Modelling Crowd dynamics

Influence factors related to the probability of a riot

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Abstract. This research aims for more understanding of behavior in crowds and riots. We state that crowd behavior can only be understood by studying the individuals and their interactions, a multi-level study. By selecting influence factors that influence the probability of a riot and translating this on how the individual is influenced, we have taken our first step in modeling and simulating human crowd behavior.

1 Introduction

Crowd behaviour is the behaviour shown by a large amount of individuals gathered on one physical location at a certain point in time. When some members in such a collective express violent/aggressive behaviour, we generally adress the crowd phenomenon as a *riot*. In the Netherlands for instance, riots regularly happen around soccer matches. Once in a while a demonstration gets out of hand and the day the Dutch celebrate the birthday of their queen has ended more than once in a violent encounter with the police. It might seem that there are many riots going on, however the contrary is true. Often large numbers of people gather at the same physical location at the same time without any problems. Daily commuters traveling to work by public transportation gather on stations, large-scale festivals and regular Saturdays in shopping centers also attract many people, to name a few examples. As crowds are so common, what makes some turn into a riot while most remain calm? Or to be more specific, what factors affect the probability of a crowd situation to turn into a riot? This study focuses on answering this question, in which this paper describes the first step, a conceptual model of crowd/collective behaviour. This model shows the relevant influence factors in a crowd context in relation to violent/aggressive behaviour. It emphasises the multi-level study and the focus on the individual that generates the behaviour being influences by all levels. The explicit/implemented model in a simulation of crowd and riot behaviour represents the following step.

Crowd behaviour is a complex and dynamic phenomenon, where a multitude of factors influences behaviours of the individuals in a crowd. This makes it difficult to diagnose a situation as being a high risk to turn into a riot. In dealing with crowds, the task for the riot police is very difficult as they are expected to act proportionally in a given situation. This requires knowledge of the ongoing processes within a crowd and the influence factors on the individual and thus

crowd behaviour. Unfortunately, only limited knowledge is available concerning the relation between micro (individual) and macro (group) levels of crowd behaviour, as current research is limited in moving beyond observational studies towards experiments. These limitations are caused by the constraints of performing real/empirical experiments with crowds in terms of methodological rigor on the one hand and the safety of subjects on the other. Due to the multitude of variables that influence each other, it is virtually impossible to keep certain variables constant whilst manipulating others. The lack of control raises an ethical issue as the safety of subjects cannot be guaranteed while studying the turnover point of a crowd to a riot. Altogether, the lack of systematic knowledge about crowd behaviour and its underlying processes prevents professionals in practice, e.g. riot police, to improve crowd management on the basis of present-day scientific knowledge.

Although knowledge of the dynamic processes in crowds is still in a rudimentary stage, crowd research has advanced a lot in the last 15 years by numerous observational studies (McPhail, 1991; Adang, 1998). These studies had a major impact as they falsified the dominating intuitive crowd theories with empirical evidence. Major assumptions made in these intuitive theories were the existence of a group mind and shared predispositions. The idea of a group mind refers to losing cognitive control when entering a crowd, which makes people behave at will of this crowd mind (LeBon, 1895). The other perspective explained crowd behaviour by claiming that similar dispositions of crowd members result in similar behaviour (Allport, 1924; Miller & Dollard, 1941). The main insights of these observational studies proved that crowd/riot behaviour is a part of human behaviour that arises on individual level and is situation driven. Another insight was that crowd behaviour is not uniform as individuals do not behave in the same way at the same time. It appears that for instance, in soccer riots, only a small part of a crowd (10 %) actually shows violent/aggressive behaviour (Adang, 1998). Besides falsifying dominating theories, this research also gave insight into the complexity of crowd behaviour and thus the difficulty of studying this phenomenon.

In this research we aim at gaining better insight in crowd behaviour by studying the interaction and influence processes between individuals in a crowd using a multi-agent simulation model. By relating these underlying processes with the behavioural patterns shown on group level, more knowledge can be gained about the process leading towards the emergence of a riot. This contributes both to a better estimation of the probability of a riot, as well as an understanding of the effect of interferences on these processes. By developing a model that represents an individual in a crowd, we are able to develop a simulation that enables us to perform experiments with arbitrary crowd scenarios. Apart from this flexibility that overcomes the limitations of real experiments, simulations also serve as a methodological tool to develop theories that enable us to study domains that are not approachable in real/empirical experiments (Helmhout, 2006).

