Cognitive Emotional Based Architecture for Crowd Simulation

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***ABSTRACT*: *This paper presents a new approach to model crowd behaviour in normal and risky situations. Our model is based on human cognitive characteristics specially personality type, perception and emotion that we assume relevant to individuals' behavioural decisions. The model supports an efficient interaction between the different architecture components to provide behaviour. A formal definition of cognitive characteristics will be given with a description of its use on the model.We demonstrate in this paper the ability of our model to provide emergent behaviour simulating realistic reactions within a crowd based on each individual's attributes and environmental changes.*

Keywords: Crowd Motion, Emotion Modeling, Perception, Personality Modeling, Human Reasoning Process, Agent-Based Representation of Individuals, Crowd Simulation

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1. Introduction

The simulation of human behaviour is challenging because the human decisions depend on individual characteristics and on environmental interactions. The challenge becomes bigger once a crowd is considered rather than an individual. Several approaches within the contexts of social cognition and crowd simulation have been developed and described extensively in the literature (e.g. [30, 9, 17]). Some of the computational models reported in literature are based on mathematical description of fluid physics. These mathematical models describe motion by the dynamic evo-lution of crowd variables[13, 12]. However, some variables are not easy to integrate mathematically because of their non-linear nature. Agent modelling approaches rely on individual attributes or a basic individual description to drive the dynamics and evolution of a crowd in a simulation [29, 3] without the complexity of mathematical equations and avoiding non-linearity through parallelism and distributed computing. That is why agent-based simulations are gaining popularity in this area of research.

A challenge in using agents-based modelling of crowd is in finding an adequate description of human behavioural process to develop virtual individuals (agents). Agents interact with their environment and each other to make decisions on which behaviour or set of actions to execute. There are two important elements are to be considered in developing an agent for crowd simulation. First is the relationship between agents and their environment, i.e. the interpretation process of the environmental information. Second is the cognitive process of each agent to manage action selection and to balance between rational and reactive performance.

In this paper, a cognitive emotional based architecture for crowd simulation is presented. The architecture is based on a cognitive emotional approach that balances between rational and reactive nature of human psychology wit the purpose of deriving realistic behaviours. The paper is organized in the following manner: section 2 provides the background for the work with the focus on perspectives that inspired this work; section 3 introduces our cognitive emotional architecture for modelling crowds, section 4 reports on implementation and tests. Finally, there is a conclusion that presents a evaluative summary of the work and potential future work.

2. Background

Crowd behaviour is a non-linear complex phenomena emerging from the action of each individual in the crowd. Modelling such a system is challenging because individuals react in different ways according to their culture, personality and experiences in addition to temporary factors that may even alter the individuals reaction to the same scenario at two different situations, i.e. change of time, place, etc. Great progress has been made in various domains to develop models that can produce near realistic human behaviour. Several models are based on cellular automata with a discrete spatial representation and discrete time-steps [6]. The models divide the space in a uniform grid where individuals are represented by a cell. Those models are used specially to study the evacuation process in normal and critical situations and the dynamic exit of pedestrians[5, 4, 8, 6]. Cellular automata approach is more easily applied to different scenarios and easy to understand, however it suffers of some limitations specially in treating all individuals as emotionless homogeneous entities with a uniformed reactions.

Henderson [13] proposes a fluid dynamic approach to overcome cellular automata limitations. He conjectured that pedestrians in a crowd behave in similar form to gases or fluids and thus he proposed a fluid dynamic model based on fluid motion properties. This work has a drawback of modelling pedestrians by fluid entities because individuals interactions do not obey to fluid properties. However he directs researches on crowd motion to the micro simulation approaches, to focus on individuals properties and their non-discrete behaviour. In this connection, a social force model of Helbing [12, 11, 10] has been developed. The model is based on force terms in normal and panic situations to direct pedestrians behaviours, but has drawbacks of relying on an excessive simplification of individuals motion decision making by utilizing the reactive approach of attractive and repulsive forces.

In the same connection of micro simulation, Agent based modelling (ABM) builds social structure from bottom-up. It models individuals with autonomous agent and controls behaviour with interactions rules. Collective behaviour emerges from the interactions of the different entities of the virtual world. The ABM is suitable to model social structure like crowd, because it provides a realistic virtual environment to simulate crowd motion in various situation with the respect of real human properties [29, 3, 24].

As we quote previously, the bulk of prior research has focused specially on defining differential equations to study the evolution of crowd behaviour or on modelling individuals interactions with the environment to produce emergent behaviours. Nowadays we can not continue to ignore cognition on individual decision process and assume that without cognition models describe honestly human behaviour process. Research conducted on the field of psychology show the relevance of perception, emotion and mental process on individual behaviour [20, 22].

Perception process enables individuals to interpret sensory information of the environment and thus provides a complete knowledge about the surrounding environment. In psychology, emotion is considered as a psychological adaptation mechanism insuring a flexible and a dynamic reaction to environment contingencies. The interaction of those two processes provides a subjective evaluation of the environment or an appraisal of the significance of events for individuals goals and well-being. Models in ABM field of research [2, 1, 26] are developed specially on robotics and on video game industry, where the challenge is to stage character with a credible behaviour.

