

HANDBOOK *of* COMPUTATIONAL SOCIAL CHOICE

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Handbook Of Computational Social Choice

Toby Walsh



Handbook Of Computational Social Choice:

Handbook of Computational Social Choice Felix Brandt, 2016 *Handbook of Computational Social Choice* Felix Brandt, Vincent Conitzer, Ulle Endriss, Jérôme Lang, Ariel D. Procaccia, 2016-04-25 The rapidly growing field of computational social choice at the intersection of computer science and economics deals with the computational aspects of collective decision making This handbook written by thirty six prominent members of the computational social choice community covers the field comprehensively Chapters devoted to each of the field s major themes offer detailed introductions Topics include voting theory such as the computational complexity of winner determination and manipulation in elections fair allocation such as algorithms for dividing divisible and indivisible goods coalition formation such as matching and hedonic games and many more Graduate students researchers and professionals in computer science economics mathematics political science and philosophy will benefit from this accessible and self contained book **Trends in Computational Social Choice** Ulle Endriss, 2017 Computational social choice is concerned with the design and analysis of methods for collective decision making It is a research area that is located at the interface of computer science and economics The central question studied in computational social choice is that of how best to aggregate the individual points of view of several agents so as to arrive at a reasonable compromise Examples include tallying the votes cast in an election aggregating the professional opinions of several experts and finding a fair manner of dividing a set of resources amongst the members of a group Back cover **Handbook of Social Choice and Voting** Jac C. Heckelman, Nicholas R. Miller, 2015-12-18 This Handbook provides an overview of interdisciplinary research related to social choice and voting that is intended for a broad audience Expert contributors from various fields present critical summaries of the existing literature including intuitive explanations of technical terminology and well known theorems suggesting new directions for research **The Future of Economic Design** Jean-François Laslier, Hervé Moulin, M. Remzi Sanver, William S. Zwicker, 2019-11-15 This collection of essays represents responses by over eighty scholars to an unusual request give your high level assessment of the field of economic design as broadly construed Where do we come from Where do we go from here The book editors invited short informal reflections expressing deeply felt but hard to demonstrate opinions unsupported speculation and controversial views of a kind one might not normally risk submitting for review The contributors both senior researchers who have shaped the field and promising younger researchers responded with a diverse collection of provocative pieces including retrospective assessments or surveys of the field opinion papers reflections on critical points for the development of the discipline proposals for the immediate future science fiction and many more The readers should have fun reading these unusual pieces as much as the contributors enjoyed writing them **Computing and Software Science** Bernhard Steffen, Gerhard Woeginger, 2019-10-04 The papers of this volume focus on the foundational aspects of computer science the thematic origin and stronghold of LNCS under the title Computing and Software Science State of the Art and Perspectives They are

organized in two parts The first part Computation and Complexity presents a collection of expository papers on fashionable themes in algorithmics optimization and complexity The second part Methods Languages and Tools for Future System Development aims at sketching the methodological evolution that helps guaranteeing that future systems meet their increasingly critical requirements Chapter 3 is available open access under a Creative Commons Attribution 4.0 International License via link [springer.com](https://www.springer.com) **Evaluating Voting Systems with Probability Models** Mostapha Diss,Vincent

Merlin,2020-12-18 This book includes up to date contributions in the broadly defined area of probabilistic analysis of voting rules and decision mechanisms Featuring papers from all fields of social choice and game theory it presents probability arguments to allow readers to gain a better understanding of the properties of decision rules and of the functioning of modern democracies In particular it focuses on the legacy of William Gehrlein and Dominique Lepelley two prominent scholars who have made important contributions to this field over the last fifty years It covers a range of topics including but not limited to computational and technical aspects of probability approaches evaluation of the likelihood of voting paradoxes power indices empirical evaluations of voting rules models of voters behavior and strategic voting The book gathers articles written in honor of Gehrlein and Lepelley along with original works written by the two scholars themselves **A Guided**

