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Teaming up humans with autonomous synthetic characters

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ABSTRACT

Autonomous synthetic characters have the potential to promote the social engagement of users in virtual environments, enhancing their interaction experience. In computer games, for example, poor interaction with game characters can drastically detract from the gaming experience, making the design of autonomous synthetic characters an important issue. In particular, in Role Playing Games (RPGs), for example, users and autonomous characters often perform in a group. Usually, the role of such characters is very limited since they lack the social skills to perform coherently in group scenarios.

The goal of the work presented here is to endow autonomous synthetic characters with social skills that allow them to perform in groups with human members. However, to successfully achieve this, it is not enough to assure that the characters behave in a coherent manner from an individual perspective or that they are able to perform the group task optimally. It is also necessary that the autonomous characters exhibit behaviours that are coherent with the group's composition, context and structure.

For this reason, we have developed a model to support group dynamics of autonomous synthetic characters (SGD model) inspired by theories developed in human social psychological sciences. This model defines the knowledge that each individual should build about the others and the group, and how this knowledge drives their interactions. The model was used in a collaborative computer game that was tested with users. The results showed that the model had a positive effect on the users' social engagement, namely, on their trust and identification with the group.

1. Introduction

The creation of autonomous synthetic characters has been widely studied in the past years, especially because such characters can improve the interaction of users with virtual environments [7]. For this reason, autonomous synthetic characters have been used in several different domains such as entertainment [11,45], business [9] and education [59,65]. They have been particularly important in computer games that make use of narrative, such as Role Playing Games (RPGs), because they constitute the main driving force to create successful narrative experiences that improve gameplay [39,66].

The crucial issue in designing autonomous synthetic characters is making them believable or creating the "illusion of life" for the user [8]. In other words, autonomous synthetic characters must be coherent with the users' expectations.

The work presented here focuses on believability issues of autonomous synthetic characters when they interact as a group. The work is focused on groups with few members (small groups) who are committed to a collaborative task and without a strong organisational structure. Thus, we are not concerned with large groups such as crowds or complex societies. In addition, our goal is to engage the user as an active member of the group.

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Typically, autonomous characters lack the necessary social skills to interact in a group. Therefore, their role in the group is very restricted, and their autonomy is limited. For example, in RPGs, the autonomous characters only take secondary roles, such as a salesperson, while the main characters are controlled by the user.

Moreover, most of the studies conducted on the believability of autonomous synthetic characters are focused on the interactions of a single user with a single character [9,57]. However, in group scenarios, it is not enough to ensure that the characters behave in a coherent manner from an individual perspective; it is also necessary that they exhibit behaviours that are coherent with the group's composition, context and structure. On the other hand, approaches to create team-oriented autonomous agents focus primarily on the optimal results of the group [46,70,77]. Although the group's performance may affect the experience of users when interacting in a group, their perception about their experience is highly influenced by their social identification and their trust of the group [3,22]. In fact, these two factors are closely related to the satisfaction of people in group interactions [4].

In order to achieve such an experience and properly engage users with the group, we argue that autonomous members' behaviours cannot be solely driven by their need to solve the task but also by the socio-emotional dimensions of the group, such as the structure of interpersonal relations.

To prove this, we have developed a model for group dynamics (SGD model) that allows each individual character to reason about other characters and the group. This model was inspired by theories developed in human social psychological sciences and is driven by a characterisation of the different types of interactions that may occur in the group, taking into account the socio-emotional interactions as well as the task-related ones.

We have implemented the model into the behaviour of autonomous synthetic characters that collaborate with the user in the resolution of tasks within a virtual environment (a collaborative game). This game was developed with the purpose of testing the effects of our model in users' interaction experiences. The results of the experiment showed that the model had a positive effect on the users' trust and social identification with the group.

This paper is organised as follows. First, we discuss related work concerning the interaction of autonomous characters in a group. Then, we present the fundamentals of group dynamics on which we grounded our model followed by the description of the model itself. Then, we describe the computer game that we developed to test our model and the experiment that was conducted to assess the effects of the model in the users' interaction experience. We finish with some conclusions and comments regarding future work.

2. Related work

The problem of multiple autonomous synthetic agents that interact in a group has been previously addressed by several researchers. The focus of their approaches can be seen in two different perspectives: (1) centred on believability issues of the group interactions or (2) centred on the efficiency of the group's performance. We will briefly describe some of the most relevant work and make some comments regarding the focus of the work presented in this paper.

The first example of the first perspective can be found in Reynolds' Boids [63], which implements a flocking behaviour in a group of flying creatures. In the same line of work, we can additionally find research concerning the generation of crowds [53] that is often used in commercial systems for film creation. One well-known example of this is "The Lord of the Rings" film trilogy [54], which includes numerous fighting scenes involving armies of thousands of warriors, most of these being played by synthetic actors generated by the MASSIVE[1] platform.

The Boids' flocking behaviour and crowd generation make use of emergent group dynamics and result in a believable life-like group behaviour. However, agents in these examples do not have deep social awareness and lack the ability to build social relations, which we believe to be essential for the interaction with a user. In addition, these groups do not have an explicit common goal.

Guye-Vuilleme [28] has extended the work on the generation of the behaviour of crowds by introducing a model for the simulation of the movement and interaction of individuals driven by the group's social context. This includes behaviours for social avoidance of collisions, social approach and the calculation of suitable interaction distances and angles. The social context consists of a model of interpersonal relationships of individuals. Although incorporating interpersonal relations to influence the autonomous characters' behaviours, Guye-Vuilleme's crowds cannot be seen as performing teamwork, since they do not have an explicit collaborative task.

Another example is the AlphaWolf [71] system, which simulates the behaviour of a pack of six grey wolves. In this system, the different synthetic characters are able to build domination-submission relationships. These relations are built in the form of emotional memories that drive the characters' behaviour. In addition, three users can interact with the system and influence the behaviour of three of the wolves. AlphaWolf has successfully implemented a believable simulation of group interactions in a pack of wolves, and it has engaged the user in such interactions. However, the user and the synthetic characters do not engage in the resolution of a collaborative task and do not have a strong notion of group.

Schmitt and Rist [67] developed a model of virtual group dynamics for small group negotiations. In their system, users delegate the task of scheduling their appointment meetings to a virtual agent. The agents will later meet in an arena and negotiate the times and dates of the meetings. Each agent has an individual personality and builds social attraction relations

[1] For more details on MASSIVE, please check http://www.massivesoftware.com.

with the others. These relations and personality guide the agents' interactions and support the generation of the negotiation dialogues. In the end, the dialogues are played for the users by a cast of synthetic characters. The believability of the group dynamics is a key factor in this example as it supports the believability of the agents' dialogues, but users do not directly engage in the group interactions. In addition, the social relationships are limited to like and dislike attitudes, disregarding the dimension of social power that is inherent to human social interactions [14]. Nevertheless, this research enhances the fact that interpersonal relationships have a key role in the achievement of believable group interactions.

This role was also stressed by Reilly and Bates [62] in their work on natural negotiation of believable agents. They have built two autonomous characters, Melvin and Sluggo, that negotiate with a user in a simulated playground for trading baseball cards. The interpersonal relationships affect characters' negotiation responses and proposals. For example, a character may decide to only make proposals to friends. In turn, the negotiation influences interpersonal relationships. If Melvin believes that the user is a friend, but s/he deceives him, he will no longer consider the user a friend, impacting future negotiations. Melvin and Sluggo interact with a user in a believable way using their ability to establish relationships, as well as personality and emotions, but they do not engage in a collaborative task.

PsychSim by Marsella and Pynadath [44,60] addresses some issues regarding the dynamics of social influence. PsychSim is an agent-based modelling tool that allows an end-user to quickly construct a social scenario, where a diverse set of entities, either groups or individuals, interact and communicate among themselves. Furthermore, each entity has its own goals, relationships (e.g., friendship, hostility, authority) with other entities, private beliefs and mental models about other entities. Then, based on the scenario specified, the tool simulates the social dynamics by generating the behaviour of all the entities. In addition, it provides explanations of the result of the simulation in terms of each entity's goals and beliefs. The simulation is based on a model of influence grounded on the effects of communication and a recursive theory of mind. PsychSim is a powerful social simulation tool that aims to generate believable behaviour of autonomous agents, which may interact in a group. However, there is no space for user interaction within the simulation and, therefore, no user integration in such groups. Nevertheless, this system enhances the importance of a theory of mind to achieve deep social believability, following Castelfranchi's thesis on the need of mind-reading agents for social action [17].

Approaches centred on the efficiency of the group's performance are more common. At their core are theories of Joint Intentions [18] and theories of Shared Plans [27], which were incorporated by Tambe in STEAM (a Shell for TEAMwork) [70]. STEAM is a hybrid teamwork model that borrows strengths from both theories. Teamwork in STEAM is based on the agents' building up a hierarchy of joint intentions and monitoring other members' and team's performances and reorganising the hierarchy when necessary. Furthermore, STEAM takes into account the costs of communications to reduce "non-necessary communications" that would affect team performance. STEAM only deals with autonomous agents and does not include human members in the group. In addition, it is focused on the optimal performance of the group, disregarding interpersonal relations.

Carley and Lin [12,13] have studied computational models of organisations using agent-based approaches. They have developed a framework CORP (Computational ORganisational Performance) that defines organisations as complex adaptive systems composed of intelligent, task-oriented, boundedly-rational [69] and socially-situated agents. CORP simulates a series of distributed decision-making problems and the coordination in and between organisations taking into account organisational processes, individual experiences and the environment of the task. CORP has been used as a testbed for organisational design applied to crisis management. Like STEAM, CORP is focused on the efficiency of the performance of the group and uses a strong organisational structure that does not apply to small groups.

STEVE (Soar Training Expert for Virtual Environments) [65] is an example of a system that simultaneously handles the efficiency of task performance and the believability of the interactions with a user. STEVE is an ECA (Embodied Conversational Agent) [15] used in a navy facility to train a team to solve possible malfunctions that may arise in a ship. The team can be composed of several human users and several autonomous characters, which interact in a 3D virtual environment that simulates the ship and its equipment. However, STEVE's concerns regarding believability are mostly centred on the communication acts (e.g., STEVE is made believable by using proper deictic gestures and gaze). Furthermore, the interactions between the group members are all related to the task, without the possibility for deeper social engagement.