This paper represents the first stage in this research: developing a model of an individual in a crowd. In doing so, relevant influence factors in a crowd and

related to aggressive/violent behaviour will be discussed in §2. As all influences on crowd behaviour go via the individual, §3 shortly addresses the various physiological and functional aspect of indivuals as human information processing systems. In this paragraph we also discuss some hypotheses that indicates how the mentioned variables are intervene. In paragraph §4 we give conclusions.

2 Influences on the probability of a riot

This section describes the influence factors that are related to the emergence of riot behaviour, but also those influences that are inherently present in a crowd context, e.g. human density. We do so by addressing the relevant environmental (inter-individual) as well as the internal (intra-individual) influences that play a role in the probability of a riot.

2.1 The environment

The environment represents the external world in which an individual is situated. In a crowd context this environment consists of people and other physical objects, from which physical and social influences originate. The distinction between both types of influence is based on the level tehy influence directly. Which is mostly physiology for the physical influences, for instance by directly increasing the arousal level when a high level of noise is observed. Whereas observing behaviour (social influence) directly influences the functional level.

The physical environment. In a crowd, individuals are gathered on the same physical location. Being situated in an environment, the physical surrounding influences human behaviour through their perception of physical information via the bodily senses, e.g. touch, sight, hearing, taste, smell. For instance in moving, visual/tactile information is used to avoid objects, e.g. walls or other people. In a crowd, avoiding collisions is a basic mechanism in which human density influences walking/moving behaviour. Human density, i.e. ρ_{human}, is an inevitable characteristic of crowds as it involves the co-presence of other individuals. Apart from human density, several other relations between physical factors and the occurrence of riots have been found, for instance temperature (weather), noise and scent. We will discuss them all shortly, however for an extensive overview we refer to Krahé and van de Sande (Krahé, 2001; van de Sande, 2006) .

Several general influence factors evolve around weather conditions, i.e. temperature. Two types of temperature-riot relations are distinguished, a contributing and a inhibiting effect. Hot temperature is related to an increased amount of riots and of crime rate. As it appears, there are more riots in summer than in winter (Anderson & Anderson, 1998). Whereas the other temperature-related relation is the dampening effect of bad weather (cold, windy, foggy, rainy), on aggression in crowds. Lastly, some influence factors worth mentioning are noise and (unpleasant) scent that appear to behave as an intensifier in an already

tensed situation, which implies that they work as a moderator on an already aggressive mood (Geen & O'Neal, 1969; Rotten, Barry, Milligan, & Fitzpatrick, 1979). Although both noise and scent are relevant phenomena in crowds, we only use noise as their effects are similar.

In sum, we mentioned influence factors restraining actions (density), improving and dampening influences (temperature) and moderators on an aggressive mood (noise, scent). In figure 1, the selected physical influence factors, i.e. human density (ρ_{human}), temperature ($^{\circ}C$) and noise, related to the probability of aggression are visualised.

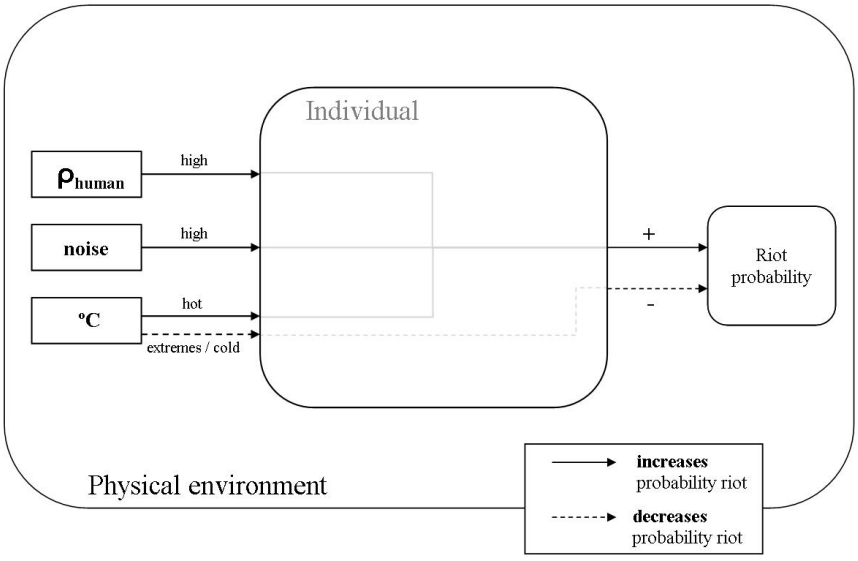

Fig. 1. Relevant physical environment factors related to aggressive/violent behaviour in a crowd

The social environment (inter-individual). A crowd is a group phenomenon that emphasises a social setting. The social environment mainly involves influences by perceiving behaviours of other individuals. In what way these perceived behaviours influence ones own behaviour depends on the connections that exists between the perceiving and observed individuals. For our crowd context we selected three social characteristics that are assumed to play an important role in crowds and thus to turn a crowd into a riot: in/out-group perception and the presence of friends and leaders.