Tour of Artificial Intelligence Research Pierre Marquis,Odile Papini,Henri Prade,2020-05-08 The purpose of this book is to provide an overview of AI research ranging from basic work to interfaces and applications with as much emphasis on results as on current issues It is aimed at an audience of master students and Ph D students and can be of interest as well for researchers and engineers who want to know more about AI The book is split into three volumes the first volume brings together twenty three chapters dealing with the foundations of knowledge representation and the formalization of reasoning and learning Volume 1 Knowledge representation reasoning and learning the second volume offers a view of AI in fourteen chapters from the side of the algorithms Volume 2 AI Algorithms the third volume composed of sixteen chapters describes the main interfaces and applications of AI Volume 3 Interfaces and applications of AI Implementing reasoning or decision making processes requires an appropriate representation of the pieces of information to be exploited This first volume starts with a historical chapter sketching the slow emergence of building blocks of AI along centuries Then the volume provides an organized overview of different logical numerical or graphical representation formalisms able to handle incomplete information rules having exceptions probabilistic and possibilistic uncertainty and beyond as well as taxonomies time space preferences norms causality and even trust and emotions among agents Different types of reasoning beyond classical deduction are surveyed including nonmonotonic reasoning belief revision updating information fusion reasoning based on similarity case based interpolative or analogical as well as reasoning about actions reasoning about ontologies description logics argumentation and negotiation or persuasion between agents Three chapters deal with decision making be it multiple criteria collective or under uncertainty Two chapters cover statistical computational learning and reinforcement learning

other machine learning topics are covered in Volume 2 Chapters on diagnosis and supervision validation and explanation and knowledge base acquisition complete the volume **Conversations on Social Choice and Welfare Theory - Vol. 1** Marc Fleurbaey, Maurice Salles, 2021-03-30 This volume presents interviews that have been conducted from the 1980s to the present with important scholars of social choice and welfare theory Starting with a brief history of social choice and welfare theory written by the book editors it features 15 conversations with four Nobel Laureates and other key scholars in the discipline The volume is divided into two parts The first part presents four conversations with the founding fathers of modern social choice and welfare theory Kenneth Arrow John Harsanyi Paul Samuelson and Amartya Sen The second part includes conversations with scholars who made important contributions to the discipline from the early 1970s onwards This book will appeal to anyone interested in the history of economics and the history of social choice and welfare theory in particular

Modeling Decisions for Artificial Intelligence Vicenç Torra, Yasuo Narukawa, Jordi Nin, Núria Agell, 2020-08-26 This book constitutes the refereed proceedings of the 17th International Conference on Modeling Decisions for Artificial Intelligence MDAI 2020 held in Sant Cugat Spain in September 2020 The 24 papers presented in this volume were carefully reviewed and selected from 46 submissions They discuss different facets of decision processes in a broad sense and present research in data science data privacy aggregation functions human decision making graphs and social networks and recommendation and search The papers are organized in the following topical sections aggregation operators and decision making and data science and data mining The conference was canceled due to the COVID 19 pandemic *AI 2021: Advances in Artificial Intelligence* Guodong Long, Xinghuo Yu, Sen Wang, 2022-03-18 This book constitutes the proceedings of the 34th Australasian Joint Conference on Artificial Intelligence AI 2021 held in Sydney NSW Australia in February 2022 The 64 full papers presented in this volume were carefully reviewed and selected from 120 submissions The papers were organized in topical sections named Ethical AI Applications Classical AI Computer Vision and Machine Learning Natural Language Processing and Data Mining and Network Analysis The conference was postponed from December 2021 to February 2022 and held virtually due to the COVID 19 pandemic *Algorithmic Decision Theory* Toby Walsh, 2015-08-27 This book constitutes the thoroughly refereed conference proceedings of the 4th International Conference on Algorithmic Decision Theory ADT 2015 held in September 2015 in Lexington USA The 32 full papers presented were carefully selected from 76 submissions The papers are organized in topical sections such as preferences manipulation learning and other issues utility and decision theory argumentation bribery and control social choice allocation and other problems doctoral consortium Algorithmic Decision Theory Dimitris Fotakis, David Ríos Insua, 2021-10-27 This book constitutes the conference proceedings of the 7th International Conference on Algorithmic Decision Theory ADT 2021 held in Toulouse France in November 2021 The 27 full papers presented were carefully selected from 58 submissions The papers focus on algorithmic decision theory broadly defined seeking to bring together researchers and practitioners coming from diverse areas of computer science economics