Furthermore, computer RPGs, such as "Star Wars: The Knights of the Old Republic" [10] or "The Temple of Elemental Evil" [72], are systems that engage the users in a group with autonomous synthetic characters that perform a collaborative task. In this type of game, the social interactions are an important part of the game, especially those that take place between the members of the group. Since the social skills of the autonomous characters are usually weak, they only perform simple roles and are not deeply involved in the group task. More recent games, such as "Neverwinter Nights 2" [56], have included some interpersonal relationship dynamics in the group of characters that follow the user, but these are still very shallow. In "Neverwinter Nights 2", the relationships are unidirectional and unidimensional. Worst of all, the characters only relate to the user's character and not to each other. Nevertheless, this effort shows the interest of the game developer community in creating better dynamics of group behaviour.

Mateas and Stern [47], as well as Evans and Lamb [23], have created tools for the specification of group behaviours and activities in order to help developers define coordinated behaviours for multiple characters. However, these tools require developers to explicitly specify, through primitive actions, all the dynamics of the behaviour. Besides needing a lot of authoring effort, this may lead to little space for emergence, one of the main characteristics of social dynamics [17].

Other examples of group dynamics in computer games can be found in First Person Shooters (FPSs) such as "Half Life" [73]. In these games, the player faces groups of enemies that apply squad tactics [64,74,75] to challenge the player effectively. This squad behaviour has successfully increased the entertainment value of FPSs by making the autonomous squads a stronger challenge, but it does not handle the user participation in the group and is merely focused on the efficiency of the group interactions.

3. Fundamentals of group dynamics

From the examples above, we see that prior research conducted on the interaction of autonomous characters in a group has addressed the issues of emergent behaviour, collaborative tasks, and user interaction separately, but seldom together. Our work addresses all three issues. The goal is to create a group simultaneously constituted of autonomous synthetic characters and users who are engaged in the resolution of a collaborative task. The synthetic characters act as active members of the group. Thus, the group's emergent behaviour must be believable and coherent with the user's expectations. The group's interactions should follow dynamics that are similar to the user's experience in human groups. To create the behaviour of the autonomous characters, we have developed a model supported by some studies and theories of group dynamics developed in human social psychological sciences. In this section, we describe those theories and studies that contributed most for the development of the model.

3.1. The definition of group

We found that it is not easy to clearly distinguish a collection of people from a group of people. Groups may emerge in many different social contexts and have many different types of interactions. Nevertheless, several definitions, restricted by context, have been proposed [14,30,50]. Group definitions are in general based on the notions of *interaction*, *interdependency* and *mutual perception and identification*:

- **Interaction:** A group of people interact frequently. Those interactions are relevant for the group members and follow the context of the group.
- **Interdependency:** The members of a group have some interdependency, which means that one member's behaviour affects the other members.
- **Mutual perception and identification:** All members of a group perceive the group. They can identify the group, its members and recognise that they belong to the group themselves.

McGrath [50] proposed an interesting and different definition inspired by the mathematical notion of fuzzy sets that defines a group in terms of degree of *groupness*. This definition is very flexible given that every collection of people is a potential group. The degree of *groupness* is influenced by four factors: (1) the number of members in the group, (2) the level of interactions between the members, (3) the history of interactions and (4) the probability of future interactions of the group. The same approach is used in the notion of member of a group. Each individual can belong to several groups having, in each, a different degree of *belongingness*.

3.2. The group's process

The term group dynamics was first introduced by Kurt Lewin [37,38] in studies he conducted between 1939 and 1946. From these studies, he formulated the field theory, known as the first group dynamics theory. After the publication of Lewin's studies, many other researchers focused their work on the study of group processes and dynamics. Consequently, several different theories on group dynamics emerged. In 1968, Cartwright and Zander [14] reviewed the theories that contributed most to group dynamics development and divided them into several categories depending on focus. Our approach to modelling group dynamics of synthetic characters mainly follows theories that Cartwright and Zander classified as *System and Interaction* theories. Nevertheless, we also include several ideas from other perspectives such as *Sociometry* and *Cognitive Theories*.

In the perspective of *System and Interaction* theories, the group process is composed of a set of interaction processes that occur during an interval of time $t = [t1, t2]$ (see Fig. 1). The interaction processes are affected by preceding factors that are present at time $t1$ and result in some consequences at time $t2$. McGrath and others [29,49,50] have studied the group process using this perspective and have defined and classified preceding factors, interaction processes and their consequences:

- **Preceding factors:** variables that influence the interaction processes; they can be categorised in three different dimensions:
  1. *Individual level*: these factors are related to the individual characteristics of each member of the group. They include the individual capabilities and skills, the attitude and motivation and other demographic and biographic traits.
  2. *Group level*: these factors relate to the group topology. They include the size of the group, its composition, its hierarchy structure, the distribution of influence and power, the role of each member and the organisation of the communication, along with other sociometric factors.

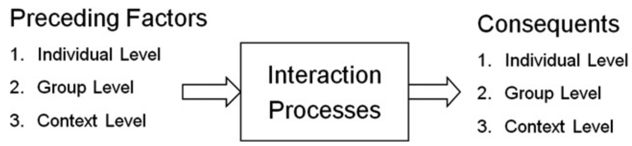

Fig. 1. The group as a system of interacting members with observable inputs and outputs.

Table 1
Bales IPA system of categories

Type	Categories
Socio-Emotional	1. Seem Friendly
	2. Release Tension
Positive	3. Agree
Instrumental	4. Give Suggestion
	5. Give Opinion
Active	6. Give Information
Instrumental	7. Ask for Information
	8. Ask for Opinion
Passive	9. Ask for Suggestion
Socio-Emotional	10. Disagree
	11. Show Tension
Negative	12. Seem Unfriendly

3. *Context level*: these factors are associated with the nature of the task and the environment where it must be performed. Additional context factors, like inter-group relations and social and cultural factors, are also considered.

- **Interaction processes:** are the interactions and exchanges that occur between the members of the group.
- **Consequences:** the interaction processes have consequences that change the situation that was initially verified when the processes first began. These changes occur at three different levels:
  1. *Individual level:* results that affect the individual members. For example, the individual social condition can change and be facilitated. Furthermore, individuals' attitudes and motivation within the group may also change.
  2. *Group level:* results that change the group topology. The group's structure may change or even emerge if the group was not previously structured. The distribution of influence and power can be modified resulting, for example, in changes in the leadership.
  3. *Context level:* results in the task level. The task efficiency and execution can change.

3.3. The interactions

The first studies regarding the interaction processes within a group are due to Bales and his associates [6]. They developed the Interaction Process Analysis (IPA), a method for group analysis based on the observation of the interactions that occur between the members of a group. Based on his studies, Bales concluded that a group, in its process, faces two different classes of problems: *instrumental problems* related to the task, and *socio-emotional problems* related to the social and emotional relations of the members. Bales proposed two major categories of interactions: the *instrumental* interactions and the *socio-emotional* ones. Furthermore, the *instrumental* interactions are divided into *active* interactions, when the members give information to the others, and *passive* interactions, when the members request information. In turn, the *socio-emotional* interactions are divided into *positive* or *negative* interactions as they raise positive or negative socio-emotional responses by the members.

The IPA system proposes twelve categories for the possible interactions that occur between the members of a group throughout its process. Table 1 shows the IPA categories and their classification according to the type of problems that they relate to (instrumental or socio-emotional).

3.4. The group's structure

One of the main factors that influences the way members in a group interact is the group's structure, which is usually divided into several different dimensions. The most common dimensions, according to Jesuíno [34], are:

- the *structure of communication*, which reflects the communication network that connects the group members,
- the *structure of social power*, which reflects the social influence that members may exert on each other,
- and the *structure of social attraction (or sociometric structure)*, which reflects the social attraction that members feel for each other.

Furthermore, according to Collins and Raven [19], the structure of a group can be characterised in terms of the interpersonal relations established between its members. This means that the interpersonal relations of social power are related to the emergence of the group's *structure of social power*, while the interpersonal relations of social attraction are related to the emergence of the group's *structure of social attraction*. Therefore, in order to understand the dynamics of the group's structure and its interactions, it is imperative to understand the dynamics of the interpersonal social relations.

3.4.1. Relations of social power

French and Raven [24] defined the notion of *social power* as the influence exerted by a social agent on a person, where the social agent can be another person, a social role, a norm, a group or part of a group. This influence is defined in terms of the psychological change on the person's perceptions, emotions and behaviours that can be attributed to the action of the social agent.

However, social power only defines a potential influence on the person. On one hand, the person may mobilise some effort to resist that influence. On the other hand, the social agent may decide to use less than his full power in the influence process. Therefore, the social influence exerted on a person results from the strength of the power that the social agent induces reduced by the strength of the resistance mobilised by the person.

Furthermore, French and Raven [24,61] have proposed a characterisation of power according to its social source and the relation between the person and the social agent:

1. **Reward Power:** based on the perceived ability to mediate rewards.
2. **Coercive Power:** based on the perceived ability to mediate punishments.
3. **Legitimate Power:** sometimes referred to as organisational authority, it is based on the perception that someone has the right to prescribe given behaviours.
4. **Referent Power:** based on perceived associations between the person and the social agent, for example, due to an affective relationship.
5. **Expert Power:** based on the perceived distinctive knowledge, expertness, abilities or skills attributed to the social agent.
6. **Information Power:** based on the perceived control of the information needed in order to reach an important goal.

These different types of social power are interrelated and are often combined in the process of social influence. For example, a speaker of renown and expertise in a given field may influence the opinion of a listener using the expert power. However, if the listener dislikes the speaker, this influence will be reduced by a negative referent power.

In addition, the process of influence depends on the perception of the person being influenced. For example, if a member is attached to a group and he conforms to its norms only because he fears to be ridiculed or expelled from the group, he is influenced by coercive power. However, if he conforms in order to obtain praise, he is influenced by reward power. Furthermore, if the member conforms to avoid discomfort or gain satisfaction independently of the group's responses, he is influenced by referent power. Finally, if the member conforms with the majority's opinion based on the respect for the collective wisdom of the group, then he is influenced by expert power.

The perception of power also has effects on the group process. For example, according to Hurwitz et al. [33] and Lippitt et al. [40], the members of a group with higher social power are usually more appreciated by the rest of the group and their interactions are more likely to drive the group's behaviour. In addition, they are more attracted to the group and are more satisfied with the group's interactions. They also tend to underestimate the efforts of the members that have less influence on the group and to use their power on them as a way of self assertion [35,36].

