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Crowdmags: Multi-Agent Geo-Simulation of the Interactions of a Crowd and Control Forces

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1. Background and Motivation of the Research

Crowd simulation is a research and development field that has been greatly expanding during the past decade (Thalmann et al. 2007) and has found applications in various domains such as computer games, animation movies, the study of crowd behaviours for egress analysis and evacuation planning; the simulation of crowd situations and control interventions, to name a few. Crowd simulation is also applied to the domain of security planning and crowd management with the goal of helping civilian and/or military control forces to devise and assess intervention plans, and to train personnel in preparation of various kinds of crowd events: evacuation of densely populated areas in emergency situations, evaluation of contingency plans for emergency planning; initiatives to secure downtown infrastructures and populations (Levesque et al. 2008). Our current work takes place in this domain and aims at developing applications of crowd simulations to support decision makers when planning or monitoring crowd events. More particularly, we consider what we call '*purposive crowds*' in which people gather for a specific collective purpose such as demonstrating against measures or regulations enforced by civil or military authorities, celebrating specific events or persons, participating in rallies to promote particular causes, and so forth. It has been observed that in a 'purposive crowd', most people come in groups, often small groups of friends or colleagues, acquaintances or even families (McPhail 1991). It is clear that in such a crowd, different groups of people may try to put different messages to the fore, but they usually fall under the 'umbrella' of the global theme that was used to call for the gathering.

As it appeared in our literature review of a large number of crowd simulations developed during the past 15 years, it is clear that most research teams consider a crowd as an emergent phenomenon resulting from the interactions of a multitude of individuals that have temporarily assembled in a given location. In such a context, researchers proposed various ways to model individual agents, their behaviours and their interactions, so that the emerging collective behaviours resemble the patterns of collective behaviours observed in real crowd phenomena. However, we suggest that when modeling and simulating a purposive crowd, the most important element is not the individual, but the group!

Indeed, individuals reason and make decisions on an individual basis, but their references are groups: groups of demonstrators that they can recognize around them ('in-groups' as sociologists call them), but also 'out-groups' that they perceive as adversaries. A bystander may observe a crowd event as an uninvolved individual, but if she decides to join the demonstration, it is most likely that she will try to join a nearby group of demonstrators which attracts her and will offer her the opportunity to participate in collective actions. Hence, there is a need to simulate the attraction and repelling of agents by groups.

Very few approaches provide ways to model groups explicitly and, to our knowledge, none of them allows for the specification of group interactions. We suggest in this chapter that this is the reason why a true social dimension is still missing in current crowd simulations. Indeed, this social dimension is at the center of the crowd phenomena that have been studied by psychologists and sociologists during the past 30 years. Scholars have shown that such notions as social identity, self-categorization, emotions and inter-group relations, play an important role in understanding and analysing crowd behaviours (Section 2). Indeed, it seems more plausible to model a purposive crowd using an approach based on 'group dynamics' rather than on one which is solely based on individuals' interactions. We adopted such an approach in the *CrowdMAGS Project* in which we developed a simulation framework to simulate the behaviours and interactions of a crowd and of control forces in urban environments in order to assess different intervention strategies using non lethal weapons (fences, tear gas, plastic bullets).

These geo-simulations (Moulin et al. 2003) take place in a virtual geographic environment (VGE) generated from GIS data (GIS = 'Geographic Information System') that faithfully reproduce urban features (roads, buildings, pavements, etc.). Individuals, be they part of the crowd or of control forces, are modelled by autonomous agents which are able to: 1) perceive the environment's characteristics and content; 2) perceive the characteristics and behaviours of other agents and groups; 3) assess all these characteristics in order to choose their own behaviours; 4) carry out individual behaviours as well as collective ones in the group in which they participate; 5) interact with other agents and groups. Our behavioural models extend and adapt in an operational way, the main principles of the *Social Identity Theory* (Reicher 1982) which essentially states that an individual tends to self-identify with one or more social groups and, then aligns her behaviour with what she finds acceptable according to her values.

The proposed approach and the associated software put forward several innovations. This is the first approach of crowd simulations that explicitly models individuals, groups and their interactions, based on their social characteristics, as well as on the assessment of these characteristics by autonomous agents. This approach enables us to plausibly simulate the interactions of a crowd and control forces resulting from both individual and collective actions. Indeed, an agent perceives individuals and groups, assesses their behaviours and may decide to join a group (to participate in its collective actions) or to leave it (and again behave individually) according to its preferences ('social values'). Moreover, agents also react to simulated non-lethal weapons (NLW) that might be used by control forces. We developed the *CrowdMAGS System* which fully implements in multi-agent geo-simulations all the above-mentioned features of our models of crowds and control forces.

In section 2 we review some of the main existing crowd simulation approaches and show how they fail to integrate the notion of individual and collective actions based on sound social theories of crowds. We also briefly review some of the main social theories of crowds that may be of interest for the simulation of crowds. In Section 3 we propose a number of extensions that might be introduced in crowd simulations to explicitly introduce social notions and mechanisms to explicitly manipulate groups and agents' and groups' interactions. Sections 4, 5 and 6 present the main characteristics of our Agent and Group models as well as their interactions that we have implemented in the *CrowdMAGS System*. Section 7 and 8 present the architecture and the main components of the *CrowdMAGS System*. They also provide illustrations of its practical use. Section 9 concludes the chapter and identifies several perspectives opened by this research work.

2. Crowd Simulation Approaches and Collective Actions

Since critical situations such as escape panic and unplanned evacuations may threaten the public safety, many research works have been carried out on the simulation of dense crowds and models based on particle and fluid dynamics have been proposed to explain people's behaviours in such constrained situations (Helbing et al. 2000, 2001). In these models individuals' behaviours are very simple and mainly consist of reactions to surrounding forces. These physics-based models try to reproduce the geometric characteristics of the observed patterns of 'group movements' in a crowd. However, with the exception of the HIDAC system (Pelechano et al. 2007), these approaches fail to explain why these patterns occur because they lack references to the psychological and sociological characteristics of crowd members. Such models are applicable to simulate certain situations such as pedestrian flows and high-density crowds (as in the case of evacuations), but they are not sufficient to plausibly simulate crowd behaviours in other situations in which people are not physically too much constrained.

Other approaches try to incorporate psychological factors in crowd simulations (Kenny et al. 2001) (Silverman et al. 2002). Most approaches offer models to specify the individual's characteristics (physiological, psychological and emotional) and the individual's behaviours. However, they do not provide sufficient constructs and mechanisms to specify and simulate the interactions between individuals and groups. When it comes to modeling police forces, we did not find any system that convincingly models agents and groups and their interactions with crowds. In the few simulations that introduce agents simulating policemen or soldiers, these agents have limited autonomous behaviours as in the *Crowd Federate System* (McKenzie et al. 2007).

Several systems are able to simulate some aspects of the dynamics of groups in a crowd. However, these systems essentially simulate the dynamics of groups in a kinematic way, taking advantage of the geometric properties (such as distance between group members, orientations, personal space) of agents moving in groups and of attraction/repulsion rules/forces that enable the system to maintain the group's geometrical coherence. Simulating groups in a kinematic way may be sufficient for animation purposes as in the *V-Crowd System* (Musse and Thalmann 2001). However, there is a need for more elaborated models integrating both the individual's characteristics (psychological, emotional) and social rules/behaviours in order to explain why agents may join or leave a group, why perceiving and interpreting the actions carried out by the members of a group (out-group) may induce an agent to change behaviour or even 'change of identity' as some sociologists call it (Reicher 1982).

In the large body of literature on the sociology of crowds and on 'collective actions', several theories have been proposed over the past hundred years such as the 'social contagion' (Le Bon 1895) (McPhail 1991), the 'social identity theory' (Reicher 1982) and the 'social comparison theory' (Festinger 1854). These theories may provide useful insights (i.e. Drury and Reicher 1999, Reicher et al. 2004) to researchers who want to explicitly introduce social interaction models in crowd simulations. However, very few have been used in current crowd simulations, and when they are used (Kaminka & Fridman 2006), the authors only tackle what we call the kinematics of groups: the dynamic geometrical properties of agents' positions in a group.

To conclude, most existing crowd simulations are based on the specification of individual agents' behaviours, and group behaviours are thought of as an emergent phenomenon. Our literature review showed that very few approaches provide ways to explicitly model groups, and none of them allows for the specification of group interactions. This is why we claim that a true social dimension is still missing in current crowd simulations.

