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Abstract. Considering the growing volume of information and services available on the Web, it has become essential to provide Web sites and applications with tools, such as recommender systems, capable of helping their users to obtain the information and services appropriate to their interests. Due to the complexity of Web adaptation and the ability of multi-agent systems to deal with complex problems, the multi-agent systems technology have been increasing. In this paper, we present a thorough survey of the use of multi-agent-based recommender systems. The results show that the use of multi-agent systems in recommender systems is increasing. The review shows the diversity of applications of multi-agent systems in recommender systems, namely on what concerns to the diversity of domains, different types of approaches, contributing to improving the performance of the recommendation systems.

Keywords: Recommender Systems, Multi-Agent Systems, Survey, Literature Review, State-of-the-art

1 Introduction

The massive growth of information available on the Web makes it difficult for users to get the information they want and when they need it. The Web sites and Web applications are using recommender systems to overcome that problem and so help them to provide the most appropriate information and resources to their visitors and users. Recommending Web pages, documents stored in Web repositories, training material, or other kinds of resources, based on the users' specific interests and preferences, improve the user experience and help users obtain the information of their interests. The complexity of the problem and the distributed nature

of the Web justify the use of the autonomous intelligent agents and multi-agent systems technology approaches.

Considering that the areas of Multi-Agent Systems and Recommender Systems plays an essential role in our research interests, it becomes fundamental to perceive the state of the art of the research domain that brings together the two technologies. As the first step in our research, we started by searching for literature reviews, surveys or state of the art that summarised work already done involving recommender systems and multi-agent systems. To do so, we started our search process by searching google scholar for publications that, in their title, satisfied the following query: *(("recommender systems" OR "recommending systems") AND (review OR survey OR "state of the art"))*. As a result, we obtained several dozens of publications, also stored in libraries like Science Direct, ACM Digital Library, IEEE Xplore and SpringerLink, satisfying that query. However, if we add to the above query the terms: *(multi-agent OR "multi-agent")*, we found no publications. Therefore, we consider helpful and relevant to develop a research work that presents state of the art in the area of multi-agent recommender systems.

In section 2, we introduce the multi-agent and recommender systems basic concepts. In section 3, we present the literature review, starting by explaining the research methodology, following with the search findings and concluding with a review of the selected papers. In section 4, a discussion, comparative analysis and main contributions of the articles are presented. Finally, in the last section, we write the conclusions and future work.

2 Multi-Agent Systems and Recommender Systems: Concepts and definitions

2.1 Defining Agent and Multi-Agent System

According to Wooldridge [1], there is no consensus definition for the concept of an agent. In the literature, it is possible to find multiple definitions [2] and different authors define agent according to the use that each one makes of the term [3]. Franklin and Graesser [3] define an autonomous agent as a system that can perceive their environment and act on it according to its purposes. Wooldridge [1, p. 21] defines an agent as "a computer system located in a given environment and capable of acting

autonomously in that environment for objectives that have been delegated to it". According to Jennings [4] agents: (i) are entities capable of solving problems with well-defined limits and interfaces; (ii) receive as input the state of the environment in which they are located through sensors, acting in that same environment through actuators; (iii) are designed to serve a specific purpose and have determined goals to achieve; (iv) have control over their behaviour and exhibit flexible behaviour in pursuit of their goals; (v) have to be reactive and proactive. Common to all definitions is the concept of autonomy that we can understand as the ability of the agent to fulfil the objectives delegated to him.

A multi-agent system can be defined as a system composed of several autonomous agents, capable of working cooperatively to achieve objectives difficult to achieve by an individual agent or by a monolithic system [5]. Being part of a multi-agent system, agents can cooperate or compete with each other. When interacting with each other cooperatively, they do so directly or through the environment to achieve common goals. However, agents inserted in a multi-agent system may also have their own objectives, and so they will have to negotiate to achieve the system goals.