3.4.2. Relations of social attraction

The relations of social attraction, first studied by Moreno [52], define the affective attitude of each member of the group towards the other members. This attitude reflects the affective ties that each member establishes with the others, which can be either positive or negative. This interpersonal attraction is not necessarily reciprocal. For example, if person A is positively attracted to person B, this does not necessarily mean that person B is positively attracted to person A. Nevertheless, some results show that reciprocity in interpersonal attraction relations is often a reality and that it is an important factor for the development of strong social attraction ties [21,55].

In addition, the relations of social attraction in a group tend to be balanced. Heider [31] justifies this fact with the need that people have to maintain balanced cognitive configurations. Furthermore, he developed a framework for studying the structural arrangements between social actors and their attitudes, which is referred to in literature as the Balance Theory [32].

The Balance Theory is centred on the concept of a *POX* triple where P is a person, O another social actor and X an object, which may be a third person, an idea, a rock group, or anything else that P and O both acknowledge. This triple represents a cognitive configuration built by P, which relates P's beliefs in O's attitude towards X and P's own attitude towards X and O. Fig. 2 represents an example of such a configuration where each line represents one of the attraction attitudes involved: P towards X, P towards O and O towards X.

Those attitudes can be either positive (e.g., P likes O, O has a favourable attitude towards X, and so on) or negative (P dislikes O, P disapproves of O, and so on). Moreover, having three different elements with two value relations between them makes it possible to build eight different configurations, which represent the eight cognitive states of the *POX* triple

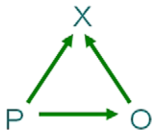

Fig. 2. An example of a *POX* cognitive configuration, according to Heider's Balance Theory.

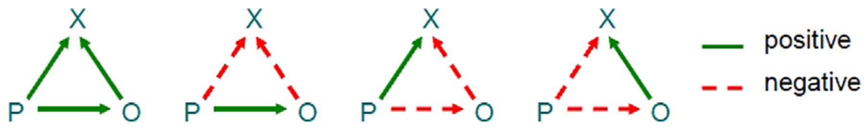

Fig. 3. Stable *POX* cognitive configurations.

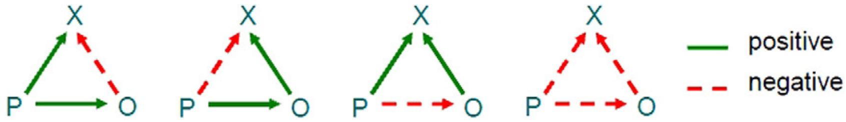

Fig. 4. Unstable *POX* cognitive configurations.

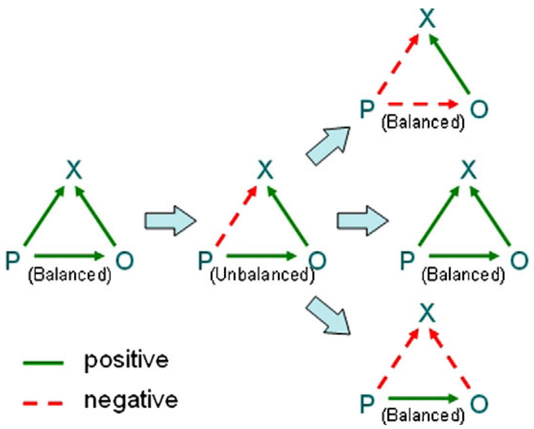

Fig. 5. Example of the *POX* configuration dynamics.

studied in the Balance Theory. Heider suggested that some of these cognitive configurations are fraught with tensions that make them unstable, particularly if the attitudes are strong. He divided the eight configurations into two different sets: the stable configurations set, shown in Fig. 3, and the unstable configurations set, shown in Fig. 4.

The Balance Theory hypothesis states that people avoid unstable cognitive configurations and that, if they realise the existence of one, they mobilise their efforts to resolve it and change it to a stable state. For example, suppose that a person *P* is initially positively attracted to an object *X* and another person *O*, and additionally believes that *O* is also is positively attracted to *X* (this is the first case in Fig. 3). The cognitive state is balanced so *P* is fine with the situation. But later *P* discovers an unpleasant feature about *X* and develops a negative attitude towards it. The cognitive state becomes unbalanced (second case in Fig. 4), which creates a certain strain and tension on *P*. Thus, *P* will try to recover the balance. According to Heider's model, *P* has two options: (1) change her/his attitude towards *O* and develop a dislike for *O* (fourth case in Fig. 3), or (2) reconsider her/his attitude towards *X* and recover the initial attitude of liking *X* (first case in Fig. 3). In addition, there is a third option in which *P* tries to influence *O* to change her/his attitude towards *X* (second case in Fig. 3). However, this situation is more uncommon because it involves additional effort, and, in certain circumstances, it may be totally impossible. See Fig. 5 for a graphical representation of the example described above.

Moreover, interpersonal attraction is often related to group cohesion [42] defined by Pepitone and Kleiner [58] as "*the number and strength of mutual positive attitudes among the members of a group*". Thus, the higher and the more frequent the positive interpersonal attraction relations in the group are, the higher the group's cohesion level. This means that the group's members interact more often [5,41] and are more satisfied with the group's interactions [26,43].

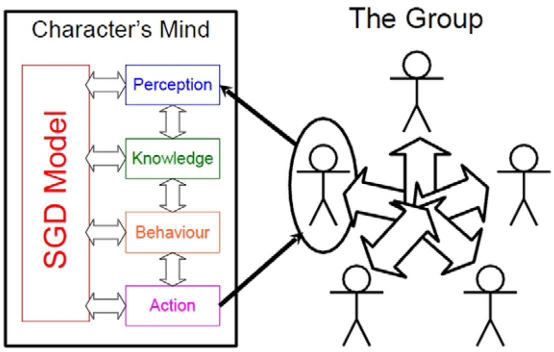

Fig. 6. The SGD model in the mind of each member of the group.

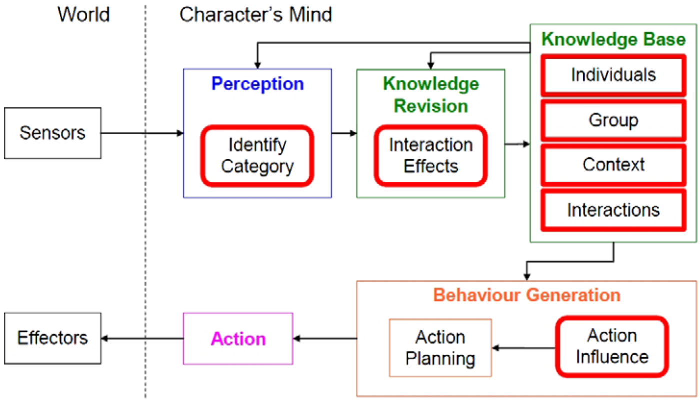

Fig. 7. The agent's mind's components and the SGD model.

4. SGD model: A model for group believability

The model proposed, the SGD Model (Synthetic Group Dynamics Model), was built on the principle that each member of the group must be aware of the other members and the group itself. In addition, s/he should be able to build proper knowledge regarding the group's social structure and to use this knowledge to drive her/his behaviour.

The group is modelled as a system composed of several autonomous agents that engage in interaction processes. These interactions create the dynamics of the system. They affect the group's state and, are simultaneously influenced by that state. In other words, the preconditions for the occurrence of an interaction depends on the state of the group and when the interaction occurs, it will change the state of the group (e.g., the social structure of the group may change).

In concrete terms, the SGD Model was created as a module that influences the usual processes of a cognitive agent. Thus, the model influences the perception, knowledge building, behaviour and action processes of each agent (see Figs. 6 and 7).

4.1. Target groups

There are several definitions and types of groups. For that reason, we would like to clarify which kinds of groups the proposed model applies to before going into detail in its description.

As discussed before, our study is focused on groups that involve a human user with several autonomous synthetic characters. These groups perform in a virtual environment and their members are committed to solving collaborative tasks. Thus, the group interactions must evolve in a way that will make the resolution of those tasks possible.

In addition, the model applies to small groups, with only a few members, and without a strong organisational structure. We are not concerned with groups as crowds or complex organisations and societies of agents.

The members of the group are implemented as autonomous software agents that can engage in conversation and can manipulate objects in the virtual environment (e.g., get, give, use and drop items). The user is represented as an agent (avatar) in the system that is not autonomous but fully controlled by the user.

The autonomous agents are assumed to be socially autonomous as discussed by Castelfranchi [16] in the sense that they have autonomy in their goals and beliefs. Nevertheless, this autonomy is only partial since the agents' performances are influenced by the other agents in the group, including the user. Note that the performance can be influenced but never controlled. The agent will always make a decision based on its own goals and beliefs.

4.2. The agents' architecture

The SGD Model is characterised by four different levels:

1. **the individual level** that defines the individual characteristics of each group member, such as personality;
2. **the group level** that defines the group and its underlying structure;
3. **the interactions level** that defines the different classes of interactions and their dynamics;
4. **the context level** that defines the environment and the tasks that the agents can perform.

These four levels represent the knowledge that the agents should build in order to implement the SGD Model in their behaviour. Furthermore, in addition to this knowledge, the agents' behaviours in the group relies on three processes (see Fig. 7):

1. **Classification of the interactions (Identify Category):** the agent is aware of the actions in the group and classifies them into categories of interaction with specific semantics. For example, in this process the agent interprets if certain actions are helpful for the group or not. This process uses knowledge from all four levels, that define the possible categories of interaction (especially from the interaction level), and from the context level that defines how the actions of the group should be interpreted (for example, by means of social norms).
2. **Propagation of the interaction consequences in the knowledge base (Interaction Effects):** then, based on the identified category, the interaction produces changes on the knowledge, in particular in the individual and the group levels. For example, the interaction may change the social relations established between the members that it engages (e.g., that interact with each other).
3. **Influence on the agent's actions decision (Action Influence):** finally, the agent's perception of the group and its members influences the actions that it performs in the group. For example, if the agent is not motivated, it will not try to solve the group's tasks.

4.3. The individual level

The individual level defines the knowledge that the agent builds concerning the individual characteristics of each member of the group. This knowledge defines each member's ability and personality:

1. **The agent's abilities:** define the actions that each agent can perform in the environment associated with their levels of expertise (e.g., how well the agent performs each of these actions). The set of abilities is important in determining the agent's level of expertise, which helps define the agent's position in the group.
2. **The agent's personality:** we define the agent's personality using two of the dimensions proposed in the Five Factor Model [48]: *Extraversion* and *Agreeableness*. We only consider these two dimensions because they are associated with the ideas of dominant initiative and socio-emotional orientation proposed by Bales [1]. The other dimensions are more related to task resolution, outside our main focus.
   2.1. *Extraversion*: is related to the dominant initiative of the agent. Thus, it will influence the agent's frequency of interaction.
   2.2. *Agreeableness*: is related to the socio-emotional orientation of the agent. It defines the type of socio-emotional interactions that the agent will favour. More agreeable agents will favour positive socio-emotional interactions, while less agreeable agents will favour negative socio-emotional interactions.