We assume that cognition processes should be included on crowd evacuation model to endow as much as possible agents with human capacities and then obtain a nearly human behaviour. It's upon this idea that we adopt a cognitive emotional architecture to study crowd evacuation flow on catastrophic situation.

3. Cognitive agent architecture

Pedestrians in our model are fully autonomous. They perceive the virtual environment around them, analyse situations, make decisions and behave in consequence. Each virtual pedestrian has an architecture as shown in figure 1.

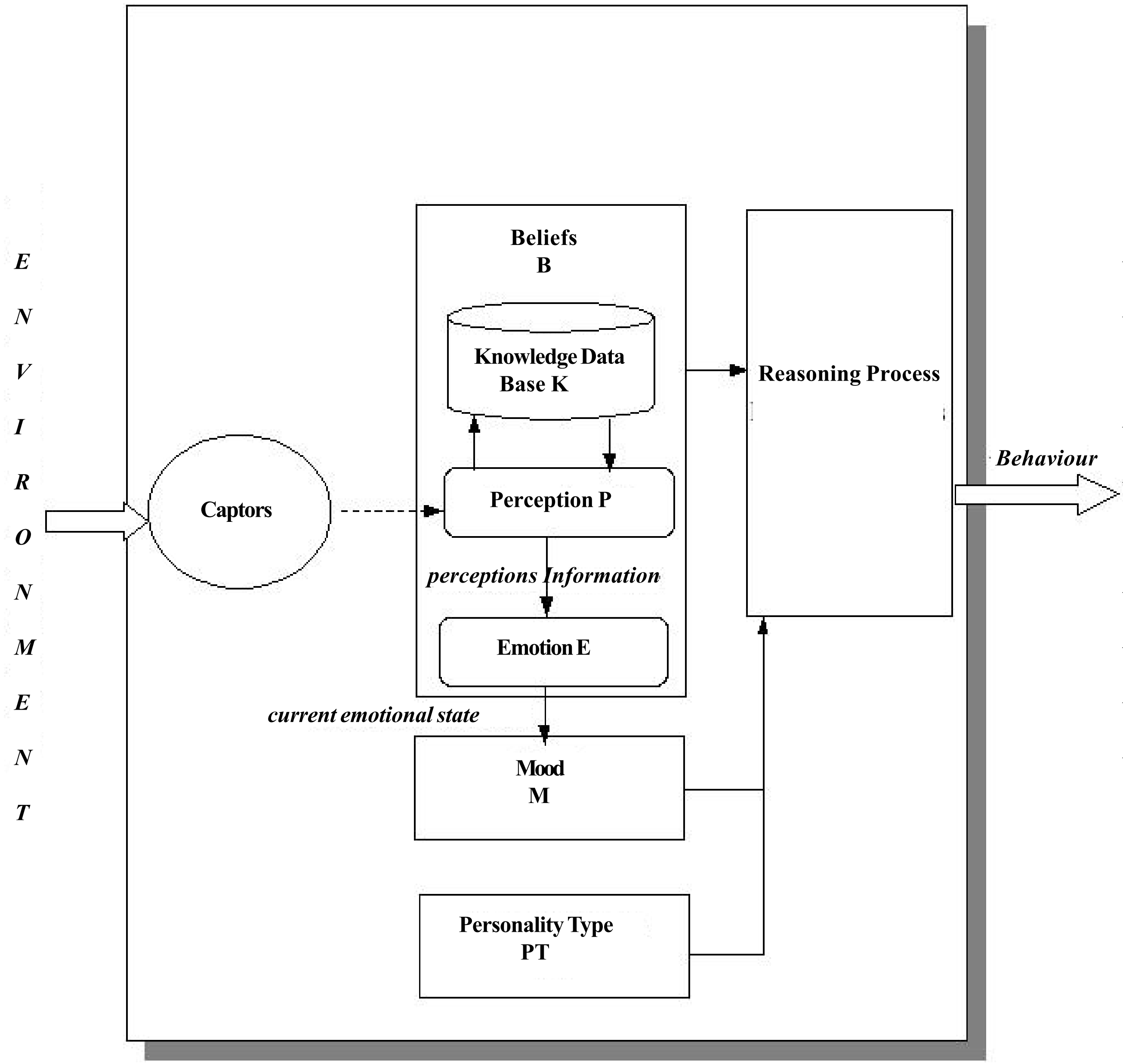

Figure 1. Agent architecture

3.1 Virtual pedestrian properties

Agent properties in our model are structured as a tuple (PT, M, B), where PT is a personality type, M is a mood, B is set of beliefs. B is a tuple in itself consists of (K, P, E), where K is knowledge, P is perception, and E is emotion Figure 1.The following sections discuss each of these components in turn.

3.1.1 Personality type

Researches on human and social sciences identified a relevant relation between personality and human behaviour. Watson and Luminet [15, 27] identify the influence of some personalities traits on individuals interpretation and assume that:

- extrovert individual senses intensely positive emotion than neutral or introvert individual, but with no influence on negative emotion
- neurotic individual senses intensely negative emotion, but with no influence on positive emotion.

• pleasant individual senses intensely empathy for other individuals.