and operations research in order to improve the theory and practice of modern decision support **Algorithmic aspects of resource allocation and multiwinner voting: theory and experiments** Kaczmarczyk, Andrzej, 2021-12-10 This thesis is concerned with investigating elements of computational social choice in the light of real world applications We contribute to a better understanding of the areas of fair allocation and multiwinner voting For both areas inspired by real world scenarios we propose several new notions and extensions of existing models Then we analyze the complexity of answering the computational questions raised by the introduced concepts To this end we look through the lens of parameterized complexity We identify different parameters which describe natural features specific to the computational problems we investigate Exploiting the parameters we successfully develop efficient algorithms for specific cases of the studied problems We complement our analysis by showing which parameters presumably cannot be utilized for seeking efficient algorithms Thereby we provide comprehensive pictures of the computational complexity of the studied problems Specifically we concentrate on four topics that we present below grouped by our two areas of interest For all but one topic we present experimental studies based on implementations of newly developed algorithms We first focus on fair allocation of indivisible resources In this setting we consider a collection of indivisible resources and a group of agents Each agent reports its utility evaluation of every resource and the task is to fairly allocate the resources such that each resource is allocated to at most one agent We concentrate on the two following issues regarding this scenario The social context in fair allocation of indivisible resources In many fair allocation settings it is unlikely that every agent knows all other agents For example consider a scenario where the agents represent employees of a large corporation It is highly unlikely that every employee knows every other employee Motivated by such settings we come up with a new model of graph envy freeness by adapting the classical envy freeness notion to account for social relations of agents modeled as social networks We show that if the given social network of agents is simple for example if it is a directed acyclic graph then indeed we can sometimes find fair allocations efficiently However we contrast tractability results with showing NP hardness for several cases including those in which the given social network has a constant degree Fair allocations among few agents with bounded rationality Bounded rationality is the idea that humans due to cognitive limitations tend to simplify problems that they face One of its emanations is that human agents usually tend to report simple utilities over the resources that they want to allocate for example agents may categorize the available resources only into two groups of desirable and undesirable ones Applying techniques for solving integer linear programs we show that exploiting bounded rationality leads to efficient algorithms for finding envy free and Pareto efficient allocations assuming a small number of agents Further we demonstrate that our result actually forms a framework that can be applied to a number of different fairness concepts like envy freeness up to one good or envy freeness up to any good This way we obtain efficient algorithms for a number of fair allocation problems assuming few agents with bounded rationality We also empirically show that our technique is applicable in practice Further we study multiwinner

voting where we are given a collection of voters and their preferences over a set of candidates. The outcome of a multiwinner voting rule is a group or a set of groups in case of ties of candidates that reflect the voters preferences best according to some objective. In this context we investigate the following themes: The robustness of election outcomes. We study how robust outcomes of multiwinner elections are against possible mistakes made by voters. Assuming that each voter casts a ballot in a form of a ranking of candidates we represent a mistake by a swap of adjacent candidates in a ballot. We find that for rules such as SNTV, k -Approval and k -Borda it is computationally easy to find the minimum number of swaps resulting in a change of an outcome. This task is however NP hard for STV and the Chamberlin Courant rule. We conclude our study of robustness with experimentally studying the average number of random swaps leading to a change of an outcome for several rules.

Strategic voting in multiwinner elections. We ask whether a given group of cooperating voters can manipulate an election outcome in a favorable way. We focus on the k -Approval voting rule and we show that the computational complexity of answering the posed question has a rich structure. We spot several cases for which our problem is polynomial time solvable. However we also identify NP hard cases. For several of them we show how to circumvent the hardness by fixed parameter tractability. We also present experimental studies indicating that our algorithms are applicable in practice.