Each individual is represented, in a logical knowledge base, as a predicate that defines its identity as shown in Eq. (4.1).

$$Agent(agentName) \tag{4.1}$$

Additionally, the agent is characterised by a set of functions, related to its personality and skills. Eqs. (4.2) and (4.3) respectively represent the dimensions of *Extraversion* and *Agreeableness*. And, for each skill, a function that represents the skill's level of expertise is defined, as shown in Eq. (4.4).

$$Extraversion(agentName) \tag{4.2}$$

$$Agreeableness(agentName) \tag{4.3}$$

$$Skill(agentName, skillName) \tag{4.4}$$

4.4. The group level

The group level defines the knowledge that the agents build concerning the group and its underlying structure and, additionally, the agents' attitudes towards the group.

First of all, the group is defined as a set of individuals that follows the definition presented in the previous section. Moreover, group is a unique and identifiable entity with an inherent structure.

1. **The group identity:** identification is an important factor in the definition of a group. For that reason, the group needs a unique name to allow it to be clearly distinguishable in the environment and to enable the agents to recognise it and refer to it.
2. **The composition:** the composition is the set of individuals that are associated with the group. The composition may change over time as new members may be admitted or old members excluded.
3. **The structure:** the group's structure is defined in different dimensions. According to Jesuíno [34] the most common ones are the structure of communication, the structure of power and the structure of interpersonal attraction (sociometric structure [52]). Because we deal only with small groups, the structure of communication is simple since all characters may communicate directly with each other. Thus, we excluded this structure from our model. The group's structure is then defined in two dimensions: the *structure of power* that emerges from the members' social influence relations, and the *structure of interpersonal attraction* that emerges from the members' social attraction relations.

In the knowledge base, the group is represented as a predicate that follows Definition 4.5, where *identity* defines the symbolic name of the group, and *members* defines a set with the names of the agents that belong to the group.

$$Group(identity, members) \tag{4.5}$$

Furthermore, since the group's structure emerges from the social relations established between its members, the group characterisation also depends on the definition of these social relations, which can be of two different types:

1. **Social attraction:** these relations define the interpersonal attraction of the members in terms of like (positive attraction) and dislike (negative attraction) attitudes. These relations are unidirectional and not necessarily reciprocal (e.g., if agent A is positively attracted to agent B, this does not necessarily mean that agent B is positively attracted to agent A).
2. **Social influence:** relations of influence define relations of power. They quantify the capacity of one agent to influence the behaviour of another. The influence is defined as the difference between the power which one individual can exert on another and the power with which the other is able to resist [24].

These social relations are defined, in the agent's knowledge base, as functions that follow the two Definitions 4.6 and 4.7.

$$SocialInfluence(source, target, S) \tag{4.6}$$

$$SocialAttraction(source, target, S) \tag{4.7}$$

Social relations are directed from one agent, the *source*, to another, the *target*, and are assessed by a value which can be positive, zero (neutral relation) or negative. Because social relations will change throughout the process of the group, the values determined by these functions will differ according to the situation S.

Furthermore, the social relations of a member in conjunction with its level of expertise determine its position in the group. This position reflects the member's relative significance in the group, which defines how important its contributions are and how well they are accepted by the group. For example, actions performed by members that have more social influence on the members of the group have stronger effects on the group's process. Thus, the position in the group defines the agent's relative power in the group, which directly depends on (1) the overall social influence that the agent may exert on the others, (2) the attraction that the others feel for the agent and (3) the agent's relative expertise in the group. The position in the group may be computed using the formula (4.8), where $SkillLevel(A, G)$ denotes the relative skill level of the agent in the group and is computed by the formula (4.9).

$$\begin{aligned}&\forall G, A\colon\ Group(G, members) \wedge A \in members,\\ &Position(A, G, S) = SkillLevel(A, G) + \sum_{m \in members}^{m} SocialAttraction(m, A, S) + \sum_{m \in members}^{m} SocialInfluence(A, m, S)\end{aligned} \tag{4.8}$$

$$\begin{aligned}&\forall G, A\colon\ Group(G, members) \wedge A \in members,\\ &SkillLevel(A, G) = \frac{\sum^{s} Skill(A, s)}{\sum_{m \in members}^{m} SkillLevel(m, G)}\end{aligned} \tag{4.9}$$

In addition to the relations that agents build with each other, they also build a relation with the group itself. This relation captures the member's attitude towards the group and reflects the agent's motivation in the resolution of the group's task and its engagement in the group's interactions. The agent's motivation is defined by a function as shown in Eq. (4.10). This function determines different values according to the situation S.

$$Motivation(A, G, S) \tag{4.10}$$

Note that agents may belong to several groups at the same time, and, therefore, may have different values for their motivation and position in the group for each one.

4.5. The interactions level

The interactions level describes the knowledge that the agent builds concerning the group's interactions and their dynamics. These dynamics reflect on (1) the changes that the group's interactions induce in the agent's perception of the group and, therefore, in the knowledge it builds about the group, and (2) in the rules that drive the behaviour of the agent in the group.

The central notion in the interactions level is the concept of *interaction*. An *interaction* occurs when agents execute actions that can be perceived and evaluated by others. In fact, it may consist of several actions that are performed in a certain pattern. These actions can be performed simultaneously, which means that more than one agent may be involved in the same *interaction*. In addition, other agents may support the *interaction* but not be directly involved in its execution. For example, agents may agree with a certain *interaction* and explicitly show their support for its execution without performing a single action concerning the *interaction* other than the declaration of support.

Moreover, each *interaction* has a certain strength in the group that defines its relative importance in the group's process. Additionally, each *interaction* may affect only certain members of the group. For example, when a member of the group encourages another to perform a task, the effects of the encouragement will only be directly reflected on the agent that was encouraged. However, it may indirectly affect other members that observe the *interaction* (see Eqs. (4.32), (4.33), (4.34) and (4.35) in Section 4.5.2).

To summarise, an *interaction* is defined by:

1. an *action* or pattern of *actions* that identify the type of interaction;
2. the set of *performers*, which defines the agents that are engaged in the execution of the interaction;
3. the set of *supporters*, which defines the agents that support the interaction without being directly involved in its execution;
4. the set of *targets*, which defines the agents that are affected by the interaction;
5. and its *strength* in the group, which determines the relative importance of the interaction in the group.

Furthermore, we have defined a predicate (4.11) to identify an *interaction* and a set of functions ((4.12), (4.13) and (4.14)) to represent the *interaction*'s performers, supporters and targets.

$$\mathit{Interaction}(I) \tag{4.11}$$

$$\mathit{Performers}(I) \tag{4.12}$$

$$\mathit{Supporters}(I) \tag{4.13}$$

$$\mathit{Targets}(I) \tag{4.14}$$

The strength of an *interaction* in the group is directly related to the position of the *interaction*'s performers and supporters in the group. It can be computed using the formula shown in (4.15).

$$\begin{aligned}&\forall G, I\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I),\\ &\mathit{Strength}(I, G, S) = \sum_{p \in \mathit{Performers}(I)}^{p} \mathit{Position}(p, G, S) + \sum_{s \in \mathit{Supporters}(I)}^{s} \frac{\mathit{Position}(s, G, S)}{2}\end{aligned} \tag{4.15}$$

4.5.1. The classification of the interactions

In order to model the dynamics of the group's process, we have divided the several possible group interactions into different categories. This categorisation is then embedded in the a priori knowledge of the agent. It will support the agent's process of perception and identification of the interactions when it asserts new interaction facts in its knowledge base.

Furthermore, although the interaction is closely related to the actions that the agents perform, its classification is more than just the categorisation of the actions themselves. Classification also depends on the actions' results, on the context of the execution, and also on the agents' perception of the group. For example, the same action can be perceived as a positive interaction for the group by an agent but as a negative interaction by another.

The classification that the SGD Model presents was based on the categories that Bales proposed on his IPA system [6]. Thus, it similarly distinguishes between socio-emotional and instrumental interactions, and divides interactions as positive or negative (see Fig. 8).

On the socio-emotional level we use six categories which are similar to those presented by Bales. We consider three positive socio-emotional interactions (*agree, encourage and encourage group*) and three negative social emotional interactions that are opposed through symmetry (*disagree, discourage and discourage group*).

- Positive socio-emotional interactions
  1. **Agree:** This class of interactions show the support and agreement of an agent towards one of the interactions of another agent, consequently raising the importance of that interaction in the group.

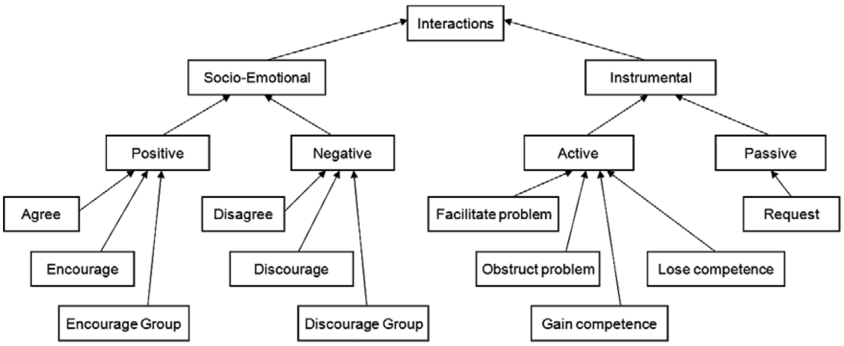

Fig. 8. The categories of the interactions.

2. **Encourage:** These interactions represent an agent's efforts to encourage another agent, consequently facilitating its social condition (e.g., increasing its motivation).
3. **Encourage Group:** This class of interactions is similar to the *Encourage* category but apply to the group itself. These interactions encourage the group and facilitate the group's social condition (e.g., everyone's motivation).

- Negative socio-emotional interactions
  1. **Disagree:** This class of interactions show the disagreement of an agent towards one of the interactions of another agent, consequently decreasing the importance of that interaction in the group.
  2. **Discourage:** These interactions represent an agent's hostility towards another agent and its efforts to discourage it.
  3. **Discourage Group:** This class of interactions are similar to those in the *Discourage* category but apply to the group itself.

