Experiments with Emotion Contagion in Emergency Evacuation Simulation

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ABSTRACT

Multi-agent systems simulation is used to predict human behaviour in emergency evacuation cases. However, as human behaviour can change under the effect of emotions, it is essential to create models of artificial agents and simulations that mimic such behaviour in order to make prediction of the overall system performance. In emotional agents, the role of emotional contagion is important. 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 in various ways, depending on the agents personality type as well as other factors. In this paper, we review various methods of emotional contagion. In order to develop emotional agent simulation, we start from a formal state-based modelling method and devise a number of variations of known emotional contagion methods. NetLogo visual simulation is used, in which a number of experiments is conducted. The results are useful to demonstrate different behaviour of different emotional contagion models in the evacuation of an open square area.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*multiagent systems*; I.6.5 [**Simulation and Modeling**]: Model Development

General Terms

Algorithms, Design, Experimentation

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Keywords

Agents, Agent Simulation Platforms, Emotions, Evacuation Modelling

1. INTRODUCTION

Multi-agent systems behaviour can change if agents are considered to operate in a complex environment which could potentially raise emotions. In such cases, agents may perceive their environment in a different way, they might communicate messages to other agents that they did not originally intend to, they might alter their rational behaviour in unpredictable ways. One of the applications of emotional agents is emergency evacuation. As human behaviour can change under the effect of emotions, it is essential to create models of artificial agents and simulations that mimic such behaviour in order to make prediction of the overall system performance.

There are several other factors that are important in emotional agents:

- the *emotions theory* on which artificial emotions will be developed,
- the *personality traits* that drive the rate of increase or decrease of emotions, and
- the *emotion contagion.*

Individual emotion strength depends on the rate of change of emotions, different for each individual, 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.

Emotional contagion (EC) 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.

This paper is concerned with EC. Starting from a formal state-based method for emotional agents, called $^eX-machines$, that contain EC as a generic characteristic, we experiment with various EC models that exist in the literature. Our aim is twofold; to show that the original formal method is generic enough to accommodate a variety of EC methods and to review and compare existing EC methods. We do that by refining the formal model into a NetLogo visual simulation and running a number of experiments. The end results are useful to demonstrate different behaviour of different EC models in the evacuation of an open square area.

The paper is organised as follows: Section 2 offers an overview of the main theoretical models of Emotional Contagion found in the literature, summarizing their major characteristics. In Section 3 the formal modelling of emotional agents with the inclusion of Emotional Contagion is discussed. Our model's implementation on a specific case study is presented in Section 4, followed by the corresponding results in Section 5. Finally, we conclude by outlining our contribution and point to further work.

2. BACKGROUND ON EMOTION CONTAGION MODELS

Spread of emotions may intuitively be considered as an important factor in emergency evacuations, however, few computational models have been suggested thus far that deal explicitly with emotion contagion. In the following section, the major models found in the literature, to the best of our knowledge, are briefly described.

2.1 Theoretical Models

In this section, three contagion models are reviewed: (a) ESCAPES, (b) ASCRIBE and (c) Durupinar's model.

ESCAPES (Evacuation Simulation with Children, Authorities, Parents, Emotions, and Social comparison) [14], a model that is mainly concerned with crowd behaviour simulated as MAS, and includes an EC parameter was built:

- to include the concept of different agent types (i.e. single travellers, families and security personnel), and
- to mimic reality more closely in similar circumstances

It has been shown that family members that are not in proximity with each other, upon acquiring knowledge of an emergency, instead of following orders to evacuate, their primary goal is to locate the remaining members of their family. The simulation described in [14] was concerned with an emergency evacuation scenario in the International Terminal at Los Angeles International Airport.

Regarding EC in particular, ESCAPES suggests that, upon interaction amongst two individual agents, the form of emotion propagation depends on the agent type, e.g. a person coming to contact with a member of the security personnel is assumed to instantly experience a calming effect, by inheriting the trained officer's lack of fear. If, on the other hand, a person comes into contact with another panicking individual, the agent is assumed to experience the opposite effect, and thus is "infected" with panic.

In ASCRIBE [7], the authors describe contagion as a form of emotion mirroring, and introduce the notion of contagion strength between two interacting people, as a measure of the influence that the emotional state of an individual has upon another. The contagion strength, according to the authors, depends on how expressive the emotion "sender" is and on how receptive the corresponding receiver is. The ASCRIBE model has been successfully used to simulate the May 4 incident in Amsterdam, Netherlands [3], during which, a person amongst a crowd of around 20,000 people, started screaming, causing panic that eventually led to physical injuries of 64 people.

A different EC model was proposed by Durupinar in [6], according to which, as a first step towards modeling EC, the agents may be categorized as being either in a *susceptible* or an *infected* state. The key points that describe Durupinar's theory are that:

- A *susceptible* agent may have an evident emotion, however, a *threshold* property defines the transition between the *susceptible* and the *infected* state.
- The *threshold* depends on the individual's empathy, implying that a more empathetic person is rather more prone to becoming *infected*, and has a lower threshold than a less empathetic one.

Various different cases of EC were discussed in [6], differentiated by the propagated emotion, such as joy (festival scenario), anger (protest scenario) and fear (escape scenario).

2.2 Empirical Evaluation of EC Models

The three aforementioned models, were empirically evaluated by Tsai et al. in [13]. The original ESCAPES model was replaced with ASCRIBE and Durupinar's respectively, and the authors ran a number of simulations in the same map to determine the sensitivity of each model. It was assumed that EC occurs when agents are in proximity of *seeing* and/or *hearing distance*. The models were subsequently validated via comparing the simulations with real video footage of two different incidents:

- the Amsterdam case [3], where in the midst of a gathering, panic was spread due to a screaming person,
- the Greece case, where a group of people within a protesting crowd was fired with tear-gas by the police.

For both incidents, a number of individuals were selected from the actual video footage and their movements traced for a particular duration of the video. Then, their coordinates in selected time frames were compared to those of the respective simulations. The authors concluded that ASCRIBE exhibited better compliance with the real data, compared to both ESCAPES and Durupinar's model.