Diese Arbeit befasst sich mit der Untersuchung von Themen des Forschungsgebiets Computational Social Choice im Lichte realer Anwendungen. Dabei trägt sie zu einem besseren Verständnis der Bereiche der fairen Zuordnung und der Mehrgewinnerwahlen bei. Für beide Konzepte schlagen wir, inspiriert von realen Anwendungen, verschiedene neue Begriffe und Erweiterungen bestehender Modelle vor. Anschließend analysieren wir die Komplexität der Beantwortung von Berechnungsfragen, die durch die eingeführten Konzepte aufgeworfen werden. Dabei fokussieren wir uns auf die parametrisierte Komplexität. Hierzu identifizieren wir verschiedene Parameter, welche natürliche Merkmale der von uns untersuchten Berechnungsprobleme beschreiben. Durch die Nutzung dieser Parameter entwickeln wir erfolgreich effiziente Algorithmen für Spezialfälle der untersuchten Probleme. Wir ergänzen unsere Analyse, indem wir zeigen, welche Parameter vermutlich nicht verwendet werden können, um effiziente Algorithmen zu finden. Dabei zeichnen wir ein umfassendes Bild der Berechnungskomplexität der untersuchten Probleme. Insbesondere konzentrieren wir uns auf vier Themen, die wir gruppiert nach unseren beiden Schwerpunkten unten vorstellen. Für alle Themen bis auf eines präsentieren wir Experimente, die auf Implementierungen der von uns neu entwickelten Algorithmen basieren. Wir konzentrieren uns zunächst auf die faire Zuordnung unteilbarer Ressourcen. Hier betrachten wir eine Menge unteilbarer Ressourcen und eine Gruppe von Agenten. Jeder Agent gibt eine Bewertung des Nutzens jeder Ressource ab und die Aufgabe besteht darin, eine faire Zuordnung der Ressourcen zu finden, wobei jede Ressource höchstens einem Agenten zugeordnet werden kann. Innerhalb dieses Bereiches konzentrieren wir uns auf die beiden folgenden Problemstellungen: Der soziale Kontext bei der fairen Zuordnung unteilbarer Ressourcen. In vielen Szenarien, in denen Ressourcen zugeordnet werden sollen, ist es unwahrscheinlich, dass jeder Agent alle

anderen kennt Vorstellbar ist beispielsweise ein Szenario in dem die Agenten Mitarbeiter eines gro ßen Unternehmens repräsentieren Es ist höchst unwahrscheinlich dass jeder Mitarbeiter jeden anderen Mitarbeiter kennt Motiviert durch solche Szenarien entwickeln wir ein neues Modell der graph basierten Neidfreiheit Wir erweitern den klassischen Neidfreiheitsbegriff um die sozialen Beziehungen von Agenten die durch soziale Netzwerke modelliert werden Einerseits zeigen wir dass wenn das soziale Netzwerk der Agenten einfach ist zum Beispiel wenn es sich um einen gerichteten azyklischen Graph handelt in manchen Fällen faire Zuordnungen effizient gefunden werden können Andererseits stellen wir diesen algorithmisch positiven Ergebnissen mehrere NP schweren Fällen entgegen Ein Beispiel für einen solchen Fall sind soziale Netzwerke mit einem konstanten Knotengrad Faire Zuteilung an wenige Agenten mit begrenzter Rationalität Begrenzte Rationalität beschreibt die Idee dass Menschen aufgrund kognitiver Grenzen dazu neigen Probleme mit denen sie konfrontiert werden zu vereinfachen Eine mögliche Folge dieser Grenzen ist dass menschliche Agenten in der Regel einfache Bewertungen der gewünschten Ressourcen abgeben beispielsweise könnten Agenten die verfügbaren Ressourcen nur in zwei Gruppen erwünschte und unerwünschte Ressourcen kategorisieren Durch Anwendung von Techniken zum Lösen von Ganzzahligen Linearen Programmen zeigen wir dass unter der Annahme einer kleinen Anzahl von Agenten die Ausnutzung begrenzter Rationalität dabei hilft effiziente Algorithmen zum Finden neidfreier und Pareto effizienter Zuweisungen zu entwickeln Weiterhin zeigen wir dass unser Ergebnis ein allgemeines Verfahren liefert welches auf eine Reihe verschiedener Fairnesskonzepte angewendet werden kann wie zum Beispiel Neidfreiheit bis auf ein Gut oder Neidfreiheit bis auf irgendein Gut Auf diese Weise gewinnen wir effiziente Algorithmen für eine Reihe fairer Zuordnungsprobleme wenige Agenten mit begrenzter Rationalität vorausgesetzt Darüber hinaus zeigen wir empirisch dass unsere Technik in der Praxis anwendbar ist Weiterhin untersuchen wir Mehrgewinnerwahlen bei denen uns eine Menge von Wählern sowie ihre Präferenzen über eine Reihe von Kandidaten gegeben sind Das Ergebnis eines Mehrgewinnerwahlverfahrens ist eine Gruppe oder eine Menge von Gruppen im Falle eines Unentschiedens von Kandidaten welche die Präferenzen der Wähler am besten einem bestimmten Ziel folgend widerspiegeln In diesem Kontext untersuchen wir die folgenden Themen Die Robustheit von Wahlergebnissen Wir untersuchen wie robust die Ergebnisse von Mehrgewinnerwahlen gegen möglicher Fehler der Wähler sind Unter der Annahme dass jeder Wähler eine Stimme in Form einer Rangliste von Kandidaten abgibt modellieren wir einen Fehler als einen Tausch benachbarter Kandidaten in der Rangliste Wir zeigen dass für Wahlregeln wie SNTV k Approval und k Borda die minimale Anzahl an Vertauschungen welche zu einer Ergebnisänderung führt einfach zu berechnen ist Für STV und die Chamberlin Courant Regel ist diese Aufgabe allerdings NP schwer Wir schließen unsere Untersuchung der Robustheit unterschiedlicher Wahlregeln ab mit einer experimentellen Evaluierung der durchschnittlichen Anzahl zufälliger Vertauschungen die zu einer Änderung des Ergebnisses führen Strategische Abstimmung bei Wahlen mit mehreren Gewinnern Wir fragen ob eine bestimmte Gruppe von kooperierenden Wählern ein Wahlergebnis zu ihren Gunsten manipulieren kann

