Computational Social Choice and Challenges of Voting in Multi-Agent Systems

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The presence of big data, online systems, collaborations of remote agents, distributed knowledge, social media interaction, and generally, digital globalization, changes the way how people make decisions, and especially those of collective importance. We face numerous challenges of human and algorithm voting in multi-agent socio-technical environments. Computational Social Choice (COMSOC) has the tendency to join several separately studied fields. The author summarizes recent efforts that testify the importance of COMSOC and voting. This paper gives insights into the nature of voting in multi-agent systems (MAS) and related challenges, from both computational and social aspects. With respect to the challenging aspects of voting and specifics of MAS, the following directions for future research in the field of COMSOC are suggested: an integrated approach to voting, iterative voting, a voting argumentation framework, and combinatorial voting.

Key words: *Computational Social Choice (COMSOC), voting, multi-agent systems (MAS), challenges, social challenges.*

1. INTRODUCTION

Voting procedures, the main issues in Social Choice Theory, are getting more complex. An increasing number of people/agents are involved in defining problems and making joint decisions (the so-called collective decision-making). The issue of allocation of available resources becomes more pronounced having in mind the number of people and their needs. Also, increasing expertise is needed for the level of the problem under consideration, which is why Computer Science is of great help. Therefore, an emerging multidisciplinary discipline, called Computational Social Choice (COMSOC), has been catching the attention of researchers recently.

Generally, the presence of big data changes the way how researchers collect and process data, and there is a scientific paradigm shift towards COMSOC [1]. There is a great number of entities, as well as data about those entities. The question is how to use the data to acquire knowledge or make correct decisions. It is important to make efforts in this area because the concept of „big data“ does not imply „big understanding“ [2]. The instrument most commonly used for voting problem solving, i.e. preferences aggregation, is an algorithm. Traditional views are focused either on the computational challenges of voting algorithms or on different social issues of voting. The aim of this paper is to consider the challenges of both aspects of voting in accordance with the nature of decision-making in multi-agent systems (MAS) which is decentralised. The importance of COMSOC and voting for modern society will be discussed. After introducing the important concepts of voting theory in a multi-agent environment, computational and social challenges of voting will be presented. A necessity for their unity will be justified and several voting directions for MAS will be suggested.

2. IMPORTANCE OF COMSOC AND VOTING

COMSOC is a bridge between social and technical sciences, as well as classic and modern topics [3]. The author summarizes recent efforts in COMSOC and voting in the form of PESTLE (political, economic, social, technological, legal, and environment) framework (Table 1). It is evident that many factors affect this research area, and recurrently, COMSOC and voting affect modern society.

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Table 1. PESTLE framework of recent influencing factors regarding COMSOC and voting

Political factors	Economic factors	Social factors
Political voting systems – e.g. in America [4] or in Europe [5], liquid democracy [6], 'Brexit' voting behaviour [7]	Crowdsourcing [8], demographic migrations [9]	Collective intelligence [10], social network and their impacts on voting [11], social welfare [12]
Technological factors	Legal factors	Environmental factors
Social technologies [13], collaborative technologies, digital technologies [14], artificial intelligence [3] and social good [15]	Adoption of new laws with impacts on voting (e.g. privacy and data protection regulations), privacy protection in electronic voting systems [16]	Energy consumption issues [17]

There are many important issues and situations when a group is asked to decide about some choice. In those situations, the group reaches out to vote in order to achieve a consensus about the collective decision.

People express their stance on important issues by giving votes to preferable options. The voting process is the central area of COMSOC. Besides the act of voting itself, the computation of votes is from great influence for outcomes and, consequently, for social activities. Therefore, the voting process is a very responsible area. Finally, the right to vote, and generally, participation in making decisions is a cornerstone of democracy.

3. VOTING IN MULTI-AGENT ENVIRONMENT

Multi-agent systems consist of agents, physical or virtual entities [18], for example, people, independent organizations, software, virtual organizations, etc., that act, interact, and exchange information with other agents in common socio-technical environment. Those systems have uncertain and dynamic behaviour. Due to a distributed network of autonomous agents, decision making in MAS is decentralised and electronic voting is increasingly represented.

Individual entities that participate in decision-making (voters or agents) can have diverging, competing, or conflicting interests ([19], [20], [21]), and even dichotomous preferences [22]. Therefore, voting has a task to reconcile these differences.

Candidates or alternatives represent possible winners or potential winning ideas/proposals/solutions /characteristics under consideration. The basic idea is that the winning option should satisfy as many agents as possible (it is oriented to the whole voters' population). The previous selection procedure for candidates is necessary. As more „tolerant" constraints expressed in the form of statements [3], preferences are central topics in decision-making. Also, they are a central focus in the field of artificial intelligence which deals with the replication of some human mind functions [23]. Especially, multi-agent preferences are not easy to introduce and elicit. Additional problematic may come from privacy issues or missing data [23].

