Trends in Computational Social Choice

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Preface

Ulle Endriss

Computational Social Choice

Computational social choice is an area of research at the interface of Computer Science and Economics that is concerned with the design and analysis of methods for collective decision making. The central question studied in the field is that of how best to aggregate the individual points of view of several agents, so as to arrive at a reasonable compromise.

For example, each individual agent might be a voter in a political election, using her ballot sheet to express her individual views regarding the candidates, i.e., to report her preferences. In this context, the relevant methods of social choice are the various voting rules we could use to aggregate the individual preferences to arrive at an election outcome that appropriately represents the preferences of society as a whole. But those individual points of view could also be very different things, such as the recommendations of different experts on climate change, the choices made by the participants of a marketing survey, or the legal opinions of the members of a panel of judges. In fact, the agents whose points of view are to be aggregated need not even be human beings, but could also be, say, machines (e.g., robots that need to agree on a joint plan of action), institutions (e.g., schools that need to agree how to divide a pool of applicants amongst them), or abstract entities such as algorithms (e.g., different search engines producing alternative rankings of websites that need to be aggregated into a single view).

The design of methods for collective decision making has a long and proud history. Many well-known historical figures have pondered the question of how groups of people should make collective decisions (McLean and Urken, 1995). For instance, in the late 13th century, the Catalan missionary, writer, and philosopher Ramon Llull suggested to first hold a majority contest between any two alternatives and to then select the alternative that wins the largest number of these pairwise contests. A few hundred years later, in the late 19th century, the English writer and mathematician Charles Lutwidge Dodgson—better known as Lewis Carroll, the author of *Alice's Adventures in Wonderland*—instead proposed to choose the alternative that would minimise the degree to which the agents would have to change their preferences before the chosen alternative would win *all* pairwise majority contests. From the middle of the 20th century onwards, questions of social choice started to get studied systematically and in mathematically precise terms. This development initially occurred in the Economics literature, sparked by the seminal contribution of the American economist Kenneth J. Arrow, who analysed what kinds of desirable properties we can possibly hope to see satisfied by a rule for aggregating individual preferences into a collective preference relation (Arrow, 1963). Political scientists, philosophers, and mathematicians joined soon afterwards. Finally, in the early years of the 21st century, social choice theory got established as a mainstream research topic in Computer Science. This development is due to two reasons. First, several application domains studied in Computer Science involve collective decision making (between autonomous computer systems rather than between people) and, maybe even more importantly, the tools and techniques of Computer Science turned out to be helpful in better understanding the intricacies of collective decision making.

The state of the art in computational social choice is represented by the *Handbook of Computational Social Choice* (Brandt et al., 2016). The present volume builds on this body of knowledge and offers insights into some of the latest research trends in the field that have developed since the conception of the *Handbook*. This concerns both novel scenarios in which methods for collective decision making are required and novel techniques for the analysis of those methods. The book also introduces a number of innovative applications of the insights obtained and techniques developed in recent research in computational social choice.

COST Action IC1205

This volume has been produced by *COST Action IC1205 on Computational Social Choice*, a European research network set up to advance the state of the art in computational social choice by supporting the international research community in this domain. It was running for four years, from November 2012 to November 2016, and received a about two-thirds of a million euros in funding. COST (*Cooperation in Science and Technology*), founded in 1971, is the longest-running European framework facilitating the cooperation of scientists, engineers, and scholars across national borders. COST funds networking activities rather than research itself. It does so by allowing researchers, in a bottom-up fashion, to set up *Actions*, i.e., research networks, on specific innovative themes that are of emerging importance and that have a certain scientific and societal urgency.

COST Action IC1205 has been one of the largest such networks funded in the history of COST. The Action's *Memorandum of Understanding*, outlining a research agenda on computational social choice in broad terms, was signed by the governments of 32 European countries: Austria, Belgium, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Luxembourg, Macedonia, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom. Furthermore, a small number of individual institutions from Australia, New Zealand, Russia, Singapore, South Africa, the Ukraine, and the United States joined the network as associate partners. In total, over 500 people got involved—around 25% of them female and at least 70% of them early-career researchers.