3. Extending Crowd Models with Explicit Social and Group Notions

Our model is based on an adaptation of the *Social Identity Theory* (Reicher 1982). This theory states that an individual tends to self-identify with one or more social groups and then aligns her behaviour with those deemed acceptable by the members of that social group (what can be called 'the norms of the group'). Depending on the situation, an individual can shift from a personal identity to a social identity, or from one social identity to another one, and change her behaviours accordingly. We claim that current crowd simulation approaches need to be extended by explicitly introducing social concepts and mechanisms to enable agents to recognize, join or leave a group, and to react to groups' behaviour. Here are the main extensions that we propose:

- Social notions in the agent models such as the social identity and mechanisms to enable an agent to adopt a new identity under certain conditions; this change being triggered by its emotional and cognitive states and by the situation that the agent perceives and interprets;
- The notion of social group to which an agent may belong, and identify to (as for example a group of agitators, a family, etc.);
- The notion of what we call a 'spatial-temporal group' (STG), a group that is easily recognizable in space and time such as a line of policemen and a group of friends walking together;
- Mechanisms for an individual agent to recognize groups (through a perception and interpretation mechanism), to assess their characteristics (by their physical appearance, their actions) and compare them to his expectations, so that the agent may wish to join the group and participate in its collective actions (at least temporarily);
- Mechanisms that enable an agent to join a group or to leave a group.

We suggest that these mechanisms are necessary if we want to simulate and explain collective behaviours and attitude changes in crowd situations involving different kinds of agents and groups such as demonstrators, instigators /agitators and police squads.

As a proof of concept we developed an agent-based model based on the proposed extensions. In the following paragraphs we briefly present these notions.

The notion of social identity. An agent modeling a crowd member should be able to change its behaviour depending on the situation (what happens around the agent), and on the way he interprets this situation. The concept of social identity is used to factor objectives and behaviours of an agent so that it can change them during the simulation. For example, a bystander observing a demonstration may decide to join the demonstrators. A demonstrator may decide to join the instigators in the crowd and consequently may adopt behaviours that are typical of instigators.

The notion of projected image. In most current crowd simulation systems the agents' perception is usually simulated by a simple function that is able to identify the presence of other agents in the vicinity of the perceiving agent. In reality, different agents may observe the same situation and react to it in different ways. Hence, the way that an individual interprets the crowd situation (essentially the perceived behaviours of other individuals or groups in the crowd or in the control forces) significantly influences her decisions and behaviour changes. Hence, it is important to model this interpretation if we want to plausibly simulate phenomena such as social identity change or social contagion. To this end, we introduce the new notion of an agent's projected image. An agent *Ai*'s projected image is a data structure that contains the information made available to the other agents when they perceive *Ai*. An agent *Ai*'s projected image contains the attributes that can be perceived from the outside such as age category, clothing, equipment and attitudes. Moreover, we extend an agent's perception mechanisms with a function that is used to interpret the information contained in the projected images of the agents that he perceives. This function is used to change the agent's beliefs and possibly to trigger some goals or identity changes.

The notion of social group. The notion of group clearly plays an important role in crowd situations, but this notion is poorly modeled in currently existing crowd simulation tools. We propose to introduce the notion of *social group* which characterizes the common characteristics of a group of agents that do not change during the simulation. Crowd members and control forces are examples of global social groups with which agents can be associated. A family, a group of friends or a police squad, are other examples of social groups. In these groups, agents may play different roles, as for example the leader, the deputy-leader and the group members. Roles are associated with typical behaviours of these agents in their social groups. Hence, an agent can belong to one or several social groups and has a current social identity, chosen among a set of possible social identities. The agent's social identity may change depending on the circumstances as it was previously mentioned. Hence, a peaceful demonstrator agent may adopt a social identity of an instigator for a while. But, it can change it during the simulation and become again a peaceful demonstrator. Let us emphasize that social groups exist in the simulation, but they do not appear as spatial entities: they are merely part of the knowledge available to the agents. In contrast, we will call STGs, the groups that spatially appear in the simulation and that can be recognized by the agents and by external observers (users of the simulation).

The notions of a spatial-temporal group (STG) and of a formation. In most simulations, groups are not explicitly modelled; group behaviours are viewed as patterns emerging from the simulation such as the formation of pedestrian flows. In contrast, we propose to introduce mechanisms that will allow agents to purposively join groups during the simulation. For example, after changing its social identity, an agent may decide to join a group of instigators. Hence, we introduce the new notion of *Spatial-Temporal Group (STG)* which models the groups that can be perceived by agents in the simulation. An STG is associated with mechanisms that allow individual agents to joint it, to dissociate from it and to recognize it. We also associate with an STG the notion of *Formation*, which characterizes the geometrical arrangement of members in the group. For example, a squad of policemen can adopt a line formation or a wedge formation. But, agents in the crowd can also move in formations as simple as 2 agents moving side by side (simplest line) or a group of instigators aligning behind a fence. Conceptually, STGs are also agents and hence have a projected image that agents can perceive.

The notions of interest point and interest area. People are attracted by various kinds of elements in the environment such as for example restaurants, tourist places, shops and monuments. Individuals may also be attracted by other people such as charismatic leaders or even by groups such as a group of demonstrators chanting songs. There is a need to model and simulate these attraction mechanisms. To this end, we introduce in the simulation environment interest points that are objects (which may not be visible to the user) that display different characteristics (thanks to a perceived image) and that the agents may selectively perceive. Hence, depending on his state, an agent may be attracted by some interest points. Interest points may be generalized in terms of interest areas, so that agents can detect areas of interest in the virtual environment.

Interest points/areas are not only associated with objects in the VGE, but also with STGs. In this way, we take advantage of the same mechanisms to simulate the agents' attraction to stationary points/areas and to moving points/and areas. For example, an instigator leader agent (with 'charismatic characteristics') may call for other agents to join. We emulate this potential group as an STG associated with the instigator leader agent. An interest point is attached to this STG and has the potential to attract members to the STG. The crowd member agents that favourably respond to the instigator's call are attracted by the STG's interest point: they move to join the STG and then participate in the associated formation.

The notion of resource. Several types of agent behaviours may need resources which are objects used to carry out these behaviours. For example, tear gas canisters are resources that control forces may launch over the crowd. Stones are resources that instigators and rioters may throw on control forces or on shop windows. A gas mask can also be considered as a resource that an agent may own or may give to another agent. Typically, resources are objects that are needed to carry out various activities. Some resources are limited and agents may compete to acquire them. There are very few crowd simulation systems that explicitly manage resources that agents may use.

4. The Agent Model

Considering Newell's pyramid (Newell 1990) which comprises the physiological, reactive, cognitive, rational and social levels of agent behaviours, we mainly concentrate on the social level in this section. According to the principles presented in Section 3, we suggest to introduce in the individual agent's model some minimal social notions in order to allow him to participate in collective actions: 1) Agent's projected image and interpretative process; 2) Social identity and mechanisms to enable an agent to adopt such an identity under certain conditions; 3) Social affiliation which characterizes social groups to which an agent may belong; 4) Mechanisms allowing an individual agent to recognize groups and assess their characteristics in order to decide to join/leave a group; 5) Mechanisms that enable an agent to join a group or to leave a group. Here are these notions.

Agent's projected image. An agent *Ai*'s projected image is a data structure that contains the information made available to other agents when they perceive *Ai*. An agent *Ai*'s projected image contains the attributes that can be perceived from the outside such as age category, clothing and equipment. We may also include in *Ai*'s projected image a list of the last *n* activities carried out by *Ai*, so that an agent observing *Ai* may get this information and act accordingly. This enables us to simply and efficiently simulate a mechanism of memory of the perceivable activities carried out by agents.

Agent's interpretative perception. It is well known that different people may interpret in different ways a given piece of information that they perceive. This interpretation process is seldom accounted for in crowd simulations. We developed a mechanism of *interpretative perception* as a function that is added to other perception functions and enables the agent to interpret the information contained in the projected images of the agents that he perceives. This function can be used to change the agent's beliefs and possibly to trigger some goals or identity changes.

Agents and interest points. In Section 3 we introduced the notion of interest point /area. We need to model and simulate agents' attraction mechanisms toward interest points. To this end, an interest point/area is defined as an object (which may not be visible to the user) which displays different characteristics (thanks to a projected image) that the agents may selectively perceive. Hence, depending on the state of an agent, he may be attracted by some interest points/areas located in the VGE.

The notion of social affiliation. An agent may belong to various social groups (a family, a group of friends, a group of co-workers, a sports association, an agitators' association such as the *Black Block*, a police squad, etc.). We suggest to introduce the notion of *social group* which is defined as a set of agents sharing common social characteristics. An agent can be affiliated with several social groups and play various roles in them. For the simulation purposes, we characterize an agent's affiliations as a knowledge structure that identifies the social groups to which it belongs. This information does not change during the simulation and provides the agent with some background knowledge which can be used to recognize agents having common affiliations. Some agents may have distinctive characteristics that highlight their social affiliation as in the case of policemen who wear uniforms and carry equipment that identify them.

