An Agent-Based Model for the Interplay of Information and Emotion in Social Diffusion

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Abstract — **The spread of information and emotion within groups is studied in models of social diffusion. Evidence has been found that the emotional states of humans affect their information processing abilities, and hence, may affect the spread of information as well. This paper introduces an agent-based model that simulates the spread of information and emotion among a group of agents. The model takes both the influence of emotions upon the spread of information and the influence of information on emotions into account. The approach is exemplified by means of a case study in the domain of emergency evacuation.**

Keywords - computational modeling; agent modeling; group processes; emotion contagion

I. INTRODUCTION

Models of social diffusion focus on the process of change within groups. Examples of social diffusion models found in the area of social sciences are: the diffusion of innovations (see e.g. [18]), social movements such as political interests and parties (see e.g. [13]), and crowd behavior, as for instance seen in emergency evacuation (see e.g. [16]). Diffusion models have also been developed in the domain of multi-agent systems in order to study and simulate the behavior of groups of agents. Hereby, models for the spread of information as well as models for the spread of emotions in agent groups have been expressed (see e.g. [19] and [4], [5], [9], respectively).

In the literature, results have been reported that indicate that the emotional state of a person influences the information processing ability (see e.g. [3], [14]). Hence, the emotions that are spread in a group and experienced by the individuals can influence how information spreads and is perceived. These influences have not yet been modeled by means of computational models.

In this paper a model is proposed that formalizes and simulates the spread of different types of emotion and information in a group. The model uses a generalization of work on emotion contagion as reported in [4] and [5] as point of departure but extends this model by incorporating the aforementioned influence of emotions upon information spreading and perception, and the occurrence of emotions based upon the information received. Different types of information have hereby been distinguished which can vary on two dimensions, namely relevance and the positiveness of the information. In order to exemplify the approach, extensive simulation runs have been performed in a evacuation domain with scenarios that include varying characteristics of the agents.

The extension of the model is based on Frederickson's broaden-and-build theory [10], which states that positive emotions broaden people's mind-sets: the scopes of attention, cognition, action and the array of percepts, thoughts, and actions presently in mind are widened. The complementary narrowing hypothesis predicts the reverse pattern: negative emotions shrink people's thought-action repertoires. Support for the broaden and narrowing hypotheses can be found in [11]. The model presented here captures these dynamics between information and emotion. To illustrate, a message containing information about the location and spread of a fire can be expected to elicit fear. Feelings of fear will reinforce the focus of a person towards information relevant to the threat. Furthermore, numerous research studies have shown that information is able to affect emotions. For example, in many psychological experiments fear is elicited by imagery or text to study the process of fear itself or the internal or external signs of fear in humans, see [17]. Another area in psychological research studies fear appeal (persuasive messages that arouse fear) in which it is investigated if fear appeals can motivate behavior change across a variety of behaviors. See for example [20]. In [6] it is argued that the media can influence the perception of fear, via the type of information they spread. Moreover, studies of nonverbal behavior have showed results that emotions can be spread through nonverbal behavior [12]. One can conclude form these many viewpoints and disciplines that emotions, such as fear, can be spread through (non)verbal and textual communications and imagery.

The paper is organized as follows. In Section 2 the existing model of emotion contagion is explained. In Section 3 the current model for the interplay between emotion and information is introduced formally. Section 4 discusses extensive simulation results, followed by a mathematical analysis in Section 5. The paper is concluded with a discussion in Section 6.

II. AN AGENT-BASED DIFFUSION MODEL

This section introduces the basic agent-based social diffusion model used as a point of departure for this research. This model is a generalization of two existing agent-based emotion contagion models: the absorption model and amplification model (cf. [4], [5]). The model formalizes different aspects and types of social diffusion of mental states, such as absorption, amplification, expressiveness and openness for cognitive and affective (e.g., information and emotion) states, which are inspired by theories on contagion mechanisms. For instance, in [2] Barsade describes an informal model of emotion contagion in which the valence (positive or negative) of the emotion and the energy level with which the emotion is expressed characterize the diffusion.

