A Review on Application Domains of Large-Scale Multiagent Systems*

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Abstract. *The paper summarizes a number of recent application domains (ADs) for large-scale multiagent systems (LSMASs) including the Industry 4.0, cooperative intelligent transport systems (C-ITSs), smart grids, smart cities, virtual & augmented reality (VAR) and electronic sports (eSports). These ADs intentionally overlap to show some of the basic building blocks of modern large scale applications - organization, cooperation, competition, robustness and (collective) intelligence. Benefits of using organization-centred LSMASs are outlined and a discussion is provided.*
Keywords. large scale multiagent systems, internet of everything, cyber-physical systems, application domain

1 Introduction

The term large-scale multiagent systems (LSMASs) represents novel framework for modelling, implementation and maintenance of massively distributed systems (M. Schatten et al., 2016; Okreša Đurić, 2017; Okreša Đurić, 2016). LSMASs allow us to not only address the various components of such systems as agents (which is by itself a very strong metaphor) (Garcia et al., 2003), but allow us to group them together into organizations facilitating model overview and modelling even more complex interaction (Markus Schatten, 2014). While holonic (Fischer et al., 2003), multilevel (Gil-Quijano et al., 2012) and swarm-based (Minar et al., 1996) multiagent system (MAS) approaches in most cases address exclusively organizational structure within agent organization, organization-centered multiagent systems (OCMASs) (Ferber et al., 2003) address much more: processes, objectives, interaction, communication, learning etc.

LSMASs go even further: they address interorganizational processes (competition, mergers, spinouts, joint ventures etc.) as well as higher order organizations (organizations of agents which are themselves composed of lower order organizations) (Markus Schatten, 2013). In this way very complex systems can be modeled, by using only simple concepts like organizational units, roles, processes, objectives, strategies etc.

In recent times, engineering complex large-scale systems has become a major challenge. A lot of various initiatives, which might be grouped under the term Internet of everything (IoE), have become the major focus of both scientific and engineering endeavours. The IoE which can be simply described as the process on connecting everything, including devices, processes, services, living beings etc. to the Internet is shaping our current reality.[1] Another common term is the term cyber-physical systems (CPSs) which "refers to a new generation of systems with integrated computational and physical capabilities that can interact with humans through many new modalities" (Baheti and Gill, 2011) and "is defined as transformative technolog[y][...] for managing interconnected systems between its physical assets and computational capabilities" (Lee et al., 2015). The result of these initiatives is a complex sociocybernetic system of systems which itself is becoming increasingly hard to understand in its entirety. Thus, it is necessary to develop new and better modelling techniques based on greater and more concise metaphors. LSMASs are one such metaphor as has already been contemplated in (M. Schatten et al., 2016) and as shall be shown in more detail herein.

In the following sections we will provide more detailed examples of how LSMASs can facilitate the modeling and implementation of complex sociocybernetic systems through a number of application domains: Industry 4.0 in section 2, cooperative intelligent transport systems (C-ITSs) in section 3, Smart Grids in section 4, Smart Cities in section 5, virtual & augmented reality (VAR) in section 6 and electronic sports (eSports) in section 7. In 8 we provide a brief discussion of our findings and draw our conclusions in the ending section 9.

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[1] Internet of things (IoT) on the other hand focuses mostly on connecting various devices, but often IoE and IoT are considered synonymous.

Table 1. Conceptual analysis of Industry 4.0 AD

Key concepts	robots, cloud services, big data, sensors, people, products, plants, companies, corporations, industries
Objects	services, data, products
Agents	robots, people, sensors
Agent organizations	plants, companies, corporations, industries

Table 2. Conceptual analysis of C-ITS AD

Key concepts	vehicles, sensors, assistant systems, infrastructure
Objects	infrastructure, data
Agents	autonomous or smart vehicles, sensors, traffic services
Agent organizations	groups of vehicles, sensors, and traffic services

2 Industry 4.0

Industry 4.0, a term used to denote the fourth industrial revolution, "focuses on the establishment of intelligent products and production processes" (Brettel et al., 2014) through the integration of CPSs with current industrial production, logistics and services (Lee et al., 2015). Such systems include (industrial) robotics, integrated cloud services, and big data analytics due to myriads of sensors generating data.

