A Formal Approach to Model Emotional Agents Behaviour in Disaster Management Situations

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Abstract. Emotions in Agent and Multi-Agent Systems change their behaviour to a more 'natural' way of performing tasks thus increasing believability. This has various implications on the overall performance of a system. In particular in situations where emotions play an important role, such as disaster management, it is a challenge to infuse artificial emotions into agents, especially when a plethora of emotion theories are yet to be fully accepted. In this work, we develop a formal model for agents demonstrating emotional behaviour in emergency evacuation. We use state-based formal methods to define agent behaviour in two layers; one that deals with non-emotional and one dealing with emotional behaviour. The emotional level takes into account emotions structures, personality traits and emotion contagion models. A complete formal definition of the evacuee agent is given followed by a short discussion on visual simulation and results to demonstrate the refinement of the formal model into code.

Keywords: Agent State-Based Modelling, Formal Methods, Emotional Agents, Emergency Evacuation.

1 Introduction

Human emotions significantly change behaviour in complex environments where resources are a primary concern [8,29]. This fact has brought new ideas and solutions to the Multi-Agent System (MAS) paradigm. For example, the use of emotions in a context-aware decision support system resulted to lesser communication time between agents [17] where in other cases emotions as well as personality and mood led to faster compromises among agents engaging in a negotiation [28]. Furthermore, an attempt was made to model the social function of emotions and their interconnection with socials norms to improve controllability in MAS [9]. Finally, emotions can be seen as a leverage to teamwork and cooperation between agents [20].

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In the current case, we investigate modelling of emotional agents in disaster management situations and in particular emergency evacuation. It is known that emotions affect the way crowd behaves in such cases. According to a non-emotional behaviour, all agents in danger follow a specific exit plan and the building is evacuated in a timely fashion. However, in reality, people's emotions drive their behaviour; certain people can start experiencing fear or panic under certain circumstances such as lose of direction, detachment from family members, delay in finding and following an exit plan. It is therefore a challenge to devise a formal model that would be able to describe emotions, personality traits and emotion contagion in a way suitable to lead towards simulation of emergency evacuation scenarios.

The aim of this paper is to introduce a formal model for emotional agents. The model is based on a type of finite state machines, namely X-Machines, which have demonstrated a number of advantages in formal modelling of agents. The main contribution is the addition of an emotional meta-level machine to the basic model, thus clearly and elegantly separating modelling of the rational (non-emotional) and that of emotional agent behaviour in cases such as emergency evacuation. We briefly demonstrate how the model can lead to simulation, thus visualising the overall behaviour of the crowd in disaster management scenarios.

The current paper is structured as follows: Section 2 deals with formal modelling of agents using a state-based method, namely X-Machines. The main contribution is in section 3, where we define an meta-level extension that deals explicitly with emotional behaviour of agents. Such behaviour is prominent in emergency evacuation and section 4 presents such a case study together with the formal agent models. In section 5, we briefly discuss how the models lead to simulation and present some results. Before we conclude, related work is presented in section 6.

2 A Formal Model for Agents

There exist numerous formal methods, either general or specialised to agent modelling [11,4,26]. Agents and MAS, as software artifacts can benefit from formal modelling in terms of unambiguous specification, verification of the model towards given properties and finally formal testing of the implementation.

2.1 X-machines

We have worked with *X-machines* for a long period of time. X-machines are state-based machines extended with a memory structure. That makes modeling more intuitive and leads towards implementation. The memory structure also makes the machine more compact compared to memory-less state machines. Another important difference is that the transitions between states are not triggered by inputs alone, but by functions that accept an input and the memory values and produce an output and new memory values. Again, this leads nicely towards the final implementation through refinement.