2.3 Other Models

The aforementioned models deal explicitly with EC in emergency evacuations. However, several researchers have attempted to incorporate EC to their models for crowd simulations that include agent emotional states. Table 1 summarizes the key characteristics of a number of EC models that are found in the literature, accompanied by the respective propagated emotion for each simulated scenario.

Table 1: Emotional Contagion Models

Model Description	**Ref.**	**Propagated Emotion**	**Scenario**
ESCAPES	[14]	Fear	Airport Evacuation
ASCRIBE	[3]	Fear	Screaming person amongst crowd
Durupinar's Model	[6]	Joy, Anger, Fear	Festival, Protest, Evacuation
Model based on Emotional Contagion Scale	[2]	Love, Happiness, Fear, Anger, Sadness	N/A (NetLogo Simulation)
Emotion Contagion with Moderating Factors	[4]	Elatedness	Students and teachers in recreational environment
Emotion intensification due to average emotion of neighbors	[1]	Anger	Protest

For example, the effect of AmI technology on emergent group formation during evacuation scenarios was investigated [12]. More specifically, the authors simulate a train station evacuation scenario, where a number of agents are equipped with AmI technology, that offers additional information about the status of clogging of the available exits. The EC model used here is similar to ASCRIBE, with the main difference that the channel strength is replaced by a *trust* factor that increases when an agent has a *positive* experience with the information source (i.e. the AmI equipped agent), and decreases on occurrence of *negative* experiences. An experience refers to the the "verbal" communication of information (e.g. the degree of congestion around an exit) between two interacting agents. This experience is characterized as either positive or negative when the recipient compares the information against its own beliefs.

An EC model that incorporates a number of *moderating factors* was proposed [4]. These factors are derived from a vast amount of psychological experiments. The authors categorize these EC moderators as: (a) *individual differences* (e.g. gender, personality), (b) *interpersonal factors* (e.g. similarity, group membership), and (c) *miscellaneous* (e.g. pre-existing mood). The model is then implemented to simulate the propagation of elatedness in a scenario with students and teachers situated in a recreational environment. Initial results suggest that variation of the EC Moderators influences the outcome in anticipated and explainable ways.

Another model for an emotion engine that incorporates EC was reported in [1]. According to appraisal theory [11], emotion is a cumulative result of the various ways a person assesses their environment with respect to their personal values, goals and well-being. The emotion engine works by assuming that when an agent perceives events in its environment, each event is mapped to one of a predefined set of appraisal patterns. Each appraisal pattern is in turn mapped to a specific emotional response. For each emotion, it is assumed that two mechanisms may affect the emotional state of the agent: Either the emotion is intensified, as a response to the perceived fact (trigger), or it naturally decays with time. To achieve the latter, a property of *Emotion Half-Time* is introduced.

In the example used in [1], a scenario of a number of agents protesting outside a guarded property is simulated. Emotional Contagion occurs in a manner that causes an agent surrounded by angry neighbors to become angry as well. The protesters are categorized as: (a) *bellicose*, who are highly susceptible to anger and have a long anger *half-life*, (b) *peaceable*, who are less susceptible to anger and have a shorter anger *half-life*, and (c) *instigators*, who have the ability to become angry without cause, and act as emotional triggers in the scenario. The occurrence of a calming effect caused when an agent interacts with an authority figure (in this scenario, a soldier who protects the gate to the property) is also introduced. The calming effect is represented by lowering the *Emotion Half Time* value. However, in this case, the calming effect is not based merely on EC, but is rather described as the guard talking to the protesters, in a pacification attempt. To control the emotion propagation rate, an additional *probability* parameter is introduced by the authors, with values depending on the simulation scenario.

3. FORMAL MODELLING OF EMOTIONAL AGENTS WITH CONTAGION

3.1 Emotional X-Machines

In order to model emotional agents with contagion, we use a formal method, namely X-machines. X-machines is a variation of state-based machines extended with a memory structure, defined as an n-tuple of values that make the machine more compact as compared to memory-less state machines. In addition, transition between states are not triggered by inputs only but functions which accept inputs and memory values and produce an output and new memory values. This model has the advantage of making the refinement from model to code much easier. We have integrated artificial emotions plug-ins withing X-machines in two different occasions [9], [8]. For the purposes of this work, we used a variation of the first [9].

An *emotions X-machine* is defined as:

$$^{e}\mathcal{X} = (\Sigma,\ \Gamma,\ Q,\ M,\ \Phi,\ F,\ q_0,\ m_0,\ E)$$

where:

- Σ and Γ are the input and output alphabets, respectively.
- Q is the finite set of states.
- M is the (possibly) infinite set called memory.
- Φ is a set of partial functions φ; each such function maps an input and a memory value to an output and

a possibly different memory value, $\varphi : \Sigma \times M \times E \to \Gamma \times M$.

- F is the next state partial function, $F : Q \times \Phi \to 2^Q$
- q_0 and m_0 are the initial state and initial memory respectively.
- E is an emotional structure formalisation.

Consequently, E is also defined as:

$$E = (E_v,\ P,\ C,\ {}^e\Phi,\ e_0)$$

where:

- $E_v = (\epsilon_1, \ldots, \epsilon_n)$ is a vector containing emotion identifiers.
- P is a personality trait type.
- C is a contagion model type.
- ${}^e\Phi : E \times P \times C \times M \times \Sigma \to E_v$ is the set of emotions revision functions ${}^e\varphi$, that given an emotions structure $e \in E_v$, a contagion model $c \in C$, a personality trait $p \in P$ and a memory tuple $m \in M$ returns a new emotion structure $e' \in E_v$.
- e_0 is the initial vector of emotion identifiers representing the initial emotional state.

