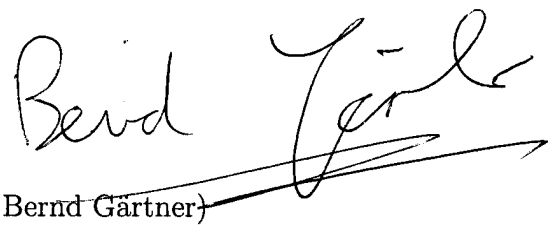
The chapters of the thesis are written in a similar style. They do have a certain flow, but I still found it hard to extract the things that are really important. Let me give just two examples.

The important concept of a slack matrix is introduced in Subsection 1.1.3 (that is not even in the table of contents), but it is not mentioned that this will be an important concept later. Yannakakis' characterization of the extension complexity (Proposition 3.1.24) is a cornerstone of much of the material in this thesis. It appears in Subsection 3.1.3, without any further comments about its high significance, and with a false reference to a proof. If I understand correctly, reference [24] gives only half of the proof.

Minor points of criticism concern a certain sloppiness in the technical material. For example, the introduction speaks about symmetry a lot, explaining that it makes a difference for some problems, but that for TSP, it has turned out to make no difference in the end, regarding extension complexity. Still, the applicant does not want to give me a definition of symmetry, and instead is trying to sell it as a technical requirement in Swart's work.

Here are some more examples. Definition 2.1.10 (rectangle covering number) completely ignores the colors of the rectangles in covering; According to this definition, the rectangle covering number would always be one. Definition 3.1.10 says that the convex hull of a certain sets of points is a clan. But a convex hull is a single polytope. In example 3.1.18, the applicant writes that "we could say" something. But in fact, the previous material allows us to actually say it. In Proposition 3.1.25, protocols computing matrices are mentioned, but there is no explanation about what X and Y are that one needs for the protocols. The introduction of Section 3.3 speaks about three canonical clans, one of them being the polytopes of non-satisfying asssignments. But these are never discussed later on. In Section 5.2.1, it is never defined how the polytopes actually arise from the languages. I was missing how a matrix alone defines a polytope. If there was a right-hand side, it would be clear. Definition 5.2.3 should introduce the term of a compact language, as this is used later one.

I also found numerous typos that a simple spell checker would find (such as "rusults" and "equiry" already on page 4).
I generally appreciate the idea of disassembling and reassembling research papers in order to get a coherent document with a proper flow. I feel that this thesis has stopped halfway, though, as during the reassembly phase, a bigger picture was somehow lost.
Having said all this, I also have to say that I do not consider the habilitation thesis itself as an item of major importance. In the habilitation process, the applicant is supposed to document that he is able to fully represent his field in research and teaching. In case of Hans Raj Tiwary, I can definitely say that he has done so, researchwise (I'm unable to comment on his teaching record, as I have no information about it). The research of Hans is of the highest quality, as the publications in top journals and proceedings, and with prominent co-authors, clearly demonstrate. It is also my clear opinion that the line of research reported about in the habilitation thesis is of high value and significance. I'm also confident that a revised habilitation thesis that addresses the issues above would make an excellent survey.
Therefore, I strongly recommend appoinment of Hans as an associate professor.



(Prof. Bernd Gärtner)