Giving Emotional Contagion Ability to Virtual Agents in Crowds

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Abstract. Recent advances in crowd simulation models attempt to recreate realistic human behaviour by introducing psychological phenomena in virtual agents. In this direction, psychology studies on personality traits, emotions and emotional contagion attempt to cope with emerging behaviours such as panic spreading and fight picking. This work depicts a way to introduce a model of emotional contagion in the scope of crowd simulation. Challenges regarding the applicability of an emotional contagion model considering great number (hundreds or thousands) of agents are depicted. Results shows that the dynamics of space and time creates emergent behaviour in crowd agents that are tuned with emotional contagion phenomena and crowd behaviour as described by literature.

1 Introduction

Models of crowd simulation have been used for applications in films and video games, architecture, security and contingency plans. Films and video games usually present crowds for visual effects, generating great number of actors for epic war tales or cheering crowd background. Applications for architecture and contingency plans are usually meant to measure the security of a building project in terms of evacuation routes, corridor and stairway width, doors and passages that might result in bottlenecks. But, whatever the application is, it is always desirable to have the most realistic simulation possible, to obtain reliable results that support serious decision making.

In the pursuit of more realistic observable behaviour in virtual crowd agents, recent works on the field have incorporated psychological theory in their models. Personality traits models such as the OCEAN, also known as Big-Five [1], and Eysenck's PEN [2] has been incorporated in virtual crowds [3] [4] [5] to create heterogeneity of agent's behaviours in the crowds. Since personality can influence emotional characteristics in people, later work [6] incorporated emotion models, such as the OCC, and also emotional contagion models to allow emotions to spread in crowds.

Following the tendency of modelling characteristics of human psychology, such as personality traits, emotions and emotional contagion, and being aware that emotions can influence decision making process, the objective of this work is to incorporate a model designed to cope with emotional contagion in crowd simulation context.

2 Related Work

The pioneering work in crowd simulation is Reynolds' flocks, herds and schools [7]. Based on a particle approach, all agents have attraction (velocity matching) and repulsion forces (collision avoidance), combined with a goal force (flock centering). Other works proposed different steering methods such as Helbing's empirical Social Force Model [8], Musse and Thallman [9] approach based on group hierarchy and the HiDAC model of Pelechano [10] which aims to controlling individual agents in high density crowds. Researchers on crowd simulation have integrated models derived from psychology studies, such as OCEAN [3] and Eysenck's PEN [5]. The objective is to promote heterogeneity of agents by adjusting steering parameters according to individual personality traits. Later, emotions and emotional contagion models are introduced [6] [4], allowing agents to change behaviour and respond to other agents' actions as the simulation evolves. Durupinar [6], applies a contagion model derived form spreading of diseases proposed by Doods & Watts [11].

The work proposed by Tsai et al. [12] performs a comparison of Bosse [13] model with Durupinar model [14] (which used the same contagion model as in Durupinar [6]) and shows slightly better performance of the first over the later, according to the metrics and scenarios tested by Tsai et al. The authors suggests that the primary cause of the statistically significantly worse performance found with the epidemiological/social contagion model of Durupinar [14] is in the mechanism of contagion itself, which is probabilistic and uses a binary representation of the effect, which means that the contagion will either take place, or not, depending on a given probability threshold. The opposite would be a contagion that occurs in a constant gradual manner, depending on contagion strength and emotional levels apprised, as in in the work of Bosse et. al [13]. The main difference of this work with the work of Durupinar [6] is the emotional contagion model adopted.

In our work we use BioCrowds [22], a collision free navigation method for agents animation. In addition, we proposed to use the model proposed by Bosse et. al [24]. The goal if this method is to cope with contagion of one unspecified emotion in agents of a group. The variables involved in this model are listed in Table 1 and must be in the range $[0, 1]$.