The categories proposed by Bales at the instrumental level mainly focus on speech acts. In addition, there is no clear connection between the instrumental interactions and the task itself. However, in the context of virtual environments, the interactions not based on speech acts are very important because agents may manipulate the objects defined in the environment. Also, the design of the interactions' influence on a problem-solving group and its members is easier if the interactions' definition is based on the concept of "problem". Therefore, following these two principles, we defined four instrumental interactions: two positive ones (*facilitate problem, gain competence*) and two negative ones (*obstruct problem, lose competence*), that do not have a direct analog in the IPA instrumental categories.

- Positive instrumental interactions
  1. **Facilitate Problem:** This class of interactions represents the interactions of an agent that solves one of the group's problems or facilitates its resolution.
  2. **Gain Competence:** These interactions make an agent more capable of solving a problem. This includes, for example, the learning of new capabilities or the acquisition of information and resources.
- Negative instrumental interactions
  1. **Obstruct Problem:** This class of interactions represents the interactions of an agent that complicates one of the group's problems or makes its resolution impossible.
  2. **Lose Competence:** These interactions make an agent less capable of solving a problem, for example, by forgetting information or losing control of resources.

Furthermore, to handle the interactions' categorisation, we have defined a set of auxiliary predicates that identify an interaction as instrumental (4.16), socio-emotional (4.17), positive (4.18) or negative (4.19). In addition, we have defined one predicate for each category of interaction that identifies the interaction as a member of that category. For example, there is a predicate $Encourage(I)$ that identifies the interaction I as an *Encourage* interaction.

$$Instrumental(I) \tag{4.16}$$

$$SocioEmotional(I) \tag{4.17}$$

$$Positive(I) \tag{4.18}$$

$$Negative(I) \tag{4.19}$$

4.5.2. The dynamics of the interactions

As previously stated, the interactions create the dynamics in the group. Such dynamics are supported by the classification presented in Section 4.5.1 and are modelled by a set of rules consistent with French and Raven's theory of social power [24] and Heider's balance theory [32]. On one hand, these rules define how the agent's and the group's state influence the occurrence of each kind of interaction and, on the other hand, how the occurrence of each type of interaction influences the agent's and the group's state.

First of all, the execution of interactions by a member in the group depends on her/his individual characterisation as well as her/his perception of the group's state. Thus, s/he will interact in a completely different way according to different group situations, for example, in groups with different elements or with different emergent structures.

In general, the frequency of the interactions depends on the agent's *motivation*, *group position* and *personality* [1,50, 68]. Thus, highly motivated agents, as well as agents with high extraversion or agents with a good position in the group, engage in more interactions. In turn, agents that are not motivated, with a low position in the group, or with low levels of extraversion will engage in few interactions or not interact at all. These elements of the model are captured by the rule synthesised in the following equation[2] (4.20):

$$\begin{aligned}&\forall G, I, A\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge A \in \mathit{members},\\ &\mathit{Poss}(A, I, G, S) \Rightarrow \mathit{High}\big(\mathit{Extraversion}(A)\big) \vee \mathit{High}\big(\mathit{Position}(A, G, S)\big) \vee \mathit{High}\big(\mathit{Motivation}(A, G, S)\big)\end{aligned} \tag{4.20}$$

To better define this rule we have introduced a predicate $\mathit{Poss}(A, I, G, S)$ that represents the possibility of an agent A to perform an interaction I in a group G in a situation S. Equations that use the *Poss* predicate follow the structure of precondition axioms[3] defined by Funge [25]. In addition, we have introduced a predicate $\mathit{High}(X)$ that determines if X is a relative high value.

Furthermore, the agents' personalities also define some of their tendencies for the social emotional interactions [1]. Agents with high levels of *agreeableness* will engage more frequently in positive socio-emotional interactions while agents with low *agreeableness* will favour the negative socio-emotional interactions. This leads us to the rules expressed in the following equations ((4.21) and (4.22)):

$$\begin{aligned}&\forall G, I, A\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge A \in \mathit{members},\\ &\mathit{Poss}(A, I, G, S) \wedge \mathit{SocioEmotional}(I) \wedge \mathit{Positive}(I) \Rightarrow \mathit{High}\big(\mathit{Agreeableness}(A)\big)\end{aligned} \tag{4.21}$$

$$\begin{aligned}&\forall G, I, A\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge A \in \mathit{members},\\ &\mathit{Poss}(A, I, G, S) \wedge \mathit{SocioEmotional}(I) \wedge \mathit{Negative}(I) \Rightarrow \mathit{Low}\big(\mathit{Agreeableness}(A)\big)\end{aligned} \tag{4.22}$$

Corresponding to the $\mathit{High}(X)$ predicate, the $\mathit{Low}(X)$ predicate, introduced in Eq. (4.22), determines if X is a relative low value.

Furthermore, the level of expertise of a member in a group determines the frequency of her/his instrumental interactions. Thus, more skillful agents will engage in more instrumental interactions than non-skillful agents [50]. This fact is expressed in the following Eq. (4.23):

$$\begin{aligned}&\forall G, I, A\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge A \in \mathit{members},\\ &\mathit{Poss}(A, I, G, S) \wedge \mathit{Instrumental}(I) \Rightarrow \mathit{High}\big(\mathit{SkilLevel}(A, G)\big)\end{aligned} \tag{4.23}$$

Additionally, the agents with a higher position in the group are usually the targets of more positive socio-emotional interactions while the agents with a lower *position* are the targets of more negative socio-emotional interactions [50].[4] In addition, when an agent is considering whether to engage in a socio-emotional interaction, its social relations with the target are very important. Members with higher social influence on the agent and/or members to which the agent is positively socially attracted will often be the targets of positive socio-emotional interactions, otherwise they will often be targets of negative socio-emotional interactions. The next two rules express these tendencies:

$$\begin{aligned}&\forall G, I, A, B\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge \{A, B\} \subset \mathit{members},\\ &\mathit{Poss}(A, I, G, S) \wedge B \subset \mathit{Targets}(I) \wedge \mathit{SocioEmotional}(I) \wedge \mathit{Positive}(I) \Rightarrow\\ &\mathit{High}(\mathit{Position}(B, G, S)) \vee \mathit{High}\big(\mathit{SocialAttraction}(A, B, S)\big) \vee \mathit{High}\big(\mathit{SocialInfluence}(B, A, S)\big)\end{aligned} \tag{4.24}$$

$$\begin{aligned}&\forall G, I, A, B\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge \{A, B\} \subset \mathit{members},\\ &\mathit{Poss}(A, I, G, S) \wedge B \subset \mathit{Targets}(I) \wedge \mathit{SocioEmotional}(I) \wedge \mathit{Negative}(I) \Rightarrow\\ &\mathit{Low}\big(\mathit{Position}(B, G, S)\big) \vee \mathit{Low}\big(\mathit{SocialAttraction}(A, B, S)\big) \vee \mathit{Low}\big(\mathit{SocialInfluence}(B, A, S)\big)\end{aligned} \tag{4.25}$$

[2] Equations presented often make a reference to high level categories of interaction. For example, *Positive Instrumental* instead of *Gain Competence* and *Facilitate Problem*. When this happens the equation matches all sub-categories, thus, the dynamics are similar for all. In this case, the sub-categories represent different ways to achieve the same effects. For example, if (1) an agent improves its skills (Gain Competence) or (2) solves part of the task (Facilitate Problem), it will gain some influence in the group.

[3] A precondition axiom is an equation in the form of $A \Rightarrow B$ where B represents the preconditions for A to be true. In other words, for A to be true, then B must be true.

[4] Note that an agent has a high position in the group if it has high influence over the others and/or if the others are highly socially attracted to it.

The previous rules define the conditions for the occurrence of an interaction in the group. But, in addition, when agents get the perception of the execution of an interaction, they react to it according to the classification that they internally give to the interaction. These reactions are translated into changes in the perceived state of the group.

In general, instrumental interactions are related to changes in the structure of social influence. For instance, positive instrumental interactions increase their performers' social influence on the members of the group, through expert and information power [24], as well as the performers' own motivation. Any member that demonstrates expertise and solves one of the group's problems or obtains resources that are useful to its resolution, will gain influence over the others. In turn, members that obstruct the problem or lose competence will lose influence on the group and become less motivated.[5] These rules are summarised in Eqs. (4.26) and (4.27).

$$\begin{aligned}
&\forall G, I, A, B\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge \{A, B\} \subset \mathit{members},\\
&\mathit{Performs}(A, I, G, S_n) \wedge B \in \mathit{Targets}(I) \wedge \mathit{Instrumental}(I) \wedge \mathit{Positive}(I) \Rightarrow\\
&\mathit{SocialInfluence}(A, B, S_n) < \mathit{SocialInfluence}(A, B, S_{n+1}) \wedge\\
&\mathit{Motivation}(A, G, S_n) < \mathit{Motivation}(A, G, S_{n+1})
\end{aligned} \tag{4.26}$$

$$\begin{aligned}
&\forall G, I, A, B\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge \{A, B\} \subset \mathit{members},\\
&\mathit{Performs}(A, I, G, S_n) \wedge B \in \mathit{Targets}(I) \wedge \mathit{Instrumental}(I) \wedge \mathit{Negative}(I) \Rightarrow\\
&\mathit{SocialInfluence}(A, B, S_n) > \mathit{SocialInfluence}(A, B, S_{n+1}) \wedge\\
&\mathit{Motivation}(A, G, S_n) > \mathit{Motivation}(A, G, S_{n+1})
\end{aligned} \tag{4.27}$$

In the definition of these rules, a new predicate $\mathit{Performs}(A, I, G, S)$ was introduced to represent the performance of an interaction I by an agent A in a group G in a situation S.