The model has a computational state as well an emotional state represented by the vector of emotional identifiers. An input may trigger the emotions revision function thus changing the emotional state and the memory. The same input may then trigger the transition function which will return a new state. It is therefore possible that the emotions vector may change the computation path by allowing bias towards one or the other function. Since the aim of this paper is to focus on contagion, we will not present the fully fledged formal definition of an evacuating agent, but only the state transition diagram which is depicted in Fig. 1.

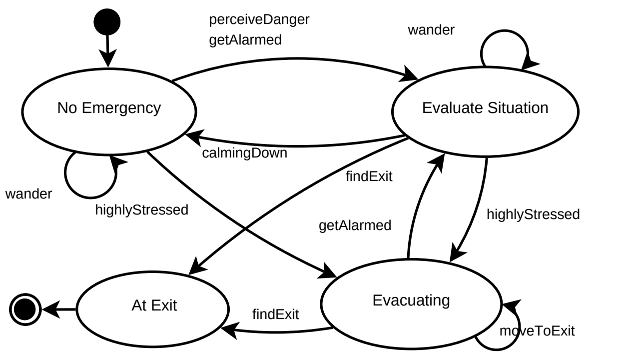


Figure 1: State Transition Diagram for the Evacuating Agents

3.2 Contagion Models

The emotion revision function updates a given emotion's strength according to the influence of emotional contagion on an agent, upon interaction with neighboring agents, and its individual personality traits. For the purposes of this paper, three different models for emotional contagion were formally described and implemented in conjunction with the emotion revision function.

Models C1a and C1b
Our first models were based on ASCRIBE [3], where we introduced *contagion strength* s_{iQj} that determines the strength by which agent j influences on some state Q agent i. In our case, since we only deal with a single emotion strength value, s_{ij} is defined as:

$$s_{ij} = expressiveness_j * channel_{ij} * openness_i \quad (1)$$

$$channel_{ij} = 1 - \frac{dis(Pos_i, Pos_j)}{dis_{infl}} \quad (2)$$

where $expressiveness_j$ and $openness_i$ are agent specific values representing personal characteristics that determine the strength by which an agent j expresses its emotional state and the degree by which agent i is influenced by other persons emotions, respectively. The factor $channel_{ij}$ determines the *channel strength*, i.e. 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:

$$s_i = \sum_{j \in AG} s_{ij} \quad (3)$$

where AG is the set of agents currently located in the area of influence of agent i.

The emotion update δE_i, for model C1a, is given by

$$\delta E_i = s_i * \left(\sum_{j \in AG} ((w_{ij}/w_i) * E_j) - E_i \right) \quad (4)$$

where w_{ij} is given by

$$w_{ij} = expressiveness_j * channel_{ij} \quad (5)$$

$$w_i = \sum_{j \in AG} w_{ij} \quad (6)$$

A different version of the emotion update equation, which corresponds to model C1b is given by equation 7. The difference of the two models concerns how emotions of other agents in the area influence, affect the agent's emotions:

$$\delta E_i = \sum_{j \in AG} (s_{ij}/s_i) * (E_i - E_j) \quad (7)$$

Model C2
The second model was based on [6] in the sense that contagion is affected by an empathy value (i.e. how susceptible someone is on changing an emotional state), which in turn affects the emotional strength (emotion value E). The personality trait of an agent is defined by the Big Five [5] basic factors that affect personality:
$P = (O, C, E, A, N)$
where O, C, E, A, N are values for the different personality factors (Openness, Consciousness, Extraversion, Agreeableness, Neurotism).

The Empathy parameter θ may be given by the following equation:

$$\theta = x * O + y * C + z * E + u * A + v * N \quad (8)$$

where x, y, z, u, v are values randomly selected from normal distributions as indicators that are defined by researching samples of human agents. For example, in [6], the empathy values for males and females are determined as follows:

$$\theta_{male} = x*0.34 + y*0.17 + z*0.13 + u*0.3 + v*0.02 \quad (9)$$

$$\theta_{female} = x*0.15+y*0.01+z*0.09+u*0.24+v*0.16 \quad (10)$$

The agent can be either infected or susceptible. Each time a susceptible agent interacts with an infected one, the former may receive a randomly selected (from a log-normal distribution) "emotion" dosage d. When the cumulative dose D that an agent has received exceeds a randomly selected (from a log-normal distribution) threshold L, the agent becomes infected. Overall, it is considered that the emotion strength increases in a susceptible agent, when it comes within a predefined distance from an infected one. It is also considered that it decreases with time at a predefined rate, for as long as the susceptible agent does not interact with an infected one. More specifically, the value for the emotion strength of a susceptible agent i that interacts with an agent j out of N infected neighbors is updated as follows:

$$E_i' = E_i + f(\theta, D + \sum_j^N d_j) \quad (11)$$

At all times when a susceptible agent has no infected agents in range, the emotion strength is updated with time t as follows:

$$E_i' = E_i - f(t, s_i) \quad (12)$$

In figure 2, a schematic representation of our emotion strength revision is demonstrated as an example. Susceptible agent $Susc_1$ receives from infected agents Inf_1, Inf_2 and Inf_3 emotion dosages d_1, d_2 and d_3 respectively. Infected agent Inf_4 does not pass any emotion to $Susc_1$, since it is out of range, which is depicted by a dashed line. Assuming that before this interaction $Susc_1$ had a cumulative emotion dosage D, the total of $D + d_1 + d_2 + d_3$ will be the factor that will eventually update its emotion strength.