2.2 Recommender Systems

The exponential growth of information available on the Web makes it difficult for the user to get the information they want and when they need it. To help users in this challenging task websites have been incorporating tools, such as recommender systems, that allow the website adaptation to provide users with improved user experience facilitating the obtention of information that is more accurate and in line with their interests. Recommender systems have two purposes. They can be used to stimulate users to do something, to make a decision, such as the acquisition of a particular good. They can also be used to alleviate information overload in users, making available to them the items that are most in line with their interests.

For Wei, et al. [6] a recommendation can be seen as a reference to an item (a webpage, for example) that is made available to the user looking for the information. For the same authors, a typical recommender system aggregates and directs the recommendations to the appropriate recipients. Wei, et al. [6] consider that recommender systems can provide quality recommendations to users because such recommendations are based

on their past preferences or the preferences of other users with similar interests.

Recommender systems are usually classified according to the way recommendations are generated. Balabanović and Shoham [7] identifies three types of approaches: (i) *content-based*, where the items recommended are those with content similar to the noes that the user has shown preference in the past; (ii) *collaborative*, in which the recommended items are those that users with preferences similar to those of the active user have liked in the past; and (iii) *hybrid approaches*, which combine techniques used in both types of approaches. According to Balabanović and Shoham [7] hybrid approaches, by incorporating "the advantages of both methods while inheriting the disadvantages of neither" [7, p. 66], "can provide more accurate recommendations than pure collaborative and content-based approaches" [8, p. 9]. There are two ways to combine collaborative and content-based algorithms. The algorithms are applied separately, and the results are then combined to produce a set of recommendations (*linear* way). One algorithm is applied first, and the results of this algorithm are after filtered by the other algorithm (*sequential* way).

As referred by Adomavicius et al.,[8], collaborative and content-based approaches only consider the item-user pair, not taking into account the circumstances in which the recommendations occur or other contextual information. According to Rahman [9], many recent studies have been demonstrating that ignoring context information may put the results of the recommendations under suspicion, pointing out that an improvement in the performance of a recommendation system begins with the collection of context-related data. This approach, which, besides the item-user pair, also considers the context information to generate the recommendations, is called a *context-based approach*.

3 Multi-agent Recommender Systems, a survey

As referred above, adapting and personalising web sites and Web applications to users' interests is a complex problem, that justifies the use of multi-agent systems technology approaches in recommender systems. In this section, it is our purpose to carry out a thorough state-of-the-art in the area of a multi-agent based recommender systems.

3.1 Research methodology

For our research work, we searched on *Google Scholar, Science Direct, ACM Digital Library, IEEE Xplore and SpringerLink* publication databases to provide a comprehensive bibliography of research papers on multi-agent based recommender systems. For this research, we follow three main steps:

1. As the first and preliminary step we searched in Google Scholar for literature reviews on recommender systems, using the following query for title search: (*("recommender systems" OR "recommending systems") AND (review OR survey OR "state of the art")),* checking, from the obtained results, which of the founded works are about literature reviews on multi-agent recommender systems approaches;
2. In the second step we searched the referred publication databases for publications that, in their title, met the criteria: (*(recommender OR recommending) AND (multi-agent OR "multi-agent" OR "agent-based")).*
3. Based on the obtained search results we identified and selected a set of papers that, in our opinion, represents the state-of-the-art in multi-agent-based recommender systems, according to purpose and domain application, types of approaches and main contributions.

3.2 Findings

Searching for literature reviews

As we have already mentioned, we started this work by looking for published works on the state-of-the-art in recommender systems and among them, those that focused their research on multi-agent approaches. While, based on searches carried out, it was not possible to find literature reviews focused on multi-agent based recommendation systems, in what concerns to recommender systems, there was an enormous quantity of research work available. From those literature reviews oriented to the recommender systems in general, deserves particular attention, by its meaning and impact, the works of Adomavicius and Tuzhilin, [10] with more than 9000, Bobadilla, Ortega, Hernando, and Gutiérrez [11], Lu, Wu, Mao, Wang, and Zhang [12], and Beel, Gipp, Langer, and Breitinge [13]. We also found many literature reviews targeting specific domains such as tourism [14] or e-learning [15]; about particular approaches, such as content-based [16], collaborative filtering

[17], hybrid [18] and context-based [19]. In more than 500 articles analysed by the previously-referred literature reviews, less than 20 of them rely on recommendation solutions based on the technology of intelligent agents and multi-agent systems.