The notions of fundamental identity and of social identity. An agent modeling a crowd participant should be able to change its behaviour depending on the situation (what happens around the agent), and on the way it interprets this situation. In line with Cronin and Reicher's *Extended Social Identity Model* (Cronin et al. 2006)(Reicher 1996, Reicher et al. 2004), we suggest that an agent be associated with a *fundamental identity* (mainly composed of its personality traits) and that, in addition, it may temporarily adopt different *social identities* when participating in collective activities. The concept of social identity is used to aggregate an agent's objectives and behaviours, so that it can change them during the simulation. During the simulation an agent may change its social identity any time and depending on the circumstances. For example, a bystander observing a demonstration may decide to adopt a demonstrator's social identity and to join a group of demonstrators. A demonstrator may decide to join a group of instigators and consequently may adopt a social identity and the associated behaviours that are typical of instigators. In our system an agent has access to a repertoire of social identities that it can use and which are consistent with its current social affiliations as well as with the groups (that we call STGs – Section 5) around him.

Knowledge, beliefs and memory. The agent has some knowledge about itself (attributes such as gender, age and profession), about its environment (location of certain buildings and places) and about other agents. Using perception mechanisms and exploiting information contained in the projected images of the entities (objects, agents, groups) that it perceives, an agent can also acquire new knowledge, while exploring the environment and participating in the crowd situation. This knowledge is application-dependent in the sense that a designer will integrate in an agent model the data structures that are appropriate to record the knowledge that is useful to this kind of agent during the simulation. These knowledge structures are part of the agent's memory: they are often called the 'agent's beliefs'. Several mechanisms can be used to manage the agent's memory (Perron and Moulin 2003).

Needs and resources. Some agents' characteristics may change during the simulation. We call them dynamic states (Moulin et al. 2003). For example, an agent's level of energy can change during the simulation. A dynamic state is represented by a variable associated with a function which is used to compute how this variable changes values during the simulation. The variable may be characterized by an initial value, a maximum value, an increase rate, a decrease rate, an upper threshold and a lower threshold which are used by the function. Using these parameters, the system can simulate the evolution of the agents' dynamic states and trigger the relevant behaviours by relating the dynamic states and the agent's goals (Moulin et al. 2003). More specifically in a crowd simulation, we can model the agent's needs and emotions using such dynamic states. As we mentioned earlier, it is important to take into account the resources that are available to the agent so that it can perform its behaviours. The knowledge of resources, available both internally and externally, and of the agent's dynamic states influence the agent's decision making process, and the selection of its goals.

Autonomy of agents and group belonging. Agents need some capabilities to recognize groups around them, to decide to join or to leave them, when needed. The interpretative perception process carried out by an individual is very important in this context. Indeed, an individual makes decisions about his own actions with respect to the actions of people who are around him. Hence, an agent will need at least to be able to assess the actions of the groups located around him: the group to which it belongs and the groups that it perceives, be they 'in-groups' (i.e. fellow demonstrators) or 'out-groups' (i.e. control forces). Our hypothesis is that an agent A_i continually monitors the actions of the groups located around it in order to determine if it is attracted or repelled by them. The attraction or repulsion occurs when the agent compares the actions of the group to its personal norms (its appreciation of what is a 'good or bad' action in given circumstances). In fact, this is not exactly the same idea as Festinger's *Social Comparison Theory* (1954), since here the objective is not to evaluate one's opinions and actions with respect to other's opinion and actions, but the opposite: an agent A_i compares the collective actions of a group (or of individuals in a group) with respect to its personal norms in relation to this type of actions. Depending on the level of 'acceptability' of the perceived actions, the agent will make a decision about its belonging (adhesion) to the group. It is clear that an agent may need some time before deciding to join or leave a group. Such a decision will result from a cumulative effect of perceived actions that reinforce the agent's opinion that the group behaves in a way that suits, attracts or repels it.

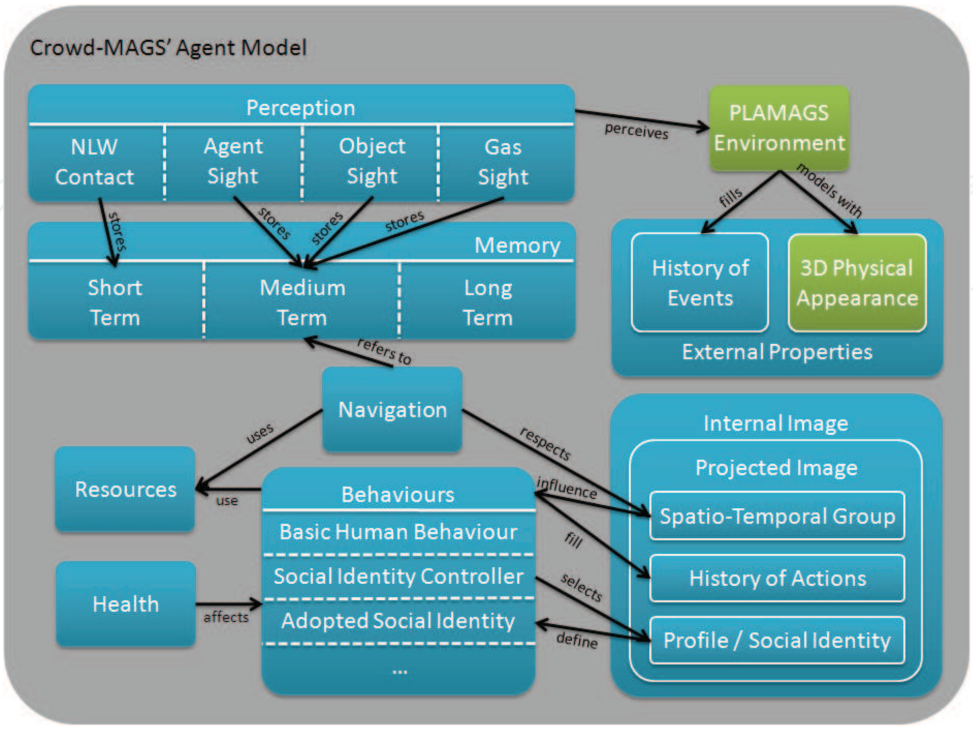

Fig. 1. The Agent Model of the *CrowdMAGS System*

The CrowdMAGS Agent Model. All these notions have been implemented in the CrowdMAGS Agent Model (Figure 1). Here, we briefly present the main elements of this model. Let us mention that the *CrowdMAGS System* has been developed on top of the *PLAMAGS* simulation platform (Garneau & Moulin 2008, 2009) which provides the fundamental functionalities of a simulation engine and an agent behaviour management engine (more details in Section 7).

Thanks to the PLAMAGS simulation engine, the agent can perceive objects, other agents, gas and the effects of Non-Lethal Weapons (NLW) such as gas and plastic bullets. The perceived data is recorded either in a short term memory for immediate processing or in a medium term memory that can be accessed during the simulation run. The agent possesses resources that can be used by its behaviours, including its navigation behaviour. Basic individual behaviours are based on the perception-decision-action loop representation (Lord and Levy, 1994) and correspond to: resource acquisition, navigation management (physical displacement, maintaining a position in an STG), perception mechanisms, memory management, appreciation of aggressiveness. Other behaviours are specifically related to the social identity that the agent currently holds (these behaviours and associated goals are defined in the agent's *Profile*). Eventually, the agent can carry out collective behaviours when it has joined an STG (see Section 5). The agent possesses an Internal Image and a *Projected Image*. In order to be able to collect simulation data for analysis purposes, we also developed mechanisms to record the *History of Events* that may occur during the simulation and that are fed by the *PLAMAGS Engine*, as well as a *History of the Actions* that each agent carries out.

In addition, the Agent Model manages the agent's health level in a simplified way in order to take into account the effects of events or of actions that influence the agent's physical health and its mobility (this needs to be considered in order to take into account the effects of NLW).

5. Spatial-temporal groups and their dynamics

The notion of group clearly plays an important role in crowd situations. However, as it has been shown in Section 2, this notion is usually poorly modeled and used in existing crowd simulations. In most simulations, group behaviours are viewed as patterns emerging from the simulation such as the formation of pedestrian flows. In contrast, we propose to explicitly introduce mechanisms to manage the dynamics and interactions of groups and of indivicual agents during the simulation. In this section we define the notion of Spatial-*Temporal Group* (STG) as well as the associated simulation mechanisms.

The creation of a spatial-temporal group (STG). We first need to examine the mechanisms that are used to create and dissolve STGs. We use a holonic approach to model STGs and to justify the structures that we suggest to include in them. The holonic approach has been used in several domains such as ecology, biology and the design of manufacturing systems. Holonic multi-agent systems have been developed in recent years (Fisher et al. 2003, Rodriguez et al. 2006). The term "*holon*" was originally coined by Koestler (1967) and defined as a self-similar structure that is stable, coherent and composed of several holons as sub-structures. A holon is itself a part of a greater whole, which is also called a holon. Holons are systems that have self-organizing properties and can be used to implement decentralized control. They are also dynamic systems in the sense that they can dynamically aggregate new members, while some members can leave the holon at any time. Indeed, the rules which govern the self-organization of agents (holons) into groups need to be carefully defined. Recently, the holonic approach has been applied to pedestrian simulation (Gaud et al. 2007), but in the context of a physics-based model that does not emphasize the social characteristics of groups.

