Multi-agent Approach to Designing an Intelligent Virtual Agent for Collaborative Virtual Environments

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Abstract. Increasing interest in Collaborative Virtual Environments (CVEs) in different applications has imposed new requirements on the design of IVAs. On the one hand, these requirements include cognitive abilities, and on the other hand social and communication behaviour. The use of a Multi-Agent System (MAS) has been a successful approach to address the variety of evolving abilities needed by an IVA. In this paper, we propose a MAS approach to design an IVA that is able to collaborate with humans in a virtual environment. The proposed model simulates humans by including input, output and processing modules. In addition, the model coordinates the IVA's verbal and non-verbal communication to convey its internal state while achieving a collaborative task.

Keywords: Collaborative Environment, Multi-agent System, Intelligent Virtual Agent, Human-Agent Collaboration, Multimodal Communication

1 Introduction

A Collaborative Virtual Environment (CVE) has been defined as "a computer-based, distributed, virtual space or set of places. In such places, people can meet and interact with others, with agents or with virtual objects." P.5 [1]. CVEs have been used as a mediation tool to facilitate the human-human collaboration across disparate spaces. Moreover, the concept of CVE includes the collaboration between human participants and virtual entities such as Intelligent Virtual Agents (IVAs). IVAs refer to humanoid virtual entities that simulate humans in their abilities and characteristics. CVEs have been used in multiple fields depending on their purpose of use, such as, business [2], entertainment, learning [3], training [4], medicine [5] and dancing [6].

The versatility of CVE usage in various and sophisticated fields requires, on one hand, IVAs to play various roles such as instructing, monitoring, counselling and teamworking. On the other hand, versatility demands that IVAs have multiple capabilities including reasoning, communication, planning, argumentation and/or negotiation. Owing to the fact that IVAs need to take complex decisions and perform sophisticated actions, there is a need for real-time processing to present satisfactory performance and believable behaviour. While, the use of the Belief-Desire-Intention (BDI) single agent approach [7] has been attractive to researchers because of its simplicity and ability to trigger agents' behaviour, BDI-based single agent alone falls short in handling sophisticated applications that require IVAs to do more than achieve desires to reach determined intentions.

To address the challenge of developing believable IVAs in complex CVEs, the increasing functionality of BDI-based single agent has been distributed to a group of agents that coordinate their behaviour towards achieving the overall desire (goal state). This group of agents is known as a Multi-Agent System (MAS). Over the past decade, MAS has been the subject of much AI research as it provides a high level of abstraction in reasoning and modelling [8]. MAS has been used to design Robots [9] and IVAs [10]. MAS has been introduced to improve the capabilities of the agents. These capabilities included cognitive skills such as decision-making and planning, or behavioral skills such as animations.

A number of studies used MAS to manage the behaviour of IVAs [11] [12] [13]. These studies have considered either the external behaviour [13] of IVAs in the virtual environment or the internal behaviour with more interest on decision-making and planning [14]. The main trend of MAS-based IVA has been the generation of behaviour to respond to a static virtual environment or other IVA. Regarding the use of MAS in the design of IVAs that are able to collaborate with humans in a CVE, the previous studies fall short in developing MAS-based IVAs that are able to form a team with human users to achieve a collaborative activity because they lack the ability to perceive, interpret, adapt and/or respond appropriately in real-time to the human's reasoning and actions [13].

This paper presents an MAS that helps to manage an IVA while collaborating with a human user in a CVE. The contributions of the proposed MAS are: first, it couples the human verbal and non-verbal responses to form input to the agent planner. Human responses represent dynamic input to the IVA. Second, the MAS manages the cognitive abilities of the collaborative IVA to make a decision about the next step. Finally, the MAS manages the verbal and the non-verbal communication of the IVA to express its internal state and decisions.

The paper is organized as follows. Trends in designing IVA for CVE are presented in section 2. Section 3 introduces the requirements needed in CVE that necessitate a special design for IVAs. Section 4 presents the proposed MAS model. Evaluation of the proposed model is presented in section 5. Discussion of the evaluation comes in section 6. Finally, section 7 presents conclusions and future work.