We are interested first on extroversion and neurotic traits, we assume relevant in our model. We plan to include more traits like intuitive, factual, intellectual, emotional and pleasantness in later work.

3.1.2 Mood

Mood is a relevant emotional state, it differs [25] from simple emotions because it is less specific, less intense, and less likely to be trigged by a particular stimulus or event. We define mood as a fixed system of variable in two sets Good and Bad. The changes occur according to fuzzy emotional rules as it presented in [28] (e.g If perception is positive and PT is extroversion and emotion is positive and mood is bad then mood is good or If perception is positive and PT is neurotic and emotion is positive and mood is bad then mood is bad.

3.1.3 Beliefs

An internal description of pedestrian current state and knowledge is indispensable to link perception to appropriate behaviour. We include these functionalities on Beliefs, which composed on closely linked components: knowledge data base, perception and emotion. Beliefs is defined as a tuple (K, P, E) where K defines agent properties and knowledge, P is a perception process and E is an emotion process. K is a tuple of attributes ($Pos^{t}_{(x,y)}$, $\theta^{t}_{(x,y)}$, $\phi^{t}_{(x,y)}$, $V^{t}_{(x,y)}$, $\phi^{t}_{(x,y)}$, $D_{(i)}$, S)

- $Pos^{t}_{(x,y)}$ is a Cartesian coordinates
- $\theta^{t}_{(x,y)}$ is an orientation
- $V^{t}_{(x,y)}$ is a speed
- $\phi^{t}_{(x,y)}$ is a field of vision
- $D_{(i)}$ is a comfort distance with other entities
- S a sensing informations from sensing module.

To perform a coherent input to virtual human mental process, we propose to link Knowledge to Perception and to Emotion. We detail in the following sections the strategy that we adopt to reach our goal.

3.2 Modelling cognitive process

We propose to link beliefs components to mood and personality type to make agent produces a suitable behaviour according to current situation.

3.2.1 Agent perception process

Perception process is relevant in this work. Virtual pedestrian modelled should detect environment changes and act accordingly.We present in this paper a perception process composed in three steps, which interact with each other. First step is selection, which sends requests to the environment to gather perceptual information, then classifies data according to their importance and their consequences on virtual pedestrian goals. Second step is decoding, which uses agent knowledge database to identify a part of collected data such as wall, door, etc. Unknowing data are added into knowledge database as a new knowledge. Finally in interpretation, perception process provides a description of the world as a set of entities and relation.

3.2.2 Agent emotion process

The challenge in the architecture is to models the relationship between perception, emotion and personality influence to provide a realistic test bed for crowd behaviour.

We are interested in this work on individual subjective evaluation of the environment and on activated emotion. In this connection, we define an emotional behavioural trigger which receives information from perception module and then activate

