Hindawi
Complexity
Volume 2020, Article ID 1425909, 3 pages
https://doi.org/10.1155/2020/1425909

Editorial

Scalable Distributed Decision-Making and Coordination in Large and Complex Systems: Methods, Techniques, and Models

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Received 16 July 2020; Accepted 17 July 2020; Published 31 July 2020

Human society, global economy, and Internet are becoming ever more decentralized, while millions of computers connected to the Internet facilitate the engineering of systems whose scale goes beyond spatial and computational boundaries of individual organizations.

The decision-making authority in this context is distributed throughout a system, and the decisions are made locally based on the interactions of an individual with the rest of the system and with its environment (see, e.g., [1]). A desired global behavior following the identifiable interest of the whole system is the result of system intelligence that emerges from the system's beliefs and system's collective actions and, as such, is a shift away from the hierarchical system paradigm. Distributed Decision-Making (DDM) models are usually used to support group decision-making in such large and complex systems, where each agent holds only limited information, and the cooperation between agents is crucial for the system's performance (see, e.g., [2]).

We are pleased to see the publication of this special issue focusing on the design and implementation of new methods, techniques, and models (see, e.g., [3]) that adapt or hybridize findings from Distributed Optimization, Multiagent Systems, Network Science, and Distributed Computing and facilitating distributed/parallel/multiagent decision-making and coordination for solving complex computational and real-life problems in large systems. The applications of DDM vary from coordination problems in groups and crowds (e.g., [4]), Internet (e.g., [5]), emergency logistics (e.g., [6]), multirobot systems (e.g., [7]) to transport (see, e.g., [8]), and beyond.

The main objective of this special issue is to provide an opportunity to study different aspects of intelligent and distributed decision-making and coordination in large and complex systems, including their formal analysis, with an intention to balance between theoretical research ideas and their practicability. Overall, this special issue collects six research articles and one review article on the state-of-the-art in DDM.

J. Li and S. Gong address the topic of coordination of closed-loop supply chain (CLSC) with dual-source supply and low-carbon concern. They construct a CLSC model with two competitive dominant upstream suppliers and one following a downstream (re-)manufacturer and then coordinate supply chain through cost-sharing contract. Based on the industrial case in the area of power battery, they analyze the optimal strategies under competition, cooperation, and coordination structures separately and then investigate the influences of emission reduction effort and collection efficiency on supply chain performance. The results reveal that collection of used products can positively affect the profit of the (re-)manufacturers, but has opposite impact on the new component supplier. Besides, recycling is beneficial to both low-carbon consumers' utility and social welfare, but hurts the total profit of CLSC because of the high investment cost of collection. Therefore, the paper designs a cost-sharing contract, which is applicable and efficient for both economic and environmental development. Furthermore, it can also

increase the profit of CLSC up to cooperation case and improve each member's profit, eliminating double marginal effect and achieving supply chain coordination.

I. G. Pérez Vergara et al. study the design of collaborative processes among stakeholders involved in inventory decision making and requiring effective communication and agreements between the leaders of the logistics processes. Traditionally, decision making in inventory management was based on approaches conditioned only by cost or sales volume. These approaches must be overcome by others that consider multiple criteria, involving several areas of the companies and taking into account the opinions of the stakeholders involved in these decisions. Inventory management becomes part of a complex system that involves stakeholders from different areas of the company, where each agent has limited information and where the cooperation between such agents is a key for the system's performance. In this paper, a distributed inventory control approach is used with the decisions allowing communication between the stakeholders and with a multicriteria group decision-making perspective. This work proposes a methodology that combines the analysis of the value chain and the Analytic Hierarchy Process (AHP) technique, in order to improve communication and performance of the areas related to inventory management decision making. This methodology uses the areas of the value chain as a theoretical framework to identify the criteria necessary for the application of the AHP multicriteria group decision-making technique. These criteria are defined as indicators that measure the performance of the areas of the value chain related to inventory management and are used to classify ABC inventory of the products according to these selected criteria. Therefore, the methodology allows us to solve inventory management DDM based on multicriteria ABC classification and was validated in a Colombian company belonging to the graphic arts sector.

M. Simão Filho et al. propose a multicriteria approach to support task allocation in distributed software development (DSD) projects. A typical decision-making problem in the distributed scenario consists of deciding which team should be allocated to each task. That decision takes into account a relative degree of subjectivity. The setting is suitable for applying Verbal Decision Analysis (VDA). This paper introduces an approach to support the allocation of tasks to distributed units in DSD projects, structured on the hybridisation of methods of Verbal Decision Analysis for classification and rank ordering applied to influencing factors and executing units. Firstly, a review of the literature is conducted aiming to identify the approaches to support the allocation of tasks in DSD contexts. Then, an approach is developed by applying VDA-based methods for classification and ordering. Bibliographic research and the application of surveys with professionals allow identifying and characterising the main elements that influence task assignment in DSD projects. Afterwards, experiences are carried out in five real-world companies. Finally, the proposed approach is evaluated by the professionals of the participating companies and by some project management experts. Results of the experiences and evaluations present evidence that the proposed approach is flexible, adaptable, and easy to understand and to use. Moreover, it helps to reduce decision subjectivity and to think of new aspects, supporting the task allocation process in DSD.