It has been demonstrated that X-Machines and its extensions are particularly useful for modelling biological and biology-inspired MAS [14]. The great advantage over other methods is their strong legacy of theory and practice in:

- modelling potential for dynamically structured MAS [30],
- refinement, animation and simulation [25],
- testing methods that prove correctness [12] with tools for automatic test generation [5],
- model checking for verification of properties [7]

Definition 1. *An X-machine ($\mathcal{X}$) is defined as:* $\mathcal{X} = (\Sigma, \Gamma, Q, M, \Phi, F, q_0, m_0)$ *[12], where:*

- Σ *and* Γ *are the input and output alphabets.*
- Q *is a finite set of states.*
- M *is a (possibly) infinite set called memory.*
- Φ *is a set of partial functions* φ*; each such function maps an input, a memory value and an emotional states to an output and a possibly different memory value,* $\varphi : \Sigma \times M \rightarrow \Gamma \times M$.
- F *is the next state partial function,* $F : Q \times \Phi \rightarrow Q$*, which given a state and a function from the type* Φ *determines the next state.* F *is often referred to as a state transition diagram.*
- q_0 *and* m_0 *are the initial state and initial memory.*

2.2 Example: An Agent Evacuating on Emergency

The $\mathcal{X}$ model of an agent that evacuates a building on emergency is shown in Fig. 1. The figure depicts the state diagram F, where transitions are labeled through functions in Φ. The agent starts at *no emergency* state until it *perceives a danger* of some sort. Then it *wanders around* in order to find an evacuation plan. While *evacuating* by following the plan, it may *get disorientated* or *loose family* members. In such cases, it keeps *wandering around* until it *finds the family* member or *finds a plan* respectively. The computation ends when the *exit is found.*

The memory of $\mathcal{X}$ agent model holds the evacuation plan (sequence of coordinates), the current position of the agent, the status of the family member and the walking speed towards the exit.

The input alphabet Σ contains sets of percepts, such as the other agents positions, the empty space positions, the emergency alarm etc. The output alphabet Γ is a set of abstract messages that at simulation could be translated to visual output on the status and position of the agent.

An example function in Φ is:

$\varphi_{found\text{-}exit} : (Percept, (Plan, Pos, S, Ch)) \mapsto (\text{“}Exited\text{”}, (Plan, Pos', S, Ch))$ *if* $(Pos', empty) \in Percept \wedge canMove(Pos, Pos', S) \wedge door(DoorPos) \in Percept \wedge distance(Pos', DoorPos) < distance(Pos, DoorPos)$

The actual model is simplified here for exposition purposes and includes a number of additional functions that deal with the agent behaviour.

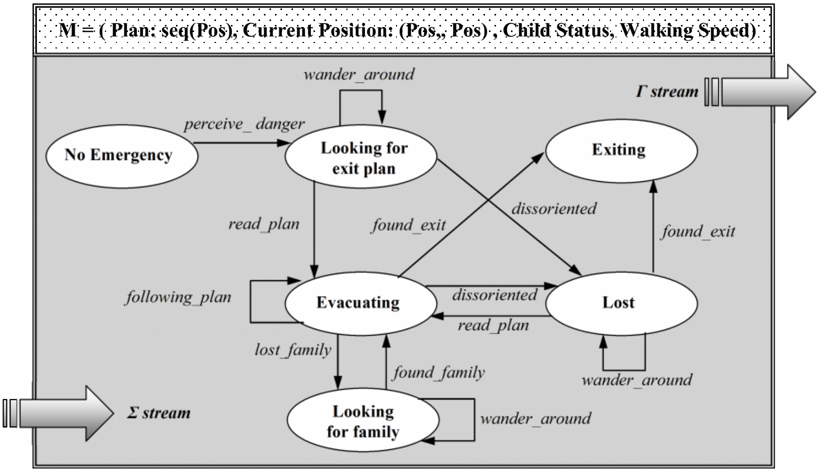

Fig. 1. An abstract $\mathcal{X}$ model of an agent that evacuates a building on emergency

2.3 Computation of $\mathcal{X}$

Definition 2. *An computation state in $\mathcal{X}$ is defined as the tuple (q, m), with $q \in Q$ and $m \in M$. A computation step, which consumes an input $\sigma \in \Sigma$ and changes the computation state $(q, m) \vdash (q', m')$ with $q, q' \in Q$, $m, m' \in M$, such that $\varphi(\sigma, m) = (\gamma, m')$ and $F(q, \varphi) = q'$.*

A *computation defined* as the series of computation steps that take place when all inputs are applied to the initial computation state (q_0, m_0), which for the case above could be, for instance, $(no\_emercency, (\epsilon, (15, 42), child\_close, 1m/sec)$.