The basic building block of the model is the definition of the contagion strength between individuals within a group. This contagion strength between agents B and A for any particular state S is defined as follows:

$$\gamma_{SBA} = \varepsilon_{SB} \cdot \alpha_{SBA} \cdot \delta_{SA}. \tag{1}$$

Here ε_{SB} is the personal characteristic *expressiveness* of the sender (agent B) for S, δ_{SA} the personal characteristic *openness* of the receiver (agent A) for S, and α_{SBA} the interaction characteristic *channel strength* for S from sender B to receiver A.

To calculate the level q_{SA} of an agent A for a specific state S the following calculations are performed. First, the overall contagion strength γ_{SA} from the group towards agent A is calculated:

$$\gamma_{SA} = \sum_{B \neq A} \gamma_{SBA} \tag{2}$$

This value is used to determine the weighed impact $q_{SA}*$ of all the other agents upon state S of agent A:

$$q_{SA}* = \sum_{B \neq A} \gamma_{SBA} \cdot q_{SB} / \gamma_{SA} \tag{3}$$

How much this external influence actually changes state S of the agent A is determined by two additional personal characteristics of the agent, namely the tendency η_{SA} to absorb or to amplify the level of a state and the bias β_{SA} towards positive or negative impact for the value of the state. The model to update the value of $q_{SA}(t)$ over time is then expressed as a combination of the absorption and amplification models. The result is a more general model of contagion for any state S:

$$q_{SA}(t + \Delta t) = q_{SA}(t) + \gamma_{SA} \cdot [\eta_{SA} \cdot [\beta_{SA} \cdot (1 - (1 - q_{SA}*(t)) \cdot (1 - q_{SA}(t))) + (1 - \beta_{SA}) \cdot q_{SA}*(t) \cdot q_{SA}(t)] + (1 - \eta_{SA}) \cdot q_{SA}*(t) - q_{SA}(t)]\, \Delta t \tag{4}$$

The new value of the state is calculated from the old value, plus the change of the value based upon the contagion. This change is defined as the multiplication of the contagion strength times a factor for the amplification of information plus a factor for the absorption of information. The absorption factor (after $1 - \eta_{SA}(t))$) simply takes the difference between the incoming contagion and the current level. The amplification factor (part of the equation multiplied by $\eta_{SA}(t)$) depends on the tendency of the agent towards more positive (part of equation multiplied by $\beta_{SA}(t)$) or negative (part of equation multiplied by $(1-\beta_{SA}(t))$) information. Table I summarizes the most important parameters and states within the model.

TABLE I. PARAMETERS AND STATES

q_{SA}	level for state S for agent A
ε_{SA}	extent to which agent A expresses state S
δ_{SA}	extent to which agent A is open to state S
η_{SA}	tendency of agent A to absorb or amplify state S
β_{SA}	positive or negative bias of agent A on state S
α_{SBA}	channel strenght for state S from sender B to receiver A
γ_{SBA}	contagion strength for S from sender B to receiver A

III. AN AGENT-BASED MODEL FOR THE INTERPLAY OF EMOTION AND INFORMATION DIFFUSION

The agent-based social diffusion model introduced in Section 2 applies to both emotion and information, but does not describe any interplay between diffusion of different states. For example, not only emotions of others, but also received information may affect emotions. On the other hand, strong emotions may affect personal characteristics for information diffusion such as openness and expressivity. To incorporate such interactions, the basic model is extended as follows:

1. To update q_{SA} for one state S, also the $q_{S'B}$ values for some other state S' may be taken into account.
2. Some of the personal characteristics for a state S may be determined dynamically depending on values $q_{S'B}$ for a certain other state S'.

A. *The Effect of Emotion upon Information*

To model the effect of emotions on information diffusion, below the personal characteristics δ_{SA}, η_{SA} and β_{SA} for an informational state S are not assumed constant, but are instead modeled in a dynamic manner, depending on emotions. As can be seen in the adopted model, multiple factors that influence diffusion of a state S have been distinguished. One can divide these into three different categories: state q_{SA}, personal characteristics ε_{SA}, δ_{SA}, η_{SA}, β_{SA} and interaction characteristic α_{BA}. One additional category is introduced here, namely informational state characteristics r_{SA} denoting how relevant, and p_{SA} denoting how positive an informational state S is for agent A. Examples of settings for an evacuation scenario can be found in Table II.