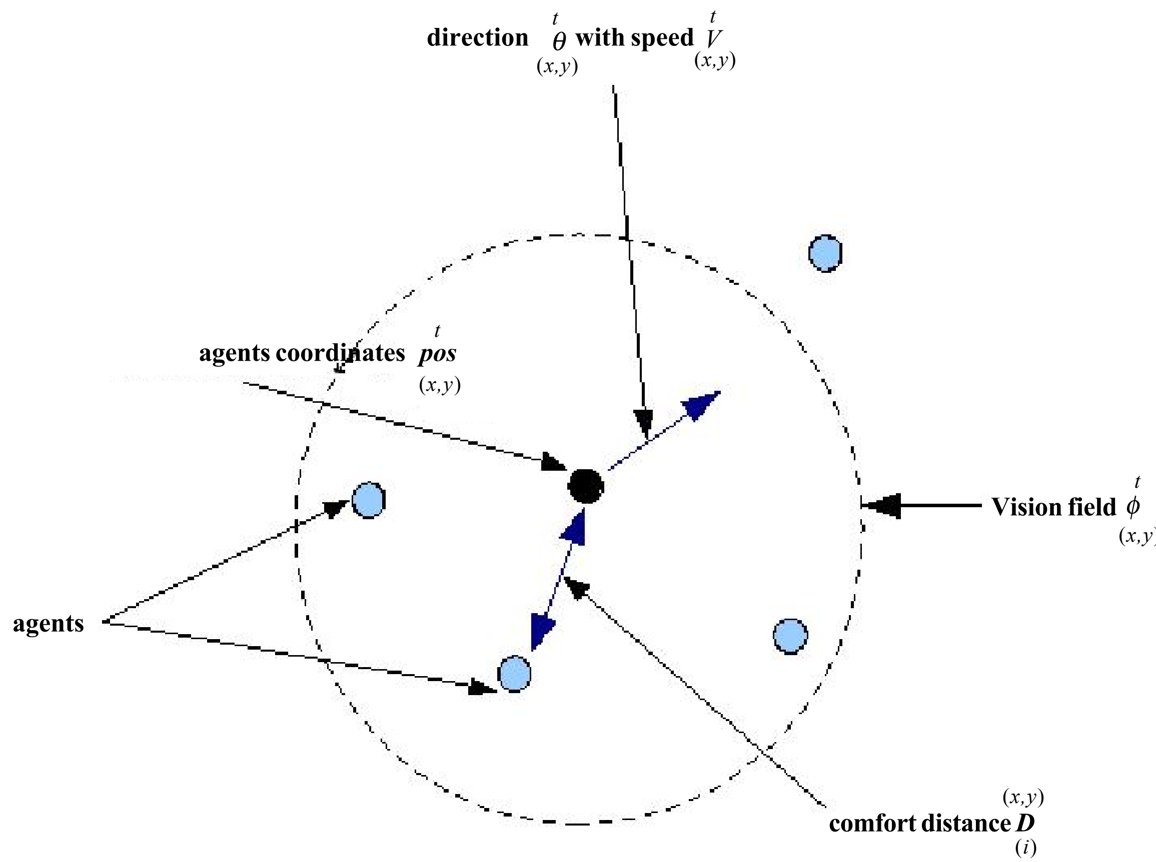

Figure 2. Agent attributes

emotion according to emotion rules [16, 7]. We integrate then personality type to evaluate the intensity of emotion felt after perturbation.

Emotional behavioural trigger is developed according to the appraisal theory proposed by Scherer [20, 21]. Scherer distinguished four major criteria to provide a subjective evaluation of a stimulus for human [22, 23]. Scherer criteria called "*Stimulus Evaluation Checks* (*SEC*)*s*" evaluate stimulus according to four connected objectives namely relevance that evaluates the pleasantness, arousal that evaluates consequences on goals, coping potential that evaluates situation control and normative significance that evaluates the significance of the situation according to social and individual norms.

In this work we limit SECs criteria in three dimension namely relevance, arousal and coping potential.We define emotion according to the individual subjective evaluation of those three dimensions.We use the three-dimensional emotion space (PAD space: Pleasure, Arousal and Dominance) as proposed by Russell and Mehrabian [19] to specify emotion. We define a routine to evaluate personality influence on emotion intensity. Personality type adds dynamism to the evaluation of emotion and makes the agent decision process to navigate on PAD space according to relevance, arousal and dominance intensities.

To give a demonstrative example of how emotion process works, we propose an alarm signal as a perturbation detected by an agent. Emotion process receives the result of perception process analyses of the environment. According to Sect. 3.2.1, agent perception is negative (e.g. unhappy, anger, sad or fear). Personality influences Sect. 3.1.1 the intensity of activated emotion and so relevance, arousal and dominance values. Resulted emotion is then specified using PAD space.

3.2.3 Agent mental process

The realism of agent behaviour depends on the selection of appropriate action for each situation. We propose a mental process with four modules Figure 5 in interaction with perception and emotion process.