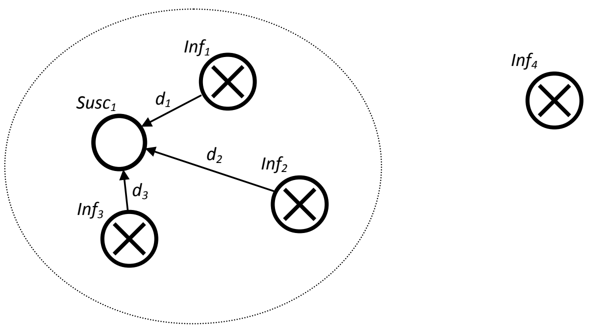


Figure 2: A schematic representation of Model C2

In the worked described we considered emotion dosages in each step t to be determined by:

$$D(t)_i = \theta_i * (\sum_{j \in AG_{inf}} d_j) \quad (13)$$

where d_j is the random dosage from the infected agent j that is a random distribution of its current emotion value. Since we would like to consider a history of five previous agent interactions, the cumulative dosage $\Sigma D(t)$ is the sum of the past 4 dosages and the current one:

$$\Sigma D(t) = \sum_{p=t-4}^{p=t-1} D(p)_i + \theta_i * (\sum_{j \in AG_{inf}} d_j) \quad (14)$$

As stated previously, if the current cumulative dosage, exceeds a threshold, then it becomes the δE_i of the agent's emotion update process for the current step:

$$\delta E_i = \Sigma D(t), \; if \, \Sigma D(t) > L \quad (15)$$

Model C3

The third model was inspired by [14], where, upon interaction of agent i with agent j, the agent with the lower emotion strength value inherits the corresponding value from the one with the higher of the two. However, if one of the two is an authority figure (which can be assumed to have lower emotion strength for emotions like fear, due to training) it is considered that the inverse occurs, and therefore the non-authority figure inherits the emotion strength value of the authority figure, thus describing a "calming effect".

In this case, the emotion strength update can be described as follows:

$$E_i' = \begin{cases} E_j, & \text{if agent } j \text{ is an authority figure,} \\ E_j, & \text{if } E_i < E_j \text{ and } j \text{ is not an authority figure.} \end{cases} \quad (16)$$

4. CASE STUDY

To examine the effect that different EC models have on the outcome of a specific scenario, we implemented models C1, C2 and C3 in a agent simulation platform (Fig. 3). For the latter model the emotion strength is only updated based on the agent's personality traits. The specifics of the selected case study follow.

4.1 Emergency Evacuation of an Open Square

In the particular scenario, we assume an open square area with four exits. Within this area, a number of people are wandering around, when at a certain point some incident occurs in the center of the square and becomes a source of alarm for the crowd. This incident is of a short duration, hence it directly affects only the emotional state of people that are in close range when it occurs. People are assumed to have a localised knowledge of the incident, defined by a danger perception radius. They are similarly assumed to be *infected* by their neighbours' emotions only when they are in close proximity, defined by a speculated vision distance. Considering that there is no constant and continuous source of alarm, the only way that emotion spreads to people that do not directly see (or hear) the event when it occurs, is through contagion. In our scenario we consider that people do not pass verbal information about the event. Some authority figures are also present, who are assumed to have a calming effect on any individuals they interact with.

People that are close to the event when it occurs, are assumed to instantly reach the highest level of emotion, which in our case is considered to be hysteria. This means that their primary goal is to reach the closest exit. Evacuating is also assumed to be the goal of people that are feeling anything more than alarm. People that have yet to experience any level of emotion are considered to have no purpose of

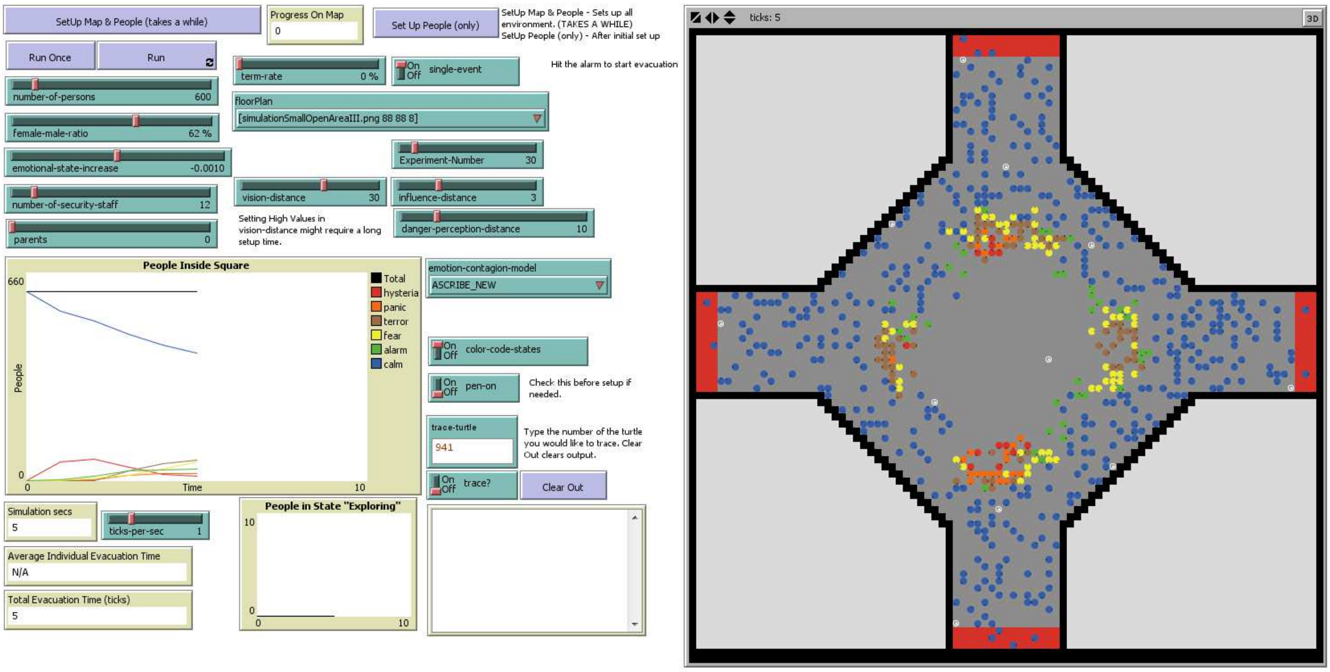


Figure 3: Simulation Environment In NetLogo, showing experiment parameters and the simulation area.

evacuating, and are thus still wandering around, whereas people that are feeling alarmed assumed to be in an alert state, considering that they have realized that something is wrong, but this is not enough to make them want to exit the area.