The intensity of the emotional state of a person will affect his ability to receive information, thereby possibly affecting individual agent characteristics. In this case the focus is on one type of emotion, namely fear. A high level of fear contributes to the levels of β_{SA}, η_{SA} and δ_{SA}. However, if fear is low, the value of the parameters should be dominated by their initial values that represent the personal characteristics of the agent instead. First the effect of fear upon the openness for an informational state S (characterized by a relevance r_{SA} and a positiveness p_{SA} for A) is expressed:

$$\delta_{SA}(t+\Delta t) = \delta_{SA}(t) + \mu \cdot (1/1+e^{-\sigma(q_{fear,A}(t) - \tau)}) \cdot [(1-(1-r_{SA})\, q_{fear,A}(t)) - \delta_{SA}(t)] \cdot \Delta t \tag{5}$$

TABLE II. TYPES OF INFORMATION

		positivity of information (p) [0-1]	
		0	1
relevance for survival (r) [0-1]	0	“The toilets are out of order”	“Local authorities have been informed”
	1	“All rear exits are obstructed”	“The front emergency exit is clear”

If $q_{fear,A}$ is lower than threshold τ (on the interval [0,1]), it will not contribute to the value of δ_{SA}. If $q_{fear,A}$ has a value above τ, the openness will depend on the relevance of the information: when the relevance is high, openness will increase, while if the relevance is low, openness will decrease. In all formulae, μ is an adaptation parameter. This proposed model corresponds to theories of emotions as frames for selective processing, as described in [10], [15]. A distinction between amplification values for different types of information is also made, depending on the emotional state fear. The dynamics for the characteristic $\eta_{SA}(t)$ that model the amplification or absorption of informational state S are described as follows:

$$\eta_{SA}(t+\Delta t) = \eta_{SA}(t\,) +$$

$$\mu\cdot(1/1+e^{-\sigma(q_{fear,A}(t)\,-\,\tau)})\cdot[r_{SA}\cdot(1-p_{SA})\cdot(q_{fear,A}(t) - \eta_{SA}(t))]\cdot\Delta t \quad (6)$$

The emotion of fear only has an influence when it is above the threshold. In that case the parameter only changes for relevant, non-positive information for which the parameter starts to move towards the value for the emotion of fear (meaning this type of information will be amplified). This property represents an interpretation of [7] on how emotion can result in selective processing of emotion-relevant information.

The bias of an agent is also influenced by its emotion, but in addition depends on the content of the information, which can be either positive or negative:

$$\beta_{SA}(t+\Delta t) = \beta_{SA}(t) +$$

$$\mu\cdot(1/1+e^{\sigma(\,q_{fear,A}(t)\;-\,\tau)})\cdot(1-q_{fear,A}(t)\,)\cdot((1-p_{SA})\text{-}\beta_{SA}(t))\cdot\Delta t \quad (7)$$

Again, the bias is not influenced by fear if its value is low. In case fear is high, p_{SA} has a high impact on the bias: a low positiveness inhibits the bias, while a high positiveness increases the bias. The agent thus has a bias towards negative information in case it has a high level of fear, which corresponds with the narrowing hypothesis from Frederickson’s broaden-and-build theory in [10].

B. The Effect of Information upon Emotion

After modeling the influence of emotion upon the information contagion in the previous section, the opposite direction is investigated in this section: emotions being influenced by information. This influence is modeled by altering the overall weighed impact of the contagion of the emotional state for fear. This is expressed as follows:

$$q_{Sfear,A}{}^{*} = \nu\cdot(\textstyle\sum_{B\neq A}\gamma_{SfearBA}\cdot q_{SfearB}/\gamma_{SfearA}) +$$

$$(1 - \nu)\cdot(\textstyle\sum_{Sinfo}\omega_{Sinfo,A}\cdot(1-p_{SinfoA})\cdot r_{SinfoA}\cdot q_{Sinfo,A}) \quad (8)$$

TABLE III. SIX SCENARIOS FOR DIFFUSION

Initial settings	emotion → info	emotion ↔ info
high fear levels	scenario 1	scenario 4
low fear levels	scenario 2	scenario 5
mixed fear levels	scenario 3	scenario 6

Here the influence depends on the impact from the emotion fear by others (the first factor, with weight *v*) in combination with the influence of the information present within the agent. In this case, information has an increasing effect on fear if it is relevant and non positive.