Mathematically, Bosse and colleagues defines the emotion of an agent as a value q in the range $[0, 1]$, that represents the intensity of an unspecified emotion in a given instant. Suppose A is an agent in group G, being G defined as the set $G = \{A_1, A_2, ..., A_{N-1}\}$, the dynamic of A's emotion level is given by the

Table 1: Variables to be considered on the emotional contagion process

Variable	Purpose
q_j	Represents instantaneous emotion level of agent j.
ε_S	Represents the S agents expressiveness.
δ_R	Represents R agents emotional susceptibility.
α_{SR}	Represents the influence S has over R, notice that α_{RS} can be different from α_{SR}.
η_j	Bias to determine the models tendency to amplify or absorb emotions on agent j.
β_j	Bias tendency to amplify emotions upward or downward on agent j.
NI	Negative Impact of the amplification model.
PI	Positive Impact of the amplification model.

variation dq/dt occurred by contagion of emotions of other group members over agent A and computed by Equation 1.

$$dq_A/dt = \gamma_A \left[\eta_A \left(\beta_A PI + (1-\beta_A)\, NI\right) + (1-\eta_A)\, q_A^* - q_A\right]. \tag{1}$$

The resulting dq_A/dt is then clamped in the range $[0, 1]$. The channel strength γ_A is computed as in Equation 2:

$$\gamma_A = \sum_{S \in G \backslash \{A\}} \gamma_{SA}. \tag{2}$$

And γ_{SA} is the strength of emotional contagion from a sender agent S over agent A (the receiver of emotional contagion) and computed as $\gamma_{SA} = \varepsilon_S \alpha_{SA} \delta_A$. The overall group's emotional influence over agent A denoted by q_A^* is an weighted average of other agents' emotional state, and can be computed by:

$$q_A^* = \sum_{S \in G \backslash \{A\}} \omega_{SA} q_S. \tag{3}$$

And the weights ω_{SA} are proportional to the contagion channel, and are computed by:

$$\omega_{SA} = \frac{\varepsilon_S \alpha_{SA}}{\sum_{C \in G \backslash \{A\}} \varepsilon_C \alpha_{CA}}. \tag{4}$$

The amplification model, identified by the terms PI and NI in Equation 1, is designed to cope with emotional spirals [16][17], and is computed respectively as in equations: $PI = 1 - (1 - q_A^*)(1 - q_A)$ and $NI = q_A^* q_A$.

This summaries the formulation on Bosses work. The results published by the authors [24] confirm the ability of the model in simulating desired emotional behaviours, such as spirals. For such reasons, it was adopted to continue in the crowd simulation scenario.

3 Methodology of Proposed Model

The main challenge of adapting the model of Bosse et. al. [13] into BioCrowds [22] is that the original Bosse model copes with one group of agents. In crowds, there are several groups, as well as individuals not belonging to any group. And they all must be able to promote and suffer emotional contagion. Another challenge is to benefit from both models: navigation and emotional contagion. The model of emotion contagion carries emotion information and also promotes the ability for agents to spread this information to other agents. The model of crowd simulation carries spatio-temporal information, since agents are instantiated in a virtual environment, and navigate in this environment as a function of time. The variables used in this model are summarized in Table 2. To benefit from variation

Table 2: Variables of the extended model

Variable	**Purpose**
$q_{A_n}(t)$	is the instantaneous emotional level of agent A_n in time frame t.
ε_{A_n}	is the expressiveness of the agent A_n. It strengthen the contagion channel when A_n is the sender of emotion.
δ_{A_n}	Is the susceptibility of agent A_n. It strengthen the contagion channel when A_n is the receiver of emotion.
η_{A_n}	Is the bias that controls the amplification model and the absorption model in agent A_n, according to Equation 11.
β_{A_n}	Bias the positive impact (PI) and negative impact (NI) in the amplification model in A_n defined in Equation 11.
og_{A_n}	determines the attenuation in the emotion contagion channel promoted by that fact that A_n does not belong to the same group as the sender.
$\boldsymbol{x}_{A_n}(t)$	determines the position of agent A_n in instant t.
$\boldsymbol{g}_{A_n}$	Denote the direction pointing to agent's A_n goal.