The calming effect of the security officers is considered to be a decrease in the level of emotion that the person interacting with them is experiencing. The level of emotion is also considered to be gradually decreasing with time in all three models, to resemble a situation that - lacking a constant threat source - people could be assumed to feel more at ease as time goes by.

Obviously, the location of the incident inside the square affects the generated evacuation patterns, in the sense that a) it can affect the size of the initial "panicking" crowd, and b) if such an incident occurs near an exit, then people in stress would evacuate sooner, thus emotion contagion would not affect the emotion levels of the rest of the crowd.

4.2 Implementation Platform

It is broadly accepted that the quest for a general approach towards a MAS-based simulation is unattainable. It goes without saying that the inclusion of emotions (with a plethora of different theories for emotions) makes the quest more complex. During the last decade we have invested considerable time to develop executable models for various types of agent architectures and multi-agent systems by building libraries to facilitate those. NetLogo was simple enough to demonstrate the validity of formal models we created and visualise properties that we could not formally verify due to state explosion of model checking. Alternative implementation frameworks were considered at some stages and reviews were published. Certainly, more sophisticated frameworks are now available but we believed that they do not offer many additional features for the purpose we would like to employ them.

The NetLogo ${}^{e}\mathcal{X}$ model was implemented using a well tested meta-interpreter developed in [10], and that allows direct execution of ${}^{e}\mathcal{X}$-machines, that are defined using a simple domain specific language. The meta-interpreter respects the ${}^{e}\mathcal{X}$-machines semantics and allows each agent to perform a single transition in each execution step to ensure fairness in the simulation. Given the meta-interpreter and the excellent rapid prototyping facilities of Netlogo, arriving to a simulation environment such as the one depicted in figure 3 is an easy task.

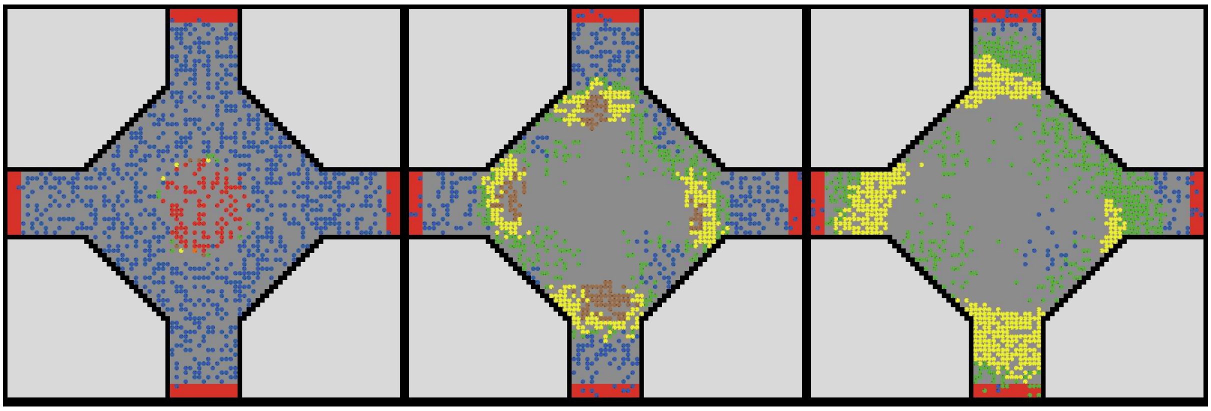
4.3 Simulation Implementation

As stated there are two types of agents in the scenario: people that wander around in the square and security officers. The former have a behaviour that is affected by emotions and described by the $e^{\mathcal{X}}$-machine presented in Figure 1. The later are stationary agents positioned in evenly distributed places in the square.

The emotion value of both agents ranges between 0 and 1, with the value 0 corresponding to the emotional state "calm" and the value 1 to "hysteria". Security officers have a fixed value of 0.1 that does not change during simulation, i.e. they are not affected by emotion contagion or the presence of danger due to their training. Additionally, officers have an expressiveness value of 1, since they are considered authoritative figures and thus, their influence on the crowd is the maximum possible.

People on the other hand do have a varying emotion value and their emotion levels at the next time point in the simulation (*tick* in NetLogo terms) is given by the following equation:

$$E_i = \delta E_{decay_i} + EC(Model)_i \qquad (17)$$



(a) 1 Tick (b) 10 Ticks (c) 20 Ticks

Figure 4: Simulation Visualization of Model C1 with 1000 people in the square and no security officers. Images depict the evolution of the square evacuation N ticks after the incident occurs.

where the first factor is the emotion decay, common to all models, that is given by the equation 18, in which $person\_trait_i$ is a value selected from a normal distribution with mean equal to 1 and the standard deviation to 0.1 ($N(1, 0.1^2)$) and E_{dec} a constant set to the value 0.001 in the experiments conducted.

$$\delta E_{decay_i} = person\_trait_i * E_{dec} \quad (18)$$

The second factor of equation 17 is determined by agent percepts and emotion contagion. There are the following cases: *the agent perceives danger*, *the agent "sees" a security officer* and finally *the agent emotion level is determined only by emotion contagion*.

When the agent directly perceives danger its emotion level is set immediately to 0.9 without considering any other aspects of the agent (expressiveness, person trait, contagion, etc). This assumption is supported by the fact that agents are exposed to an event that causes panic, thus $EC(M)_i = 0.9$, where M is one of the models.