3 $^{em}\mathcal{X}$-Machines

Emotions influence agent perception, learning, behaving, communication, etc. An agent acting under emotions exhibits a different behaviour than the same agent acting in a rational (emotion-less) way. This is clear in situations where disaster management is required, such as emergency evacuation. In such events, agents, depending on their personality, appear to have increased chances to experience *fear* that may eventually turn into *panic*. Such emotions could alter what they perceive and what they communicate to other agents. It is also important to note that agents behaviour is altered when they operate as a family group, for instance if there are parents accompanying children.

So far, there is not yet a widely accepted definition of emotions supported by a complete theory that can describe how emotional processes affects reasoning in general [15]. Most commonly used psychological theories in agent design today refer to appraisal process of stimulus [16] and the reactions to three types of stimuli (OCC model) [21].

There exist two basic options to achieve emotional behaviour of artificial agents: (a) to hard-wire emotions into the agent, (b) to model emotions at a different level than the rational behaviour. In this work, we chose the latter as a more elegant approach to emotions modelling.

Definition 3. *An Emotional X-machine is defined as a tuple* ${}^{em}\mathcal{X} = (\mathcal{X}, \mathcal{E})$ *where* $\mathcal{X}$ *is an X-machine and* $\mathcal{E}$ *is a meta-machine defined as* $\mathcal{E} = ({}^{e}\Sigma, {}^{e}\Gamma, \rho_\sigma, \rho_\gamma, \rho_\varphi, E, P, C, {}^{e}\Phi)$*, where:*

- ${}^{e}\Sigma$ *and* ${}^{e}\Gamma$ *are the input and output alphabet.*
- ρ_σ *and* ρ_γ *are the input and output revision functions.*
- ρ_φ *is the behaviour revision function.*
- E *is a representation of an emotional theory.*
- e_0 *is the representation of the initial emotional state.*
- P *is a personality trait type.*
- C *is a contagion model type.*
- ${}^{e}\Phi : E \times P \times C \times M \times \Sigma \rightarrow E$ *is the set of emotions revision functions* ${}^{e}\varphi$*, that given an emotions structure* $e \in E$*, a contagion model* $c \in C$*, a personality trait* $p \in P$ *and a memory tuple* $m \in M$ *returns a new emotion structure* $e' \in E$*.*

Fig. 2 shows an abstract ${}^{em}\mathcal{X}$ model. The upper meta-layer represents $\mathcal{E}$ and the lower layer the ${}^{em}\mathcal{X}$ machine.

It is important to note that agent models in this context do not have an affective behaviour towards humans, and thus factors like body language, speech etc. are not taken into account.

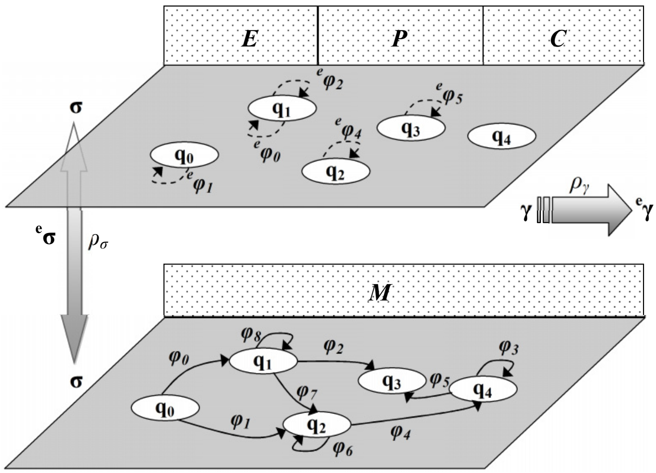

Fig. 2. An abstract ${}^{em}\mathcal{X}$ model with non-emotional behaviour as $\mathcal{X}$. at the lower layer and emotional behaviour as $\mathcal{E}$ at meta-level.