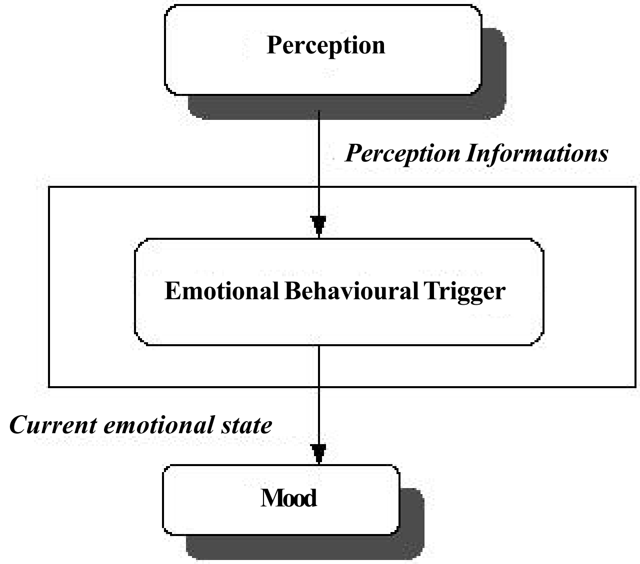

Figure 3. Agent emotion process

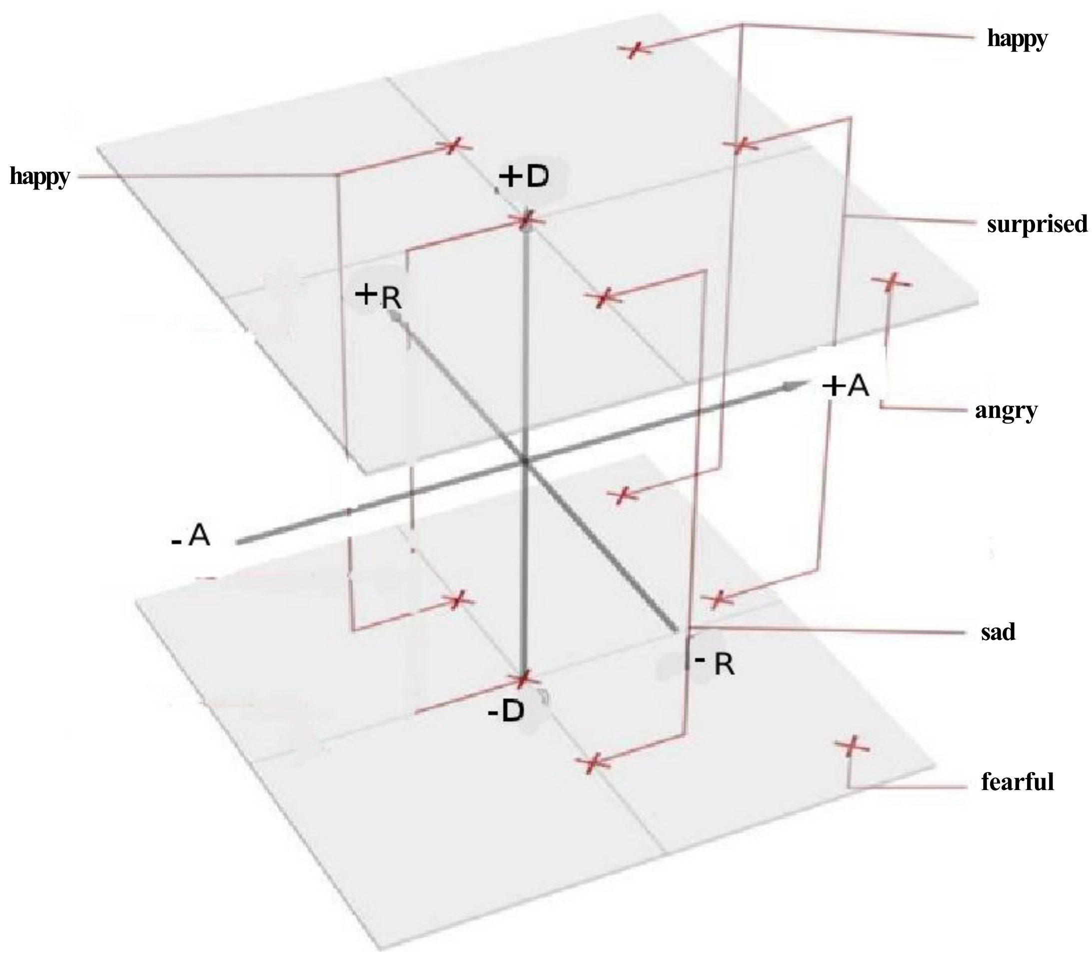

Figure 4. Three dimensional emotion space (PAD space)

• Goal library data-base stores the different goals to reach and interacts with the goals classification trigger to keep agent behaviour coherent with the environment variation.

It consists of three containers:– Goals container defines goals to be accomplished.

– Task container defines tasks related to a specified goal.

– Sub-task container defines actions to do to accomplish task.

• Behaviour rules container stores rules related to personal experience, culture and behaviour rules like walking behaviour (e.g. avoiding agents and other fixed obstacles) and behaviours description for some relevant emotion.

• Goals classification trigger interacts with goal library data-base to extract goals. It classifies goals by priority order according to beliefs, mood and personality information.

• Task planning running directs agent to the action to perform from the task container.

We take a closer look on Behavioural rules container to detail decision process.This module contains navigational rules like a collision avoidance rules or way selection rules to enable pedestrians to move around freely.We include in this module a set of plan composed by a set of actions that provide chronological actions to do to reach goal. A selection mechanism is defined to trigger plan and pedestrian evaluated emotion.