Activities of COST Action IC1205

The activities of the Action were plentiful and wide-ranging. First, there were the large Action Meetings, organised around the formal gatherings of the Action's Management Committee in the form of 3-day workshops with 10–12 invited speakers each. For every such meeting, the Action was able to fund the participation of 40-50 individuals, with participation being open to (and free of charge for) others as well. These meetings enabled in-depth scientific interaction between the participants, without the usual pressures of quickly getting through as many presentations as possible, as is often the case at regular scientific conferences. Such meetings were held in Oxford (April 2013), Barcelona (October 2013), Maastricht (April 2014), Sibiu (October 2014), Glasgow (April 2015), and Istanbul (November 2015). In addition, a *Workshop on Future Directions in Computational Social Choice* was held in Budapest in November 2016.

The Action also organised four one-week Action Summer Schools, each attracting between 40 and 80 participants—typically PhD students, but also a few Master's students, postdoctoral researchers, and senior faculty members. This included the *Summer School on Matching Problems, Markets and Mechanisms* in Budapest in June 2013, the *Summer School on the Interdisciplinary Analysis of Voting Rules* in Caen in July 2014, and the *Summer School on Fair Division* in Grenoble in July 2015, each of which focused on a specific topic within computational social choice. It also included the *Summer School on Computational Social Choice* in San Sebastián in July 2016, which provided a broader overview of several of these individual topics.

In addition to these two main types of events, the Action also organised several smaller workshops on specific topics, such as simple games, network formation, iterative voting, and logical models of collective decision making. The Action also contributed to the organisation of events chiefly organised by others, e.g., by providing a keynote speaker or by financially supporting early-career researchers to allow them to attend the event. This included two summer schools on autonomous agents and multiagent systems (in Chania in 2013 and 2014), the *International Workshop on Matching under Preferences* in Glasgow in 2015, two editions of the *International Workshop on Computational Social Choice* (in Pittsburgh in 2014 and in Toulouse in 2016), and the *Meeting of the Society for Social Choice and Welfare* in Lund in 2016.

While the focus of the Action and its activities has been on scientific foundations, it also reached out to stakeholders outside of the academic community and to the general public. For instance, in June 2014 the Action organised a panel session on *Democracy in the Digital Age* at the EuroScience Open Forum in Copenhagen. And in June 2016 the Action organised an *Industry Day* in Toulouse, with a technical programme consisting of invited keynote talks by practitioners, from both the private and the public sector, who make innovative use of collective decision making technologies for which computational social choice provides the scientific foundations. These keynote talks were delivered by representatives of Google Research, Orange Labs, the Association for Interactive Democracy, National Matching Services Inc., and NHS Blood and Transplant.

On top of organising this diverse range of events, the Action also made prominent use of another networking instrument available to a COST Action, namely the facilitation of so-called *short-term scientific missions*. A short-term scientific mission is a research visit, of between one week and three months, of an individual researcher to an institution in another country. COST Action IC1205 financed over 130 individual research visits of this kind.

Resources Collected by COST Action IC1205

Another important aspect of the mission of COST Action IC1205 has been the dissemination of knowledge on computational social choice. The production of this volume forms an important part of these efforts. In addition, the Action collected a number of resources, all of which are available via its public website:

`http://research.illc.uva.nl/COST-IC1205/`

These resources include information on social choice mechanisms used in practice, particularly information on voting rules used in different European countries and information on matching schemes used around the world for student admission, job markets, and kidney exchange. The website also lists links to datasets available to researchers in computational social choice and to several online software tools for experimenting with different types of social choice mechanisms. Finally, the website makes available a list of surveys, books, and expository articles, and it provides access to educational resources that can be used for teaching computational social choice at a variety of levels.