When the agent perceives an officer that has an emotion value $E_{officer}$, depending on the contagion model used, the $EC(M)_i$ is updated according to the model used:

- In $C1$ models, the agent reduces its emotion level based on the difference of its current emotion level and that of the officers given the current openness of the agent, thus:
  $EC(C1)_i = E_i - (E_i - E_{officer}) * openness_i$
- In the $C2$ model, a similar situation takes place, i.e. the difference in the emotions of the two interacting agents is multiplied by θ_i, thus:
  $EC(C2)_i = E_i - (E_i - E_{officer}) * \theta_i$
- In the $C3$ model the agent adopts the emotion level of the officer it "sees" according to the original model, thus:
  $EC(C3)_i = E_{officer}$

In all other cases, the emotion levels is determined by the previous emotion-level and the δE_i given in section 3.2. For both the $C1$ and $C2$ models, EC_i is given by

$$EC(C1 \mid C2)_i = E_i + \delta E_i \quad (19)$$

For the $C3$ model, the value taken is maximum value of emotion in the area of influence, i.e.

$$EC(C3)_i = max\{E_i, E_j\} \; j \in AG_{inf} \quad (20)$$

Obviously a number of other parameters where set, as for instance range of the area the initial event (danger) can be perceived, normal distributions of various agent parameters such as expressiveness, θ related values, etc.

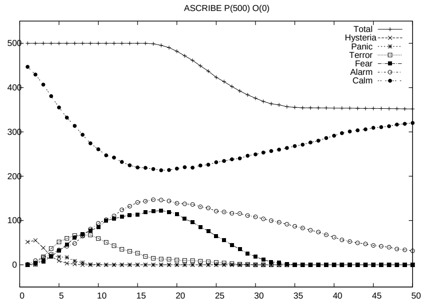
The simulation was implemented in NetLogo (Fig 3), with an user interface that allows to modify various simulation parameters, such as contagion models, number of people present in the square, the number of security officers, etc. and provides both visual output and real-time recording of the evolution of the experiment.

Figure 4 depicts different snapshots of the simulation area in different time points (ticks). The experiment depicted concerns simulation under the emotion model C1 and in Fig. 4(a) one can observe the initial perception of the incident by the crowd, as a circle of agents in hysteria (red color) around the place where the event occurs, with all other agents in state calm (blue colour). Fig. 4(b) depicts the evacuation state 10 ticks after the event, with a number of people in high emotional state moving towards the exits (agent colours yellow and brown) clearing the center area where the event occurred. Finally, 20 ticks in the simulation, some agents repopulate the center of the area since there is no "visible" danger and thus the area can be consider once again safe.

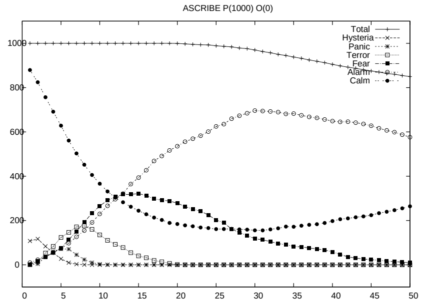
Probably the most interesting aspect to observe in similar situations is the evolution of the people's emotion levels under the presence of contagion. In the simulation implemented people are color coded according to their emotional state (calm, panic, hysteria, etc.) so as to provide both a view of their emotion level, but also the spatial distribution in the area of people with different emotional states.

5. RESULTS

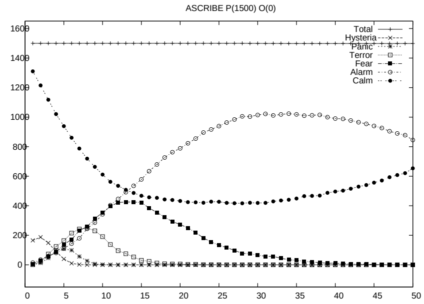
We ran numerous experiments with different values for a number of parameters. Since one of our goals was to demonstrate the different outcomes that might occur when the EC model varies, we executed a set of simulation runs by al-



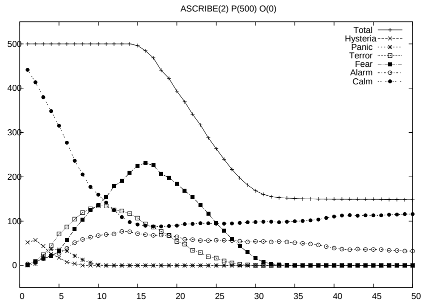
(a) Model C1a (500, 0)



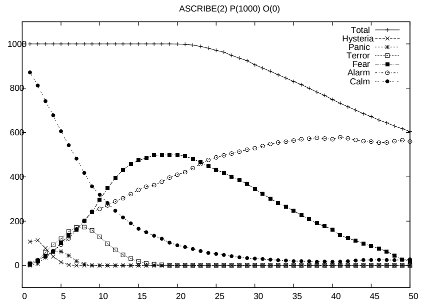
(b) Model C1a (1000, 0)



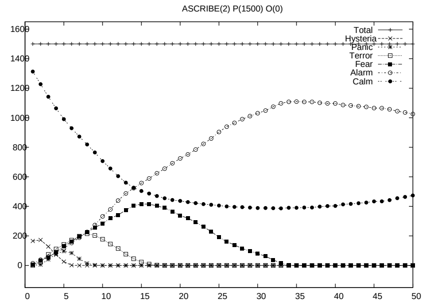
(c) Model C1a (1500, 0)



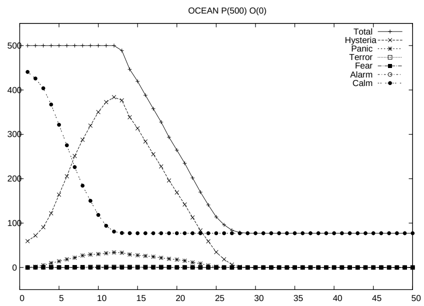
(d) Model C1b (500, 0)



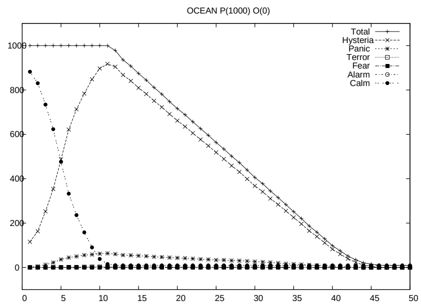
(e) Model C1b (1000, 0)