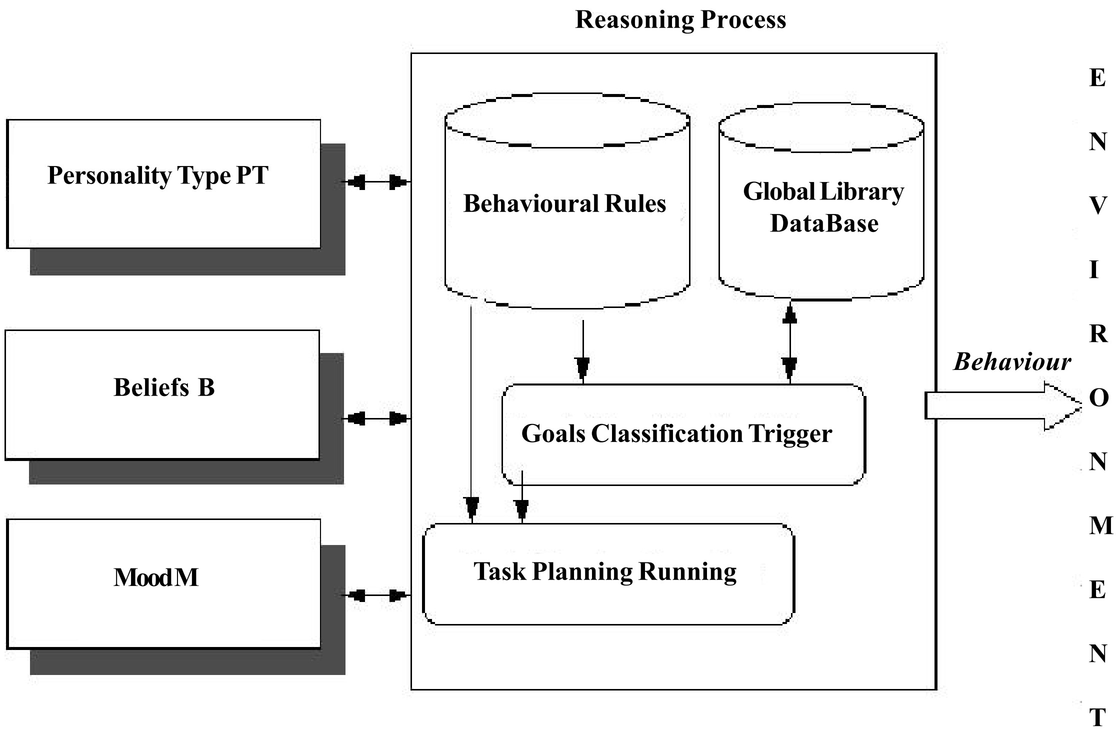

Figure 5. Agent mental process

4. Implementation and Testing

Netlogo 4.0.3 platform is used to implement a prototype to test and evaluate our model. It is a well-suited platform for modelling complex systems that enables the exploration of emergent phenomena resulted from the interaction of many agents. Simulations are performed in 41 *41 Netlogo lattice, with 200 heterogeneous virtual agents spread randomly on the space.

At each time step, virtual agent uses captors to detect and select pertinent information on neighbourhoods. *Decoding procedure* decodes the gathered information and identifies the type and the properties of neighbouring entities. In the end of perception process, *Interpretation procedure* analyses information perceived and determines if the perception is positive or negative (i.e. negative if the perturbation detected harm agent goal, positive otherwise).

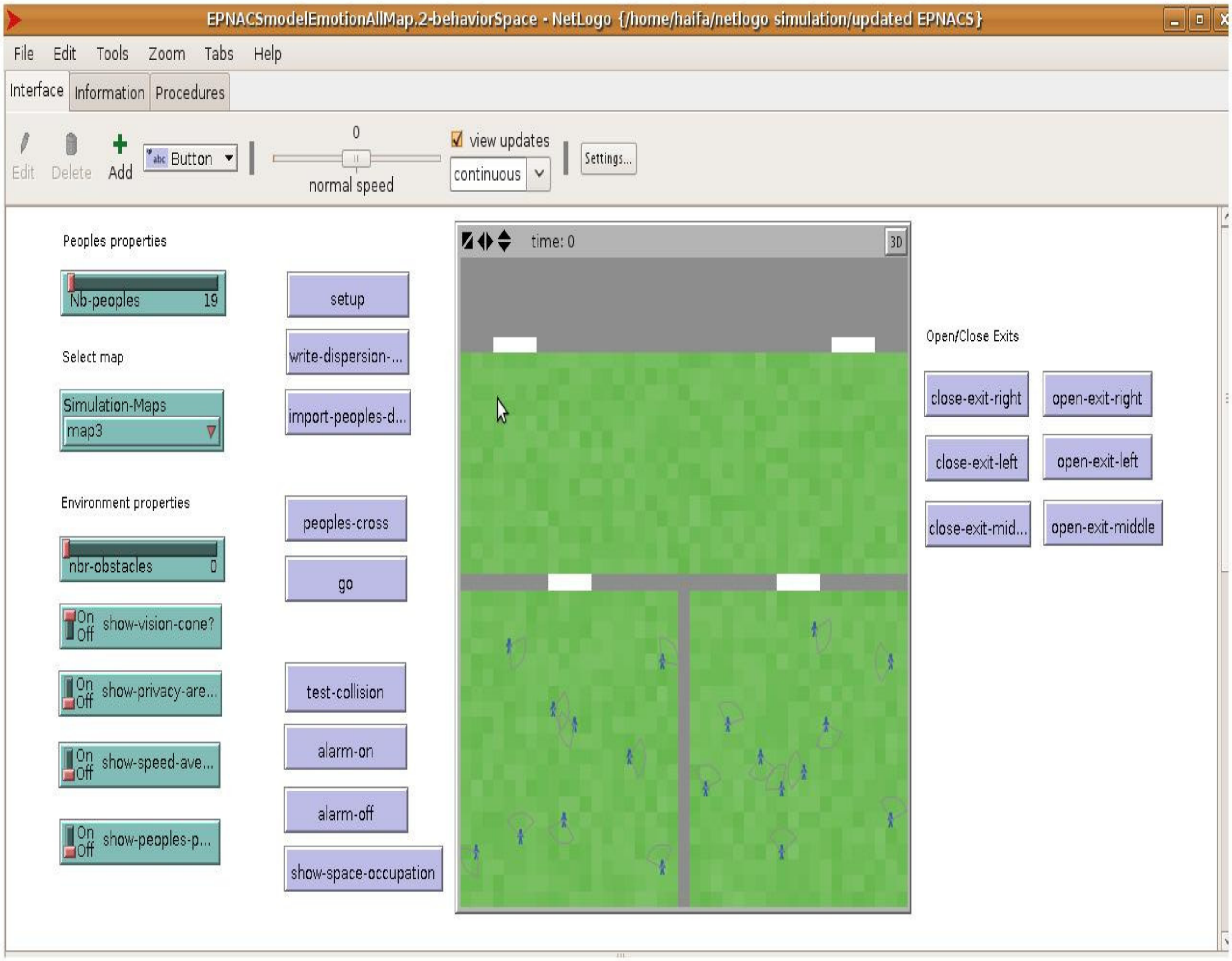

Figure 6. Screen shot of the model implementation

4.1 Testing

Two scenarios in normal situation are used to study the model. Simulations are performed in 41 *41 Netlogo lattice, with 200 heterogeneous virtual agents spread randomly on the space.We propose different maps with different exits location and number to variance evacuation scenarios. The model provides seven maps as agents' virtual environment, the first scenario is done with map 3 Figure 7 and the second with map 7 Figure 9.