Overview of the Book

This book consists of three parts. Part I is dedicated to *scenarios* in which some form of collective decision making is required, Part II reviews a number of *techniques* that are useful for the analysis of such scenarios, and Part III presents several innovative *applications* that illustrate the wide-ranging relevance of the field of computational social choice.

Part I: Scenarios

The scenarios that have most commonly been studied in the literature on computational social choice to date include the election of a single official on the basis of the preferences of a group of voters, the fair allocation of a set of goods to a number of agents, and the partitioning of a group of agents into coalitions in a manner that satisfies some notion of stability. The chapters in Part I go beyond these familiar scenarios in a number of ways.

In Chapter 1, Felix Brandt gives an introduction to probabilistic social choice and reviews a number of recent results in this domain. Here the outcome of an election may not always be a winning alternative, but rather a lottery over alternatives. This is important, given that some level of randomness may be unavoidable in case of ties, at least if we want to guarantee certain basic fairness properties. In Chapter 2, Piotr Faliszewski, Piotr Skowron, Arkadii Slinko, and

Nimrod Talmon introduce the topic of multiwinner voting. In this setting, the outcome of an election is a set of winning alternatives rather than a single winning alternative. Gaining a better understanding of multiwinner voting is important for a number of scenarios in which people vote, e.g., when shortlisting job applicants (rather than choosing one applicant to offer the job to) or when electing a parliament (rather than a president). In Chapter 3, Federica Ricca, Andrea Scozzari, and Paolo Serafini address a specific instance of multiwinner voting in great detail by reviewing several algorithmic methods for the apportionment problem, i.e., for the problem of allocating parliamentary seats to political parties in a manner that reflects, as best as possible, the vote share each party received. They also discuss the related problem of political districting, i.e., the problem of dividing the land, and thus the voters living on it, into electoral districts in a manner that does not give one party an undue advantage.

The next two chapters also deal with voting, but move away from the standard scenario even further. In Chapter 4, Reshef Meir discusses a model of iterative voting, where voters can inspect the outcome of an election and choose to respond to that outcome by changing their vote. If we iterate this process, a number of interesting questions arise, the most fundamental of which is whether such a process can be guaranteed to terminate eventually. Iterative voting can model, for instance, the deliberations of the members of a committee who take a number of straw polls before coming to a final decision. In Chapter 5, Andreas Darmann and Jérôme Lang introduce the family of group activity selection problems, where the members of a group each have to vote on a number of joint activities they may wish to participate in. Their preferences depend not only on the activities as such, but also on the number of fellow group members choosing the same activity. Thus, this novel scenario is related both to voting and to coalition formation.

In Chapter 6, Ágnes Cseh gives an introduction to popular matchings. In matching theory, the goal is to find a way of pairing up agents with either each other or with objects in a way that is socially optimal in some sense, such as not giving anyone an incentive to look for an alternative match. In the context of popular matchings, optimality is defined in terms of the preferences of the majority of the agents, i.e., we are looking for a matching such that no majority of agents would rather implement a different matching.

The next two chapters deal with the aggregation of judgments and beliefs, rather than with the aggregation of preferences. In Chapter 7, Patricia Everaere, Sébastien Konieczny, and Pierre Marquis compare the frameworks of propositional belief merging and judgment aggregation. While both frameworks offer means to aggregate the views of several agents regarding the truth of a number of logically related statements, the approaches taken to formalise this scenario and the types of results obtained differ significantly. In Chapter 8, Dorothea Baumeister, Jörg Rothe, and Ann-Kathrin Selker focus on one specific family of questions within judgment aggregation, namely those that relate to the strategic behaviour of agents. For instance, an agent may try to obtain a more favourable outcome by misrepresenting her own judgments, or an outside party may seek to do the same by bribing some of the agents.

Finally, in Chapter 9, Umberto Grandi gives an overview of the various opportunities for fruitful interaction between social choice theory and social network analysis. This symbiosis goes two ways: we may try to take the social structure of a group into account when designing (or reasoning about) a collective decision making rule for them, and we may use aggregation rules, as studied in social choice theory, to model the manner in which agents on a social network update their opinions based on those of their neighbours.