1.1 Why MAS for Designing IVA for CVE?

There are a number of reasons why the MAS approach is superior to the single BDI-agent approach when it comes to designing IVAs for CVE [15]. The first reason is the simplicity; although the single agent systems might be considered simpler than multi-agent systems, the opposite is in fact the case. Distributing control among multiple agents simplifies the design of each agent. The second reason is the Parallelism; having multiple agents tends to speed up system overall performance by providing a method for parallel computation. Another reason is robustness; distributing the responsibilities among interacting agents is more likely to improve fail tolerance of the system. Last but not least, compared to a single agent approach, MAS efficiently control the various components of CVE with different goals and resources.

2 Trends in Designing IVA for CVE

Over the last decade a number of studies have aimed at coupling MAS and IVAs. Within these studies, we can identify three trends of utilizing MASs in IVAs using MAS to manage the physical behaviour of IVAs, MAS to manage the cognitive capabilities of IVAs and Hybrid approaches that combine the cognitive capabilities and the physical behaviour.

2.1 MAS to Manage the Physical Behaviour of IVAs

Studies that fall under the first trend include studies that use MAS for IVA animation and social interaction (e.g. [10]). Grimaldo et al. [13] presented a multi-agent framework to animate group of IVAs to balance between task-oriented and social behaviour. The presented framework permitted agents to include social tasks to produce realistic behavioural animations. To verify the framework functionally, the authors used a 3D dynamic environment simulating a virtual university bar, where a group of IVAs representing waiters and customers interacted and showed social behaviour. Another study that used a MAS in animating an IVA, Barella et al. [16] separated IVA visualization from intelligence and presented a social-oriented MAS framework to simulate a group of IVAs in a social situation. The agent's beliefs, plans and decision-making were defined in a specification file.

2.2 MAS to Manage the Cognitive Capabilities of IVAs

Following the second trend, in the study of Amo et al. [14] an MAS was integrated into IVAs to create autonomous intelligent agents guided by their own motivations, which live in a virtual world inhabited by other similar agents. The use of MAS concentrated on the cognitive and social role of each individual agent.

2.3 Hybrid Approaches that Combine the Cognitive Capabilities and the Physical Behaviour.

The previous two trends resulted in a gap in the research because the separation of the physical and cognitive aspects of an IVA did not allow coordination between the internal and external behaviours of the IVA. To address this gap in research, Oijen and Dignum [17] proposed a communication model for IVAs. This model tries to balance between being cognitively efficient in managing MAS communication on the one hand and physically believable realizations of human-like interactions on the other hand. The authors found that it was beneficial to use middleware to join the reasoning layer of MAS with the physical interaction of the IVA. The result shows a successful agent-agent communication in a dynamic VE. However, the study [17] does not address IVA-Human communication.

As another example of the hybrid approach of using MAS in IVA, Buche et al. [18] proposed a model called MASCARET to organize the interaction between IVAs and an avatar that represents a human. MASCARET aimed to provide the IVA with physical, cognitive and social abilities to collaborate with a human avatar in a virtual training situation. However, the proposed model did not demonstrate the nature of the communication that may exist between the collaborative agents and an avatar. In addition, the agent was not designed using an MAS. In other research that used MAS to manage IVA behaviour, Cai et al. [19] presented a multi-agent framework to design an IVA in an underground coalmine VE. The framework improved the ability of the IVA to interact with the dynamic surroundings of the virtual coalmine. Similar to the study of Buche et al., this study did not include a communication model between the IVA and the other virtual entities or human users.

3 Requirements for IVAs in CVE

The modern sophisticated CVE imposes requirements on designing enclosed IVAs. We distinguish the following requirements for IVA in CVE:

1. **Perceiving autonomously the teammate's action**…CVE requires IVAs to receive teammates' actions/behaviour autonomously as well as perceive the meaning of the received actions in a specific situation. For instance, moving away from the target spot after taking a decision may mean giving way to the teammate to take his turn, whereas before taking a decision moving away may mean unwillingness to take action at all.
2. **Perceiving autonomously the teammate's requests/prompts**…In addition to perceiving the meaning of teammates' action, IVAs should be able to convert teammates' verbal messages into a meaningful notation that builds on the IVAs' understanding of the teammates' intentions.
3. **Working toward the task**…IVAs' focus needs to be directed to achieve the shared task. IVAs should have a main strategy to reach the common task. Despite the dynamic

nature of CVE, IVAs have to stay focused on the target task and the best way to achieve it.
4. **Adaptability to changing teammate's decision**...Although IVAs should have a prior plan to achieve the shared task, IVAs have to adapt their plans in real-time to match the changes in teammates' decisions.
5. **Observable non-verbal behaviour**…IVAs need to express the inner state physically through the selection of the appropriate animation to the current situation. The selected animation should be complementary with the verbal communication to convey the IVA's intention.
6. **Believable/Appropriate verbal response**… is another communication channel that an IVA should master. The verbal responses should be used either to prompt the human teammate to take a certain action or defend the IVA's viewpoint in achieving the task.