Searching for publications on multi-agent based recommender systems

In the second step of our research work, we found more than 150 publications that meet the search criteria referred in section 3.1. After a thorough analysis, we select a set of 14 papers that we consider representative of the state-of-the-art in the field of multi-agent-based recommender systems.

E-commerce

E-commerce was one of the areas whose need for recommendation systems was most felt. Lee, Liu, and Lu [20] proposed two intelligent agent-based systems to address two kinds of recommendations: (i) based on customer's purchasing history; and (ii) based on customer's current preferences obtained from customer interactions. For both types of recommendations, the authors proposed two different multi-agent approaches. To address the first type of recommendations, each intelligent and autonomous agent, performing specific tasks, worked together to achieve the overall task of recommending the best items to users. The other approach considers an *interface agent* to deal with the consumer; an *expert agent* to collect external data useful for decision making and a *decision-making agent* that, based on collected data, product database, and user's interests, make suggestions to the consumer through the *interface agent*.

Considering the need to provide personalised recommendation on e-service, e-commerce and e-business sites, Miao, Yang, Fang, and Goh [21] proposed a solution based on fuzzy cognitive agents. Those fuzzy cognitive agents follow an agent knowledge model based on the Fuzzy Cognitive Map (FCM) theory [22], and they support the following behaviours: communication with users; perception of the environment; learning from most recent users' behaviour; and making inferences based on user's current personal preferences, as well as on other user's common preferences, and expert's domain knowledge.

General-purpose.

To deal with information overload and help users find the needed information, Birukov, Blanzieri, and Giorgini [23] proposed *Implicit*, an agent-based recommendation system, where personal agents, representing the user in the system, use data mining techniques to learn and discover user's behaviours. The implicit knowledge that personal agents are capable of extracting from the user's behaviours is used to suggest web page links to the user, or other personal agents. Based on experiments, the authors concluded that their solution could improve the Web search in a more qualitative way.

In their work, Weng, Miao, Goh, Shen, and Gay [24] proposed a solution to overcome the limitations related to the similarity-based recommendation solutions, where similar users' opinions are typically collected by users' agents to make predictions about a new item. The authors proposed a trust-based agent community that incorporates trust in the item recommendations. The authors claim that, compared to other works, their proposal contributes with a trust metric that allows an agent to quantify the degrees of trust it places on others.

Recommender systems are being used to create personalised information based on personal user data. Concerned with users' privacy, Cissée and Albayrak [25] developed an approach to address that problem. In their work, the authors proposed an agent-based privacy-preserving recommender system that allows the generation of recommendations while preserving the participant's privacy. The authors justify the use of a Multi-Agent System (MAS) technology due to agents' properties, such as autonomy, adaptability and the ability to communicate. The novelty of the solution relates to the fact that it addresses the privacy of both users and service providers.

For Huang, Dai, Wei, and Huang [26], the existing recommender systems lack initiative, intelligence, and self-adaptation. To address these disadvantages, the authors presented *APRS*, a personalised recommender system based on a multi-agent system. The architecture of the *APRS* consists of three layers: at the top layer, an *Intelligent User Agent* deals with human-machine interaction; in the middle layer, the *Learning*, *Selection & Recommendation*, and *Analysis & Filter* agents take care of the processing of information, and; at the bottom layer, an *Information Collection Agent* searches for products related to users' interests. The recommendations to the users are generated based on explicit information, through user's feedback, and implicit information, obtained from users' behaviour by the Intelligent User Agent.

In their research work, Morais [27] and Morais et al. [5] proposed a multi-agent-based recommender system where two recommender agents, running two different algorithms, compete with each other to provide the best bid of recommendations to website visitors. Based on an auction, the *user agent* selects the best set of recommendations and forwards it to the user it represents. The proposed system is based on implicit classification of items, and the recommendation algorithms are memory and item-based, and incremental. The results obtained in the offline test phase were later confirmed in real-time tests [28], and showed that this multi-agent approach combining different algorithms is capable of improving user's satisfaction.