IV. SIMULATION RESULTS

In order to see whether the approach indeed exhibits the patterns that can be expected from literature, a case study has been conducted in the domain of emergency evacuation. The states as shown in Table II have been used in combination with the emotion of fear. Furthermore, the value of the channel strength α_{SBA} has been made dependent upon the distance:

$$\alpha_{SBA} = 1\text{-}(1/(1+e^{-4\sigma(d_{AB}\,\text{-}\tau)}) \quad (9)$$

This formula expresses that information is only heard in case the distance between agent A and B (d_{AB}) is below the distance threshold (τ).

The full model has been implemented in Matlab, and six different scenarios have been created (see Table III). In the scenarios, the emotional levels have been varied. The influence of information upon emotion has been left out of to allow the sole analysis of the influence of emotions upon information contagion. In each scenario, 4 agents have been used. The most important results are discussed below. Note that for all scenarios the value for the maximum distance ($\tau_{distance}$) has been set to 4, which represents that one can not hear or see a (non)verbal communication properly anymore when it is farther than the distance of 4. The threshold value for fear (τ_{fear}) is set to 0.5.

Scenario 1. First the general scenario and the interpretation of the values of the parameters is briefly described. In scenario 1, all agents initially are unaware of any danger and thus have low fear (q_{fear} = 0.1). Each agent has access to one out of four types of information (the four types can be made out of the four combinations of high/low relevance versus high/low positiveness of information). That is, agent 1 is located near the front exit and observes it is clear. Agent 2 just read on his phone that local authorities have been informed that there is smoke emerging from the building. Agent 3 just received word that all rear exits are blocked and agent 4 noticed that the toilets are out of order.

In order to clearly demonstrate the functioning of the model, all agents in this scenario have the same openness for all information and fear states (0.5) and they have the same amplification rate for fear (0.5). However, they differ in their amplification rate for information they receive. Agent 1, agent 3 and agent 4 all have relatively low amplification rates for all information states, while agent 2 is more expressive and has a strong amplification for all information states. In this scenario, agent 1 and agent 3 have a low bias for all types of information and are not easily primed by it.

Agent 2 has an average bias for all information states and agent 3 is easily primed by any kind of information. Details on the translation of this information into parameter settings can be found in Table IV. Fig. 1 shows the simulation results for scenario 1. The rows in the figure represent the various states: the first row shows values for the state fear (q_{fear}), row 2 represents the state of highly relevant, positive information (q_{HH}), row 3 of low relevant, positive information (q_{LH}), row 4 of highly relevant, negative information (q_{HL}) and row 5 shows values for the state of low relevant, negative information (q_{LL}). The columns represent the values for the state itself, and those for the openness, amplification, and bias for that state. Analysis of the simulation results leads to the following conclusions. First, the perceived fear remains constant for all agents, since this scenario does not capture the influence of information on emotion. The same holds for the individual values for openness, amplification and bias due to the fact that fear is so low that it does not influence the contagion of the information. Second, all types of information are quickly relayed to the other agents but after some time there is a slow decay of all types of information.

Scenario 2. The only difference between scenario 1 and 2 is the initial level of fear, which is low for all agents in scenario 1, but high for all agents in scenario 2. In the simulation of scenario 2, which can be found in Fig. 2, different patterns emerge. Although the fear is still a constant factor, the high state of fear of all agents affects their values of openness, amplification and bias for particular information states. For example, all values increase of the parameters for highly relevant, negative information. While the levels for positive information decrease or stay constant over time, the levels for negative information show a significant increase due to these changes of the parameters.

Scenario 3. In scenario 3 the agents all have different personalities and different levels of fear and information, represented by different personal settings for all parameters. Simulation results show that due to the personal settings, some agents develop higher fear levels over time than others. The Figure has been omitted for the sake of brevity, but can be found in the online appendix [1].