In/out-group perception relates to an typical riot setting, i.e. a *two-block setting*, which is composed of two (or more) opposing groups (van de Sande,

2006). This distinction between *them* and *us* gives rise to certain group processes. For instance, when a clear out-group is present, the membership of the in-group becomes more salient, which gives rise to the so-called *ingroup-outgroup bias*. This bias reflects the tendency of group members to selectively favor the in-group, but to derogate the out-group (Forsyth, 2006). Apart from studying the interactions within a group, also the interplay between groups has practical relevance. For instance, studying the interplay between a rioting group and the riot police gives insight in the effect of different strategies to prevent or deescalate riots.

Friendship indicates the unique relations an individual has with its social surrounding. For example, some people are emotionally more close, due to friendship, club-membership or blood-bond. This bond has an effect on how a person is influenced by the other, which exceeds the rough distinction of in- and out-group effects. Furthermore, it is usually the case that people attend crowds with friends/family/acquaintances that makes an in-group being composed out of smaller subgroups that are closer connected.

Leadership implies that some people exert a larger influence on others than average, which is being perceived and accepted by most (sub)group members. Opinion leaders, according to Glock and Nicosia (1964), are a source of social pressure and social support that influences the decision making process of others. Whereas the effects of leadership have not experimentally been explored in a crowd and riot context, it seems plausible that opinion leaders play a more central/influencing role during riots.

Through interacting an individual is influenced. This is represented in terms of a social network that describes the connections/ties an individual has as well as characteristics it consists of (Wasserman, 1994). In our crowd context the characteristics of a social network consist of ties that represent in-group/out-group membership, friendship and leadership. This is visualised in figure 2. The *existence of a relation* in terms of a pattern gives rise to the division of an in and out group. Friendship can be characterised externally in terms of *frequency and direction* of interaction, and leadership in terms of the *amount of in- and outgoing connections* someone has.

2.2 The individual - intra-individual -

Besides the external influences (physical and social environment), behaviour is also determined by internal (physiological and mental) factors. To be more precise, one's bodily & mental states and constraints play an essential role in determining behaviour at the individual and consequently at the group level.

Physiological. Being embodied (having a human body) implies having behavioural and cognitive constraints. Not only does our autonomy define our perceptual range and behaviour options (hearing 20-20.000 Hz, not capable of flying, etc.), it also has impact on mental processes. In a crowd setting physiological measures such as arousal and energy are assumed to play an important

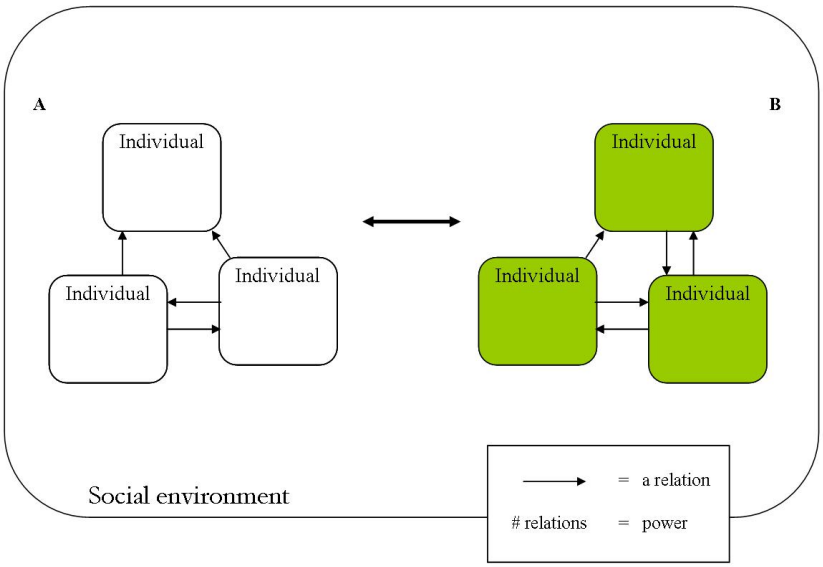

Fig. 2. The relevant influence factor of the social environment is the social network of an individual that describes if the existence of a relation, group individuals and the power someone has.

role in the course of a crowd gathering, but also factors such as alcohol and drugs influencing behaviour via physiology are very relevant in crowd situations.