A vote is a preference of an agent about given candidates that can be expressed in an ordering scale (the candidates are ranked) or on a cardinal scale (a utility index is assigned to each candidate). Also, it is possible only to name a favourite candidate/alternative. The outcome of voting can be one winner, more winners or their final order. The problem of aggregation of preferences is one of the crucial in the field of COMSOC. Listed are some of the most known voting rules in the literature [24], [25]:

- Majority – counting only first-place rated candidates (the winner has majority votes);
- Plurality – counting only first-place rated candidates (the winner has more votes than other candidates);
- Borda count method – counting the number of points that corresponds to the number of candidates which are ranked lower (the winner is a candidate with the highest score);
- Approval/K-approval – counting "approvals" so that each voter can approve any or k number of candidates and k is less than the total number of candidates (the winner is a candidate with the most „approvals");
- Copeland's method – counting the number of pairwise victories (the winner is a candidate with the highest number of pairwise victories);
- Veto – counting negative votes (the winner is a candidate with the least negative score).

Although apparently everything seems easy, the presence of social choice paradoxes illustrates shortcomings of voting systems. Namely, the outcome may not only depend on the voters' actions, for example:

- Condorcet paradox (voting paradox) – we can have cyclic collective preferences even if the individual ones are not cyclic;
- Arrow's paradox or Arrow's impossibility theorem – the impossibility of having an ideal social ordering that, under an unrestricted domain, it is Pareto efficient, independent of irrelevant alternatives, and not dictatorial and at the same time [26];

- Gibbard-Satterthwaite impossibility theorem – the impossibility of satisfaction the absence of the following undesirable properties: dictatorial voting, tactical voting, reducing the choice to only two alternatives.

The voting procedure can be expressed in the form of a set of instructions, i.e. algorithm, that decides about the winner. An understanding of algorithms requires examination of their full socio-technical assemblage [27]. Therefore, both computational and socials challenges must be considered.

4. COMPUTATIONAL CHALLENGES OF VOTING

Computational aspects of voting come from Computer Science and related fields as Artificial Intelligence – AI (with Machine Learning), Mathematics, Operations Research. They involve voting algorithm design and optimization, mathematical modelling, collective decision-making processing and analysing. Because of the non-linearity of MAS, there is a challenge in exact sciences known as computational complexity. Also, the decentralization of MAS opens the question of how to aggregate preferences. A lot of criteria should be satisfied. Computational challenges of voting are given in Table 2.

Table 2. Computational challenges of voting

Aspect	Definition	Author(s)
Monotonicity criterion	It is not possible that a candidate loses/wins if we rank them higher/lower (other candidates are ranked the same).	[28]
Computational efficiency vs. NP-hard voting problem, parameterized complexity	Input-output transformation with minimum resources and with respect to the complexity of the voting rule.	[29], [30], [31]
Consistency criterion	The election of a joint set of divided sets of voters with the same results gives also the same result.	[24]
Missing data	Incomplete preferences	[32]
Fairness, accountability, and transparency (FAT) of algorithmic decision-making	Decisions and proceeding without discrimination, i.e. equitability, responsibility for the results, the openness of procedures.	[33], [34]
Independence of irrelevant alternatives	The order between the two alternatives does not change regardless of the presence of the third alternative.	[26], [35]

5. SOCIAL CHALLENGES OF VOTING

The social outcome of voting is very dependent on social dilemmas that exist between collective and individual rationality of self-interested agents [36]. Therefore, social aspects of voting are oriented toward humans (their behaviour, ethics, cognitive reasoning) and the broader idea of higher purpose and justice, and they are placed in a voting social context. The aspects come from Social Choice Theory and related fields as Economics, Political Science, Philosophy, and Psychology.

The voting process takes place under the veil of interactions among intelligent agents that can be human or artificial ones. Therefore, the voting population as a complex adaptive system has uncertain behaviour. Social challenges of voting are given in Table 3.

Table 3. Social challenges of voting

Aspect	Definition	Author(s)
Selection of candidates	The way how candidate close list is created.	[37]
Voter turnout	It presents the percentage of votes relative to the voter population.	[38], [39]
Manipulation vs. strategy-proof	Strategic voting vs. nonmanipulable voting	[40], [41]
Privacy issues	Voter privacy data protection	[42]
Different negative aspects of voter behaviour	Bias – favouritism of some candidate(s)	[43], [44]
	Prejudice – unfounded preconceptions	[45]
	Bribery – corrupt voting	[46]
The presence of paradoxes in Social Choice Theory	Condorcet paradox (voting paradox)	[47], [48]
	Arrow's paradox (Arrow's impossibility theorem)	[26], [49]
	Gibbard-Satterthwaite impossibility theorem	[50]
Anonymity and neutrality	The outcome of a voting rule does not depend on voters'/candidates' identities or the order they are considered.	[24], [51]
Non-dictatorship voting	There is no single powerful voter whose preference decides group preference.	[26]

6. IMPLICATIONS FOR FUTURE WORK

Having in mind the social and computational challenges of voting and specifics of MAS, some possible directions for future research can be suggested, which are in the spirit of COMSOC.