TABLE IV. PARAMETER SETTINGS FOR SCENARIO 1

Parameter	Qfear	QHH	QLH	QHL	QLL
A1 (init Q)	0.1	1	0.1	0.1	0.1
A2 (init Q)	0.1	0.1	1	0.1	0.1
A3 (init Q)	0.1	0.1	0.1	1	0.1
A4 (init Q)	0.1	0.1	0.1	0.1	1
A1 (δ)	0.5	0.5	0.5	0.5	0.5
A2 (δ)	0.5	0.5	0.5	0.5	0.5
A3 (δ)	0.5	0.5	0.5	0.5	0.5
A4 (δ)	0.5	0.5	0.5	0.5	0.5
A1 (η)	0.5	0.3	0.3	0.3	0.3
A2 (η)	0.5	0.8	0.8	0.8	0.8
A3 (η)	0.5	0.1	0.1	0.1	0.1
A4 (η)	0.5	0.2	0.2	0.2	0.2
A1 (β)	0.5	0.1	0.1	0.1	0.1
A2 (β)	0.5	0.5	0.5	0.5	0.5
A3 (β)	0.5	0.9	0.9	0.9	0.9
A4 (β)	0.5	0.3	0.3	0.3	0.3

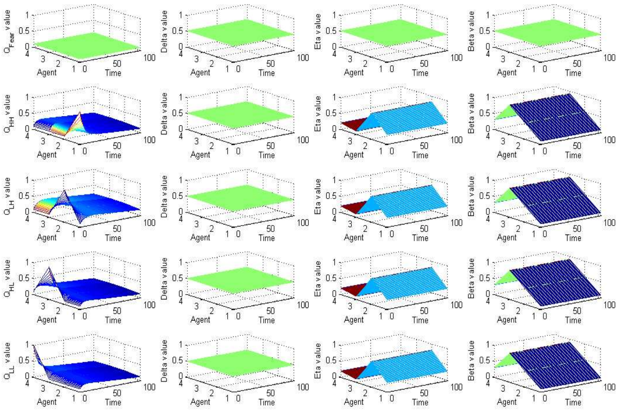

Figure 1. Simulation results of scenario 1

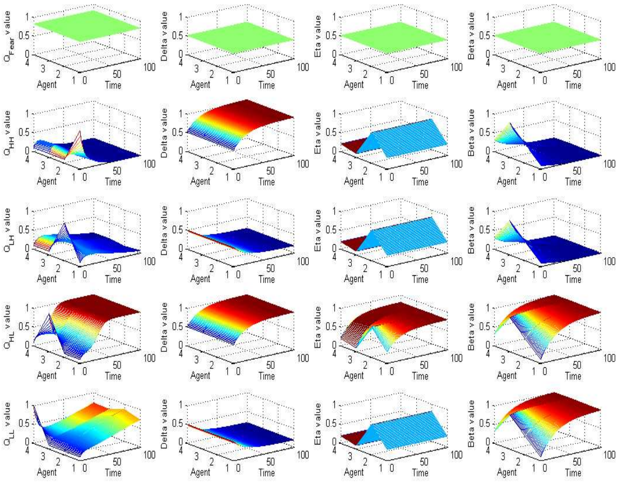

Figure 2. Simulation results of scenario 2

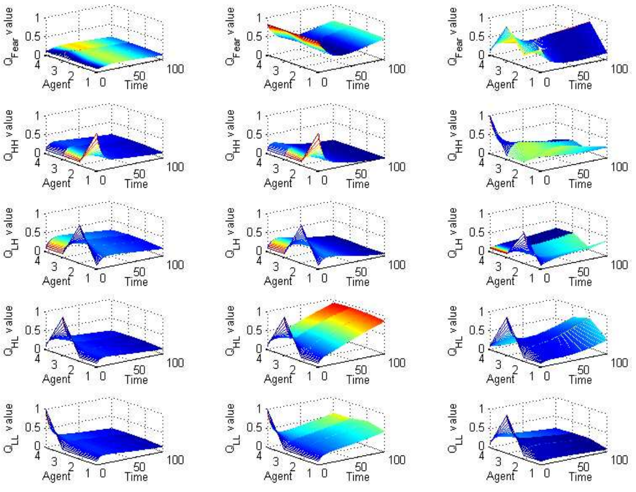

Figure 3. The Q-values for scenario 4 (leftmost column), 5 (center column), and 6 (rightmost column)