3.1 Input and Output Revision

Input and output revision refer to the way the environment is perceived and what the agent communicates to its environment (and other agents) under emotions. This may significantly differ from a situation where the agent behaves rationally. Especially in disaster scenarios, the personality trait and the dominant emotions would greatly affect perception and outward communication. In principle, the two revision functions may be defined as:

$\rho_\sigma : {}^e\Sigma \times E \times P \times C \rightarrow \Sigma$ and $\rho_\gamma : \Gamma \times E \times P \times C \rightarrow {}^e\Gamma$

3.2 Behaviour Revision

The behaviour revision function ρ_φ determines which functions of $\mathcal{X}$ are applicable in a given emotional state E. It is defined as: $\rho_\varphi : E \times \mathcal{X} \rightarrow \Phi$

3.3 Emotions

Artificial emotions are plugged-in to the $\mathcal{E}$ meta-level definition in order to facilitate modelling of emotional agents. By extracting E at a meta-level, various opportunities are open to experiment with different theories. In fact, E serves as a formal structured representation of artificial emotions or an emotional theory, for instance the OCC model [21].

3.4 Personality Trait

Individual emotion strength updates depend on the rate of change of E, different for each evacuee, since evidence suggests that there exist individual differences in affective response to emotion eliciting stimuli. *Personality trait*, for example, is one relevant factor. Some individuals have a predisposition (sensitivity response) towards experiencing certain emotions, so different personality traits are responsible for how quickly an emotional state is reached, maintained and recovered from, resulting to some agents reaching a state of panic or hysteria more easily [2].

Psychologists argue about the *Big Five* basic factors that affect personality traits: (a) openness, (b) conscientiousness, (c) extroversion, (d) agreeableness, and (e) neuroticism [18]. So, either P can be represented as crisp values of different personality traits (some count more than a hundred) or a vector with any of the five factors above, expressed as NEO-FFI or any other psychological personality inventory.

3.5 Contagion

Emotional contagion is a result of interaction between agents which could affect each others emotions. It is the case that in emergency situations, emotions (especially calmness, fear and panic) may propagate when agents of various personalities interact. For example, security personnel is assumed to have a calming effect to evacuees, and on the contrary, detachment of a family member during evacuation may result into increased level of fear.

There are various contagion models depending on the situation, most of them based on perception, message exchange and proximity of agents [10], [6]. The above definition allows flexibility to define one that suits the situation as well as change it, if necessary, without affecting the basic rational $\mathcal{X}$ model.

3.6 Computation of ${}^{em}\mathcal{X}$

The computation of ${}^{em}\mathcal{X}$ is similar to this in $\mathcal{X}$ but it includes an additional number of steps which deal with emotions.

Definition 4. *An ${}^{em}\mathcal{X}$ computation state is defined as the tuple (q, m, e), with $q \in Q$ and $m \in M$ and $e \in E$. A computation step, which consumes an input $\sigma \in \Sigma$ and changes the computation state $(q, m, e) \vdash (q', m', e')$ is essentially composed of the following substeps:*

- *firstly, the input revision function produces the input σ to be consumed by $\mathcal{X}$, thus $\rho_\sigma({}^e\sigma, e, p, c) \vdash \sigma$, where ${}^e\sigma \in {}^e\Sigma, e \in E, p \in P, c \in C$ and $\sigma \in \Sigma$.*
- *the behaviour revision function ρ_φ produces a set of functions φ^a of $\mathcal{X}$ that are applicable in the current emotional state.*
- *a transition in $\mathcal{X}$ takes place by triggering a function $\varphi \in \varphi^a$ at the lower layer: $(q, m, e) \vdash (q_1, m', e)$ with $q, q_1 \in Q$, $m, m' \in M$ and $e \in E$, such that $\varphi(\sigma, m) = (\gamma, m')$ and $F(q, \varphi) = q_1$.*
- *an emotions revision in ${}^{em}\mathcal{X}$ takes place by triggering an emotional function at meta-level (changes emotions structure E): $(q_1, m', e) \vdash (q', m', e')$ with $q_1, q' \in Q, e, e' \in E$ and $m' \in M$ such that ${}^e\varphi(e, p, c, m', \sigma) = (e')$.*
- *finally, the output revision function produces the final output γ of ${}^{em}\mathcal{X}$, thus $\rho_\gamma(\gamma, e, p, c) \vdash^e \gamma$, where $\gamma \in \Gamma, e \in E, p \in P, c \in C$ and ${}^e\gamma \in {}^e\Gamma$.*

In the above, a transition in $\mathcal{X}$ takes place first. Then a function in ${}^{em}\mathcal{X}$ revises the emotions but not the states. A *computation* is defined as the series of computation steps that take place when all inputs are applied to the initial computation state (q_0, m_0, e_0).