4 The Proposed MAS Model

In order to fulfil the requirements of an IVA in a dynamic CVE, all of the above requirements need to be embodied and contained within a single IVA; in addition, the IVA should be able to handle parallel processing as the inputs from a CVE have the characteristics of being variable and dynamic. Creating an IVA that is able to manage its verbal and non-verbal behaviour is a challenging task [20]. To address these challenges, a MAS approach was utilized to design the IVA. MAS consists of a group of autonomous agents that work independently on their own part of the problem towards solving a bigger problem. Therefore, this feature could be used to break down the complex work into smaller tasks that a single agent can achieve. The proposed model used this feature to break down the process of receiving human action, planning for the next step and coordinating the verbal and non-verbal responses. The proposed MAS model simulates the human brain in receiving stimuli, processing the input data, managing the physical behaviour in VEs. The model consists of three modules: reception, processing and communication modules, as shown in Figure 1. Each module includes a manager agent to coordinate the flow of information from this module to another one. The main components of the proposed model are briefly described as follows:

- The reception module is responsible for receiving both the actions of the human user as well as the verbal messages of the human teammate. It consists of the following agents:
  - *Sensor Agent:* receives the stimuli from the surrounding CVE, filters these stimuli to determine which ones are related to the current task, perceives the meaning of these stimuli using a rule-based technique and finally passes the filtered action committed by the human to the *Reception Manager Agent*. *Sensor agent* was proposed to achieve the first requirement of perceiving autonomously teammate's action.

- *Receiver Agent:* was presented to fulfil the second requirement of perceiving autonomously the teammate's verbal communication. The *Receiver Agent* was designed to receive the verbal messages from human teammates, encode the possible intention behind that message using a rule-based technique and finally passes the digested message to *Reception Manager Agent*. These messages may include requests from humans to IVA to perform specific actions or replies to the IVA's requests. *Reception Manager Agent*: its role is to couple both verbal and non-verbal responses of the human teammate in order to give the *Planner Agent* in the processing module a picture about the humans' behaviour. A case-based technique is used to couple verbal and non-verbal responses and to deduce an appropriate conclusion. The case-based technique consists of a group of cases that include both verbal and non-verbal responses of the teammate along with conclusion/label for this case. For instance, if the teammate moves away from the working area and says "be right back", that would be perceived by *Motor Agent* (see below) that the teammate is not interested in completing the shared task; however, coupling the action with verbal responses and matching existing cases, *Reception Manager Agent* would conclude that the teammate is going to be back, hence the processing module should suspend planning for the next step, until the teammate gets back.

- The roles of the processing module are to contrast the human's verbal reply along with his /her action in order to figure out the human's commitment to collaborate, plan for the next step the agent should take and pass the result to the communication module.

  - *Manager Agent*: To achieve the requirement of working toward the task, the *Manager Agent* behaves like the brain in humans. It receives responses from the *Reception Manager Agent*, forwards the decision made by the *Planner Agent* to the *Communication Manager Agent* and determines turn-taking in the collaborative activity. *Manager Agent* may manage turn-taking based on succession or through negotiation between collaborators. In the implemented scenario (section 5.1), successive turn-taking was followed where both IVAs and humans take a turn to make a decision after the other teammate finishes taking his/her own decision.
  - *Planner Agent*: calculates the next step that the IVA should take. Next step calculation is based on a group of rules and beliefs that are located in the Rules and Knowledge Base. These rules may capture the best time to execute the task, the shortest path, and so on. The rules are continuously updated according to the behaviour of the teammate and the changes in the dynamic CVE. The continuous update to these rules was proposed to achieve the requirement of adaptability to changes in the teammate's decision.

- The aim of the Communication module is to translate an IVA's internal state and intentions into a physical behaviour. The behaviour includes coordinated verbal and non-verbal communication to give more believability to the IVA's behaviour.