Coming back to the simulation of purposive crowds and to our concept of STG, we consider that an STG emerges around what we call a '*seed*': an agent that is the origin of the STG. A leader agent may call for the creation of an STG by broadcasting messages around it in order to attract other agents. But, an STG may also be automatically created around its seed as for example police squads are created around their leaders when they appear in the scene. Using a 'holonic vocabulary', we will say that a leader agent is the *head* of its STG. A leader agent provides its STG with directives (objectives) that are used by the STG to coordinate the collective actions carried out by its members. The leader agent also provides the STG with some characteristics that will be recognizable by agents observing it. An example of such characteristics is the STG type. For our crowd simulation we distinguish three types of STGs: demonstrator STG, Instigator STG and Squad STG. Another example of such a STG characteristic is the maximal number of members that the STG can accept. In cases where group membership needs to be limited, the STG is associated with a mechanism that enables it to accept or refuse new members. This is a standard function of a holon's head. Consequently, an agent that wants to join an STG must request the STG's acceptance. If the agent is accepted, it becomes a member of the STG and must behave accordingly. If the agent is not accepted by the STG, it must find another STG that will accept it. If an STG does not have any member left, its leader may decide to dissolve it. Indeed, the dissolution conditions depend on the STG's properties and on the application domain. An STG is also associated with mechanisms that allow individual agents to recognize it, to join it and to leave it. We discuss these mechanisms in Section 6.

STG's projected image. As other entities that can be perceived by agents in the VGE, an STG is associated with a projected image (Section 3) which contains the information that agents may get about the STG when perceiving it. Examples of such information are: the characteristics of the STG (such as the STG's type and number of member agents), information about the collective actions carried out by the STG's members (during a parameterized duration), and possibly the global emotions that result from these actions. These actions can be computed using an algorithm based on the results of socio-psychological studies of collective actions performed by groups in crowds. As for the general mechanisms related to projected images (Section 3), all agents perceive STGs' information, but each agent can interpret it in its own way.

The hot-spot and the STG's attraction mechanism. Using another general notion introduced in Section 3, we use the notion of interest point or area (that we call hot-spot when it is associated with an STG) in order to allow agents to locate the STG in the VGE and to get information from its perceived image. We associate each STG with a hot-spot (interest point/area) which is attached to the leader agent that controls the STG. Hence, an STG's hot-spot moves with the leader agent. This simple mechanism enables us to efficiently simulate the agents' perception of STGs. Consequently, an individual agent can easily identify the STGs located around it, in order to eventually decide to join one of them. Suppose for example that an instigator leader agent calls for agents to join it. We simulate this potential group as an STG Some crowd member agents perceive the STG's hot-spot and projected image content and may decide to favourably respond to the instigator's call. Hence, they move toward the STG's hot-spot in order to join the group and to participate in its collective actions. When joining the STG, the individual agents take a position in the STG's formation.

STG's choreography and the notion of a formation. Depending on its specific characteristics, an STG is associated with a particular geometric configuration and rules that govern the movements of its member agents, when they participate in collective actions requiring particular coordinated movements. We call this aspect: the *STG's choreography*. Typical examples are the different geometric configurations (also called formations) of police squads. In the police procedures (also called 'doctrine') there are standard geometric configurations such as the line and wedge formations, that a squad may adopt when facing demonstrators. In order to deal with this aspect, we introduce the notion of *Formation* which characterizes the geometrical arrangement of members in the group. An STG is associated with a number of formation types that can be used when carrying out certain collective activities. In the simulation, when an agent is accepted by the STG's leader, it is assigned a position in each formation associated with the STG. The position corresponds to parameters that refer to the relative movements that the agent will have to perform in the formation. The formation management mechanisms that we developed are fairly generic and allow for a variable number of participants and various geometric configurations and agent movements in these formations (wedge and line formations in relation to the leader agent's position, two agents side by side, unorganized formation of agents around a hot-spot in a given area, etc.). Since an STG formation is represented in the VGE, the associated area can be perceived by the agents: this area is used as a 'hot-spot' by attraction mechanisms. We can see such areas in Figure 3B: these areas are displayed so that the user can easily identify the STGs which have been formed during the simulation.

STG's attraction / repulsion. In our approach, we consider that an STG assigns behaviours to its member agents according to their roles and to the 'choreography' of the collective action performed by the members of the STG. Consequently, whenever an agent has decided to join an STG, it agrees to carry out the actions imposed by the STG in the context of the collective behaviour. Empirical observations of structured groups in crowd situations show that the members of these groups usually behave as if they were performing actions imposed by the role they play in such a group. For example, let us mention military and police groups as well as sports teams that are trained for such coordinated behaviours (movements), but also agitator and demonstrator groups when they are well supervised and trained. It is clear that in reality, leaders of less structured groups find it more difficult to impose uniform behaviours to their members: hence we allow for loose formations of agents around a leader agent. Moreover, an agent can always leave an STG if it does not agree with the individual actions that are collectively imposed by the STG.

Acting collectively or individually. Since we are particularly interested in collective actions, we distinguish the individual and collective actions that agents may perform during the simulation. All the agents that do not participate in collective activities as STGs' members, act on their own and hence carry out individual actions. Members of STGs participate in collective actions. Drawing such a distinction helps us to simulate collective actions in a more efficient way since we do not have to trigger complex reasoning mechanisms while agents act as members of STGs. When it comes to individual behaviours, we distinguish two categories of agents: the leaders of STGs and the other agents acting on their own. In agreement with our assumption that STGs' members carry out collective actions imposed by the STG to which they belong, we propose that a leader agent makes decisions on behalf of the STG that he leads. Examples of such leader agents' activities are: managing collective goals, collective needs and resources in relation to the current situation. Using such an approach, the more complex decision making activities are carried out by a limited number of agents, the STGs' leaders, which again enhances the performance of the simulation. Agents who are not leaders or members of STGs, also carry out individual actions: we call them 'uninvolved agents'. However, in the simulation of purposive crowds, the actions of uninvolved agents are usually less complex because most of these agents are observers (bystanders) that may eventually decide to leave the scene or to join demonstrators (and consequently participate in collective actions).

The role of the STG's leader agent. We mentioned that for simplification purposes an STG is created around a leader agent using one of three possibilities: 1) there exists a social group that appears in the scene with the leader (i.e. police squads); 2) a leader agent moves around in the VGE and is able to attract other agents that adhere to its STG; 3) a pre-existing social group appears with its leader agent in the VGE and creates an STG that is able to attract new members during the simulation. We also assume that the leader agent makes decisions for its STG and that member agents perform collective actions under the command of the leader agent. Certain categories of agents may be 'programmed' to follow the orders of the STG leader without questioning them, as in the cases of control forces or of groups of trained instigators. In the case of other agent categories, an agent may decide to leave a group if the imposed collective actions do not agree with its personal values/standards

STG's resources. Makie and her colleagues (2000) emphasized the crucial role that the availability of resources plays when one group actively aggresses against another one and that the appraisal of the in-group's strength produces emotions (anger or fear) towards the opponent group ('out-group'). Hence, we can reasonably posit that the power of a group can be evaluated by considering certain characteristics such as the number of group members, the equipment that they possess, the material or 'moral' possibility for group members to use this equipment, and the training that group members have acquired in carrying out collective actions with or without equipment. In our approach, a leader agent manages the tactics of its STG with respect to its goals (which are assumed to coincide with the goals that the agent pursues on behalf of its STG) and to the resources that it manages. We consider a number of variables which characterize an STG's resources such as the number of STG members, their skills to perform collective actions, the 'compound power' of the individual resources.

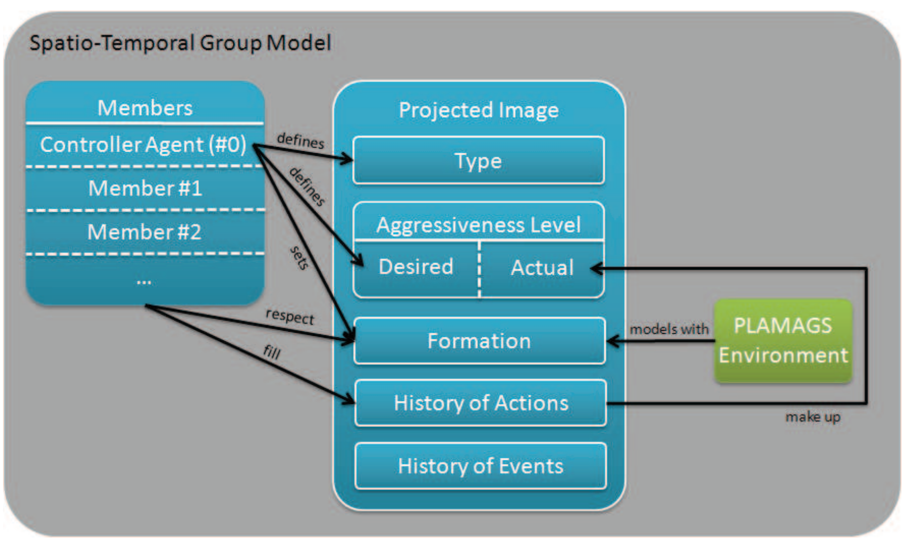

Fig. 2. The CrowdMAGS' STG Model for Spatio-Temporal Groups

The formations are managed by the PLAMAGS engine and are used to coordinate the group members displacements in different ways (Figure 3).