of agents' positions, we propose the strength of contagion to be impacted with distance, since it might be harder to identify people's facial, gestural and vocal expressions with increasing distance. To accomplish this feature, we propose to replace the relationship (or attachment) measure between agents, denoted by α_{A_i,A_j}, for a function of the distance between agents $\{A_i, A_j\} \in C$, resulting in a new α_{A_i,A_j} which is not constant. As a result, the attachment between agents (α) vary in time, as agents move. The variation of contagion strength is one characteristic that differs this model from Bosse's model.

$$\alpha_{A_j A_i} = \begin{cases} min(1, 1/d) & d \leq p_{A_i} \\ 0 & d > p_{A_i} \end{cases}, \tag{5}$$

where d is the Euclidean distance between agents A_i and A_j. In order to profit from the group information already present in crowds, we propose a measure of outer group affinity, denoted by og_{A_n}. It measures the affinity of agent A_n to catch emotions from agents that does not belong to his/her group. So, α_{A_i,A_j}, considering group information, can be rewritten as in Equation 6.

$$\alpha'_{A_jA_i} = og_{A_i}\alpha_{A_jA_i}. \tag{6}$$

To cope with inter-group emotional contagion (since intra-group contagion is already contemplated by Bosse's model) we explore a property of the original model when the interaction is *dyadic*, i.e., interaction between exactly two agents. In this case, C equals the set $C = \{A_i, A_j\}$ with only two agents A_i and A_j. The contagion strength channel for agent A_i can be written as in Equation 7.

$$\gamma_R = \gamma_{A_i} = \sum_{A_j} \gamma_{A_jA_i}, \text{ when } A_i = R \text{ and } A_j = S. \tag{7}$$

And since A_j is the only agent in the sum, this results in Equation 8.

$$\gamma_{A_i} = \gamma_{A_jA_i} = \varepsilon_{A_j}\alpha'_{A_jA_i}\delta_{A_i}. \tag{8}$$

Also, the weights to compute q^*, denoted by ω_{SA} in Equation 3, for the dyadic particular case can be written as in Equation 9.

$$\omega_{SA} = \frac{\varepsilon_S\alpha_{SA}}{\sum_{C\in G\setminus\{A\}}\varepsilon_C\alpha_{CA}} = \omega_{A_jA_i} = \frac{\varepsilon_{A_j}\alpha'_{A_jA_i}}{\sum_{A_j}\varepsilon_{A_j}\alpha'_{A_jA_i}} = \frac{\varepsilon_{A_j}\alpha_{A_jA_i}}{\varepsilon_{A_j}\alpha_{A_jA_i}} = 1, \tag{9}$$

And the total influence of the group over agent A_i is given by q_{A_j} as in Equation 10.

$$q^*_{A_i} = \sum_{S\in G\setminus\{A_i\}} \omega_{SA_i}q_S = \sum_{A_j}\omega_{A_jA_i}q_{A_j} = q_{A_j}, \tag{10}$$

because all weights $\omega_{A_jA_i} = 1$ in the case of two agents in the group. The variation of emotional level dq/dt can now be computed by Equation 11.

$$dq_{A_i}/dt = \gamma_{A_i}\left[\eta_{A_i}\left(\beta_{A_i}PI + (1-\beta_{A_i})\,NI\right) + (1-\eta_{A_i})\,q_{A_j} - q_{A_i}\right], \tag{11}$$

where η_{A_i} and β_{A_i} are both parameters of agent A_i, $\gamma_{A_jA_i}$ is given by Equation 8, q_{A_i} and q_{A_j} are the current emotional level for agents A_i and A_j respectively. Also, the Positive Impact PI and the Negative Impact NI are computed by Equations 12 and 13 respectively, replacing $q^*_{A_i}$ for q_{A_j}, according to Equation 10.