6.1 Integrated approach to voting

The study of decision making in MAS demands a holistic approach. Voting, or collective decision making, takes place in the dual socio-technical environment, where humans and algorithms parallelly make decisions substantial for society. COMSOC demands theoretical modelling and algorithm design [52], as well as social context consideration of voting.

There are many examples that put clear the connection and the need for integrated studies in this complex field. For example, we can parallelly discuss computational complexity and social complexity of voting in MAS, incomplete preferences and privacy issues [22], human and algorithmic biases, or we can work on how to design an NP-hard voting rule that makes difficult to cheat [53], etc. Although manipulation of voting is a social phenomenon, computational hardness is the main obstruction to manipulation [54].

6.2 Iterative voting

Iterative voting is convenient in dynamic and unpredictable MAS because it allows voters to change their preferences iteratively, toward collective consensus – equilibrium [55]. It allows them to get the additional information and gain insight into the broader picture, after learning in each iteration [56], which is not possible in a priori approach. This is an important prerequisite for better understanding and meeting the voting criteria. The approach is especially useful in the domain of AI where artificial agents or "voting avatars" [57] are capable of reinforcement learning.

Generally, a fertile ground for this challenge is possible to find in the intersection of AI, social science, and human-computer interaction, called human-agent interaction or Explainable AI [58]. Sequential or multistage approach [59] in combination with an interactive approach, for example, by asking users a series of informative questions [60], is one of the possible ways of learning about agent's preferences that should be done iteratively.

6.3 Voting argumentation framework

In voting, besides the central question „how to aggregate", there is also an important question „what to aggregate" [61]. Therefore, Karanikolas et al. [1] suggest the voting argumentation framework that combines preference aggregation with preference argumentation (i.e. COMSOC with argumentation). Justification of agents' preferences is not the focus of classic social choice methods [63]. Unjustified preferences itself are not enough and there is a need for its reasoning [62]. Furthermore, some authors are developed computational models for a better understanding of individual preferences (for example, VAMP or Voting Agent Model of Preferences [64]), which can be useful before its aggregation.

6.4 Combinatorial voting

Combinatorial voting refers to voting in multi-issue domains which means that the set of alternatives has a combinatorial structure [65]. Hence, voting in combinatorial domains deals with complex combinatorial structures [66]. One example is sequential voting when agents vote by a local voting rule on one issue at a time [24], which represents one kind of decomposition of the initial problem. Depending on a specific context, the same voting rule does not have to be equally efficient throughout all steps of a voting procedure.

7. CONCLUSION

The importance of voting in multi-agent systems is emphasized in this paper. COMSOC as a multidisciplinary field connects several significant spheres of influence of today's global scientific and technological trends. PESTLE framework of recent influencing factors underlines the importance of COMSOC and voting for solving significant problems in society.

Voting, as the main collective decision-making mechanism in multi-agent systems, demand consideration of both computational and social aspects, which are interwoven in voting problematics. The challenging aspects are presented in the paper.

The paper also contributes to the existing corpus of knowledge by suggesting and explaining several possible research directions on the basis of the previous study of both aspects and the nature of voting in multi-agent systems.

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REZIME

RAČUNARSKI DRUŠTVENI IZBOR I IZAZOVI GLASANJA U MULTIAGENTNIM SISTEMIMA

Prisustvo „big data“, „online“ sistema, saradnja udaljenih agenata, distribuirano znanje, interakcija na društvenim medijima, i uopšte, digitalna globalizacija, menja način na koji ljudi donose odluke, a posebno one od kolektivnog značaja. Suočavamo se sa brojnim izazovima glasanja u multiagentnom društveno-tehničkom okruženju, koji dolaze kako od ljudi tako i od algoritama. Računarski društveni izbor (engl. Computational Social Choice – COMSOC) ima tendenciju da objedini nekoliko odvojeno proučavanih oblasti. Autor rezimira nedavne napore koji svedoče o važnosti COMSOC-a i glasanja. Ovaj rad pruža uvid u prirodu glasanja u multiagentnim sistemima, kao i sa njom povezanim izazovima, kako sa računarskog tako i sa društvenog aspekta. Uzimajući u obzir izazovne aspekte glasanja i specifičnosti multiagentnih sistema, predloženi su sledeći pravaci za buduća istraživanja u oblasti COMSOC-a: integrisani pristup glasanju, iterativno glasanje, okvir za argumentovano glasanje, i kombinatorno glasanje.

Ključne reči: *Računarski društveni izbor, glasanje, multiagentni sistemi, računarski izazovi, društveni izazovi*