4 Case Study: Emergency Evacuation

The above described agent for evacuation can be modelled as a ${}^{em}\mathcal{X}$ by adding the meta layer $\mathcal{E}$ for emotional behaviour. One needs to define the elements for the ${}^{em}\mathcal{X}$ tuple. In this paper, we will assume for the sake of simplicity that ${}^e\Sigma = \Sigma$, ${}^e\Gamma = \Gamma$, $\rho_\sigma = \rho_\gamma = \epsilon$, which means we consider agents whose incoming perception and outgoing messages are not affected by emotions.

As emotional structure E, we will use a simplified approach with a vector $E = ((e_1, v_1), (e_2, v_2), ..., (e_n, v_n))$ where e_i are basic emotions and v_i its *strength*, i.e. $v_i = 0..100$. One of the basic emotions is *Horror* [23] which can be assigned with different crisp *emotion descriptors*, such as {*calm, alarmed, fear, terror,* *panic, hysteria*}. Thus, the initial value of *Horror* in E_0 is $(calm, 0)$. In the following $SV_H(E)$ stands for the strength value v_H of $Horror$ given the emotion vector E.

As personality trait P, we could define different types in a set such as $\{confident, helpful, coward, self-centered\}$. Alternatively, we choose a sample of factors that determine a personality type, i.e. $(openness, extraversion)$. These factors would represent the rate with which the *emotion strength* changes.

A contagion model C for the evacuee, such as ASCRIBE [1], can be adopted. It introduces *contagion strength* s_{iQj} that determines the strength by which agent j influences on some state Q agent i:

$$s_{ij} = expressiveness_j * (1 - \frac{dis(Pos_i, Pos_j)}{dis_{infl}}) * openness_i \tag{1}$$

where the middle factor determines the *channel strength*, in our case the euclidean distance between the agents $dis(Pos_i, Pos_j)$, in the area of influence dis_{infl} (the radius of the area containing agents). The overall contagion strength is determined by:

$$s_i = \sum_{i \in Agents} s_{ij} \tag{2}$$

where $Agents$ is the set of agents currently located in the area of influence of agent i. Contagion is used in the emotion revision functions to update the *strength* of the basic emotions in E, in this case the *emotional descriptors* of *horror*.

The emotion revision function is similar to that reported in [27], i.e. the emotion level is determined by an *individual emotion update* (f_{ind}) and a *social emotion update* (f_{social}), the latter being determined by emotion contagion. Thus, emotion revision function is given by the following equations:

$$f_{ind}(M, P, E) = c_{inc} * P - f_{dec}(\Sigma, E, P) \tag{3}$$

where P is the personality trait and c_{inc} a constant defined as a model/experiment parameter. In equation 3, f_{dec} determines the set of inputs that decrease the emotion level of the agents, such as the perception of a plan in Σ:

$$f_{dec}(\Sigma, E, P) = \begin{cases} c_{dec} * P * SV_H(E), & \textit{if } (seq(Pos_i), plan) \in \Sigma \\ 0, & \textit{otherwise} \end{cases} \tag{4}$$

where c_{dec} is a constant that determines the decrease in emotional strength, given the perception of the agent (plan). The social part of the revision function is determined by:

$$f_{social}(\Sigma, E) = \sum_{j \in Agents} \frac{(s_{ij}/s) * (SV_H(E) - SV_{H_j}(E_j))}{|Agents|} \tag{5}$$

where s is the overall contagion strength of the agent as given in equation 2, and $|Agents|$ is the number of agents in the area of influence. Thus, the overall emotion function ${}^eF$ of Definition 3 is given in equation 7.

$$v'_H = SV_H(E) + f_{ind}(M, P, E) + f_{social}(\Sigma, E) \quad (6)$$

$$^{e}\Phi = (F_H(v'_H), v'_H) \quad (7)$$

where F_H is a mapping function between the emotion strength value v'_H and the crisp values of $Horror$. In the specific example the behaviour revision function ρ_φ, is simply given by equations 8 and 9.