Having the organizational background of industrial companies in mind, Industry 4.0 seems like a natural application domain (AD) for LSMASs which focus on organization. Additionally, robots are the physical incarnation of agents, and thus perfectly suitable to be modelled and implemented in this way. Besides the obvious (robots, services, and people grouped into agent organizations), such organizations of agents have to cooperate (exchange data, services, products etc.) on plant, company, corporate, and industry level. Whilst systems on plant level are mostly connected and integrated, this is an increasingly infrequent case on the higher company, corporate, and industry levels. Such cooperation between organizations of higher level can be modelled and implemented using LSMASs and thus can be made more autonomous and robust. A summary of key concepts and various examples of objects, agents, and agent organizations in Industry 4.0 AD is presented in Table 1.

3 Cooperative Intelligent Transport Systems

C-ITSs or car-2-X communication systems commonly denotes the ability of vehicles, traffic sensors, traffic assistant systems, and roadside infrastructure to communicate and exchange information (Festag, 2014). Especially in the current domain of ad-hoc vehicular networks (Boban et al., 2011) as well as autonomous vehicles (Falcone et al., 2007) and the rising flying vehicle and drone traffic momentum (Markus Schatten and et al., 2015) communication and cooperation facilities become increasingly important.

Traffic systems have been, and are still, considered a natural AD for multiagent development approaches (see for example (Gaud et al., 2008)). LSMASs can extend this tradition with additional and important features: groups of vehicles, sensors, and traffic services can be considered organizations that cooperate or compete with other (agent) organization and deal with complex traffic situations that might emerge on a daily basis. Two detailed modeling examples in this regard are given in (M. Schatten et al., 2016). Key concepts, along with particular examples of objects, agents, and agent organizations for the C-ITS domain are shown in Table 2.

4 Smart Grids

Smart grid is a term referring to the electric grid that is "enhanced" with the ability to deliver electricity from a producer to consumers in an electronically controlled environment, with consumers being the integral part of the smart grids, since they can modify their behaviours and patterns based on the grid feedback (Siano, 2014; Li and Yao, 2010; Initiative et al., n.d.). Smart grid intelligently integrates actions of all parties involved in the network for the purpose of an efficient delivery of "sustainable, economic and secure electricity supplies" (Tamilmaran and Dwarkadas Pralhadas, 2011).

Demand side management is considered to be an integral part of smart grids, including automated metering, sensors, communication systems, intelligent devices and specialized processors (Siano, 2014), primarily aimed to reduce the power consumption at consumer side during peak periods. A multiagent development approach towards energy manipulation in the demand side management context has been implemented in the agent-based framework for modelling and simulating smart self-sustainable systems (Tomičić and Markus Schatten, 2015; Tomičić and Markus Schatten, 2016), where producers, consumers, and storage systems are modelled as reactive agents that are able to connect, communicate, and negotiate between themselves, and modify their own behaviours based on the current information perceived from the environment, in order to prevent the loss of resources within the system.