Social networking websites (SNS) are bringing people from all walks of life together. Through SNSs people remain in contact and share their feelings. SNSs are using recommender systems to provide information to their users, namely, for marketing and advertising almost every kind of products, most of the times of no interest for the users. To address that problem Moin, Muhamamd, and Martinez-Enriquez [29] designed and developed an adaptable, intelligent agent-based interface to make recommendations based on users friends circle on different SNS site. The system helps a user to get what he needs from his social Web site without wasting time in dealing with complex search procedures.

E-tourism.

Recommender systems are increasingly used in e-Tourism generally with the purpose to recommend appropriate destinations to tourists. In their work, Batet, Moreno, Sánchez, Isern, and Valls [30] present *Turist@*, an agent-based recommender system to address a less explored problem in the literature: recommend cultural and leisure activities to the tourist when he has already arrived at the destination. Turist@ was implemented as a multi-agent system, composed with four types of agents: user agents, that represents the tourist in the system and provides a graphical interface to the users; activity agents, one for each kind of activity; broker agent, a gateway between user agents and activity agents; recommendation agents, whose purpose is to recommend activities to tourists according to their interests. The recommender agent follows a hybrid approach, incorporating both content-based and collaborative recommendation strategies. Another significant contribution of this work was the system modularity. That modularity allows the addition of new activity agents in runtime, and the possibility of splitting the system into several

parts to be executed on the server or client sides, making it possible to run in lightweight devices such as smartphones.

E-learning.

E-learning is another area of where the use of recommender systems is growing. In their work, Rodríguez, Duque, and Ovalle [31] presented a knowledge-based recommender system (KRS) based on K-means clustering technique. According to the authors, the experiments shown that the KRS can retrieve relevant LO as well as improve the recommendation precision.

Ubiquitous learning (u-learning), allows learning to take place independently of time and place. Salazar, Ovalle, and Duque [32] proposed a multi-agent context-aware u-learning system aimed to offer functionalities such as: context-aware learning planning, personalised course evaluation, search and selection of learning objects according to student profile, search for thematic learning assistants, and access of current context-aware collaborative learning activities. Results demonstrate that this kind of approaches may improve learning processes.

Financial markets.

Financial markets are another well-known area of application for multi-agent systems and recommender systems. In their approach Taghavi, Bakhtiyari, and Scavino [33] proposed a multi-agent recommender system for computational investing. The solution uses a hybrid filtering technique to recommend the most profitable stocks at the right time, according to the investor's interest. The novelty of their solution is a new way of combining content-based and collaborative filtering, different from the *linear* and *sequential* way.

Internet of Things (IoT).

In the Internet of Things (IoT) environments, the recommendation of useful things is an essential task for many applications such as urban computing, smart cities or healthcare. In their paper, Twardowski and Ryzko [34] present MAS that generates personalised recommendations on mobile devices, based on contextual data acquired from the IoT.

Energy Management.

Multi-agent systems are common solutions in power and energy systems, [35] propose case-based reasoning (CBR) multi-agent recommender system for intelligent energy management in buildings. In their

approach, the system recommends the amount of energy reduction that should be applied at the moment, based on similar past cases. The complexity and dynamics of power and energy systems have led researchers to use an agent-based solution. The proposed architecture, relies on multiple independent MAS, each dealing with its part of the energy system. Interoperability between the different multi-agent systems is ensured through ontologies. The agents were implemented on the JADE platform.

4 Discussion

The research work carried out showed the increasing presence of recommender systems in websites and Web applications, as well as a growing number of recommendation solutions based on intelligent agent technology and multi-agent systems. As already mentioned, when we searched for published literature reviews on Recommender Systems, we found plenty of them. However, none is found exclusively dedicated to Multi-agent based Recommender Systems, which seems to be a demonstration of the interest of this work.

