# Report on the doctoral thesis dissertation presented by M. Krzysztof Magiera

Algorithms for and Computational Complexity of the Election Control Problems in Restricted Domains

The overall scientific context of the work presented by M. Krzysztof Magiera is Computational Social Choice. More precisely, the dissertation deals with voting, seen from the point of view of computer science. Situations involving voting are numerous and not restricted to political elections. To name a few, choosing a candidate or shortlisting candidates for a position, choosing a collective shared resource, electing a set of representatives are examples of real-world single-winner or multiwinner voting situations.

There exist many voting rules, and choosing the right one for each situation is a somewhat delicate problem. Among the properties that can be used to characterize the rules, some of them focus on their resistance to manipulation. In a context where different actors may act in a malicious way to change the result of an election at their own benefit, knowing to which extent the rules can be manipulated is a crucial information. The work presented by M. Krzysztof Magiera contributes to the understanding of the resistance of several single- or multiwinner voting rules to different kinds of manipulation. This work shows in particular that some voting rules that can be computationally resistant to manipulation in general may actually not be anymore when the voters' preferences have a certain form (namely, single-peakedness, single-crossingness and top-monotonicity). Really being able to exploit this weakness also implies to be able to recognize when the voters' preferences exhibit this regularity. This is another important contribution of the thesis, that proposes original polynomial-time algorithms to recognize the three aforementioned restricted domains.

The document is organized in seven chapters. One of them is dedicated to the restricted domain recognition problem, and three of them to the election control problems. The three remaining chapters are the introduction, the technical preliminaries and the conclusion.

The first chapter (Introduction) provides the general context, sketches the contributions of the work and outlines the content of the document.

The second chapter is dedicated to the technical preliminaries and notation. In this chapter, M. Krzysztof Magiera introduces the main useful notions about elections: voting rules, restricted domains like single-peaked and single-crossing preferences, and the control problems that will be studied in the thesis, namely, Constructive or Destructive Control by Adding or Deleting Voters or Candidates (which makes eight variants of the control problem in total). Some basic and useful computational complexity notions are also introduced in this chapter.

The third chapter investigates the problem of recognizing restricted domains, namely, given an election context, deciding whether the voters' preferences are single-peaked, single-crossing, or top-monotonic. The problem of recognizing single-peaked and single-crossing profiles have already been extensively studied, and efficient algorithms have

been proposed before. However, the major contribution of this chapter is a novel approach for this recognition problem, that extends to the more general case of top-monotonic preferences, for which no known recognition algorithm existed before. This approach is based on encoding the problem as a propositional formula in 2-Conjunctive Normal Form, by focusing on triples of candidates for single-peakedness, on pairs of candidates and triples of voters for single-crossingness, and triples of alternatives and pairs of voters for top-monotonicity. Using this technique, M. Krzysztof Magiera can prove that the three aforementioned recognition problems can actually all be reduced to 2-SAT, for which there is a deterministic polynomial-time algorithm. The main part of the chapter is dedicated to the proof of these results.

The next part of the thesis is dedicated to Election Control Problems of different kinds. In Chapter 4, M. Krzysztof Magiera investigates this problem for single-winner elections under Plurality, Condorcet and Approval voting rules, and single-crossing preferences. After a few additional technical preliminaries about single-crossingness, the chapter starts with the case of plurality rule, before dealing with Condorcet elections, and ending with Approval voting (which, due to the nature of the voting rule, requires a slight adaptation of single-crossingness, called voter-interval restriction). The chapter shows that under these three voting rules, for all settings for which the election control problem was previously known to be NP-complete in the general case, it can be solved in deterministic polynomial-time if the preference profile is single-crossing. It essentially means that for the eight variants of the election control problem studied in the thesis, plurality, Condorcet and approval voting rules are vulnerable to manipulation. In the plurality case, the results are mostly based on the introduction of a tailored dynamic programming algorithm, whereas for approval or Condorcet elections, an *ad hoc* algorithm adding or deleting voters in the right place is introduced.