– *Communication Manager Agent*: works like the hub in the communication module. It receives the message from the *Manager Agent* and decides which agent is more suitable to express the IVA's reaction to the human teammate's behaviour. In addition, the *Communication Manager Agent* will pass the values given in the IVA's responses such as location coordinates, numbers, name agreement/disagreement and so on. The *Communication Manager Agent* works is a similar way to the *Reception Manager Agent* in organizing both the verbal and non-verbal response.
– *Replying Agent:* when the *Communication Manager Agent* calls it, the *Replying Agent* selects the most appropriate message template from *Message Norm DB* and fills in the template with the values passed by *Communication Manager Agent*.
– *Motor Agent:* is responsible for the physical behaviour of the IVA. The physical behaviour includes animations, gestures and physical movements. The *Motor Agent* will select a suitable animation from the animation DB, and use the data fed by the *Communication Manager Agent* to generate appropriate responses that are related to the context situation.

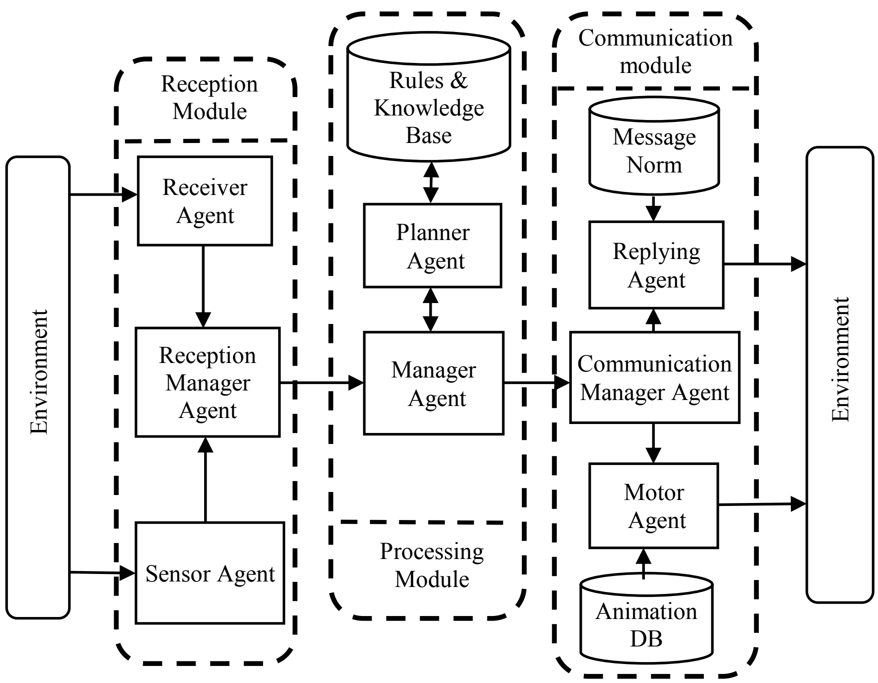

Fig. 1. The proposed MAS approach to design IVA

5 Evaluation

In order to evaluate the model at the functional level we re-implemented a scenario using our MAS architecture, where both the human and an IVA must collaborate to achieve a specific task. For testing purposes, we used human patterns of communication behaviour that we had extracted from a previous study using the same scenario [21] to simulate human behaviour and reactions. This would enable us to verify that our MAS-based IVA was communicating similarly to our original non-MAS IVA before re-running studies with human participants who are more difficult, costly and time-consuming to access. Our new MAS-designed IVA provides a more scalable design that better manages the cognitive and behavioural aspects of our IVA while allowing both to be integrated. The scenario, method of evaluation and results are presented below.

5.1 Scenario

In the scenario, the human and the agent must collaborate together to trap an animal for scientific research. The animal is surrounded by eight regions (four pairs of regions), see Figure 2. Both the human and the agent should select one region at a time to build a fence around the animal, and then observe each other's action, i.e. non-verbal behaviour. Meanwhile, they exchange verbal messages to convey their intention and request a recommended selection from the other counterpart. The human and the agent should be able to select only neighbouring regions. A neighbouring region is one that is before or after the already selected regions. We call the process of selecting each pair of regions out of the four pairs a cycle. That is to say, there are four cycles. Each cycle includes the human and the agent selecting a region. Except for the first cycle, they should exchange requests and replies verbally.