4.1.1 Scenario 1

Agents in map 3 are spread randomly in the three parts of the space (i.e. right-first-part, left-first-part and second-part). Agent in map 3 are spread in two parts up and down part. This scenario is an agent evacuation flow in normal situation. Each agent in the simulation has few steps to perform to achieve the unique goal in the simulation, which is "*exit the space*". Agent's steps are:

- In the first-part of the environment agent's goal is to reach the middle-exit (i.e right-middle-exit for the agents on the right side and left-middle-exit for the agents on the left side).

- In the second part of the environment agent's goal is to reach one of the two final-exit (i.e agent's final exit is specified in the creation of each agent).

We perform this simulation to study agents behaviour in normal situation and compare it to human behaviour and other agents

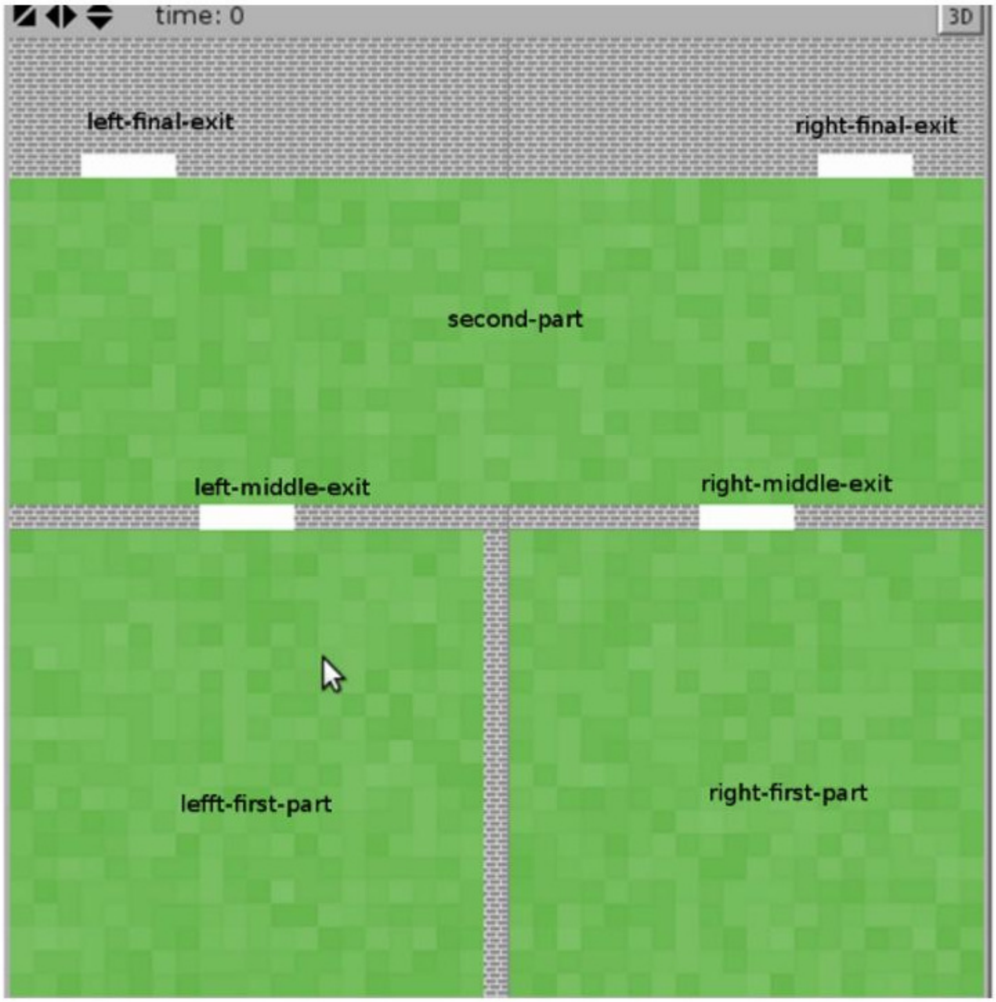

Figure 7. Screen shot of map 3 and its exits

motion model. Inspire of the simplicity of our model, we can observe some phenomena empirically observed and modeled by dynamic models or ABM models.

The scenario reproduces a lane formation phenomena Fig. 8 observed in realistic environment and in other models [12]. Those lanes are dynamically varying during the simulation because they depend on agents density and environment boundary. In the simulation agents have a less constraint space to move so lanes have a large frequency to change which is different in a much constraint space.

Generally the formation of coherent behaviour assumes that there is a communication between entities and specified rules. However, in this simulation lanes appear as an emergent behaviour from entities' interactions. In each interaction, agent analyses obstacles, generates an emotion and then takes appropriate decision like moving a little aside to avoid agents in the opposite side of walking. This behaviour separates moving agents in groups and creates lanes formed by agents with a same side of walk.