In the fifth chapter, another variant of the election control problem is investigated: the counting variant. Here, the idea is to go further than the simple decision problem, by counting the number of potential solutions. The counting variants of decision problems have their own complexity classes, reminded in the preliminary section of the chapter. Then, the counting variants of election control problems are introduced, and their complexity is investigated in the case of single-peaked preferences, first for plurality, then for $k$-approval voting, and finally for Condorcet. For all these voting rules, the chapter introduces several tractability results in the case of single-peaked preferences. All these results are based on the proof that the number of possibilities of control can be exactly computed by a dynamic programming algorithm.

Chapter 6 extends a little bit the scope of the thesis by investigating multiwinner elections. The results in this chapter somewhat differ from the rest of thesis, mostly because they are essentially hardness results, and do not rely on restricted domains. The voting rules concerned in this chapter are approval voting and satisfaction approval voting, whose definitions are reminded in the preliminary section. The remainder of the chapter is dedicated to the complexity results themselves and their proofs, that all rely on a reduction from the Exact-Cover-by-Three-Sets problem.

The last chapter concludes the document, summarizing the main contributions and proposing a list of possible ideas for further investigation.

## Opinion on the dissertation and the work presented

Even if the central topic of the work is on Election Control problems, this thesis actually concerns different fields. The first one is restricted domain recognition, the second one is election control in single-winner elections, and the third one is election control in multiwinner elections.

None of the problems addressed in the thesis is original, but there are nevertheless several major proper technical contributions in M. Krzysztof Magiera's work. These contributions are essentially an extensive set of theoretical results about the control problem, supported by technically involved proofs.

In Chapter 3, the results concerning the restricted domain recognition problem is an important contribution. But the main interest of this chapter probably resides in the proof technique used, that proposes a reduction to the 2-SAT problem.

In Chapter 4, M. Krzysztof Magiera fully completes the landscape of election control results for three voting rules under single-crossing preferences. That, together with the previous results on single-peaked elections, provides an important insight about the vulnerability of these rules to manipulation. What it shows is that, in spite of some NP-

completeness results in the general case, for some reasonable restrictions, these rules are vulnerable to manipulation. This is an important step towards the full characterization of manipulation for these rules.

Chapter 5 gives another perspective on the problem. By studying counting variants, M. Krzysztof Magiera actually investigates the problem of figuring out to which extent an election can be subject to control. This question is crucial in an environment involving true or epistemic uncertainty, which is almost always the case in practical situations. As reminded by M. Krzysztof Magiera, counting potential control actions can give some insight on how vulnerable a voting rule is. This chapter does not give a direct answer to this question, but provides practical algorithms to compute the number of manipulations for a given election, which is a major contribution.

Finally, Chapter 6 goes a little bit beyond the scope of the thesis by leaving aside the restricted domain assumption. Even if this part appears to be the weakest of the thesis, it brings out nice reductions and interesting complementary results.

The document presented by M. Krzysztof Magiera is overall rather well written and has a clear structure. The chapters are meant to be almost independent of each other. As a consequence, we could slightly regret a small lack of consistency between different chapters, but in the end, the thesis still remains easy to read and to follow. And in spite of the diversity of the problems tackled in this thesis, M. Krzysztof Magiera successfully manages to tell a convincing story all along the thesis.

The technical contribution is solid and the work presents an impressive set of technical results. The complexity of the proofs that constitute the main part of the work sometimes make the understanding of high-level insights a bit harder. However, in spite of this complexity, the results can be followed quite easily and examples help a lot.

To sum up, there is no doubt that the work presented in this thesis will contribute to a significant advance in the understanding of control election problems, by completing the overall picture of complexity results on several points. Moreover, the proof techniques provided in this work will probably be helpful and give some insights that will be applicable to other problems in the field of election control.

## Conclusion

For all the aforementioned reasons, I give a positive evaluation on M. Krzysztof Magiera's dissertation entitled *Algorithms for and Computational Complexity of the Election Control Problems in Restricted Domains*.

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