In the beginning, the human selects one region. After choosing one region, the two possible selections will be the two neighbouring regions that are directly before and after the

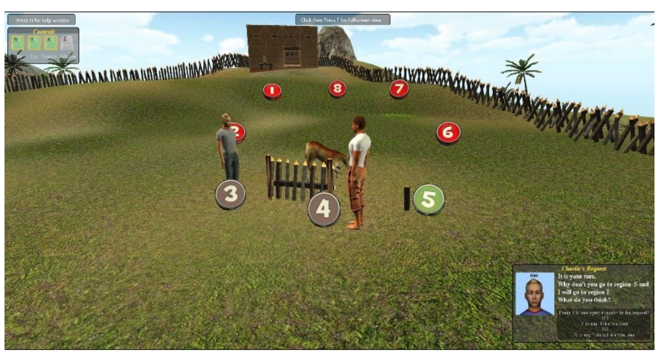

Fig. 2. A Snapshot from the implementation of MAS model for IVA

selected region. In his turn, the virtual agent will observe the surrounding environment, human action (non-verbal communication), any request from the human (verbal communication) and finally from his plan to select the decision to take in the next step. Before the agent selects a region, he will verbally reply to the human's request. A fence will be built automatically between the two selected regions and the turn will go back to the human. Dividing the data collected from the log files during the task into cycles helps to understand the effect of the continuous communication on the achievement in successive cycles.

5.2 Integrating Human Patterns

The technique of integrating the human factors such as decisions, actions and perception in avatars and IVAs has been used before for testing and simulation purposes [22]. This technique aims to model the influential human factors. In order to functionally evaluate the proposed MAS which is integrated into an IVA, we used human factors extracted from a previous study and formed patterns for human behaviour. In the previous study, real human users had to collaborate with the IVA to complete the task described in 5.1 in a VE. We determined which factors in the human's behaviour are influential while interacting with the teammate IVA. These influential factors were tracked and saved in log files. Out of sixty-six human users, we extracted six patterns that represent the general directions of humans who used the implemented scenario in a previous study. These six patterns were used to simulate possible human behaviour in order to examine IVA reactions.

5.3 The Output

The extracted human patterns were used to show the interaction of the IVA with possible human behaviour. The interaction between the human and IVA was registered in a log file to diagnose the flow of actions and communication. Two factors were considered for analysis: the IVA's acceptance of the human's request and the human's acceptance of the IVA's request.

The result of running the scenario shows that the IVA's acceptance of the humans' requests continuously increased over the cycles, see Figure 3. The increase ranged from 16.67 % in the first cycle to 83.33% in the third cycle. Moreover, the results show that the human's acceptance of the IVA's requests increased over the cycles. The increase ranged from 33.33 % in the first cycle to 66.66% in the last cycle.

6 Discussion

In this paper, we have presented a MAS approach to design IVAs that meets a number of requirements specific for CVEs, see section 3. This design simulates humans in separating input, output and processing modules. On one hand, the input module coordinates verbal

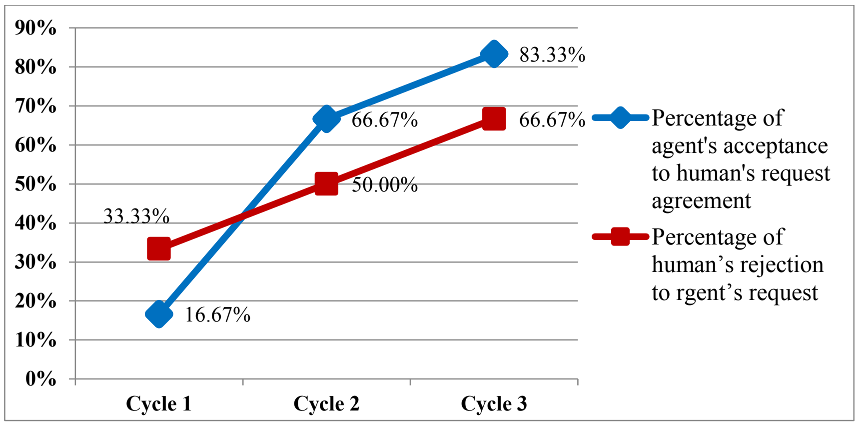

Fig. 3. Result interaction between IVA and human behaviour patterns

and non-verbal responses from the human teammate. One the other hand, the output module coordinates the response of the IVA to express its decisions and requests to the teammate. In addition, the processing module takes into account the teammate's actions and requests before planning for the next step. Furthermore, the proposed MAS-based IVA addresses the issue of coordinating the internal side of IVAs as represented in the intellectual behaviour and the external side of IVAs as represented in the social and animation behaviour. This coordination was the focus of the proposed MAS to develop a believable IVA behaviour in a real-time collaborative situation where decisions and communication should be dependent on the teammate's own decisions and communication. Another feature our MAS model focused on was the coordination between the verbal and non-verbal communication in a human-like manner.