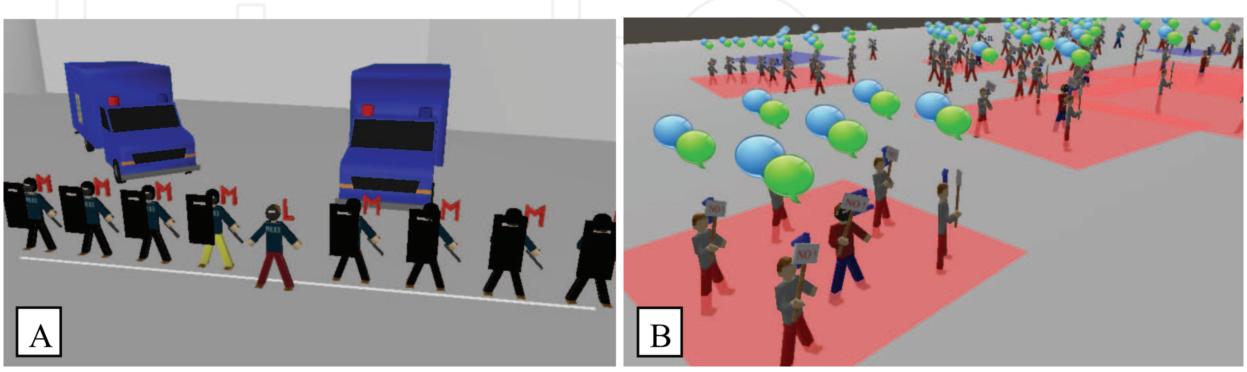

Fig. 3. A: Formation of squad members (M) around the squad leader (L). B: Chanting demonstrators gathered in different groups (STGs identified by their interest areas)

The CrowdMAGS' STG Model. All the above mentioned notions have been implemented in the *CrowdMAGS*' STG Model (Figure 2) which provides the data structures and behaviours required to manage the STGs. An STG possesses a Projected Image in which are accessible the STG type, its History of Actions and History of the Events in which it has been involved during the simulation. It also contains information about the formation(s) that the STG members should adopt when participating in the STG's collective actions. At any given simulation step, the formation is chosen by the STG leader. An STG also contains a list of its agent members. The STG leader is distinguished and provides the decisions (goals) that influence the STG's collective actions carried out by its agent members. The STG possesses all the basic behaviours that enable it to manage its membership, as well as the procedures that are needed to compute the STG overall aggressiveness.

6. Dynamics of Individual Agents and STGs

An individual can be attracted by a group because it feels some commonalities with this group; either because it wants to participate in the collective actions performed by the group's members, or because the emotions displayed by the group fit the individual's mood. From a psychological point of view, we can say that the group offers the individual the opportunity to express her feelings and emotions through the participation to certain collective actions (Smith 1993, Mackie et al. 2000). In our approach, we emphasize that for an agent A_i an important individual process consists in constantly choosing if it will join a new STG, or continue to stick to the STG it belongs to, or dissociate from it; while considering the STG's actions (resulting from the collective actions of the agents, members of the STG) as they are perceived/interpreted by agent A_i. The decision to join or leave an STGs is based on the individual agent's appreciation of aggressiveness.

Enthusiasm and Appreciation of Agressiveness. By observing the collective activities that take place around him, an agent may become excited and feel an urge to participate in the collective actions. Conversely, an agent may be disapproving the collective activities that it observes and become reluctant to participate in them. To this end, we introduce the notion of enthusiasm which basically represents the overall appreciation of the collective actions being carried out around an agent. Thus, enthusiasm takes its values in [-1, +1] with +1 expressing an extreme enthusiasm (or excitation), 0 being neutral and -1 expressing a complete reluctance to participate in collective actions.

In order for agents to plausibly make decisions based on the collective actions carried out in their surroundings, it is hypothesized that agents must express a certain appreciation for different levels of aggressiveness. For example, a bystander might highly appreciate chanting and probably does not appreciate instigators throwing projectiles. On the other hand, instigators might appreciate throwing projectiles and may find chanting too 'passive'. Due to the complexity of simulating these 'feelings', each agent cannot interpret in its own manner the actions carried out around it. Thus, we propose that agents be characterized by appreciation profiles, which can be adopted by multiple agents. For normalization purposes, aggressiveness takes its values in [0, +1] with +1 expressing an extreme aggressiveness and 0 expressing a complete absence of aggressiveness.

In crowd control events, violence is a major concern: peaceful demonstrators want to avoid violence, instigators may seek opportunities for violent actions and control forces want to limit violence and disruption of public order. Consequently, collective actions are often qualified on an aggressiveness scale. We propose that this scale range from -1 (very peaceful) to +1 (very aggressive). Estimating a ranking of collective actions on such a scale is feasible. For example, McKenzie and his team (McKenzie et al., 2005) qualified the actions of individuals and groups in a crowd using an aggressiveness scale. Once an acceptable set of collective actions has been defined, the scale of the agents' appreciation of aggressiveness can also be defined. In CrowdMAGS System, different scales can be defined depending on the agent's profile.

Adhesion to Spatio-Temporal Groups.

It has been already mentioned that individual agents seek to participate in STGs based on the collective activities being carried out. In addition, if an agent is already participating in the collective activities of an STG, it needs to decide if it will stay or leave the STG. Thus, these decision rules must be modelled taking into consideration the collective actions. Because all STG members are autonomous, the collective actions being performed might change quite rapidly. Current members might not appreciate the actions of some new members, but they may not necessarily want to leave the STG immediately. In consequence, we introduce the notion of *support* which is defined as an agent's long-term appreciation of the STG's collective actions. Because the appreciation of aggressiveness takes its values in [-1, +1], support is constrained to the same range. Coming back to the previous example, the new members' actions might bring down the other members' support values towards the STG, but the recent actions will bear only a certain weight with respect to the history of actions that have been performed before. Thus, some members might eventually leave, when their support towards the STG drops below a certain level. Agents who want to join a STG might also wait before their support goes above a certain threshold.

All these notions have been implemented in the *CrowdMAGS System*.

7. The CrowdMAGS System

In order to develop micro-simulations of crowd situations, we needed a software platform that provides agents with basic capabilities such as reactive navigation in a virtual geographic environment (VGE), perception of agents and of features/objects of the VGE, decision making capabilities including the manipulation of hierarchies of goals. Several platforms allow such agent micro-simulations such as (Moulin et al. 2003, Lamarche et al. 2004, Paris et al. 2007, Pelechano et al. 2007, Garneau and Moulin 2008, 2009), to name a few. We chose the PLAMAGS Environment (Garneau et al. 2008) that provides us with a 3D engine to manage the 3D Virtual Geographic Environment and the agents immersed in it (physical appearance, navigation and collision avoidance, etc.), as well as a powerful behavioural engine that manages the agent's behaviours in relation to their goals and available resources.

Figure 4 presents CrowdMAGS' main architecture (the main components and mechanisms) and its relationship with the PLAMAGS Platform.

At the lowest level of all components sits the PLAMAGS simulation engine, which can be viewed as the "master" component. The engine creates the PLAMAGS environment (i.e. the VGE) to handle physical interactions of agents and it manages on its own the behavioural aspects of the agents. In fact, it is the simulation engine that starts counting iterations and increases the iteration number after all components in the iteration have been executed. The Crowd-MAGS' architecture simplified this process by ensuring that only two types of components would be executed by the simulation engine at every iteration. First of all, the behavioural graphs are executed for each agent (Garneau and Moulin, 2008, 2009). Then, the simulation engine notifies the *Scheduler*, which executes the components that need to be executed at this particular iteration (since not all components are executed at every iteration).