$$\rho_\varphi(E, X) = \begin{cases} \Phi_{panic} & \textit{if } SV_H(E) > 80 \\ \Phi \text{ - } \{dissoriented\} & \textit{otherwise} \end{cases} \quad (8)$$

$$\Phi_{panic} = \{wander\_around, dissoriented, found\_exit, read\_plan\} \quad (9)$$

5 From Formal Modelling to Simulation and Results

One the most important benefits in specifying a model using $^{em}\mathcal{X}$, is that due to the state based orientation of the latter, an executable model can be derived with relative ease. Such an executable model can be implemented in an agent simulation platform, for initial testing and evaluation of the agent specification. Refinements of $^{e}\mathcal{X}$ models to executable simulations in NetLogo [34] are reported in [31,27]. In this work we follow the same approach, by reusing parts of a domain specific language (DSL) for $^{em}\mathcal{X}$, augmenting the work described in the aforementioned papers appropriately to support the new meta model for emotions.

The evacuation area the agent model was tested against, was a shopping mall as the latter is depicted in Fig 3. In the figure, white areas represent shops were people (evacuees) are initially located. Exits are depicted a darker areas (red) on the top left and bottom center of the shopping mall. The figure presents the state of evacuation several time points after the alarm event occurs.

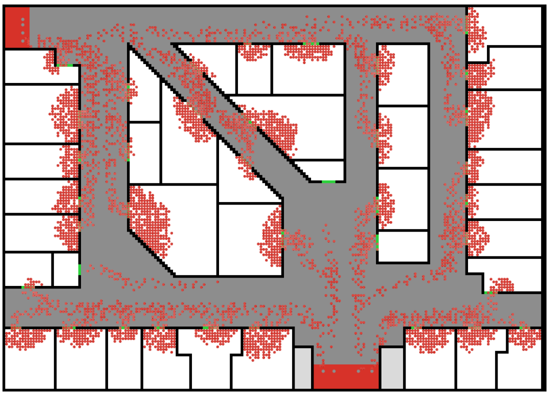

Fig. 3. The Shopping Mall Simulation Area

In the simulation environment, each individual is considered to occupy a 0.4 × 0.4 m space, as usual in evacuation simulations that follow the discrete space approach. The total area is about 3000 square meters. Evacuees located initially inside shops, upon perceiving the alarm, proceed to the exits, following evacuation plans (paths) that can be found in the form of instructions at shop doors. During the evacuation, increased emotional levels lead to the agent getting "lost", i.e. the agent is randomly exploring the shopping mall space, until it perceives new instructions from a door location and resumes evacuation. Such agents are depicted by a yellow (light) color in Figure 4.

Fig. 4. The Shopping Mall Simulation Area a while after an alarm was issued

A set of experiments was conducted to demonstrate the feasibility of the model refinement and to obtain an initial insight on how emotions and emotion contagion can affect evacuation times. An initial set of experiments concerned 2000 evacuees on the office floor and the evacuation time was on average (10 runs with different initial conditions) 2200 time units. When the number of evacuees was increased to 4000, evacuation times were considerably longer, at an average of 5000 time units. This was due to evacuees staying longer inside the evacuation area due to congestion at the corridors and exits, their emotional level increasing and more being "pushed" to the state "Lost" and engage in a random exploration. Evacuation time are further increased in the case of parents, since the latter have to ensure at each step of the evacuation that their children are near, and in the case the latter does not hold, they have to abort evacuation and look for their children.

Although the initial experiments are in accordance with what is expected in such situations, further experimentation and model validation is required for the model. However, such an analysis is beyond the scope of the present work, that aims to introduce a formal approach to emotion agents modelling. An interested reader may refer to [27] for a more detailed set of results.