Dabei konzentrieren wir uns auf die k Approval Wahlregel Wir zeigen dass die Berechnungskomplexit t der besagten Manipulation eine reiche Struktur besitzt Auf der einen Seite identifizieren wir mehrere F lle in denen das Problem in Polynomzeit l sbar ist Auf der anderen Seite identifizieren wir jedoch auch NP schwere F lle F r einige von ihnen zeigen wir wie die Berechnungsschwere durch parametrisierte Algorithmen umgangen werden kann Wir pr sentieren zudem experimentelle Untersuchungen welche darauf hindeuten dass unsere Algorithmen in der Praxis anwendbar sind **ECAI 2020** Giuseppe De Giacomo,Bistra Dilkina,Michela Milano,Senén Barro,Alberto Bugarín,Jérôme Lang,2020-09-15 This book presents the proceedings of the 24th European Conference on Artificial Intelligence ECAI 2020 held in Santiago de Compostela Spain from 29 August to 8 September 2020 The conference was postponed from June and much of it conducted online due to the COVID 19 restrictions The conference is one of the principal occasions for researchers and practitioners of AI to meet and discuss the latest trends and challenges in all fields of AI and to demonstrate innovative applications and uses of advanced AI technology The book also includes the proceedings of the 10th Conference on Prestigious Applications of Artificial Intelligence PAIS 2020 held at the same time A record number of more than 1 700 submissions was received for ECAI 2020 of which 1 443 were reviewed Of these 361 full papers and 36 highlight papers were accepted an acceptance rate of 25% for full papers and 45% for highlight papers The book is divided into three sections ECAI full papers ECAI highlight papers and PAIS papers The topics of these papers cover all aspects of AI including Agent based and Multi agent Systems Computational Intelligence Constraints and Satisfiability Games and Virtual Environments Heuristic Search Human Aspects in AI Information Retrieval and Filtering Knowledge Representation and Reasoning Machine Learning Multidisciplinary Topics and Applications Natural Language Processing Planning and Scheduling Robotics Safe Explainable and Trustworthy AI Semantic Technologies Uncertainty in AI and Vision The book will be of interest to all those whose work involves the use of AI technology *ECAI 2016* G.A. Kaminka,M. Fox,P. Bouquet,2016-08-24 Artificial Intelligence continues to be one of the most exciting and fast developing fields of computer science This book presents the 177 long papers and 123 short papers accepted for ECAI 2016 the latest edition of the biennial European Conference on Artificial Intelligence Europe s premier venue for presenting scientific results in AI The conference was held in The Hague the Netherlands from August 29 to September 2 2016 ECAI 2016 also incorporated the conference on Prestigious Applications of Intelligent Systems PAIS 2016 and the Starting AI Researcher Symposium STAIRS The papers from PAIS are included in this volume the papers from STAIRS are published in a separate volume in the Frontiers in Artificial Intelligence and Applications FAIA series Organized by the European Association for Artificial Intelligence EurAI and the Benelux Association for Artificial Intelligence BNVKI the ECAI conference provides an opportunity for researchers to present and hear about the very best research in contemporary AI This proceedings will be of interest to all those seeking an overview of the very latest innovations and developments in this field **Information Processing and Management of Uncertainty in Knowledge-Based Systems** Marie-Jeanne