Furthermore, in turn, socio-emotional interactions are associated with changes in the structure of social attraction. An agent changes its attraction for another agent positively if it is the target of positive socio-emotional interactions by that agent and, negatively, otherwise. Interactions of the category *Encourage* have the additional effect of increasing the target's motivation in the group. The following equations (4.28), (4.29), (4.30) and (4.31) present these rules:

$$\begin{aligned}
&\forall G, I, A, B\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge \{A, B\} \subset \mathit{members},\\
&\mathit{Performs}(A, I, G, S_n) \wedge B \in \mathit{Targets}(I) \wedge \mathit{SocioEmotional}(I) \wedge \mathit{Positive}(I) \Rightarrow\\
&\mathit{SocialAttraction}(B, A, S_n) < \mathit{SocialAttraction}(B, A, S_{n+1})
\end{aligned} \tag{4.28}$$

$$\begin{aligned}
&\forall G, I, A, B\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge \{A, B\} \subset \mathit{members},\\
&\mathit{Performs}(A, I, G, S_n) \wedge B \in \mathit{Targets}(I) \wedge \mathit{SocioEmotional}(I) \wedge \mathit{Negative}(I) \Rightarrow\\
&\mathit{SocialAttraction}(B, A, S_n) > \mathit{SocialAttraction}(B, A, S_{n+1})
\end{aligned} \tag{4.29}$$

$$\begin{aligned}
&\forall G, I, A, B\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge \{A, B\} \subset \mathit{members},\\
&\mathit{Performs}(A, I, G, S_n) \wedge B \in \mathit{Targets}(I) \wedge \mathit{Encourage}(I) \Rightarrow\\
&\mathit{Motivation}(B, G, S_n) < \mathit{Motivation}(B, G, S_{n+1})
\end{aligned} \tag{4.30}$$

$$\begin{aligned}
&\forall G, I, A, B\colon\ \mathit{Group}(G, \mathit{members}) \wedge \mathit{Interaction}(I) \wedge \{A, B\} \subset \mathit{members},\\
&\mathit{Performs}(A, I, G, S_n) \wedge B \in \mathit{Targets}(I) \wedge \mathit{Discourage}(I) \Rightarrow\\
&\mathit{Motivation}(B, G, S_n) > \mathit{Motivation}(B, G, S_{n+1})
\end{aligned} \tag{4.31}$$

Agents also react to socio-emotional interactions when they are not explicitly the targets of the interaction. Following Heider's balance theory [32], if an agent observes a positive socio-emotional interaction towards an agent that it feels positively attracted to, then its attraction for the performer of the interaction will increase. Similar reactions occur in the case of negative socio-emotional interactions. If, in the latter example, the agent performed a negative socio-emotional interaction, then the observer's attraction for the performer would decrease. These rules are shown in the following equations (4.32), (4.33), (4.34) and (4.35):

[5] It can be argued that certain people with certain personality traits become more motivated when they fail to achieve a task. However, this is not the most common behaviour and, therefore, we did not model it.

$$\forall G, I, A, B, C\colon\ Group(G, members) \wedge Interaction(I) \wedge \{A, B, C\} \subset members,$$
$$Performs(A, I, G, S_n) \wedge B \in Targets(I) \wedge SocioEmotional(I) \wedge Positive(I) \wedge High\big(SocialAttraction(C, B, S_n)\big) \Rightarrow$$
$$SocialAttraction(C, A, S_n) < SocialAttraction(C, A, S_{n+1}) \tag{4.32}$$

$$\forall G, I, A, B, C\colon\ Group(G, members) \wedge Interaction(I) \wedge \{A, B, C\} \subset members,$$
$$Performs(A, I, G, S_n) \wedge B \in Targets(I) \wedge SocioEmotional(I) \wedge Negative(I) \wedge High\big(SocialAttraction(C, B, S_n)\big) \Rightarrow$$
$$SocialAttraction(C, A, S_n) > SocialAttraction(C, A, S_{n+1}) \tag{4.33}$$

$$\forall G, I, A, B, C\colon\ Group(G, members) \wedge Interaction(I) \wedge \{A, B, C\} \subset members,$$
$$Performs(A, I, G, S_n) \wedge B \in Targets(I) \wedge SocioEmotional(I) \wedge Positive(I) \wedge Low\big(SocialAttraction(C, B, S_n)\big) \Rightarrow$$
$$SocialAttraction(C, A, S_n) > SocialAttraction(C, A, S_{n+1}) \tag{4.34}$$

$$\forall G, I, A, B, C\colon\ Group(G, members) \wedge Interaction(I) \wedge \{A, B, C\} \subset members,$$
$$Performs(A, I, G, S_n) \wedge B \in Targets(I) \wedge SocioEmotional(I) \wedge Negative(I) \wedge Low\big(SocialAttraction(C, B, S_n)\big) \Rightarrow$$
$$SocialAttraction(C, A, S_n) < SocialAttraction(C, A, S_{n+1}) \tag{4.35}$$

The intensity of the interactions' effects, described in the previous rules, directly depend on the strength of the interaction in the group. For example, *Encourage* interactions performed by members with a better position in the group will have a higher impact on the target's motivation.

4.6. Behaviour generation

The agents' behaviour is generated by the base algorithm shown in Fig. 9. This algorithm relies on 5 main functions:

NProactiveIdleCycles returns the number of "mind" update cycles that agents wait until they execute their proactive behaviours. This function supports the ideas behind the agents' frequency of interaction in the group expressed by Eq. (4.20). It uses a combination of the agent's current position in the group, its extraversion, its motivation and a small random factor to produce the result. The higher the agent's position in the group, its extraversion and the motivation, the lower the result will be (e.g., smaller waiting intervals).

UpdateState processes incoming perceptions and updates the agents' internal state. This includes the categorisation of events into the interactions' categories, described in Section 4.5.1, and changes in the group model expressed by Eqs. (4.26)–(4.35). The most important update is on the interpersonal relations among the members of the group and consequent position of each member in the group—computed by Eq. (4.8). Fig. 10 shows the pseudo-code for an implementation of the *UpdateState* function in the case of the occurrence of and *Encourage* interaction, corresponding to the implementation of the rules expressed by Eqs. (4.28), (4.30) and (4.32).

ReactiveBehaviour generates a reactive reply to the group's events. These behaviours enable agents to react to the occurrence of interactions categorised in the *UpdateState* function. For example, agents can encourage members that failed the execution of an important action for the task (*Obstruct Problem* category) or politely reply to agents that just encourage them. The reactive rules follow Eqs. (4.21), (4.22), (4.24) and (4.25). Fig. 11 shows the pseudo-code for an implementation of the *ReactiveBehaviour* function in the case of the occurrence of an *ObstructProblem* interaction, corresponding to the implementation of the rules expressed by Eqs. (4.21), (4.22), (4.24) and (4.25).

MotivatedToAct is complement to *NProactiveIdleCycles* to implement the ideas of the frequency of the interaction of members in the group. It uses the same arguments (position in the group, extraversion, motivation and a small random factor) to decide if the agents have the chance to perform their reactive behaviours. This function is important to make the reactive behaviours follow the same rules as proactive behaviours, regarding the frequency of the

```
LOOP FOREVER
   LOOP NProactiveIdleCycles()
      UpdateState()
      IF MotivatedToAct()
         ReactiveBehaviour()
      END IF
   END LOOP
   ProactiveBehaviour()
END LOOP
```

Fig. 9. Base algorithm for the generation of the agents' behaviour.

```
IF Encourage(A,B,G)
   SocialAttraction(B,A) = IncrFunction(SocialAttraction(B,A),
                                Strength(I,G))
   Motivation(B,G) = IncrFunction(Motivation(B,G), Strength(I,G))

   IF SocialAttraction(Self, B) > 0
      SocialAttraction(Self, A) = IncrFunction(SocialAttraction(Self,A),
                                     Strength(I,G),
                                     SocialAttraction(Self,B))
   END IF
   UpdateGroupPositions()
END IF
```

Fig. 10. Base algorithm for the function *UpdateState* in the case of the occurrence of an *Encourage* interaction. This captures the situation where agent *A* encourages agent *B* and a third agent *Self* observes the interaction, where all three of them are members of group *G*. The changes are made in the perspective of *Self*. *IncrFunction* is a function that increases the value of the first argument by an amount weighted by the latter arguments. For example, in the second line, the increase of agent *B*'s attraction for agent *A* depends on the strength of the interaction in the group (e.g., the position of agent *A* and other agents that supported the interaction in the group). The *UpdateGroupPositions* function computes the new values for the positions in the group given the changes just made to the interpersonal relations.

```
IF ObstructProblem(A,G)
   p = GenerateProbability(Position(A,G), Agreeableness(Self),
          SocialAttraction(Self, A), SocialInfluence(A, Self))
   IF Random() < p
      EXECUTE Encourage(Self,A,G)
   ELSE
      IF Random() < 1 - p
         EXECUTE Discourage(Self,A,G)
      END IF
   END IF
END IF
```

Fig. 11. Base algorithm for the function *ReactiveBehaviour* in the case of the occurrence of an *ObstructProblem* interaction. This captures the situation where agent *A* makes the group's task harder to achieve (e.g., by failing the execution of a particular action) and this is observed by agent *Self*, both members of group *G*. The decision to reply to this event is based on a probability p computed by the *GenerateProbability* function that returns a value in the interval $[0, 1]$. This value increases as the value of any of the arguments increases (e.g., the probability is higher if *A* has a high position in the group). Value p corresponds to the probability of having a positive reply to the event, thus, encouraging the one(s) responsible for it, while $1 - p$ corresponds to the probability of having a negative reply. *Random* is a function that generates random values in the interval $[0, 1]$.

interaction. For example, despite being highly agreeable, an agent should not encourage other members if it is extremely shy and has a low position in the group.

ProactiveBehaviour starts the proactive decision process. This process includes the planning of the agents' next actions. The planning algorithm is centred on the group's task keeping in mind the contributions of the other members of the group. Thus, the algorithm does not necessarily outputs a task action for the agent. It may generate a task action for another member of the group. For example, the agent may feel that others have higher chances of performing the task successfully. In such cases, the agent will deliberately encourage the other member to act. This behaviour follows Eq. (4.23).

5. Case study: Perfect circle, a collaborative game

To assess the effects of the SGD Model we developed a collaborative game called "Perfect Circle: the Quest for the Rainbow Pearl".[6] The game places four autonomous characters and one user-controlled character in a virtual environment and defines a context of interaction and a task for the group.

The group's goal is to search the world for a magic item. To achieve this, the group must travel around the world through magic portals that are activated by the powers of gemstones. Their task is to gather and manipulate the gemstones in order to get the required ones that will open the portal (see Fig. 12). To achieve this, characters need to apply their individual abilities in order to change the gems' forms, sizes and colours. For example, if the group has two small rubies but it needs one medium-sized ruby, one character can use its ability to merge the small stones into a bigger one. In addition, two or more characters can combine their efforts if they all have the same ability. As a result, the probability of success of the action becomes higher.