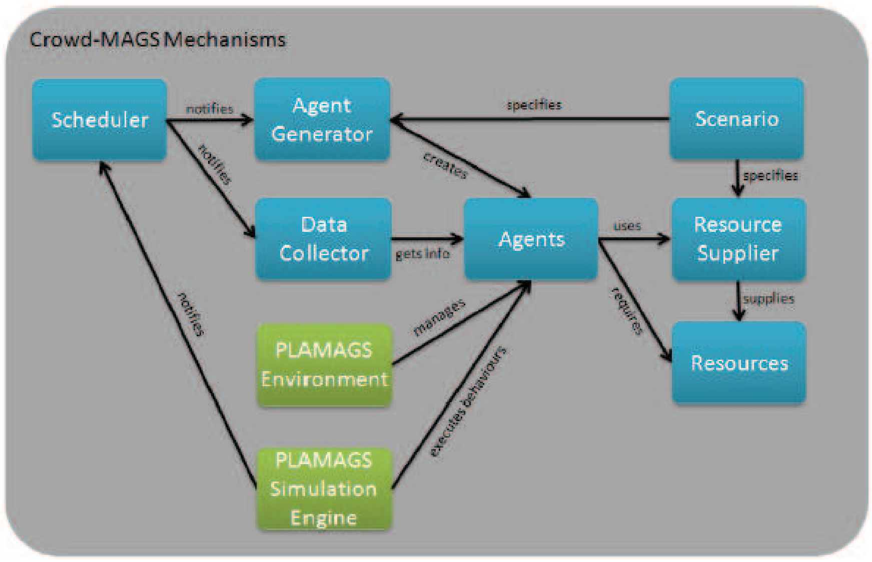

Fig. 4. Overview of the CrowdMAGS' Architecture

The *Scheduler* is one of the most generic and important mechanisms in the *Crowd-MAGS System*. Not all components need to execute code at every iteration. For example, the navigation behaviour needs to be called ten times per second, but the behaviour that regulates social identity changes is called only once per minute. The Scheduler has been created to manage these different requirements. The simulation engine notifies the Scheduler at every iteration, which in turn notifies only the components that need to be activated at that iteration. The Scheduler can also allow a single component to be called at different frequencies for different purposes. The Scheduler can also be used to register punctual events rather than periodical events. For example, gas cans last for only a short moment once they are set off. Thus, when thrown, the gas can objects register with the Scheduler to be called once to start the emission of gas, and once again to stop it.

The resource supplier is a fairly complex component that can provide agents with one or more specific resources. The resources provided by a resource supplier may be anything from a physical object (e.g. banner, tear gas can) to less concrete concepts (e.g. "relaxation" and "healing power" to aid agents who have been hurt). Thus, a resource supplier can represent any concept from a pile of banners left on the ground to a first aid tent. In fact, a resource supplier does not even need to be embodied in the VGE (e.g. a zone such as a park could provide "relaxation" to bystanders). When considering a simulation scenario (Section 8) a designer must indicate which resources can be provided by each resource supplier of the simulation. Three parameters are required as inputs: the name of the resource to be provided, the quantity available (0 to infinity), and the time necessary to obtain the resource. The interactions that agents can have with resource suppliers consist of requesting and cancelling resources. Agents may request multiple resources at one time from the same supplier. For example, if an agent requests three resources that each have a delivery time of 15 seconds, then he can get its three resources after 15 seconds, not 45 sec. For example, it may take 15 seconds for an officer to get his helmet from the back of a police truck, and it would take approximately the same time to get a helmet and a baton. After an agent has made a request, it may cancel it, or cancel all of its pending requests. Resource suppliers can answer queries with respect to which resources they provide and to how many are left. Suppliers can also be refilled with more units of certain resources, whenever necessary.

The agent generator. This component allows the scenario designer to specify the types of agents to be generated at certain locations and at certain moments during the scenario. An agent generator is a component in the VGE that is not embodied, but that has a conceptual location. Using a generator is very simple: first it must be created and then generation requests must be assigned to it. The first step to add an agent to the simulation is to create an agent object. Then, *PLAMAGS* creates the component that will represent this agent in the environment. This PLAMAGS component mostly contains the physical attributes of the agent such as its mass, its perception capabilities and its visual representation. Next, the *Data Collector* is notified that a new agent was created, so that the collector can keep track of this agent. Then, agent configurators perform initialization and configuration tasks. Each agent possesses an initialization method that it uses to adopt its fundamental social identity and profile, effectively giving it the appropriate behavioural graphs, icons, and color of clothes. The initialization method also sets the necessary variables such as destination, speed, and projected image. Finally, the initialization method registers the agent with the *Scheduler* for all generic mechanisms and behaviours such as perception and the evaluation of enthusiasm. Once the initialization is complete, an event is added to the agent's *History of Events* recording that it has been added to the simulation.

Generic Data Collection. There is no central algorithm to collect simulation data, but rather a collection of small algorithms distributed throughout various components of the system. However, there is a central repository (called the *Data Collector*) that stores all data collected system wide. The reason for this decentralization is that a multi-agent simulation is so dynamic that monitoring all components entails a large overhead. For example, a central "monitor" would have to maintain lists of components in the simulation and run through every element periodically to gather whatever information is necessary. Instead, all components in the *Crowd-MAGS System* are free to register themselves with the *Data Collector* and to provide any information that they want to make available publicly. Overall, most of the data collection work is done when actions and events happen to individual components, such as an agent being dragged or receiving a plastic bullet.

One of the only active tasks of the Data Collector is to write a text file about each agent when it is removed from the simulation. This file can contain basic information, the histories of actions and events, and any other information that may be useful for the analysis of simulation results. Similar files are created for STGs as well.

The Scenario Manager. This component manages the scenarios that the user has created for the simulation. The user can create scenarios, edit them and record them. More details in Section 8.

System Main Interface. The *CrowdMAGS System* offers a sophisticated interface (Figure 5) that enables the user: 1) to create a virtual geographic environment (VGE) and agents (both for the crowd and for control forces); 2) to specify various scenarios for the simulation; 3) to play the role of a commander of control forces who chooses intervention strategies (mobilization level and choice of NLW) that agents composing the control forces will carry out autonomously. Using the control bar on top of the main window (see letter A in Figure

5) the user can control the simulation (accelerate the simulation step, pause, search for a particular agent. The main window displays the simulation in the VGE: the user can navigate in it (controlling the camera) to observe the simulation from different angles. When the simulation is paused, the user can modify the content of the VGE: he can add or remove fences and agents and objects in the VGE. The user can also modify the control forces' strategy using the panel located under the main window (see letter C in Figure 5). The user does not dictate the behaviours of the control forces, but rather chooses a degree of involvement (which conforms to control forces' doctrine) that he communicates to the squad leaders by clicking on the corresponding button in the panel. The user, playing the commander's role can also allow the use of tear gas and/or plastic bullets. We can see in Figure 5 that the user has allowed the use of tear gas.
The window on the left hand side (see letter B in Figure 5) enables the user to inspect all the agents and the STGs using different tabs: basic information, resources, memory content, spatio-temporal group information, history of actions and history of events.

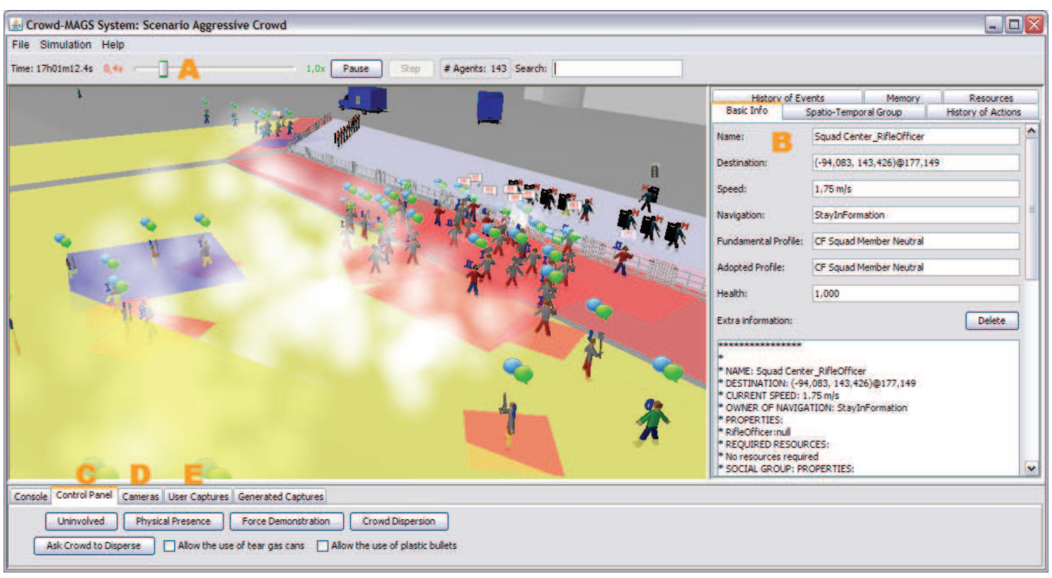

Fig. 5. The Main Interface of the *CrowdMAGS System*

When clicking in the *Cameras* tab (see letter D at the bottom of Figure 5), the user can activate new cameras for inspecting the scene from different view-points. The camera is set at the position from which the user is currently observing the scene. Another window is created and opened and will display the scene from the chosen point of view as long as it is opened. The user can create several external camera windows (Figure 6). The user can also take still pictures of the scene using the tab *User Captures* (see letter E at the bottom of Figure 5) and record them in files for future use.

8. Specifying Scenarios and Running Simulations using the CrowdMAGS System

Scenarios. The user can specify and play different scenarios. Each scenario is recorded as an XML file for inspection and subsequent use, either for replay purposes or to be used as a basis for the creation of variations of a given scenario.