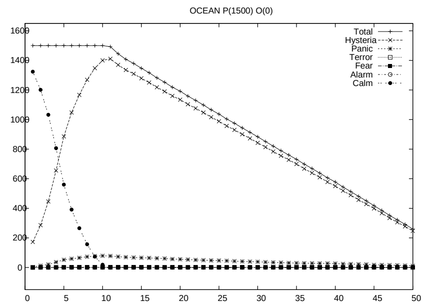
(f) Model C1b) (1500, 0)



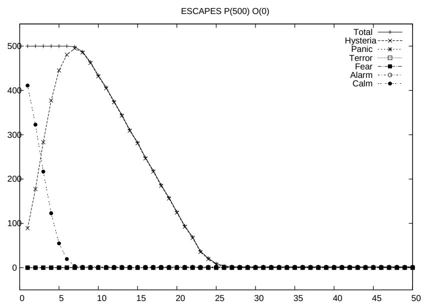
(g) Model C2 (500, 0)



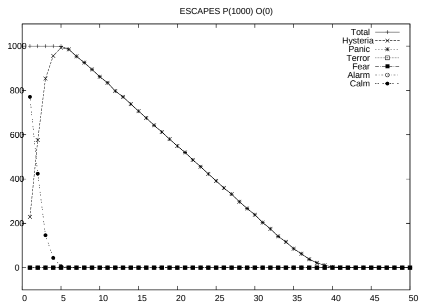
(h) Model C2 (1000, 0)



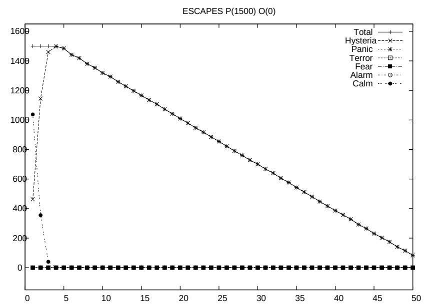
(i) Model C2 (1500, 0)



(j) Model C3 (500, 0)



(k) Model C3 (1000, 0)

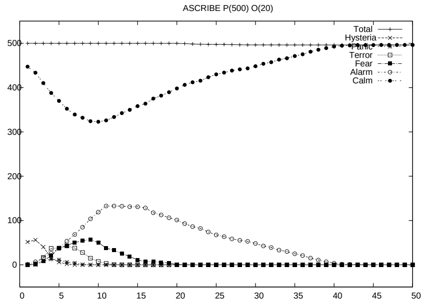


(l) Model C3 (1500, 0)

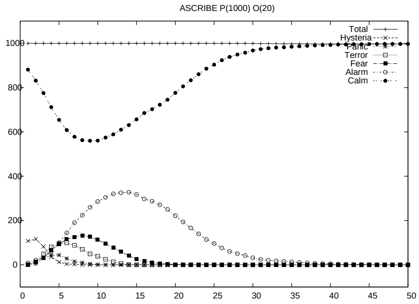
Figure 5: Simulation results with no security officers present in the area, 50 ticks after alarm

ternating the implemented model and keeping all remaining parameters unchanged.

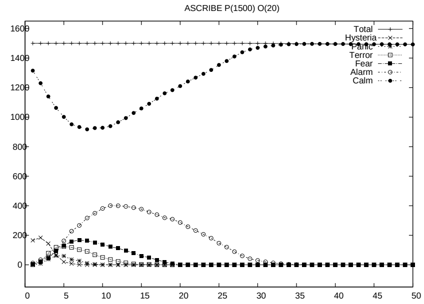
Our initial set initiated with no officers present, and with 500, 1000 or 1500 people respectively. The corresponding plots are shown in Figure 5. We observed that both versions of Model $C1$ appear to maintain a similar behaviour, that is that the plotted curves for each emotion level maintain a similar form. Few people reach the level of Hysteria, and a peak is observed for the levels of Fear and Alarm. For models $C2$ and $C3$ however, this is not the case. In fact, we see a very sharp increase on the number of agents with



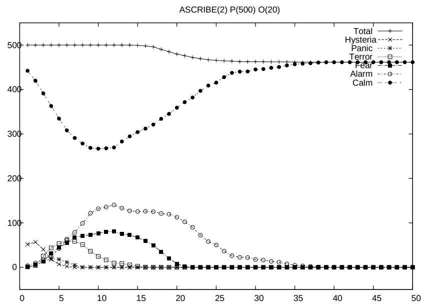
(a) Model C1a (500, 20)



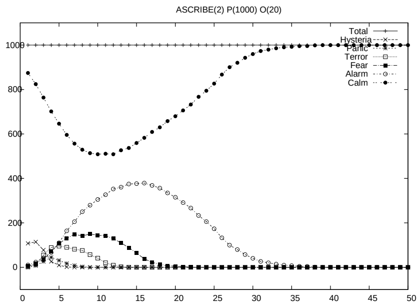
(b) Model C1a (1000, 20)



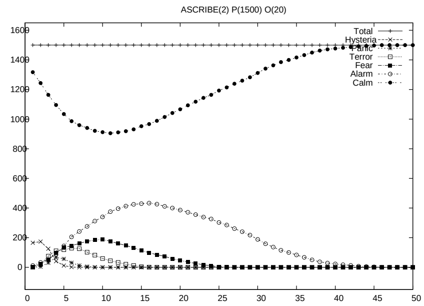
(c) Model C1a (1500, 20)



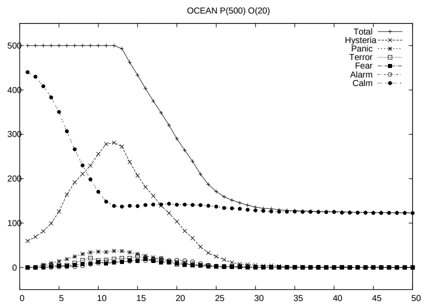
(d) Model C1b (500, 20)