$$PI = 1 - (1-q_{A_j})(1-q_{A_i}). \tag{12}$$

$$NI = q_{A_j}q_{A_i}. \tag{13}$$

The model must be able to manage more than one emotion, which we now denote as $e_m \in \{e_0, e_1, ..., e_{M-1}\}$, describing a scenario with M emotions. We can define one emotion profile, denoted by $E^{e_m}_{A_n}$ as in Equation 14.

$$E^{e_m}_{A_n} =< q^{e_m}_{A_n}, \varepsilon^{e_m}_{A_n}, \delta^{e_m}_{A_n}, \eta^{e_m}_{A_n}, \beta^{e_m}_{A_n}, og^{e_m}_{A_n}, \boldsymbol{g}^{e_m}_{A_n} > . \tag{14}$$

And the set of all emotion profiles in a scenario, denoted by E_{A_n} for agent A_n, can be written as follows: $E_{A_n} = \{E_{A_n}^{e_0}, E_{A_n}^{e_1}, ..., E_{A_n}^{e_{M-1}}\}$. Allowing us to define agent $A_n =< E_{A_n}, \boldsymbol{x}_{A_n}, p_{A_n}, \boldsymbol{g}_{A_n} >$. Finally, the current emotional state of agent A_n, denoted by ψ_{A_n}, can be defined as $\psi_{A_n} = e_m \implies q_{A_n}^{e_m} = max(q_{A_n}^{e_0}, q_{A_n}^{e_1}, ..., q_{A_n}^{e_{M-1}})$.

The emotional state ψ_{A_n} is the label of the emotion denoted by e_m which has higher emotional level $q_{A_n}^{e_m}$ than any other emotion in Ψ. So, the emotion that the agent actually responds to is the one pointed by ψ_{A_n} and evaluated each simulation iteration.

Notice that the parameter $\boldsymbol{g}_{A_n}$ seems redundant with the parameters $\boldsymbol{g}_{A_n}^{e_m}$ contained within each $E_{A_n}^{e_m} \in E_{A_n}$ (see Equation 14), but that is on purpose. The objective with apparent redundancy is to allow the agent to overwrite its original goal with the goal defined by its current emotional state ψ_{A_n}. This way, agents can change goals as they change emotional state. Also, goals associated to emotions are optional. If one particular emotion profile $E_{A_n}^{e_k}$ does not have a goal defined, whenever $\psi_{A_n} = e_k$ the original agent's goal $\boldsymbol{g}_{A_n}$ is used. The new variables used in the model for contagion in crowds are summarized in Table 2.

4 Simulations and Results

In all tested scenarios, there is always one agent A_0 generating emotional energy by means of upward spiral. To accomplish this, parameter $\eta_{A_0} = 0.5$ and $\beta_{A_0} = 1$. The objective is to observe how the emotional energy of A_0 will spread through the crowd. Also, it was decided that $\varepsilon_{A_i} = 0.5$ and $\delta_{A_i} = 0.5$ for all agents $A_i \in C$ where $i = [0..N-1]$. This choice makes both expressiveness and susceptibility of agents active, but not so strong, and not so weak. Finally, a control emotion is defined in all scenarios. Since this emotion is meant as control, it does not spread ($\varepsilon = 0$ and $\delta = 0$), and is set to $q_{initial} = 0.8$ working as a threshold. The emotion A_0 creates energy is represented in RED, and the emotion used as control is represented in $BLUE$.