There are many other examples of using the multiagent systems in the smart grid domain. The use of multiagent systems to control a distributed smart grid

Table 3. Conceptual analysis of Smart Grid AD

Key concepts	electricity, consumer, producer, storage systems
Objects	infrastructure, data, electricity
Agents	consumer, producer, storage systems
Agent organizations	smart grid comprising consumers, producers, and storage systems

Table 4. Conceptual analysis of Smart Cities AD

Key concepts	structures, materials, sensors, electronics, appliances, networks, people, data
Objects	data, materials, structures
Agents	sensors, appliances, people
Agent organizations	smart- flats, buildings, neighborhoods, cities, and various similar groups

in a simulated environment is presented in (Pipattanasomporn et al., 2009), with the architecture that includes control agent, user agent, database agent and distributed energy resource agent, each with their own unique objectives and responsibilities. Other works include multiagent smart grid automation architectures (Zhabelova and Vyatkin, 2012), distributed control concepts using multiagent technology (Hommelberg et al., 2007), multiagent system architecture for smart grid management and forecasting of energy demand in virtual power plants (Hernández et al., 2013), agent-based restoration with distributed energy storage support in smart grids (Nguyen and Flueck, 2012) and others, all pointing to appropriateness of smart grid AD for multiagent development approaches.

Table 3 contains a summary of key concepts, followed by basic objects, agents, and agent organizations, identified in the smart grid AD of LSMASs.

5 Smart Cities

Smart cities present a concept only dreamed about not a long time ago, and envisioned in numerous pieces of popular literature and video as a proof of the coming future and technological advancement. The rising popularity of the idea of IoE encourages research of this particular application domain of LSMAS. The idea of smart cities is put nicely by Hall and associates in (Hall et al., 2000):

> "The vision of 'Smart Cities' is the urban center of the future, made safe, secure environmentally green, and efficient because all structures - whether for power, water, transportation, etc. are designed, constructed, and maintained making use of advanced, integrated materials, sensors, electronics, and networks which are interfaced with computerized systems comprised of databases, tracking, and decision-making algorithms."

The potential of organizational modeling in the domain of smart cities is somewhat underlined in Sec. 4 of this paper. Further motivation for organizational approach to building smart cities is found in the benefits of OCMAS - emphasizing processes, resources, communication, interaction, learning, etc. Having imagined a smart city as a rich society in a broad sense of the word, comprising urban elements, safety, various sorts of structure, sensors, electronics, and information, one can easily deduce that organizational features might improve the effectiveness of such a society.

Organizational features may be incorporated in forming organizations of individual flats agents live in (both artificial (i.e. computer) and natural (i.e. human)), or higher level organizations, such as those comprising individual flats grouped in a building, or numerous buildings in an organizational unit of a neighbourhood or a whole city. Furthermore, it is clear that organizational concepts and ideas from intelligent transport systems (Sec. 3) and smart grids (Sec. 4) can be applied to the domain of smart cities as well, as its integral parts.

Several of the key concepts of the smart cities AD are listed in Table 4, followed by selected examples of objects, agents, and agent organizations of the same AD of LSMASs.

6 Virtual & Augmented Reality

While virtual reality uses completely virtual surroundings based on computer-generated graphics and animations, augmented reality utilizes real-world surroundings augmented with virtual objects in real time (Tang et al., 1998). Virtual reality offers a potential for rich interactive experiences aimed at entertainment, education and training (Traum and Rickel, 2002).

Face-to-face dialogues with virtual humans, i.e. embodied agents, are a common challenge in virtual and augmented realities, where intelligent agents are used for multi-party dialogues (Traum and Rickel, 2002), simulating instructors (Evers and Nijholt, 2000) and substitutes for missing team members (Rickel and Johnson, 1999), simulating fighter pilots in large battlefield simulations (Hill et al., 1997), simulating crowd evacuation management under terrorist bomb attacks in public areas with a BDI software agents (Shendarkar et al., 2008). Other work is also related to disaster management, employing both virtual/augmented real-

Table 5. Conceptual analysis of VAR AD

Key concepts	experience, dialogue, emergency situation management
Objects	data, experience, situations
Agents	artificial agents, people
Agent organizations	various grouping possibilities in a multitude of simulation scenarios

Table 6. Conceptual analysis of eSports AD

Key concepts	cooperation, competition, players, teams
Objects	data, computer games of various genre
Agents	players, artificial agents
Agent organizations	teams of players or artificial agents

ity and multiagent systems. In (Uno and Kashiyama, 2008), authors have presented a simulation system for disaster evacuation based on a multiagent model, using virtual reality as a visualization technique. DrillSim (Massaguer et al., 2006) is an augmented reality simulation environment based on a multiagent simulation, where the simulation of the disaster response activity can be achieved "by modeling each person involved as an agent".