In table 1, we present a comparing overview of the reviewed research papers according to the following dimensions: application domain; main contributions; recommender approaches, and theoretical vs practical papers. Concerning application domains, most of them were categorised as "general purpose" in the sense that the proposed solutions address problems like information overload or website personalisation, and are domain application-independent. E-commerce, E-learning, and E-tourism are areas of application where we found many research works, and we select some of them for our review. Most of the works reviewed are practical applications, most of them being developed with JADE[1] framework, and present results of the experimental tests carried out. Concerning the types of recommendation approaches, most of the works follow collaborative approaches, being significant the presence of hybrid approaches, which is not surprising given the typical characteristics of multi-agent systems. Regarding the contributions of each paper, table 1 is exhaustive in this matter. However, it is essential to highlight the aspects related to

[1] http://jade.tilab.com/

the modularity of the systems, resulting from the use of multi-agent systems technology, as well as the proposed solutions to overcome issues related to privacy and trust.

Paper	App. domain	Main contribution	Recommender approach	
Lee, Liu, and Lu [20]	E-commerce	One system uses implicit information (users' past behaviour); the other uses explicit information) users' feedback)	Collaborative: Content-based	Prac
Birukov, Blanzieri, & Giorgini [23]	General-purpose	Implicit knowledge based on data mining technique: Combines search engine results with suggestions from community members	Collaborative	A p show
Huang, Dai, Wei, & Huang [26]	General-purpose	based on explicit (users feedback) and implicit (users behaviour information	hybrid	Theo
Weng et al.[24]	General-purpose	Incorporation of trust; Contributes with a trust metric that allows an agent to quantify the degrees of trust it places on others	Collaborative	Simu
Miao, Yang, Fang, & Goh [21]	E-commerce	Implicit an explicit information; Use Fuzzy Cognitive Maps; Personalised recommendations based on: current user's preferences; general user's common preferences and the expert's knowledge	Collaborative	A p show Mul
Cissée & Albayrak [25]	General-purpose	Addresses privacy-preserving in Recommender systems	Collaborative	A p show
Batet, Moreno, Sánchez, Isern, & Valls [30]	E-tourism	System Modularity; addition of new activities agents in runtime; possibility of splitting the system into several parts, making it possible to run in lightweight devices such as smartphones	Hybrid	Prac Mul
Morais et al. [5] Neto and Morais [28],	General-purpose	Market-based approach; Auction (sealed-bid auction protocol); Item-based collaborative filtering; implicit information; System modularity allows the addition of new recommendation agents in runtime	Collaborative	Prot on r Mul
Taghavi, Bakhtiyari, & Scavino [33]	Financial Markets	A new way of combining collaborative and content-based algorithms	Hybrid	Theo
Moin, Muhamamd, & Martinez-Enriquez [29]	General-purpose	Recommendations based on social circle	Collaborative	And show
Rodríguez et al. [31]	E-learning	Based on the K-means clustering technique;	Knowledge-based	A p show
Salazar, Ovalle, & Duque [32]	E-learning	Context-aware; u-learning; Allows students' interaction within the e-learning system; allows teachers to know the students' interest within the virtual course.	Context-based	A pr show
Twardowski & Ryzko [34]	IoT	Based on contextual data acquired on IoT	Context-based	Theo
Pinto et al. [35]	Energy Management	Proposes a MASs Society, composed by de different MAS. Ontologies support the interoperability among the MAS. Uses k-NN clustering algorithm.	Collaborative	Test JAD

Table 1. Comparison of reviewed publications according to the domain of application, contributions, type of approach and whether they concern pr

[2] http://www.jiac.de/

5 Conclusion and future work

Helping users to obtain the information or services they need and when they need, or to alleviate them from information overload, are complex tasks that may be overcome by incorporating recommender systems in Web sites and Web applications. Due to the distributed nature of the internet and their propensity to assist in solving complex problems, the multi-agent systems appear as support for recommender systems. In our survey, we identify and describe several multi-agent-based approaches applied to recommender systems in areas of application as diverse as the financial markets, energy management, e-commerce, e-learning, social networks, tourism and IoT, as shown in table 1.