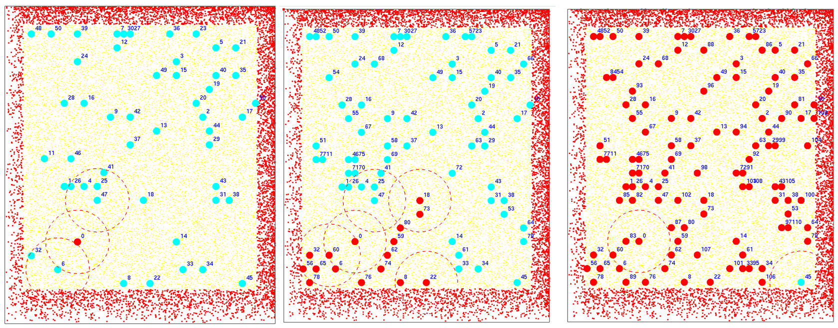
4.1 Standing Agents

Figure 1 shows the last simulation frame for standing crowd (agents not moving) with 50, 80 and 110 agents in scenarios with same dimensions. This way, agent density increases case-by-case. It is possible to notice that, as the number of agents increases, also more agents of the crowd change their initial status $BLUE$ to RED. This is because in low densities, agents' get isolated from each other, since the contagion is limited to the proxemics space (circles in the figure). Also, it is possible to observe that emotions converge to a monotonicity in concordance with Hatfield et. al findings [15].

4.2 Counterflow scenario

We propose varying the expressiveness (ε) and the susceptibility (δ) of the agents in group G by four manners: i) $\varepsilon_k = 0.1$ and $\delta_k = 0.9$, ii) $\varepsilon_k = 0.1$ and $\delta_k = 0.1$,

Fig. 1: Standing Agents experiment with 50, 80 and 110 agents in the crowd. In Figure 1(a) one can observe that no agents suffer contagion, because there is no agent inside A_0 interaction space. In Figure 1(b), some agents suffer contagion, but are isolated from the rest of the crowd as the circles representing interaction spaces shows. In Figure 1(c) only agent A_{45} does not suffer contagion because he/she is isolated from the rest of the crowd.



(a) 50 agents. (b) 80 agents (c) 110 agents

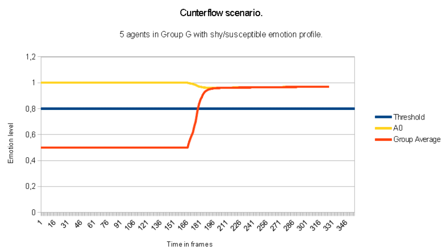
iii) $\varepsilon_k = 0.9$ and $\delta_k = 0.9$, and iv) $\varepsilon_k = 0.9$ and $\delta_k = 0.1$. And for every case, we want to measure the speed in which the emotion spreads in the crowd, by comparing the curves of emotions of some agents in the crowd.

In Figure 2 it is possible to observe curves of instantaneous emotional levels for the four proposed emotional profiles. In Figure 2(a), the emotion profile with agents shy (low expressiveness) and susceptible (high susceptibility) tends to achieve emotional equilibrium above threshold, meaning that the group tends to follow the influence of A_0, which is expected due to the fact that the susceptibility is set high. But Figures 2(b) and 2(c) suggests that susceptibility does not handle alone the impact of A_0 over the group and vice-versa. Actually, in both cases where group expressiveness is high the resistance of the group in changing emotional status rises. Supposedly, since group agent's expressiveness is high, giving agents have more strength to influence each other and A_0. This makes a sort of resistance (or inertia) of a group to be impacted with different emotion due to stronger contagion channel from one member of the group towards others. Other tests performed but not presented here also suggests that increasing the number of agents in the group the resistance to contagion also increases.

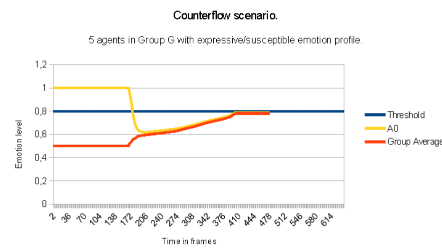
4.3 Same direction scenario

Finally, emotions are known to drive actions. Furthermore, emotion monotonicity is known to strengthen group bonds if they are positive emotions (such as joy) increasing feelings of acceptance in group members[20][21]. Knowing this, with the objective of measuring behavioural responses to emotions, we propose a scenario with agent A_0 generating RED energy ($\eta_{A_0} = 0.5$ and $\beta_{A_0} = 1$) , plus 110 agents (with $\eta_{A_k} = 0$) in a virtual environment of measures 17×20, and

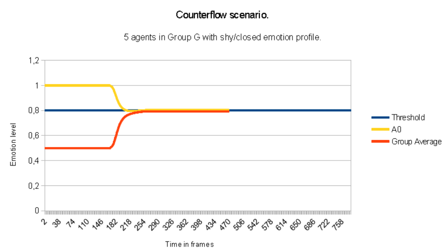
Fig. 2: Counterflow experiment with 5 agents in G, varying emotion contagion profile in agents of group G.