Part II: Techniques

Research in computational social choice makes use of a wide-ranging set of techniques from a variety of disciplines, including in particular Mathematics, Economics, and Computer Science, whilst also regularly looking for inspiration to Philosophy and Political Science. Part II of this book presents a number of techniques, particularly techniques of a computational nature, that have gained prominence in computational social choice research in recent years.

In Chapter 10, Edith Elkind, Martin Lackner, and Dominik Peters review recent work on structured preferences. While social choice in its most general form is notoriously difficult, both from a normative and a computational point of view, positive results are often within reach when we can assume that the preferences of the agents share some underlying structure. The most famous example is the condition of 'single-peakedness', which is satisfied in case all agents agree that the alternatives can be arranged on some common axis (e.g., modelling how 'rightwing' a given party is on the political spectrum) and the plot of each agent's preferences relative to that common axis only has a single peak.

The analysis of the computational complexity of problems arising in the context of collective decision making has always had an important place in computational social choice. The next two chapters introduce the reader to two specific sets of techniques within this broad domain. In Chapter 11, Britta Dorn and Ildikó Schlotter give an introduction to parameterized complexity analysis and review how this technique has been applied to a variety of problems in computational social choice. The central idea in parameterized complexity theory is that computational intractability of a problem is often due to specific parameters only, and if these parameters can be held relatively small, then practical algorithm design may still be feasible. In Chapter 12, Evangelos Markakis shows how approximation techniques can be put to good use in computational social choice, and specifically so in the context of computing approximately fair allocations of goods to agents when finding a (not just approximately) fair allocation is computationally intractable. Besides such positive results, the chapter also discusses inapproximability results, i.e., cases where even finding an approximately fair solution is intractable.

The next two chapters illustrate how one can use techniques developed in the field of automated reasoning to tackle problems in computational social choice. In Chapter 13, Christian Geist and Dominik Peters report on recent results where automated reasoning tools, particularly highly optimised satisfiability solvers for propositional logic, have been used to both verify existing proofs of theorems in social choice theory and to assist in the discovery of new such theorems. This concerns, in particular, impossibility theorems that show that certain combinations of desirable properties may be impossible to realise in a mechanism for social choice, such as a voting rule. In Chapter 14, Bernhard Beckert, Thorsten Bormer, Rajeev Goré, Michael Kirsten, and Carsten Schürmann show how logic-based program verification technology can be used to formally verify that a given implementation of a voting rule satisfies a given property of interest. This, crucially, is a different question from the question traditionally studied by social choice theorists, namely whether a given voting rule (a mathematical object, rather than a piece of software) satisfies a given property.

Concluding this part of the book, in Chapter 15, Nicholas Mattei and Toby Walsh, the creators of PrefLib, an online reference library for preference data, reflect on some of the lessons learned from building this important resource. PrefLib provides the computational social choice researcher with a host of data on people's preferences in real-world decision making scenarios, ranging from voter preferences in political elections, to ratings of athletes in sports competitions, to reviewer choices when bidding for papers to review for a conference.

Part III: Applications

Questions of social choice are directly relevant to a wide range of applications. The obvious one is the analysis of political elections and the systems by which we conduct such elections, but it goes much further than that. Part III of this book discusses several examples.

In Chapter 16, László Kóczy, Péter Biró, and Balázs Sziklai survey the apportionment methods used in different countries for allocating parliamentary seats to parties, given the vote shares received by these parties. They then discuss how these different methods fare in view of the recommendations of the European Commission for Democracy through Law, better know as the Venice Commission. They also demonstrate how some of these policy recommendations can conflict with basic monotonicity requirements. Thus, work in computational social choice can help clarify what are and what are not reasonable requirements to impose when designing electoral laws.