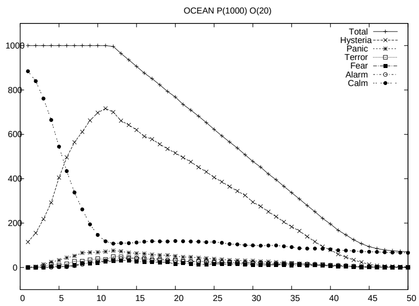
(e) Model C1b (1000, 20)



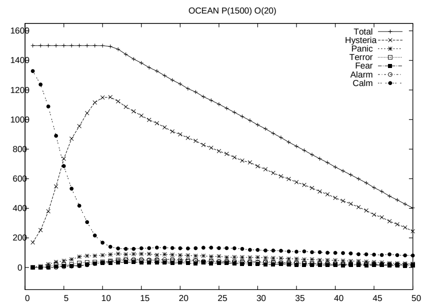
(f) Model C1b (1500, 20)



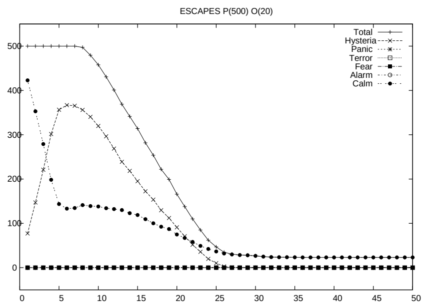
(g) Model C2 (500, 20)



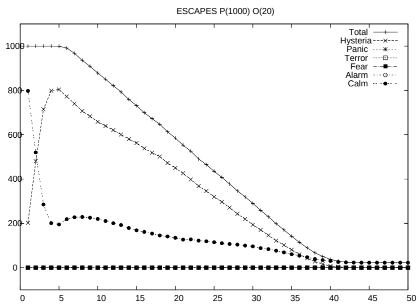
(h) Model C2 (1000, 20)



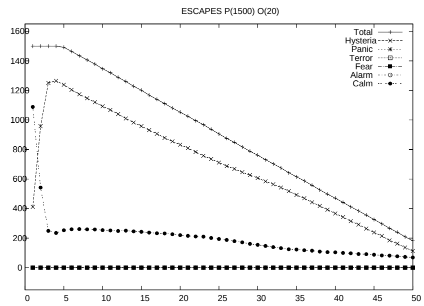
(i) Model C2 (1500, 20)



(j) Model C3 (500, 20)



(k) Model C3 (1000, 20)



(l) Model C3 (1500, 20)

Figure 6: Simulation results with security officers, 50 ticks after alarm

Hysteria, with a peak that indicates that the vast majority of the agents in the area experience Hysteria at some point.

A direct result of this is that in $C1a$ and $C1b$ models, there is an evident tendency for the emotion level to spread and converge to a "mean" value. Thus, in large crowds (case of 1500 agents), panic drops after a while, leading to no evacuation whatsoever. This is expected and reflects the fact that the initial incident happens once (e.g. explosion). The behaviour is different if the incident continuous to exist after the initial alarm (e.g. fire).

On the contrary, after 50 ticks, in model $C2$ few agents remain in the area, and in model $C3$ almost all agents have evacuated. In general, there is a strong indication of shorter evacuation times for models $C2$ and $C3$, even with smaller crowds.

The noticeable differences between $C1a$ and $C1b$ appear to concern cases with fewer agents (i.e. 500 and 1000 agents) rather than larger crowds. Indeed, in model $C1b$, and for smaller crowds, the "fear curve" appears to be is more steep while the corresponding emotion "infects" at its maximum point almost half the population. Additionally, the "calm curve" in smaller crowds indicates that a very small percentage of agents that have left the calm state ever go back at being calm. This is not the case however for $C1a$, where more agents are returned to the state of calm with time. Regarding the percentage of agents that reach fear, the peak is quite lower than this of $C1b$. Interestingly, these differences are not evident in larger crowds.

We also conducted a set of experiments under the presence of officers in the simulation area. Similar runs were executed, with 500, 1000 and 1500 people respectively, whereas the number of officers was constant and set at 20. The corresponding plots are depicted in Figure 6. The observed differences in behaviour among the different models remained consistent. However, in the cases of models $C1a$ and $C1b$, there were very few agents that evacuated the area. This indicates that in the specific model, the panic spread was quickly and effectively contained, and especially in cases with large crowds, only a short time was needed for agents to return to calmness. On the other hand, in models $C2$ and $C3$, the effect of the officers appears to be significantly less important. There is a minimal decrease on the number of evacuees after 50 ticks, however, once again, the vast majority of the agents do leave the area, and the predominant emotion observed is Hysteria.

In experiments with the presence of officers, any observed differences between models $C1a$ and $C1b$ for smaller crowds are minimal, indicating that

6. CONCLUSIONS

Emotion Contagion is a well-known phenomenon, which has been recently gaining the attention of researchers that attempt to model it, and study its effects on situations of paramount interest, such as emergency evacuations. However, few models have been currently proposed. We have selected three of the more sophisticated ones, based upon which we introduced four different versions into formally modelled Emotional X-Machines. The resultant models were subsequently implemented in NetLogo, and visual simulations were produced. By refining our models in a way that all parameters were kept constant, except for the factor of emotional contagion, we were able to reach some initial conclusions on its effects on emotion spread in emergency situations.

After running various experiments, some interesting indications have emerged. Different contagion models appear to have a significantly strong impact on emotion spread, evacuation times and total number of evacuees. By the additional inclusion of security officers in our experiments, we observed that their presence seem to influence the outcome by adding to the containment of panic spread. However, this effect is not observed with the same intensity in all implemented models. Lacking real experimental data, there is currently no way of validating how close the models are to real-world scenarios. However, our contribution focuses on verifying that emotions and EC is an important factor in realistic simulation of such scenarios.

An interesting venue for future research would be to simulate scenarios that have occurred in reality, and for which visual data are available. This would assist in further evaluating the models, and determining possible ways to further improve them.

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