6 Related Work: Emotions in Artificial Agents

In previous work [31,27], we have attempted to plug-in emotions within the agent model. In fact, the definition of emotions $\mathcal{X}$-Machine contained E as a separate memory element with personality trait as part of the memory and with contagion only implied and hard-wired in emotion revision functions. That initial model was created to facilitate refinement to simulation and build confidence on validity of the models. The proposed revision of ${}^{em}\mathcal{X}$ with a meta-level machine is more elegant with respect to theory of state-based machines and leads to a more natural development of agent models; rational and emotional behaviour are modelled as two separate entities and thus susceptible to change without affecting one another.

There also exist a number of computational models of emotions, most of them logically formalised through the BDI framework. One of the first attempt was dMars, a BDI descendant, that comprised four modules, one of them being an emotional module [22]. The system was also provided with a personality component inside the emotional module which is comprised by three traits (a) the motivational concerns, i.e. tendency to specific goals, (b) an emotion threshold which represents the point at which an emotion is asserted and (c) the rate of decay for an emotion.

Another attempt is reported for the BDIE architecture, a modular model with embedded emotional capabilities and four segregated modules/systems: (a) *Perceptual* (belief), (b) *Emotional*, (c) *Behaviour* (Intentions), and (d) *Motivational* (Desires) [3]. The Emotional system takes into account primary (fear and surprise) and secondary emotions (happiness, sadness and anger) for the purpose of affective and cognitive appraisal respectively through the use of first and second level evaluators associated with the Perceptual system (Belief). Connected to all three other components, the Emotional system can affect the perceptual process, provide reactive capabilities and finally modifies behaviour.

Similar to the above is a conceptual BDI architecture with internal representations of *Affective Capabilities* and *Resources* for an Emotional Agent [24]. Capabilities were abstract plans available to the agent and Resources were the means that turn Capabilities into plans. Two new modules were introduced: (a) a *Sensing and Perception Module*, and (b) an *Emotional State Manager*. The first is responsible for capturing information from external stimuli. The latter comprised a set of artificial emotions with a decay rate function, and also controls capabilities and resources.

The DETT architecture for situated agents in combat simulation was presented in [33]. The emotional aspect of the DETT design lay on the OCC model [21] and is supported by two reasoning processes: an appraisal and an analysis process. Agents within the system sense their surroundings and other agents through a digital pheromone that they emit in the environment and decays over time. DETT introduces four new concepts: (a) *Disposition*, (b) *Emotion*, (c) *Trigger* and (d) *Tendency*. Dispositions are closely related to emotions in one-on-one relationship, e.g. irritability and anger or cowardice and fear, and can be thought as personality traits associated with an affective state. The appraisal process takes in to account the agents disposition and the current trigger belief (pheromone) and elicits an emotion that affects the analysis process by imposing a tendency on the resulting intention.

Finally, the PEP-BDI architecture [13] considers physiology, emotions and personality in the decision-making process. Emotions are based on OCC model [21]. A simplified personality model is used mapping specific personality traits as emotional tendencies. Later, the PEP-BDI was updated to model (a) *empathy* (the ability to understand and share the feeling of other), (b) *placebo* (a simulated and ineffectual treatment that has psychological benefits) and (c) *nocebo* (the opposite effect of placebo). The agent's emotions are a combination of three mechanisms: (a) *internal dynamics*, (b) *event dynamics* and (c) *external dynamics*.

In terms of emergency evacuation simulation, the role of emotions as well as the type of agents in emergency evacuation was widely explored. Since the focus of this work is on the theoretical model, an interested reader may refer to [32,35,19].

7 Conclusions

We have presented a formal method for emotional agent development. The basic characteristic of ${}^{em}\mathcal{X}$ is that formalising non-emotional and emotional behaviour can be regarded as two separate modelling activities, since there are two state-based machine, one for the former and a meta-machine for the latter. This also has a number of significant advantages on software development process, such as incremental refinement, testing and verification. We briefly showed how the models can turn to simulation by using the NetLogo framework and some results to demonstrate the visual behaviour of the model were presented.

It would be interesting to develop other models using different emotional structures, personality traits and emotional contagion approaches. Although ${}^{em}\mathcal{X}$ seem to be generic enough, it is a challenge to acquire valuable experience when dealing with a variety of theories, especially appraisal and communication. The next step towards this would be further experimentation with modelling and of course simulation of case studies on emergency evacuation and comparison of simulation results with real scenarios.

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