In Chapter 17, Ioannis Caragiannis explains how ideas from computational social choice can be helpful in designing systems for large-scale peer grading. Such systems are needed, for instance, in the context of massive online open courses (MOOC's), where there are too many students for it to be feasible for the work of the students to get graded by teaching assistants. The setting is similar to a voting scenario, except that the set of voters (the graders) and the set of alternatives (the students) coincide. One of the main challenges here is to arrive at an accurate ranking of the full student population, even though each grader only gets to see the assignments of a tiny subset of that population.

In Chapter 18, Péter Biró offers an overview of the application of matching mechanisms, i.e., algorithms for matching agents with either other agents or objects on the basis of the preferences of those agents. These applications include matching students with college places, children with kindergarten spots, and kidney patients with donors. The chapter covers a large number of specific case studies, explaining the intricacies of designing algorithmic solutions that account for specific legal or cultural requirements in different countries of the world.

In Chapter 19, Katarína Cechlárová focuses on one specific use of matching technology, namely the placement of trainee teachers into schools. The chapter specifically focuses on the case of trainee teacher allocation in Slovakia, where each trainee specialises in two disciplines, say, Mathematics and French, and thus a school needs to be found where there is a teachers who is formally qualified to act as the supervisor of a trainee teacher for each of the two disciplines in question. This combinatorial feature of the problem significantly increases the computational complexity of finding a good match for all trainees. Nevertheless, it turns out that designing algorithms that work well in practice is possible.

Finally, in Chapter 20, Sylvain Bouveret points out the enormous potential for using social choice theory in helping people with their everyday problems. This potential is created by the Internet in combination with the ubiquity of mobile devices. It is nowadays feasible to implement sophisticated collective decision making methods that are grounded in social choice theory and that can be used by anyone with very little effort through their own personal mobile device. The chapter exemplifies these possibilities by reviewing one such online tool, WHALE, and by reviewing some of the lessons learned in designing and fielding it.

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This book is the final piece of output produced by COST Action IC1205, so this seems like a good place to also acknowledge my gratitude to everyone who helped make this enterprise a success. To start with, I would like to thank my good friends and colleagues who, in 2010, encouraged me to put together a proposal for a COST Action on Computational Social Choice. History is somewhat murky on this point, and it is not entirely clear anymore how the idea was born exactly. What I do remember is that Iannis Caragiannis was, if not its earliest, then certainly its most persistent supporter. I also recall warming to the idea during a get-together in Coimbra, just before the eruption of the Eyjafjallajökull left several of us stranded all over Southern Europe. Coincidentally, that get-together in Coimbra was happening thanks to a meeting of another COST Action, COST Action IC0602 on Algorithmic Decision Theory. I'm very grateful to Alexis Tsoukiàs, the chair of that Action, for his advice and his support of the idea to create a new Action. And, of course, I wholeheartedly want to thank the dozens of people who have contributed to or have given feedback on the proposals I wrote in 2010 and 2011 to get the project funded.

Once the Action was up and running, every single one of its over 500 participants has made a valuable contribution, including Management Committee members, organisers and attendees of workshops and summer schools, and people who carried out or hosted short-term scientific missions. Still, a few people deserve a special mention. Mike Wooldridge, Péter Biró, Flip Klijn, Hans Peters, Annick Laruelle, Vincent Merlin, Constantin-Bala Zamfirescu, David Manlove, Bahar Rastegari, Sylvain Bouveret, Nicolas Maudet, Murat Ali Çengelci, Umberto Grandi, Elena Iñarra, Jérôme Lang, and Ági Cseh were the organisers of one or more of our main meetings and summer schools. I was personally present at most of them and remember them fondly. Bettina Klaus, Britta Dorn, Annick Laruelle, Nicolas Maudet, Jérôme Lang, Péter Biró, and myself formed the Steering Committee of the Action, and I was most fortunate to be able to rely on their advice and counsel. Special thanks are due to Britta, who invested many, many hours into running the Action's short-term scientific mission programme.

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