Figure 7 shows the main window used for editing scenarios. The middle part shows the simulation window, just like in the regular interface (Figure 5). The only difference is that all elements are motionless, since the simulation is not running. On the left of Figure 7 is the palette, which allows adding simulation components to the scenario with a single click. The user must first select what type of component he wants to add to the scenario, and then click in the main window wherever he wants one instance of the component to appear. The available types are: agent, fence, interest point, police truck, agent generator, media truck, journalist, and tear gas can. An information panel to edit components can be seen on the right of Figure 7.

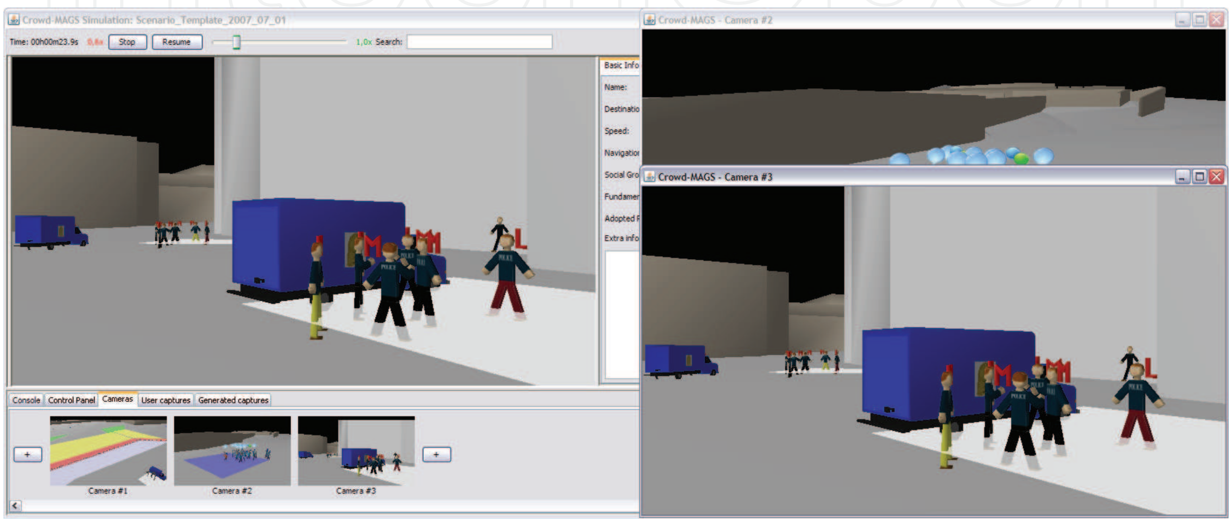

Fig. 6. External Camera Windows

Options are available to select the time of appearance, the position, the fundamental social identity for agents, the available resources, and other details. Finally, scenario parameters, such as the start time, the crowd distribution, and non-lethal weapons impacts, can be edited with the configuration panels, shown in Figure 8. This panel is accessible from the menus in Figure 7. Nearly all parameters in the XML scenario File can be edited with these configuration panels.

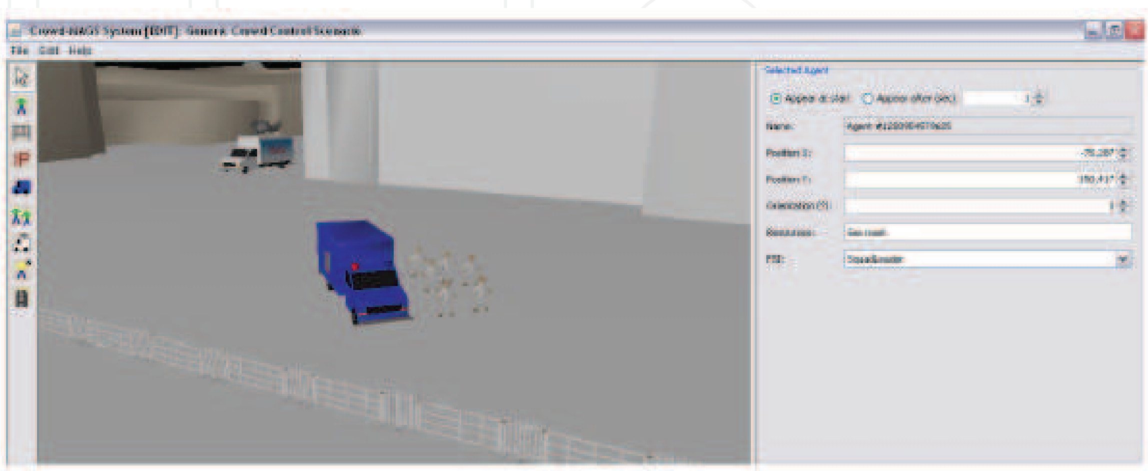
Fig. 7. The Scenario Specification Main Screen

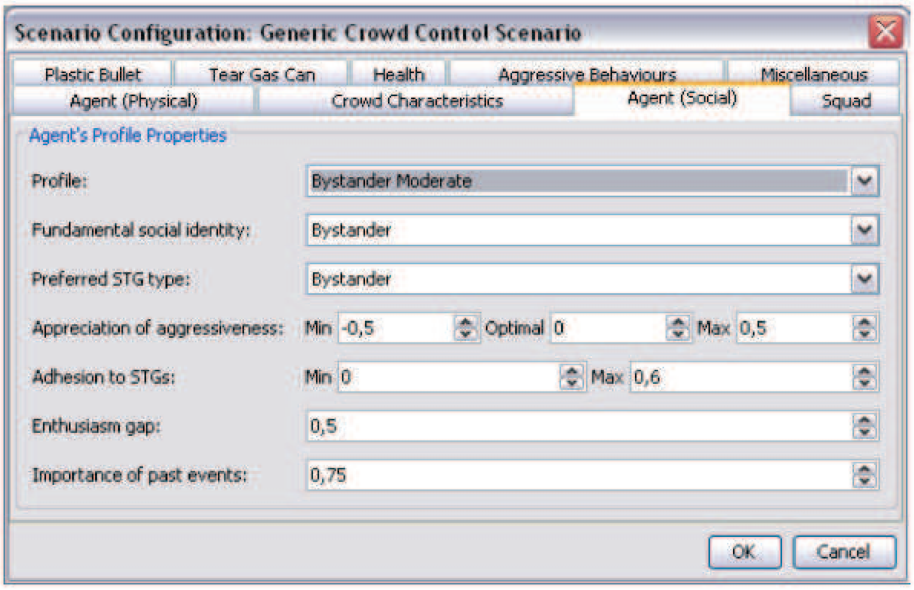

Fig. 8. The Scenario Configuration Panel

In a scenario the user can choose how many agents of each category he wants to be involved in the simulation. In Figure 5 one can notice that crowd members wear outfits of different colours that show their fundamental social identity (combinations of yellow, blue and red pants). They have also an adopted social identity which is shown by a letter on top of their shoulder. Agents can also carry out accessories such as placards, helmets, guns, and shields. When the agents are shouting or chanting, this is shown as the dialogue bubbles on top of them (see the blue and green bubbles for example in Figure 5). These icons are easy to understand and enable the user to have a global view of the crowd simulation. In a scenario the user chooses the locations in which each agent or set of agents (agents are created in a set at the same time by an agent generator) must appear and when during the simulation. If required, the user can also assign particular itineraries to specific groups of agents (as for example the succession of interest points where a march should move through).

When the simulation runs, the agents are autonomous and behave according to their behaviours, profile, decision making process (taking into account the agent's objectives, behaviours, appreciation of aggressiveness, etc.). The user can pause the simulation to modify the VGE (i.e. add fences), add or remove agents. He can also give orders to the control forces as we mentioned earlier. Moreover, the *CrowdMAGS System* contains another model, that we call the Information Model, managed by the *Data Collector* (Section 7), and which is used to record the history of events and actions of the agents and STGs. Taking advantage of this model, the user can specify which variables he wants to be recorded during the simulation and in which format. After the simulation, he can use the generated files for thorough analyses using statistical packages. More details in (Moulin and Larochelle 2009).

Calibration and Experimentations. The Crowd-MAGS system allows for the customization of a large number of parameters, some of which can be calibrated based on isolated tests and on scientific studies found in the literature. Others, mostly related to crowd characteristics, must be calibrated in plausible test scenarios before being considered acceptable for more complex scenarios. As an illustration, let us comment upon the calibration approach that we followed to develop our prototype of crowd simulation. Many parameters were initially calibrated while the system was being developed. The values were calibrated on the basis of available data in the literature, and relying on the qualitative assessment of the realism of the effects of each parameter during isolated tests. To further calibrate the models, we chose a fundamental scenario taking place in front of the Quebec Parliament involving a crowd and a fixed number of control forces' squads. We created 3 kinds of crowds (passive, moderate and aggressive) with different proportions of bystanders, demonstrators and instigators (the proportion of leaders of each category was also adjusted).