6 References

[1] M. Wooldridge, "An Introduction to MultiAgent Systems - Second Edition by Michael Wooldridge Published May 2009 by John Wiley & Sons ISBN-10: 0470519460 ISBN-13: 978-0470519462," *2nd Edition. John Wiley & Sons, Inc.* 2009.

[2] A. Dorri, S. Kanhere, and R. Jurdak, "Multi-Agent Systems: A survey," *IEEE Access*, vol. 6, pp. 28573--28593, 2018.

[3] S. Franklin and A. Graesser, "Is it an Agent, or just a Program?:A Taxonomy for Autonomous Agents," in *Proceedings of the Third InternationalWorkshop on Agent Theories, Architectures, and Languages*, 1996, pp. 21–36.

[4] N. R. Jennings, "On agent-based software engineering," *Artif. Intell.*, vol. 117, no. 2, pp. 277–296, 2000.

[5] A. J. Morais, E. Oliveira, and A. M. Jorge, "A multi-agent recommender system," in *Advances in Intelligent and Soft Computing*, 2012, vol. 151 AISC, pp. 281–288.

[6] Y. A. N. Z. Wei, L. U. C. Moreau, and N. R. Jennings, "A Market-Based Approach to Recommender Systems," vol. 23, no. 3, pp. 227–266, 2005.

[7] M. Balabanović and Y. Shoham, "Fab: content-based, collaborative recommendation," *Commun. ACM*, vol. 40, no. 3, pp. 66–72, 1997.

[8] G. Adomavicius, R. Sankaranarayanan, S. Sen, and A. Tuzhilin, "Incorporating contextual information in recommender systems using a multidimensional approach," *ACM Trans. Inf. Syst.*, vol. 23, no. 1, pp. 103–145, 2005.

[9] M. M. Rahman, "Contextual Recommender Systems Using a Multidimensional Approach," *Int. J. Intell. Inf. Syst.*, vol. 2, no. 4, p. 55, 2013.

[10] G. Adomavicius and A. Tuzhilin, "Toward the Next Generation of Recommender Systems: a Survey of the State of the Art and Possible Extensions," *IEEE Trans. Knowl. Data Eng.*, vol. 17, no. 6, pp. 734–749, 2005.

[11] J. Bobadilla, F. Ortega, A. Hernando, and A. Gutiérrez, "Recommender systems survey," *Knowledge-Based Syst.*, vol. 46, pp. 109–132, 2013.

[12] J. Lu, D. Wu, M. Mao, W. Wang, and G. Zhang, "Recommender system application developments: A survey," *Decis. Support Syst.*, vol. 74, 2015.

[13] J. Beel, B. Gipp, S. Langer, and C. Breitinger, "Research-paper recommender systems: a literature survey," *Int. J. Digit. Libr.*, vol. 17, no. 4, pp. 305–338, Nov. 2016.

[14] J. Borràs, A. Moreno, and A. Valls, "Intelligent tourism recommender systems: A survey," *Expert Syst. Appl.*, vol. 41, no. 16, pp. 7370–7389, Nov. 2014.

[15] A. Klašnja-Milićević, M. Ivanović, and A. Nanopoulos, "Recommender systems in e-learning environments: a survey of the state-of-the-art and possible extensions," *Artif. Intell. Rev.*, vol. 44, no. 4, pp. 571–604, 2015.

[16] P. Lops, M. de Gemmis, and G. Semeraro, "Content-based Recommender Systems: State of the Art and Trends," in *Recommender Systems Handbook*, F. Ricci, L. Rokach,