Multiagent systems are also used for pedagogical purposes in virtual environments (Buche et al., 2003), and virtual environments can provide test beds for creation and evaluation of multiagent systems (Kaminka et al., 2002). A toolbox for performing alternative experimentation on complex biological systems was designed on the framework of multi-agent systems and virtual reality (Desmeulles et al., 2006), presenting a new type of investigation for the complex systems study called the *in virtuo* experiment. The virtual and augmented realities thus can be seen as a "natural habitat" for multiagent systems, that can be practically utilized for a number of purposes.

Table 5 offers a conceptual analysis of the key concepts, along with examples of objects, agents, and agent organizations, of the VAR AD.

7 Electronic Sports

It was evident that computers will play a big role in various digital and analogue games, ever since IBM DeepBlue beat the world chess champion after a six-game match (Corporation, 2012), and more recently AlphaGo successfully won a game of Go against top-tier players (Hassabis and Silver, 2017). Modern computer games are more aligned with a different idea of gaming - cooperative and competitive computer gaming in human versus human matches. Such games, generally classified as first-person shooters (FPSs) and multiplayer online battle arenas (MOBAs) include various titles, the most popular being League of Legends, World of Tanks, Call of Duty, HearthStone, and DOTA2[2]. Even though competitive gaming is not an entirely new idea, it has gained immense popularity in the last decade, both in the context of audience and revenue (Armstrong, 2017).

Seen as an AD of LSMASs, various currently popular games could benefit from organizational features of intelligent agents that would operate from inside a game. A general idea visible from the time of BigBlue and AlphaGo is a competition of computer versus human players. Since most popular games in eSports are based on team-play, no single agent can beat human players who cooperate. That is where organization of artificial intelligent agents shines - the advancing technology poses questions such as would a team of artificial agent players win in a competitive team game against a team of human players, where teammates in both teams cooperate?

Selected key concepts of the eSports AD of LSMASs are shown in Table 6, accompanied by several chosen examples of objects, agents, and agent organizations of the said AD.

8 Discussion

As has been shown in the previous few examples, various IoE and CPS initiatives can greatly benefit from LSMASs. The main benefit of using an organizational approach (as LSMASs do) to such complex systems is the possibility of modeling higher order organizations which are then considered as single entities. This metaphor allows us to develop even more complex distributed and concurrent systems, by approaching their subsystems as (simplified) entities.

It is simpler to model a situation in which two (possibly higher order) organizations cooperate with each other, then to model all the interacting components of two complex systems. For example, it is easier (for a human) to grasp that two industrial plants A and B need to exchange information to synchronize production pace, then that operating stations X_1 to X_{25} from line L_1 and stations Y_1 to Y_{17} from line L_2 need to send their current production data to a control station G which in turn analyzes the data, generates synchronization deltas and sends them to the adequate operating station. In the end effect, the system that operates the plants might be implemented this way, but on a higher-level of abstraction one might understand the

[2]Statistics data from 19 July 2017, available at https://www.statista.com/statistics/506923/esports-games-number-players-global/

operation quite easier and even detect possibilities for optimization.

9 Conclusion

In this paper we have presented a number of contemporary ADs of LSMASs which are closely related to the IoE and CPSs initiatives. It has been contemplated that an organization-centred LSMASs approach which has been mostly developed during the ModelMMORPG[3] project can highly benefit the modelling and implementation of such complex sociocybernetic systems. Detailed modeling examples of such systems are subject to our future research.

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[3]http://ai.foi.hr/modelmmorpg

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