Control Forces' Strategy	**Crowd**		
	Passive	**Moderate**	**Aggressive**
Uninvolved	1a	1b	1c
Force Demonstration + Communication	2a	2b	2c
Physical Presence + Tear Gas		3b	3c
Force Demonstration + Tear Gas		4b	4c
Physical Presence + Plastic Bullets		5b	5c
Force Demonstration + Plastic Bullets		6b	6c
Physical Presence + Tear Gas + Plastic Bullets		7b	7c
Force Demonstration + Tear Gas + Plastic Bullets		8b	8c
Crowd Dispersion		9b	9c
Crowd Dispersion + Tear Gas		10b	10c
Crowd Dispersion + Plastic Bullets		11b	11c
Crowd Dispersion + Tear Gas + Plastic Bullets		12b	12c

Table 1. An overview of scenarios involving different control forces' strategies for different types of crowds.

Then, we created different scenarios in which the commander chooses different degrees of involvement for the control forces, eventually using NLWs (tear gas and/or plastic bullets) (See Table 1). One of the purposes of this experiment was to assess how Control Forces adopting different levels of involvement (and eventually using different types of NLWs) would influence the crowd behaviour. Using Keeney's top-down approach (Keeney and Gregory, 2005) we identified fundamental attributes, such as '*Ensuring public safety*' and '*Minimizing costs*', that were relevant for analysis purposes. Then, we refined these general attributes in terms of variables that would be either measured by the system or computed from variables measured during the simulation. Here is a partial list of these variables: *Control forces' intervention level*, *Number of people harmed*, *Amount of resources used*, *Crowd size and ratio with respect to initial size* (every 15 seconds), *Crowd aggressiveness* (every 15 seconds).
Several parameters needed to be set in the simulation. For instance, we chose initial settings to assess the aggressiveness associated with typical collective actions such as: *Chanting* (0.15), *Showing banner* (0,15), *Yelling* (0,2), *Insulting* (0,3), *Fighting* (1). Let us emphasize that it was chosen to assess the overall behaviour of the crowd by computing the crowd's aggressiveness every 15 seconds during a simulation run (5 minutes). The tests carried out with these initial settings were surprising and showed relatively small differences in the resulting aggressiveness of our 3 crowds. Several elements could be changed in addition to these settings, in particular the functions that set the tolerance to aggressiveness for the different categories of crowd members. We did a series of trials for the different scenarios and for different settings of these parameters. For illustration purposes, Table 2 shows a

comparison of the aggressiveness of the 3 crowds for scenario 2 (see Table 1) as obtained after the 6th trial. Obviously, we cannot detail further these experiments in this chapter. See for more details (Larochelle 2009).

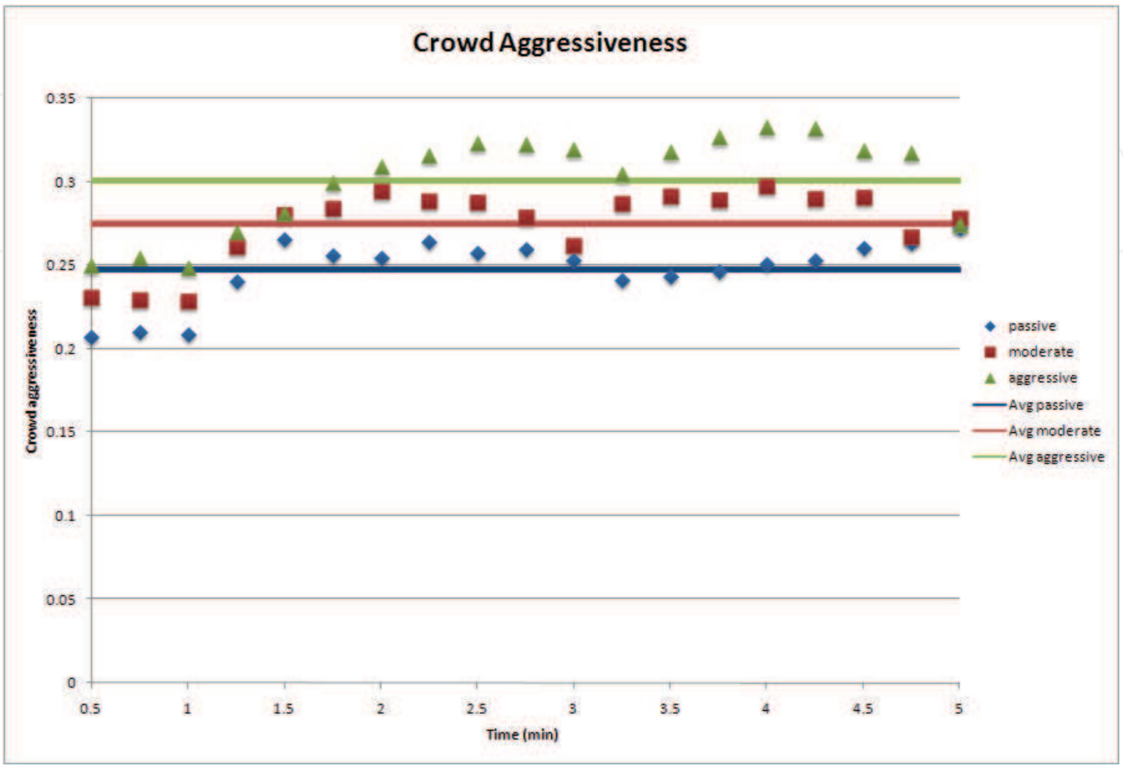

Table 2. Comparison of the aggressiveness levels of the three crowds for Scenario 2

9. Conclusion

In this chapter we proposed new agent and group models that explicitly take into account the social dimension that is used for the management of collective actions in groups of agents that we call spatial-temporal groups (STG). Our models apply to the simulation of both crowd members and control forces' officers, as well as to their collective behaviours in groups and their interactions with groups. These new models push further currently existing approaches for crowd simulation, while explicitly introducing a social dimension in relation to the management of groups of agents. These generic models have been adjusted in the context of the CrowdMAGS Project while using the PLAMAGS platform.

We used PLAMAGS as a development environment and a language to create multi-agent geo-simulations and we extended its capabilities in order to create the proposed models. Hence, we discussed in details the architecture of our CrowdMAGS system and presented details of the system's practical use (scenario-based development, user interface, data collection and analysis).

We developed an Information Collection Model which is composed of the various structures that are used to collect and organize data obtained during the simulation. This data can be used for analysis purposes.

In conclusion, we must mention that this project has been fairly effective in opening new grounds for the development of crowd simulations with agent models in which the social dimension is explicitly taken into account not only at the individual level, but also at the group level. Still numerous enhancements might be considered as a continuation of this project. The current simulations allow the introduction of a maximum of 800 agents with reasonable execution time. These performance limits are mainly related to the PLAMAGS behaviour engine which, it must be emphasized, provides a sophisticated management of agents' behaviours, states, goals, pre- and post-conditions of actions, concurrent resource management, as well as the management of concurrent goals. We need to examine how PLAMAGS' behaviour engine can be improved.

For our demonstration purposes we developed a set of profiles, social identities and behaviours for the different types of agents involved in the simulation of crowd members as well as control forces. These models could be greatly improved as a result of careful socio-psychological analyses of the typical behaviours of people that can be observed in various crowd situations. Such analyses should be carried out by multi-disciplinary teams that might take advantage of the *CrowdMAGS Platform* to test and compare them.

It would also be very fruitful to develop a variety of simulation scenarios in different urban environments, with different kinds of crowds (more or less aggressive) gathering agents of different categories (and variable numbers) and to further calibrate the system and models.

Acknowledgements

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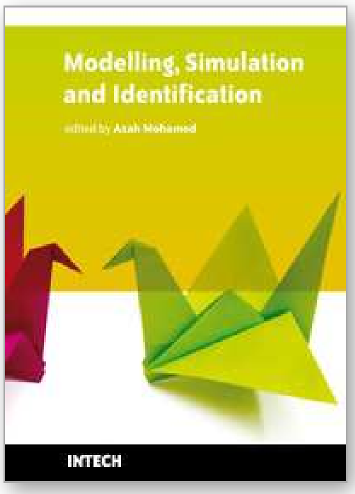

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Modeling, simulation and identification has been actively researched in solving practical engineering problems. This book presents the wide applications of modeling, simulation and identification in the fields of electrical engineering, mechanical engineering, civil engineering, computer science and information technology. The book consists of 17 chapters arranged in an order reflecting multidimensionality of applications related to power system, wireless communication, image and video processing, control systems, robotics, soil mechanics, road engineering, mechanical structures and workforce capacity planning. New techniques in signal processing, adaptive control, non-linear system identification, multi-agent simulation, eigenvalue analysis, risk assessment, modeling of dynamic systems, finite difference time domain modeling and visual feedback are also presented. We hope that readers will find the book useful and inspiring by examining the recent developments in the applications of modeling, simulation and identification.