Lesot, Susana Vieira, Marek Z. Reformat, João Paulo Carvalho, Anna Wilbik, Bernadette Bouchon-Meunier, Ronald R. Yager, 2020-06-05 This three volume set CCIS 1237 1239 constitutes the proceedings of the 18th International Conference on Information Processing and Management of Uncertainty in Knowledge Based Systems IPMU 2020 in June 2020 The conference was scheduled to take place in Lisbon Portugal at University of Lisbon but due to COVID 19 pandemic it was held virtually The 173 papers were carefully reviewed and selected from 213 submissions The papers are organized in topical sections homage to Enrique Ruspini invited talks foundations and mathematics decision making preferences and votes optimization and uncertainty games real world applications knowledge processing and creation machine learning I machine learning II XAI image processing temporal data processing text analysis and processing fuzzy interval analysis theoretical and applied aspects of imprecise probabilities similarities in artificial intelligence belief function theory and its applications aggregation theory and practice aggregation pre aggregation functions and other generalizations of monotonicity aggregation aggregation of different data structures fuzzy methods in data mining and knowledge discovery computational intelligence for logistics and transportation problems fuzzy implication functions soft methods in statistics and data analysis image understanding and explainable AI fuzzy and generalized quantifier theory mathematical methods towards dealing with uncertainty in applied sciences statistical image processing and analysis with applications in neuroimaging interval uncertainty discrete models and computational intelligence current techniques to model process and describe time series mathematical fuzzy logic and graded reasoning models formal concept analysis rough sets general operators and related topics computational intelligence methods in information modelling representation and processing **Combinatorial Optimization and Applications** Weili Wu, Jianxiong Guo, 2023-12-08 The two volume set LNCS 14461 and LNCS 14462 constitutes the refereed proceedings of the 17th International Conference on Combinatorial Optimization and Applications COCOA 2023 held in Hawaii HI USA during December 15 17 2023 The 73 full papers included in the proceedings were carefully reviewed and selected from 117 submissions They were organized in topical sections as follows Part I Optimization in graphs scheduling set related optimization applied optimization and algorithm Graph planer and others Part II Modeling and algorithms complexity and approximation combinatorics and computing optimization and algorithms extreme graph and others machine learning blockchain and others Agreement Technologies Marin Lujak, 2019-04-03 This book constitutes the revised selected papers from the 6th International Conference on Agreement Technologies AT 2018 held in Bergen Norway in December 2018 The 11 full papers and 6 short papers presented in this volume were carefully reviewed and selected from a total of 28 submissions The papers discuss new ideas and techniques for the design implementation and verification of next generation open distributed systems centered on the notion of agreement among computational agents They are organized in the following topical sections AT foundations and modelling of reasoning agents argumentation and negotiation coordination in open distributed systems with applications **Multi-Winner Voting with Approval**

Preferences Martin Lackner, Piotr Skowron, 2022-11-17 From fundamental concepts and results to recent advances in computational social choice this open access book provides a thorough and in depth look at multi winner voting based on approval preferences The main focus is on axiomatic analysis algorithmic results and several applications that are relevant in artificial intelligence computer science and elections of any kind What is the best way to select a set of candidates for a shortlist for an executive committee or for product recommendations Multi winner voting is the process of selecting a fixed size set of candidates based on the preferences expressed by the voters A wide variety of decision processes in settings ranging from politics parliamentary elections to the design of modern computer applications collaborative filtering dynamic Q A platforms diversity in search results etc share the problem of identifying a representative subset of alternatives The study of multi winner voting provides the principled analysis of this task Approval based committee voting rules in short ABC rules are multi winner voting rules particularly suitable for practical use Their usability is founded on the straightforward form in which the voters can express preferences voters simply have to differentiate between approved and disapproved candidates Proposals for ABC rules are numerous some dating back to the late 19th century while others have been introduced only very recently This book explains and discusses these rules highlighting their individual strengths and weaknesses With the help of this book the reader will be able to choose a suitable ABC voting rule in a principled fashion participate in and be up to date with the ongoing research on this topic

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