The game's task was carefully designed having in mind that the group's task has a very important role in the group's process and is particularly important for groups used in research studies, because the choice of the task may influence the

[6] This game can be downloaded from http://gaips.inesc-id.pt/~rprada/perfect-circle/.

Fig. 12. The group is trying to activate one of the portals in order to advance in the game.

results [51]. For example, certain types of tasks are more suitable to be solved by groups (e.g., conjunctive and associative tasks) and, therefore, encourage group interactions while others do not.

Following the suggestions of Mennecke and Wheeler [51] we designed a task such that:

1. it is *appropriate for all the subjects*, since, all the necessary knowledge to execute the task is within the game and all the elements of the group have access to it;
2. it *promotes subjects' intellectual engagement* by presenting a background story and rewarding the group with points after the correct execution of each puzzle;
3. it has *a good level of complexity*. The task is not trivial and requires a certain engagement of the user to be perfectly understood. However, the task does not require any special skills other than a good understanding of the abilities of the characters. In addition, the difficulty increases as the group gains experience in the resolution of tasks (e.g., the puzzles get more difficult);
4. it is *conjunctive*, because characters have to choose their abilities from many different ones, no single character can perform the task alone. In addition, several characters will solve the task faster than a single character and time is an important factor for the reward;
5. finally *the differences in the subjects' experiences* are controlled because the environment is shared between all the members and the available interactions are similar for all of them.

Furthermore, the game makes every character in the group engaged in solving the same task. However, there are many ways to reach a solution, and if each of the characters follows its own way,[7] the group may never solve the task. Hence, characters have to coordinate their actions in order to follow a similar strategy in the search for the correct gems to activate the portal.

For this reason, every action that is performed in the group, concerning the resolution of the task, is discussed by the group beforehand. The discussion protocol has three different steps:

1. First, one character declares that s/he wants to take a certain action (e.g., "*I think that it will be best if I merge these two sapphires*").
2. The other characters can respond to the proposal with one of the following: (1) *Agree* with the course of action; (2) *Join* the action and help in the execution; (3) *Disagree* with the course of action.
3. Then, based on the opinions expressed by the group, the character decides to proceed with the execution of the action or to withdraw the proposal. If s/he decides to proceed with the action then s/he starts its execution. All of the other characters that have decided to join the action start their contributions to the joint execution.

In addition, the group's interactions are not restricted to the execution of the task. Each member (user and autonomous) can, at any time, engage in socio-emotional interactions by encouraging or discouraging the other members of the group.

[7] All characters use the same planning algorithm, but the solutions depend on individual skills and heuristics. For example, heuristics may take into account the agents' interpersonal relations when considering introducing others' actions in the plan.

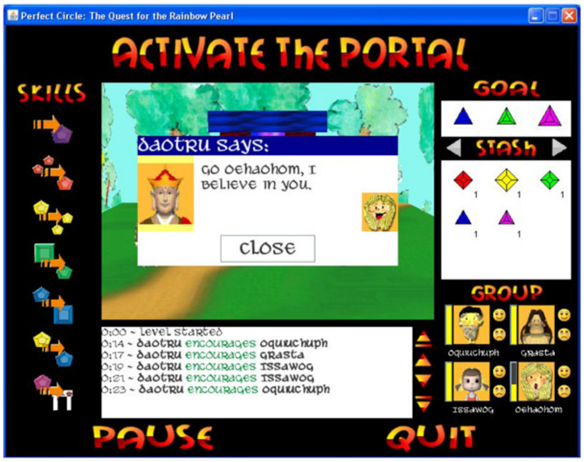

Fig. 13. Character Daotru encourages Oehaohom.

5.1. The SGD model in the game

To implement the SGD Model in the Perfect Circle game it was necessary to define the knowledge regarding context that establishes the relation between actions and events in the game and the categories of interactions of the model (see Section 4.2). These relations influence, on one hand, how particular actions are perceived by agents as group interactions (see Section 4.5) and, on the other hand, how intentions to perform group interactions are generated and transformed to particular actions in the game. In this case, agents are able to use 2 instrumental interactions (*Facilitate Problem*, *Obstruct Problem*) and 4 socio-emotional interactions (*Agree*, *Disagree*, *Encourage* and *Discourage*).

The rest of the model is independent of the context, so no additional work was needed.

5.1.1. From game actions to group interactions

The *Facilitate Problem* interaction corresponds to the event of a successful execution of a manipulation on a gemstone (e.g., merge, split, etc.) and the *Obstruct Problem* corresponds to a failure. This means that every time an agent or group of agents, including the user, execute an action on a gem all agents will interpret that as an instrumental interaction, which is positive (*Facilitate Problem*) if the execution was successful[8] and negative (*Facilitate Problem*) otherwise.

Socio-emotional interactions have direct correspondence to actions in the game. This means that there is a specific action in the game to agree, disagree, encourage and discourage. This makes the identification of socio-emotional interactions trivial. For example, every time an encouragement action is performed in the game all agents perceive it as an *Encourage* group interaction.

The join action described in the previous section corresponds to an *Agree* interaction but, additionally, binds the agent to perform an action on a gem if the proposal is accepted.

We chose to have this direct correspondence between game actions and group interactions to simplify the process of perception and identification of the group interactions. We believe that this process is not trivial in more complex scenarios (e.g., if the interactions are based on speech). It can be an interesting research problem by itself. Our intention was to minimise that effort on our work.

5.1.2. From group interactions to game actions

The agents decision process (see Section 4.6) generates requests of interaction that need to be translated into specific actions in the game.

In the case of the socio-emotional interactions, this process is trivial. As seen before, each socio-emotional interaction in the SGD Model has a corresponding action in the game. For example, if the agent decides to start an *Encourage* interaction, this corresponds to performing an encouragement action in the game.

Encouragement actions take the form of positive sentences (see Fig. 13), such as: "I believe you." or "Keep the good work." In turn, discouragement actions are negative sentences, such as: "Stop doing that!" or "I don't care, just shut up." These sentences are predefined and are chosen automatically by the game according to the situation, for example, if the encouragement is a reply to another encouragement. Therefore, agents (and the user) can only state their intentions to encourage/discourage a character, the actual sentence used is beyond their control.

[8] The success of the execution of an action in the game follows a probabilistic function that depends on the skill level of the performer of that particular action.

Facilitate Problem corresponds to raising the discussion of a proposal for action. The action is only started if the proponent feels supported by the group (e.g., if members with better position in the group agree with the action). In Perfect Circle, agents do not deliberatively mess up the group's task, thus, *Obstruct Problem* interactions are not pro-actively generated.

The decision process is also influenced by the context, in particular, it needs a model of the task to properly execute the planning algorithm and to support the decision to *Agree* or *Disagree*. In this case, agents' decide to *Agree* or *Disagree* with a proposal based on their planning algorithm. The nodes explored during planning are kept in the agents' memory. If the proposal matches one of the actions on these nodes the agent is inclined to *Agree*; otherwise, it is inclined to *Disagree*. Note that, since *Agree* and *Disagree* are socio-emotional interactions, this decision is not based only on the task model but also follows the socio-emotional rules described in Section 4.5.2.

6. Study

In order to evaluate the effects of the SGD Model on the interaction experience of a user, we performed an experiment using the Perfect Circle game. This experiment was conducted at our university with 24 students of computer science, 20 of them being male and 4 being female. The subjects' ages ranged between 19 and 31 years old.

6.1. Independent variables

The experiment was conducted with two main independent variables: the use of the SGD Model to convey the believable group dynamics and the initial structure of the group:

1. **Use of the SGD Model:** two different versions of the game were built: one where the characters followed the SGD Model and one where they did not. When the characters did not use the model, they were unable to engage in socio-emotional interactions, with the exception of *Agree* and *Disagree* with a proposal (without any socio-emotional connotation). In addition, their frequency of interaction was always constant and the decision to proceed with a proposed action was not weighted by the members' position in the group (as in the SGD Model). Rather, it was simply according to the majority. Note that in both cases the characters' planning algorithm is able to solve the task.
2. **The Group Initial Structure:** subjects can start the game in a group with non-neutral initial social relations, which means that the initial group can have levels of cohesion that may be either very high or very low. Two different scenarios were considered: one where the group had neutral social relations and a second one where the members of the group disliked each other, which took the group cohesion to very low levels. Note that this condition could only be applied when the game was run with the believable group dynamics model.

6.2. Dependent variables

To assess the quality of the subjects' interaction experience while playing the *Perfect Circle* game, we measured their satisfaction with the game as well as their trust and social identification with the group, since, according to Allen et al. [2], these two variables are related to the satisfaction of people when interacting in a group. Thus, our three dependent variables are:

1. **Group Trust:** people's trust in a group has a positive effect on their perceptions about their experiences in the group [22], which consequently leads to more satisfactory interaction [3].
2. **Group Identification:** according to Ashforth and Mael [4], social identification is, in addition to social trust, one of the factors that allow the members of a group to be more engaged and more satisfied with the group.
3. **Satisfaction with the Game:** by definition, computer games are supposed to be fun, thus, the user should enjoy every moment that s/he spends with the game. Hence, improving the interaction experience, as stated in the initial hypothesis, would also imply increasing the user's fun.

6.3. Measures

To measure the variables discussed in the previous section, we have referred, whenever possible, to questionnaires found in the literature and previously applied in other studies. In the case of group trust, we relied on the questionnaires that Allen et al. [2] used in their studies. They proposed a seven items' questionnaire with five positive items and two negative ones. To keep the questionnaire consistent and, therefore, easier to understand by the user we have decided to balance the positive and negative items. For this reason, we have only used six items and changed one of the positive sentences for a negative one. The items of the resultant questionnaire are presented in Table 2.

Since we changed the initial questionnaire we computed the Cronbach's Alpha for the new items to check the questionnaire's reliability. The result was 0.787, which tell us that the questionnaire is acceptable.[9]

[9] We did not have access to the original questionnaire's Cronbach's Alpha for comparison, but usually a value above 0,7 is considerable acceptable.

Table 2
The items of the group trust questionnaire

The Group Trust Questionnaire
1. Most people on this team are honest and can be trusted.
2. Team members are always interested only in their own welfare.
3. Members in this team are always trustworthy.
4. One has to be alert or someone is likely to take advantage of you.
5. If I have a problem there is always someone to help me.
6. Nobody in the group is willing to help me with my tasks.

Table 3
The items of the social identification questionnaire

The Social Identification Questionnaire
1. I feel strong ties with the members of this group.
2. I did not enjoy playing with this group.
3. I feel accepted as a member of this group.
4. I experience a sense of not belonging to this group.
5. If I play again I would like to play with the same group.
6. I am not sufficiently acknowledged in this group for my expertise.