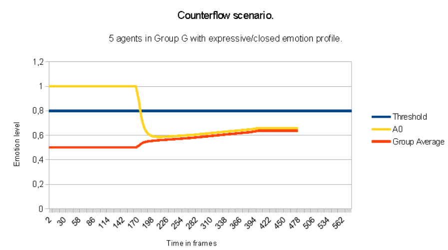
(a) Shy/Susceptible.



(b) Expressive/Susceptible.



(c) Shy/Closed.



(d) Expressive/Closed.

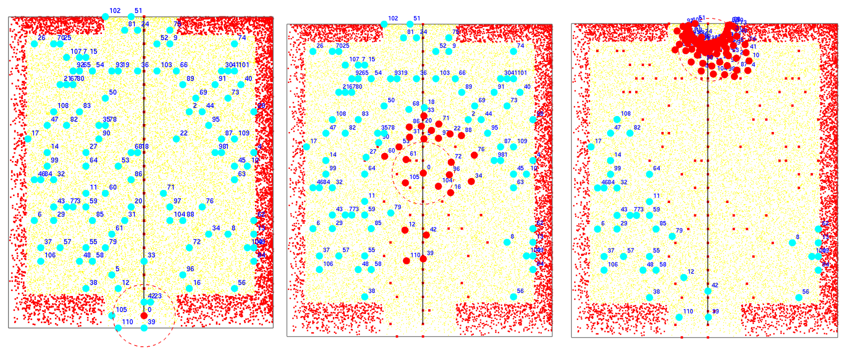
with two exits. In Figure 3 some frames of this scenario simulation are pictured. Figure 3(a) pictures the first frame of the simulation. There it is possible to observe agent A_0 in red in the bottom entrance of the scenario, with current goal pointing to the top exit since their emotional state is RED. The remaining agents have emotional state $\psi_{A_k} = BLUE$, indicated by their colour. No goals are associated to emotional state $BLUE$, so they remain with a goal to its current position by default. In Figure 3(c), the last frame of the simulation is pictured. Notice that many of the agents that turned RED were never inside agent's A_0 interaction space, but instead had suffered contagion indirectly from other agents, resulting in contagion beyond dyads[18].

In this experiment, it was possible to observe the emergence of a group leader. Although the scenario is configured with 111 individuals (110 plus A_0) with no group predefined, as agents interact and converge emotionally, they also approach each other as they converge to common objective.

5 Final Considerations

This work presented an emotional contagion model adapted for crowd simulation context. This gave origin to a new Bosse-Biocrowds extension which benefit from both models. To implement those features, the parameters had to be integrated into a new set of parameters, keeping information about agent movement and goal (BioCrowds) along with information related to agents' emotional profiles

Fig. 3: Agents walking in the same direction.



(a) First simulation frame (b) Frame 250. (c) Last simulation frame

(parameters derived from Bosse's model). We measured the impact of density of agents over contagion. It was observed that, due to a limitation in contagion distance imposed by our parameter setting, some groups of agents are isolated, and thus they do not suffer contagion from the leader agent. Furthermore, by associating goals with emotions, it was possible to observe agents changing their goals as they changed emotional state. As a result, agents that suffer emotional state changing due to contagion tend to converge to the same goal, getting physically close to each other. All this emergent behaviours are result of the emotional energy generated by one single agent, the position and trajectories of remaining agents in the crowd, and the time window agents keep inside each other interaction space. Results are in tune with theories by Le Bon [19] and Hatfield & Cacioppo [15].

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