X. Pu and C. Xiong study the weighted couple-group consensus of continuous-time heterogeneous multiagent systems with input and communication time delay. They design a novel weighted couple-group consensus protocol based on cooperation and competition interaction, which can relax the in-degree balance condition. They obtain the time delay upper limit that the system may allow by using graph theory, the general Nyquist criterion, and the Gershgorin disc theorem. The conclusion indicates that there is no relationship between weighted couple-group consensus and communication time delay. When the agents input time delay, the coupling weight between the agents, and the systems control parameters are satisfied, and the multiagent system can converge to any given weighted coupling group consistent state. The results of the experimental simulation support the conclusion.

Open challenges of coordination in distributed decision-making systems (DDMS) include finding the relation between the complexity of the decision problem, the problem's predictability and its dynamics, and the applicable coordination mechanisms. These challenges apply to DDMS resided by human decision-makers like firms as well as to systems of software agents in the domain of multiagent systems (MAS).

F. Wall studies the adaptation and emergence of coordination in the course of growing decision-making organizations. For this, an agent-based simulation model based on the framework of NK fitness landscapes is employed. NK landscapes are stochastically generated pseudo-Boolean functions with N bits (genes) and K interactions between genes. The study controls for different levels of complexity of the overall decision problem, different strategies of search for new solutions, and different levels of cost of effort to implement new solutions. The results suggest that, with respect to the emerging coordination mode, complexity subtly interferes with the search strategy employed and cost of effort. In particular, results support the conjecture that increasing complexity leads to more hierarchical coordination. However, the search strategy shapes the predominance of hierarchy in favor of granting more autonomy to decentralized decision-makers. Moreover, the study reveals that the cost of effort for implementing new solutions in conjunction with the search strategy may remarkably affect the emerging form of coordination. This could explain differences in prevailing coordination modes across different branches or technologies or could explain the emergence of contextually inferior modes of coordination.

The work by G. Xiao et al. deals with the problem of autonomous separation of traffic flows in smart reversible lanes. Spacer bars in the smart reversible lanes periodically broadcast messages to share their local observed traffic information with each other. This aims to help other spacer bars acquire the global traffic information and make consistent movement when separating the flows. However, radio interference and vehicles in the traffic may degrade the

qualities of wireless communication links and cause frequent message losses in the broadcast. Existing solutions tend to use data forwarding to enhance the message dissemination, which may cause imbalanced load in the spacer bars. The unbalanced distribution of network load has a high risk of blocking the wireless communication links and yield inconsistent movement in the reversible lanes. They propose a Cooperative Bargain (CoB) scheme where each spacer bar carries some received messages to help other spacer bars recover their lost messages. Since the spacer bars can only acquire the local information, they formulate a cooperative bargain game to negotiate how to allocate the task of message recovery with a balanced network load until a consensus is achieved. CoB is evaluated with the real-world Wi-Fi communication traces in isti/rural. Simulation results show that CoB can recover an average of 98.6% messages within 100 milliseconds in a 50-node network. CoB does not require the global network information, but it can still achieve a comparable performance to other broadcast schemes.

Finally, the guest editors of this special issue present a review article on the topic of decentralizing coordination in open vehicle fleets for scalable and dynamic task allocation. One of the major challenges in the coordination of large and open collaborative and commercial vehicle fleets is dynamic task allocation. Self-concerned individually rational vehicle drivers have both local and global objectives, which require coordination using some fair and efficient task allocation method. They review the literature on scalable and dynamic task allocation focusing on deterministic and dynamic two-dimensional linear assignment problems. They focus on a multiagent system representation of open vehicle fleets where dynamically appearing vehicles are represented by software agents that should be allocated to a set of dynamically appearing tasks. They give a comparison and critical analysis of recent research results focusing on centralized, distributed, and decentralized solution approaches. Moreover, they propose mathematical models for dynamic versions of the following assignment problems well-known in combinatorial optimization—the linear assignment problem, bottleneck assignment problem, fair matching problem, dynamic minimum deviation assignment problem, $\sum_k$ – assignment problem, the semiassignment problem, the assignment problem with side constraints, and the assignment problem while recognizing agent qualification—all while considering the main aspect of open vehicle fleets: random arrival of tasks and vehicles (agents) that may become available after assisting previous tasks or by participating in the fleet at times based on individual interest.

Conflicts of Interest

The editors declare that they have no conflicts of interest regarding the publication of this special issue.

Acknowledgments

The editors would like to take this opportunity to thank all the authors for their valuable contributions to this special issue. Also, the editors are particularly grateful to all peer reviewers whose valuable work, suggestions, and detailed feedback have greatly helped to improve the quality of the papers included in the special issue.

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