Arousal is a powerful physiological state as it is related to an important basic mechanism of the sympathetic nervous system: *fight or flight*, which prepares us to act fast in a situation of threat (Baron & Richardson, 1994). Several theories of aggression are based on the notion that arousal is closely related to aggression (Berkowitz, 1981, 1988; Zillmann, 1988). This implies that all non-calm crowds, e.g. festivals, demonstrations, soccer matches, which elicit above average arousal levels, are potential riot situations. This makes the inclusion of arousal in our model very relevant.

Energy is an other important physiological measure that relates to the bodily resources an individual has. Energy is a necessary resource for life (behave, think, etc.). A low energy level may drive people toward the decision to leave the crowd as to get food, drinks or to rest, and so to restore the energy level. Both arousal and energy correspond with primitive/basic behaviours that provide in short term survival mechanisms (fight/flight, food search) that allow humans to respond to a subsistence/life-threatening situation.

As physiological measures can strongly influence behaviour, also factors influencing physiology are important to address here. In many crowd contexts the use of alcohol and drugs is a common phenomenon. Alcohol consumption is often linked with the occurrence of group violence. Even though there is no causal re-

lation between alcohol usage and aggression, evidence shows that a little amount of alcohol leads to increased aggressive behaviour (Baron & Richardson, 1994; Russel, 1993). The role of drugs on the other hand, is probably less important than one would expect. Mostly, the effect of drugs (apart from alcohol) in relation to aggression is not that well explored (van de Sande, 2006). However, the effects of marihuana or combined party drugs, e.g. XTC, LSD, etc., do not appear to effect the course of a riot (van de Sande, 2006). In case of marihuana it even seems to decrease the probability of violent behaviour (Baron & Richardson, 1994) as it makes an individual less aware of its social surrounding. In sum, although many physiological factors mentioned are relevant for a crowd/riot context, the relation between alcohol/drugs and aggressive behaviour has only been proven to correlate respectively positively/negatively, but remains unexplained at the mental level.

Functional. The functional part of an individual is where the behavioural preprocessing takes place. In this, we are interested in those mental processes, characteristics or content types that are involved in the preprocessing of aggressive/violent behaviour. Before addressing some relevant concepts, we will shortly describe the view we have on the cognitive system.

In describing the cognitive system, a cognitive architecture provides a blueprint of the organisation of the human mind in a fixed structure. The cognitive architectures like ACT-R (Anderson & Lebiere, 1998), Soar (Newell, 1990), and Clarion (Sun, 2003) describe functional components that cooperate to process information and to result in behaviour. In this description two other concepts play an important role: representations and processes. A mental representation contains information or other representations. These representations are manipulated by the mental processes. Figure 3 gives an overview of the components and relevant processes that correspond with the hybrid cognitive architecture ACT-R (Anderson & Lebiere, 1998; Helmhout, 2006).

On a more abstract level three main components are normally be distinguished with regard to the human information processing system: perception, cognition (mainly memory) and action. Each have their own substructures and ways of interacting with the other components. Memory in general represents the knowledge an individual has. This includes knowledge about performing an action, such as throwing a rock (procedural knowledge), knowledge of facts, such as knowing what it is you can use rock throwing for (declarative knowledge), and other forms of knowledge. Furthermore, goals are also represented as memory elements. Perception and action on the other hand are the components that allow interaction between the internal and external world, by receiving input via the bodily sensors, i.e. perceiving, and output by behaving, i.e. acting.

To select relevant functional influence factors, a certain content of memory, e.g. knowledge and functions, we need to address the distinction between the way we talk and the way we model. When observing behaviour we tend to talk in terms of motivation, attitude, identity, and self to relate the behaviour we observe with internal settings. It is a way in which we talk about our inner

system. Because we want to model intra-individual in according to the general view in AI, we need to translate these terms by operationalise them in terms of representation and mental processes. In including relevant influence factors we mainly focus on mechanisms that contribute to moods, tendencies or actual behaviour of aggression. We selected saliency, motivation, and insecurity to play an important role in the probability of showing aggressive behaviour, which need to be translated in terms of content of the cognitive architecture.