4.1.2 Scenario 2

This simulation is done with map 7 Fig. 9 where agents are spread in up and down part of the environment randomly. To exit environment, agents in each part have to reach the middle exit and then the exit in the second part. As in previous simulation, we observe an emergent phenomenon, which are bottlenecks on exit. Agents with a same walking direction are grouped in the same side and when one of agent passes the exit some of them follow. Hence, the number of agents passing the middle exit change during the time, consequently passing direction oscillates during that time.

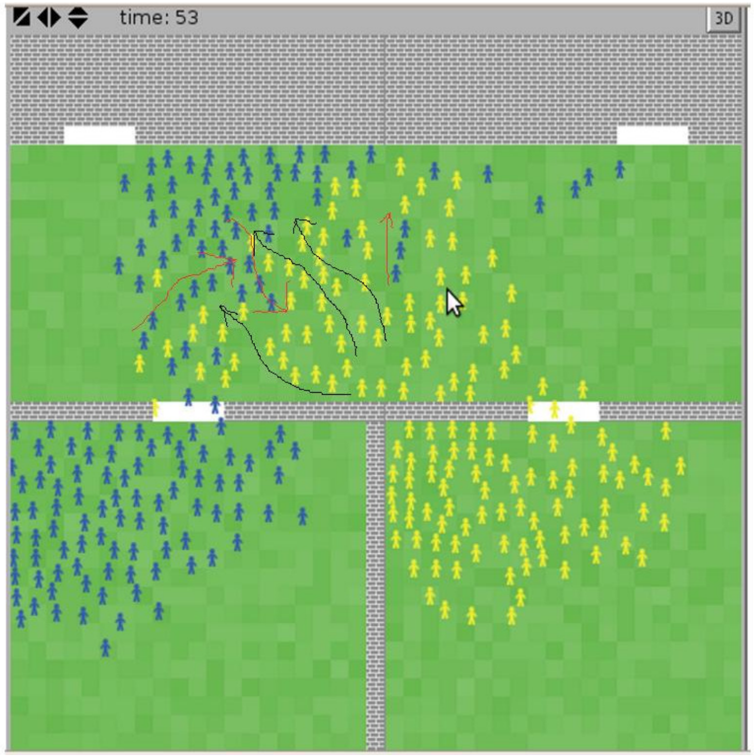

Figure 8. Formation of lanes in the second part of the environment

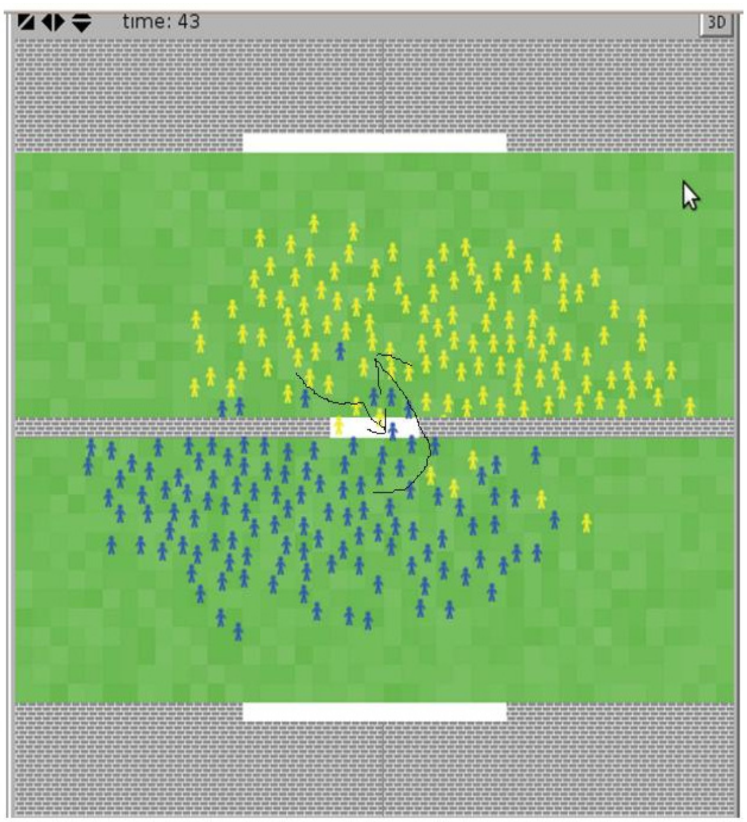

Figure 9. Formation of bottlenecks on middle exit

5. Conclusion

We presented in this paper a proposition to model crowd motion based on cognitive agent properties specially perception and emotion process. The experimentations performed replicate emergent phenomena empirically observed and modelled by dynamic models and Cellular Automata based models. Results of the simulations let us consider our cognitive model as a promising model for crowd motion. In fact, emotion controls human decision in every situation especially when a problem happens. Emotion guides human decision, so including emotion concept on crowd modelling may explain some emergent phenomena on crowd especially on panic situation.

In the future work, we aim to improve emotion process with psychological study on emotion. Simulations will concern normal and catastrophic situation to study the impact of perturbation on evacuation flows.

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