Table 4
The items of the game satisfaction questionnaire

The Game Satisfaction Questionnaire
1. I loved to play this game.
2. I felt bored while playing the game.
3. The game was very interesting.
4. I would not suggest this game to anybody.
5. I would like to play this game again.
6. The game was too complex.

In the case of social identification with the group, we once again relied on the work of Allen et al. [2], since they also proposed a questionnaire to measure this variable. Their questionnaire is composed of five different elements, all with a positive nature. These items formed the basis of our questionnaire; however, we made some significant changes (again for consistency): (1) some of the sentences were changed to meet our gaming scenario, (2) three of the items were changed to negative, and (3) a new positive item was added to complete the set of six. The resulting questionnaire is shown in Table 3. The Cronbach's Alpha for these items was 0.797.

We have found several questionnaires in the literature to measure the users' satisfaction with computer systems, such as the End User Computing Satisfaction questionnaire [20]. However, these questionnaires focus on questions related to the system's accuracy, ease of use and effectiveness, and do not take into account the user's joy during the experience. In fact, as stated by Wiberg [76], these classical measures are not completely appropriate for attaining the users' satisfaction in entertainment systems. For example, if the user spends a lot of time on a particular task this is not necessarily a bad sign, since this may happen because the user is having fun with the task. For these reasons, we have developed our own questionnaire that is shown in Table 4. It was based on the idea that, if a user's interaction experience is fun, then s/he would like it, repeat it and suggest the experience to others. The Cronbach's Alpha for these items was 0.739.

All questionnaires asked the subjects to rate each of the items in a scale of 1 (Totally Disagree) to 7 (Totally Agree).

6.4. Procedure

Each subject participated in a trial of two hours. In the first half-hour, subjects read the game's instructions and questions were answered about the game's mechanics. Then, they created their own character and played the game for one hour. After that, subjects filled out a questionnaire, which included several items related to the three dependent variables (group trust, the group identification and satisfaction with the game).

The game was installed according to three different conditions (8 subjects per condition):

(C1) In the first condition, the game was installed without the SGD Model.
(C2) In the second condition, the game was installed with the SGD Model and the group had neutral social relations in the beginning of the game.

Table 5
Results from the Kruskal–Wallis test comparing the sample across the experimental conditions ($N = 24$)

	Age	Gender	Gaming experience
Chi-Square	2.584	.575	.147
df	2	2	2
Asymp. Sig.	.275	.750	.929

Table 6
Results from the Kruskal–Wallis test comparing all the experimental conditions ($N = 24$).

	Trust	Identification	Satisfaction
Chi-Square	6.492	5.960	4.503
df	2	2	2
Asymp. Sig.	.039	.051	.105

Table 7
Results from the Mann–Whitney test comparing conditions 1 and 2 ($N = 16$)

	Trust	Identification	Satisfaction
Mann–Whitney U	13.000	16.000	20.500
Asymp. Sig. (2-tailed)	.045	.090	.226

(C3) In the third condition, the game was installed with the SGD Model but the members of the group started with negative social attraction relations, thus, the level of cohesion of the group was very low.[10]

Furthermore, apart from the differences mentioned, all the other details were similar in the three conditions. The four autonomous characters had the same name, the same appearance, the same personality and the same skills. In addition, the sequence of the game puzzles was predefined and the same for all the subjects. This sequence was randomly generated beforehand. The subjects were selected on the fly at the beginning of each session and they freely chose which computer to use (they were unaware of the different conditions).

In all of the conditions, players were focused on the game for the whole hour and never showed signs of boredom. The game was complex enough to keep the subjects motivated, but not too complex to make them frustrated. Furthermore, during the trial, subjects never interacted with each other.

6.5. Results

Before analysing the dependent variables we checked the sample in order to identify possible significant differences across the experiment's conditions. This verification was made in three different items: age, gender and gaming experience. These items were part of the questionnaire presented to the subjects. Gaming experience was accessed by questions asking if the subjects liked to play computer games and if they played computer games often.[11] Results showed that there were no significant differences in the three groups of subjects regarding age, gender and gaming experience (see Table 5).

Comparing the different experimental conditions in relation to the dependent variables reveals statistically significant differences in Trust (see Table 6). Furthermore, the difference between the conditions in relation to Social Identification approaches statistical significance.

The previous result, however, does not show if all the conditions differ or if the difference comes from the comparison of a particular pair of conditions. In order to check out possible differences between pairs of experimental conditions, a series of Mann–Whitney tests were run.

Table 7 gives the results of the Mann–Whitney test comparing condition 1 and 2. It shows that subjects' trust in the group was significantly higher when the autonomous characters' behaviour followed the SGD Model (Mean Rank for condition $1 = 6.13$; Mean Rank for condition $2 = 10.88$).

The comparison of conditions 1 and 3 can be seen in Table 8. The results show that subjects' trust in the group is significantly higher when the autonomous characters follow the SGD Model even if the cohesion of the group is initially very low (Mean Rank for condition $1 = 5.69$; Mean Rank for condition $3 = 11.31$). Furthermore, subjects identify themselves better with the group if the SGD Model is used and the initial cohesion of the group is low (Mean Rank for condition $1 = 6$;

[10] We include this condition to check if the initial structure of the group influences the users' experience, but not to carefully explore how this influence works. For this reason, we did not include all possible combinations of social relations (e.g., having a very high social cohesion group). For this, a new and different study should be performed.

[11] Actual sentences used were: "I love to play computer games." and "I play computer games frequently." Subjects were asked to rank each sentence from 1 (Totally Disagree) to 7 (Totally Agree).

Table 8
Results from the Mann–Whitney test comparing conditions 1 and 3 ($N = 16$)

	Trust	Identification	Satisfaction
Mann–Whitney U	9.500	12.000	24.000
Asymp. Sig. (2-tailed)	.018	.035	.397

Table 9
Results from the Mann–Whitney test comparing condition 2 and 3 ($N = 16$)

	Trust	Identification	Satisfaction
Mann–Whitney U	29.500	19.500	12.000
Asymp. Sig. (2-tailed)	.792	.187	.035

Mean Rank for condition $3 = 11$). Note that this difference was not significant when the initial cohesion of the group was neutral (see Table 7).

In relation to the comparison of conditions 2 and 3, Table 9 shows significant differences for Satisfaction. Participants were more satisfied with the game when the initial cohesion of the group was low (Mean Rank for condition $2 = 6$; Mean Rank for condition $3 = 11$).

The above results suggest that, by using the SGD Model to drive the behaviour of the autonomous members of the group, the levels of Trust (when comparing condition 1 with 2 and 3) and Social Identification (when comparing condition 1 with 3) of users were higher. However, the same cannot be said regarding their levels of Satisfaction. There are differences in the Satisfaction of users when the initial group's cohesion changes (comparing condition 2 with 3). It seems that the most cohesive group induced lower levels of satisfaction in the subjects. We believe that this effect may be related to the fact that the socio-emotional interactions in the most cohesive group are essentially positive, which is probably less believable than a scenario where negative socio-emotional interactions occur more often, as is the case in condition 3. Furthermore, subjects might not find the group to be challenging. Because everyone agrees with each other, group interactions are more boring. However, with this study we cannot confirm these hypotheses.

Note that, if Bonferroni's correction is used when comparing the three conditions with each other, the threshold for the acceptance of a significant result drops to 0.017 (instead of the usual 0.05). Thus, the results described become less significant. However, this is due to the fact that we did not have many subjects in our experiment (only 8 per condition). Nevertheless, we believe that the results presented are still interesting, although we should conduct a new study with more subjects to substantiate them.

7. Conclusions and future work

In this paper, we describe a model to improve the believability of groups of autonomous synthetic characters in order to promote user collaboration with such groups. This model was successfully used in the context of a collaborative game. The experiment conducted in this scenario demonstrated the positive effect that the model can have on the users' interaction experience. Specifically, the experiments showed that user trust and identification with the synthetic group increased.

These positive results support our argument that to ensure that users have a good interaction experience in group scenarios, it is not enough to have members perform optimally in the group, and, furthermore, members should behave according to the group's context, or, in concrete terms, within the structure of interpersonal relationships. The first point is supported by the fact that, in all three conditions of the study, agents used the same planning algorithm that was able to reach an optimal solution for the game's task. The second point is supported by the fact that when the SGD Model was used, users' interaction experience was better.

Something that we still want to explore is the impact of each individual component of the model. For example, it could be interesting to understand if the relations of social influence have less/more impact on the interaction experience than the relations of interpersonal attraction, or to understand the impact of having different frequencies of interaction or individual personality. From our observations, different players seek different experiences. For instance, some players gave much importance to the socio-emotional relations and acted as socio-emotional leaders encouraging others to perform, while other players tried to perform most work for themselves. For this reason, we believe that different model components may appeal differently to different people. Nevertheless, results from this study can help us to identify less important components of the model and, eventually, to simplify it.

On the other hand, we foresee some possible extensions to the model, because there are aspects of the group dynamics that could be further explored. For example, we have not addressed the dynamics of the group regarding its composition. We did not explore the rules for the acceptance of new members into the group or the rules to support the decision of a member to leave the group. This, among other things, is related to the individual expectations concerning the group (e.g., the goal that led the individual to join the group), which is not considered in our model, and should, therefore, be addressed in the future.

In addition, the structure of the group could be more complex and include, for example, specific organizational roles.

Another possible extension is related to the personality of the members. We could include factors such as the level of individualism of each member that could assess the level of commitment of the members to the goals of the group in contrast to their own individual goals. In fact, in our example, the autonomous members of the group were always focused on the resolution of the task and were always performing in the group's best interest. However, in real life, this is often not the case, and we have some evidence, from our experiment, that groups with a certain amount of conflict were preferred by the users. Therefore, we believe that the study of the balance between the cohesion of the group and the amount of conflict that stimulates the user can be an interesting theme for future research.

Furthermore, inter-group relations were not explored by our model. The model was centred on the interaction of the group members with each other without taking into account their interaction with external groups. This would be a very interesting extension and would be essential for scenarios where several different groups engage in collaboration and competition.

Moreover, we believe that the SGD Model can be used in different applications apart from the entertainment scenarios that we explored. For example, it could be used in systems for training leadership, to support the collaboration of humans in computer-mediated scenarios, or in a tool for sociologists to perform their studies of group dynamics.

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