Concerning the functional-level evaluation, the result of running the virtual scenario that includes the IVA and the human patterns showed that the IVA successfully completed the collaborative task. The MAS-based IVA was able to adapt to different behaviours coded in the human patterns file. The behaviours tested included matching or opposite decisions to the IVA's plan. In both cases, the IVA was able to re-plan for the next step. Furthermore, to evaluate the performance of the proposed MAS in managing the flow of communication between the IVA and human patterns, we logged the flow of requests and replies between the human-IVA teammates. The result shows that the ratios of mutual acceptance between the IVA and the patterns that represent human behaviour increased over the following cycles. This consecutive increase in the ratio of requests acceptance represented continuous increase in the mutual understanding of the plan of the human teammate. This result is consistent with other studies that stressed the importance of communication as a crucial requirement for developing common understanding between team members [23].

7 Conclusion and Future Work

This paper presented the requirements for an IVA to successfully function in a CVE. In order to fulfil these requirements, an IVA design using a MAS was proposed. The proposed MAS exhibited a number of features, including parallel and distributed processing, a manager agent for both verbal and non-verbal communication and balancing between the reasoning capabilities of IVAs and its animated behaviour. Despite the fact that numerous issues still need to be addressed for the system to be used in a more complex situation, the initial implementation shows that the design is robust and IVA's behaviour is plausible. Besides proving to be a successful tool to manage the behaviour of IVAs, MAS could be extended to include further capabilities to IVA by adding additional modules with agents. Future work will include re-implementing the proposed MAS using different technologies such as MAS programming languages (e.g. Jason, Jade) with supporting game engine platform (e.g. UT game engine) and in a less constrained scenario.

REFERENCES

1. Snowdon, D., Churchill, E., Munro, A.: Collaborative Virtual Environments: Digital Spaces and Places for CSCW: An Introduction. In: Churchill, E., Snowdon, D., Munro, A. (eds.) Collaborative Virtual Environments, pp. 3-17. Springer London (2001)
2. Nass, C., Fogg, B.J., Moon, Y.: Can computers be teammates? International Journal of Human-Computer Studies 45, 669-678 (1996)
3. Giraldo, F., María, À., Rojas, J., Esteban, P., Trefftz, H.: Collaborative Virtual Environments for Teaching Physics. In: Iskander, M. (ed.) Innovations in E-learning, Instruction Technology, Assessment, and Engineering Education, pp. 89-93. Springer Netherlands (2007)
4. Holmberg, N., Wunsche, B., Tempero, E.: A framework for interactive web-based visualization. In: the 7th Australasian User interface conference (AUIC '06), pp. 137–144. Australian Computer Society, Inc., (2006)
5. Chee, Y.S., Hooi, C.M.: C-VISions: socialized learning through collaborative, virtual, interactive simulations. Proceedings of the Conference on Computer Support for Collaborative Learning: Foundations for a CSCL Community, pp. 687-696. International Society of the Learning Sciences, Boulder, Colorado (2002)
6. Zhenyu, Y., Bin, Y., Wanmin, W., Nahrstedt, K., Diankov, R., Bajscy, R.: A Study of Collaborative Dancing in Tele-immersive Environments. In: Eighth IEEE International Symposium on Multimedia (ISM'06), pp. 177-184. (2006)
7. Bratman, M.E.: Intentions, Plans and Practical Reason. Harvard University Press (1987)
8. Anastassakis, G., Ritchings, T., Panayiotopoulos, T.: Multi-agent Systems as Intelligent Virtual Environments. In: Baader, F., Brewka, G., Eiter, T. (eds.) KI 2001: Advances in Artificial Intelligence, vol. 2174, pp. 381-395. Springer Berlin Heidelberg (2001)
9. Rockel, S., Klimentjew, D., Jianwei, Z.: A multi-robot platform for mobile robots - A novel evaluation and development approach with multi-agent technology. In: IEEE Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI '12), pp. 470-477. (2012)