Saliency relates to the phenomenon where something, such as norms or identity, is in focus and therefore has more influence than other norms/identities. (Kallgren, Reno, & Cialdini, 2000; Mullen, Migdal, & Rozell, 2003). We relate this with the *activation* level of the memory elements, which implies that in showing aggressive/violence the elements representing these behaviours have to be highly activated. This activation causes a dynamical ranking of behaviour based on perception or an internal source of a motivation or goal.

Crowd behaviour is very diverse, and thus are the underlying goals/motivations. This makes the dynamics between goals and thus the resulting behaviour essential within crowds. With motivation we mean: "[...] *Motivation is a modulating and coordinating influence on the direction, vigor, and composition of behaviour. This influence arises from a wide variety of internal, environmental, and social sources and is manifested at many levels of behavioural and neural organization*" (Wilson & Keil, 1999). To have a simple representation of driving forces for behaviour we use the concepts of *needs* (Max-Neef, 1993), which represent a fixed set of abstract goals that can be fulfilled with satisfiers/explicit goals. The set of needs we found relevant for crowd behaviour are: *Subsistence (biological)*, *Safety*, *Belonging* and *Autonomy*. Where subsistence is need for self-preservation in terms of energy, safety relates to a need to feel safe, belonging to a group and autonomy to remain self sufficient. These needs are represented as memory elements that are constantly addressed and updated.

The last influence factor we want to mention is insecurity. Insecurity relates to a situation where no behavioural rules, i.e. norms, are present but also not known in terms of experience. For instance, when in a supermarket standing in line waiting on your turn to pay, you know exactly how you are supposed to behave. Most crowd situations are always insecure in some way, as it is not exactly clear what will happen and what is the norm how to behave. For instance, when joining a demonstration there are no clear rules of conduct for a demonstration. So, if there are not really strong associations with behaviours it might explain why some behaviours are very surprising. This factor is also represented in terms of memory elements. Insecurity is a measure of the strength of associations in a certain situation. The absence of norms and expectancies makes the behaviour selection more depending on activation, as no good differentiator in comparing behaviour is present.

In sum, we described the relevant intra-individual influence factors that are physiological (energy and arousal) and the functional (reformulated concepts of: activation, motivation representations, insecurity). The cognitive system as well as its moderating influences are shown in figure 3.