B. Shapira, and P. B. Kantor, Eds. Boston, MA: Springer US, 2011, pp. 73–105.
[17] X. Yang, Y. Guo, Y. Liu, and H. Steck, "A survey of collaborative filtering based social recommender systems," *Comput. Commun.*, vol. 41, pp. 1–10, Mar. 2014.
[18] R. Burke, "Hybrid Recommender Systems: Survey and Experiments," *User Model. User-adapt. Interact.*, vol. 12, no. 4, pp. 331–370, Nov. 2002.
[19] K. Verbert *et al.*, "Context-Aware Recommender Systems for Learning: A Survey and Future Challenges," *IEEE Trans. Learn. Technol.*, vol. 5, no. 4, pp. 318–335, 2012.
[20] W.-P. Lee, C.-H. Liu, and C.-C. Lu, "Intelligent agent-based systems for personalized recommendations in Internet commerce," *Expert Syst. Appl.*, vol. 22, no. 4, pp. 275–284, May 2002.
[21] C. Miao, Q. Yang, H. Fang, and A. Goh, "A cognitive approach for agent-based personalized recommendation," *Knowledge-Based Syst.*, vol. 20, no. 4, pp. 397–405, May 2007.
[22] B. Kosko, "Fuzzy cognitive maps," *Int. J. Man. Mach. Stud.*, vol. 24, no. 1, pp. 65–75, 1986.
[23] A. Birukov, E. Blanzieri, and P. Giorgini, "Implicit: An Agent-based Recommendation System for Web Search," in *Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multiagent Systems*, 2005, pp. 618–624.
[24] J. Weng, C. Miao, A. Goh, Z. Shen, and R. Gay, "Trust-based Agent Community for Collaborative Recommendation," in *Proceedings of the Fifth International Joint Conference on Autonomous Agents and Multiagent Systems*, 2006, pp. 1260–1262.
[25] R. Cissée and S. Albayrak, "An Agent-based Approach for Privacy-preserving Recommender Systems," in *Proceedings of the 6th International Joint Conference on Autonomous Agents and Multiagent Systems*, 2007, pp. 182:1--182:8.
[26] L. Huang, L. Dai, Y. Wei, and M. Huang, "A Personalized Recommendation System Based on Multi-agent," in *2008 Second International Conference on Genetic and Evolutionary Computing*, 2008, pp. 223–226.
[27] A. J. Morais, "A Multi-agent Approach for Web Adaptation," in *7th International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS 2009)*, 2009, pp. 349–355.
[28] J. Neto and A. J. Morais, "Multi-agent web recommendations," in *Advances in Intelligent Systems and Computing*, 2014, vol. 290, pp. 235–242.
[29] S. Moin, A. Muhamamd, and A. M. Martinez-Enriquez, "Agent based mobile recommender system," in *2014 11th International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE)*, 2014, pp. 1–6.
[30] M. Batet, A. Moreno, D. Sánchez, D. Isern, and A. Valls, "Turist@: Agent-based personalised recommendation of tourist activities," *Expert Syst. Appl.*, vol. 39, no. 8, pp. 7319–7329, 2012.
[31] P. Rodríguez, N. Duque, and D. A. Ovalle, "Multi-agent System for Knowledge-Based Recommendation of Learning Objects Using Metadata Clustering," in *Highlights of Practical Applications of Agents, Multi-Agent Systems, and Sustainability - The PAAMS Collection*, 2015, pp. 356–364.
[32] O. M. Salazar, D. A. Ovalle, and N. D. Duque, "Adaptive and Personalized Educational Ubiquitous Multi-Agent System Using Context-Awareness Services and Mobile Devices," in *Learning and Collaboration Technologies*, 2015, pp. 301–312.
[33] M. Taghavi, K. Bakhtiyari, and E. Scavino, "Agent-based Computational Investing Recommender System," in *Proceedings of the 7th ACM Conference on Recommender Systems*, 2013, pp. 455–458.
[34] B. Twardowski and D. Ryzko, "IoT and Context-Aware Mobile Recommendations Using Multi-agent Systems," in *2015 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT)*, 2015, vol. 1, pp. 33–40.

[35] T. Pinto, R. Faia, M. Navarro-Caceres, G. Santos, J. M. Corchado, and Z. Vale, “Multi-agent-based CBR recommender system for intelligent energy management in buildings,” *IEEE Syst. J.*, vol. 13, no. 1, pp. 1084–1095, Mar. 2019.