10. Rodríguez, S., de Paz, Y., Bajo, J., Corchado, J.M.: Social-based planning model for multiagent systems. Expert Systems with Applications 38, 13005-13023 (2011)
11. Norling, E., Sonenberg, L.: Creating Interactive Characters with BDI Agents. In: Proceedings of the Australian Workshop on Interactive Entertainment (IE'04), pp. 69-76. (2004)
12. Evertsz, R., Pedrotti, M., Busetta, P., Acar, H., Ritter, F.: Populating VBS2 with Realistic Virtual Actors. In: Proceedings of the 18th conference on Behavior Representation in Modeling and Simulation, pp. 1-8. (2009)
13. Grimaldo, F., Lozano, M., Barber, F., Vigueras, G.: Animating groups of Socially Intelligent Agents. In: International Conference on Cyberworlds (CW '07), pp. 136-143. (2007)
14. Amo, F.A., Velasco, F.F., Gómez, G.L., Jiménez, J.P.R., Camino, F.J.S.: Intelligent Virtual Agent Societies on the Internet. In: Antonio, A., Aylett, R., Ballin, D. (eds.) Intelligent Virtual Agents, vol. 2190, pp. 100-111. Springer Berlin Heidelberg (2001)
15. Stone, P., Veloso, M.: Multiagent Systems: A Survey from a Machine Learning Perspective. Autonomous Robots 8, 345-383 (2000)
16. Barella, A., Carrascosa, C., Botti, V.: Agent Architectures for Intelligent Virtual Environments. In: IEEE/WIC/ACM International Conference on Intelligent Agent Technology (IAT '07), pp. 532-535. (2007)
17. Oijen, J.v., Dignum, F.: Agent Communication for Believable Human-Like Interactions between Virtual Characters. Proceedings of the International Workshop on Emotional and Empathic Agents, AAMAS '12, vol. 3, pp. 1181-1182, Valencia, Spain (2012)
18. Buche, C., Querrec, R., De Loor, P., Chevaillier, P.: MASCARET: pedagogical multi-agents systems for virtual environment for training. In: Cyberworlds, 2003. Proceedings. 2003 International Conference on, pp. 423-430. (2003)
19. Cai, L.-q., Wang, T., Zhang, J., Luo, Z.-y.: Modeling Mine Virtual Environment Based on Multi-agent. In: Intelligent Human-Machine Systems and Cybernetics, 2009. IHMSC '09. International Conference on, pp. 257-261. (2009)
20. Gillies, M., Robeterson, D., Ballin, D.: Direct Manipulation Like Tools for Designing Intelligent Virtual Agents. In: Panayiotopoulos, T., Gratch, J., Aylett, R., Ballin, D., Olivier, P., Rist, T. (eds.) Intelligent Virtual Agents, vol. 3661, pp. 430-441. Springer Berlin Heidelberg (2005)
21. Hanna, N., Richards, D., Hitchens, M.: Evaluating the Impact of the Human-Agent Teamwork Communication Model (HAT-CoM) on the Development of a Shared Mental Model. In: Boella, G., Elkind, E., Savarimuthu, B., Dignum, F., Purvis, M. (eds.) PRIMA 2013: Principles and Practice of Multi-Agent Systems, vol. 8291, pp. 453-460. Springer Berlin Heidelberg (2013)
22. Edward, L., Lourdeaux, D., Barthes, J.P.: Cognitive Modeling of Virtual Autonomous Intelligent Agents Integrating Human Factors. In: IEEE/WIC/ACM International Joint Conferences on Web Intelligence and Intelligent Agent Technologies (WI-IAT '09) pp. 353-356. (2009)
23. Bradshaw, J.M., Feltovich, P., Hyuckchul, J., Kulkarni, S., Allen, J., Bunch, L., Chambers, N., Galescu, L., Jeffers, R., Johnson, M., Sierhuis, M., Taysom, W., Uszok, A., Van Hoof, R.: Policy-based Coordination in Joint Human-agent Activity. In: IEEE International Conference on Systems, Man and Cybernetics, pp. 2029-2036 vol.2022. (2004)