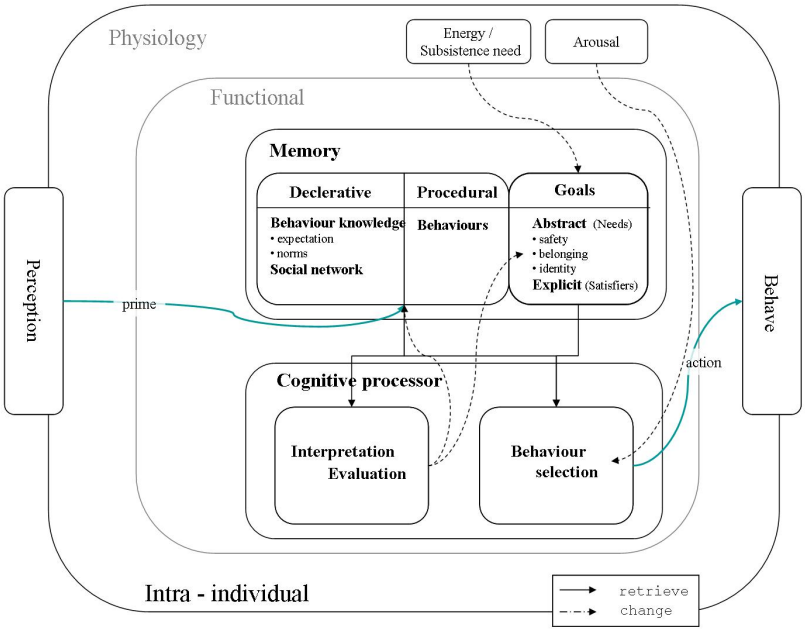

Fig. 3. Internal processes and components of an individual

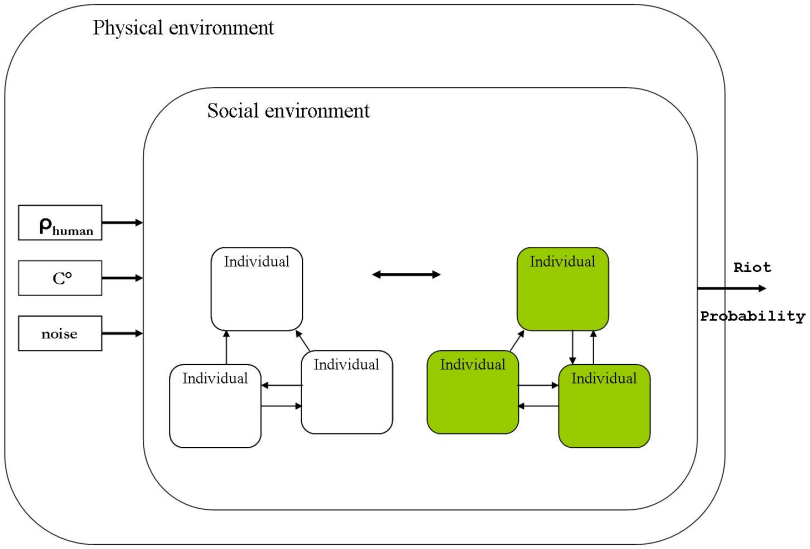

Fig. 4. Overview multi-level influence factors that are related with aggressive, violent or riot behaviour.

This section addressed the known influence factors that are related to aggressive/violent behaviour that are applicable or specifically related to a crowd context. In figure 4 we give the overall view on the influences that are related to the probability of a riot. The physical influences that count for all individuals as well as the social environment, which depends on the social network a person individually has. All these influences go via the individual where they influence behaviour pre-processing. Altogether, the behaviours shown on group level give rise to a riot or not.

3 Influence factors on individual level

In modeling crowd behavior, we want to develop a model of an individual in a crowd. As we mentioned earlier, crowd behavior arises from the behaviors of its individuals, see figure 4. This implies that all the influence factors we mentioned in §2, influence the probability of a *riot* via the individual. The model choices are represented by the translation of each factor on the individual level. In this short paper we can not discuss all the hypotheses we formulated for the various influence factors at the various levels. We will discuss three hypotheses concerning arousal (physiology), leadership (social) and needs (functional).

We assume arousal to play an important role in the turn of a riot. The arousal level is related to the functioning of the behavior selection process. This means that when an aggressive/violent behavior is salient and arousal is high, the evaluation and comparing process is inhibited due to time, which increases the probability of showing aggressive behavior.

Hypothesis 1: High levels of arousal increases the probability of turning a crowd into a riot by 'impairing' the behavior selection process.

A leader has a major influence on people who perceive him/her as such. This makes the behavior or (dis)approval of a leader a dominant influence in the behavior selection process. These normative boundaries set by a leader can play a crucial role whether a riot will arise or not.

Hypothesis 2: If a leader is engaged in aggressive behavior, the likelihood of a riot will increase.

The dynamics between dominance in needs give rise to different behaviors. We expect that this dominance of needs is related to a higher activation of a subset of behaviors, where need dominance depends on the situation. In a crowd situation where some people show aggressive behavior high dominance of the need *belonging to a group* in the surrounding individuals will give rise to the 'contagion' process/pattern of violent/aggressive behavior.

Hypothesis 3: If some individual show aggressive behavior, high dominance of the need *belonging to a group* in the surrounding individuals, will increase the probability of a riot.

To move on to the next stage of our research all the relations will be formalised in a fixed structure that represents the cognitive system of an individual. This involves a framework that allows for modeling the internal processes, as well as for the interaction with a social and physical environment. A framework suitable for our domain is an integration of a cognitive architecture with a multi-agent systems framework, in which the first takes care of the internal processes and embodiment related to cognitive capabilities and the latter with the social interaction. In doing so we will explore the possibilities to use RBOT (Helmhout, 2006), which is a cognitive agent based social simulation system that implements ACT-R in Java and allow for social interaction. Only after the formalising and implementing the model into a simulation of crowd behaviour, experiments can be performed to explore the dynamics of crowds/riots and test the efficiency of intervening strategies.

4 Conclusion

In the approach of our simulation research of which we here only presented the conceptual structure we emphasised four design elements. In the first place we showed the necessary multi-level relationships in crowd and riot behavior. The physical, the social, as well as the cognitive level are important in the interdependencies and influence factors. In the second place we included the cognitive plausibility of the individual agents even in crowds in our model. In the third place the various levels are integrated via the cognitive agent itself. Finally, the conceptual structure is constructed out of modular components. This modularity allows for extending components on each level within the overall multi-level structure. All in the light of gaining understanding of crowd and specifically riot behavior.

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