Scenario 4, 5, and 6. Simulations 4, 5 and 6 also take the influence of information upon the level of fear into account. In these scenarios, the value for the weights of the influence of the information state upon fear is set to 0.1, 0.7, 0.1, and 0.1 for q_{HH}, q_{LH}, q_{HL} and q_{LL} respectively. Furthermore, the value for ν has been set to 0.5. The initial settings of scenario 4, 5 and 6 are the same as scenario 1, 2 and 3, respectively. Since in the presented model the information directly affects the emotion (and not the openness, amplification and bias), only the q-values will be discussed. They are displayed in Fig. 3. For the scenario with low fear (scenario 4) the q_{fear} increases slightly for all agents due to availability of information. However, just as the information levels decay, the q_{fear} levels decrease again after some time. More interesting are the results from scenario 5 and 6. The results of the simulation of scenario 5 show that (i) negative information - in particular relevant negative information - spreads quickly through the network of agents, and (ii) the spread of q_{fear} first decreases and then spreads again causing an increase of this level for each of the agents. Note that the increase of q_{HL} and, in a somewhat lesser extent, q_{LL} cause the higher levels of q_{fear}. Looking at the simulation results of scenario 6 two main observations can be made. First, the q_{fear} of agent1, agent 3 and agent 4 does not increase as much as it did in scenario 5, due to the fact that they have lower values for negative information states than agent 2. Second, q_{fear} is reduced as the agents obtain more positive information and soon after increases when the obtained information has a less positive content.

V. MATHEMATICAL ANALYSIS

In this section it is analyzed which are equilibria values that occur. In particular it is focused on the characteristics in the model and the fear state.

A. *Analysis of $\delta_{Sinfo\ A}(t)$, $\beta_{Sinfo\ A}(t)$ and $\eta_{Sinfo\ A}(t)$*

The openness $\delta_{Sinfo,A}$ is described in differential equation format by

$$d\,\delta_{Sinfo,A}(t)/\,dt \;=\; \mu_{\delta_{Sinfo,A}}\,(1/1+e^{-\sigma(q_{fear,A}(t)\,-\,\tau)})\cdot$$
$$[(1-(1-r_{Sinfo\ A})\ q_{fear,A}(t)) - \delta_{Sinfo\ A}(t)]$$

It is assumed that $\mu_{\delta_{Sinfo,A}} > 0$. First of all, it follows that when $q_{fear,A} < \tau$, then always $d\delta_{Sinfo,A}(t)/\,dt = 0$, so for these cases any value for $\delta_{Sinfo,A}$ is an equilibrium. Next, assuming $q_{fear,A} \geq \tau$, it holds

$\delta_{Sinfo,A}$ is in equilibrium iff
$[(1-(1-r_{Sinfo\ A})\ q_{fear,A}) - \delta_{Sinfo\ A}(t)] = 0$

$\delta_{Sinfo,A}$ is strictly increasing iff
$[(1-(1-r_{Sinfo\ A})\ q_{fear,A}) - \delta_{Sinfo\ A}(t)] > 0$

$\delta_{Sinfo,A}$ is strictly decreasing iff
$[(1-(1-r_{Sinfo\ A})\ q_{fear,A}) - \delta_{Sinfo\ A}(t)] < 0$

From this the following equilibrium values can be determined (see also Table V, upper part):

$q_{fear,A} < \tau$ and any value for $\delta_{Sinfo,A}$ or
$q_{fear,A} \geq \tau$ and $\delta_{Sinfo,A} = 1-(1-r_{Sinfo\ A})\ q_{fear,A}$

For example, $q_{fear,A} = 1 \Rightarrow \delta_{Sinfo\ A}(t) = r_{Sinfo\ A}$ and $r_{Sinfo\ A} = 1$ and $q_{fear,A} \geq \tau \Rightarrow \delta_{Sinfo\ A} = 1$. The following monotonicity conditions hold for $q_{fear,A}(t) \geq \tau$

$\delta_{Sinfo\ A}(t)$ is strictly increasing iff
$\delta_{Sinfo\ A}(t) < 1-(1-r_{Sinfo\ A})\ q_{fear,A}(t)$

$\delta_{Sinfo\ A}(t)$ is strictly decreasing iff
$\delta_{Sinfo\ A}(t) > 1-(1-r_{Sinfo\ A})\ q_{fear,A}(t)$

These conditions show that $\delta_{Sinfo\ A}(t)$ is attracted by the value $1-(1-r_{Sinfo\ A})\ q_{fear,A}(t)$, so when $q_{fear,A}(t)$ is stable, this value is a stable equilibrium for $\delta_{Sinfo\ A}(t)$. Similarly the equilibrium values of the characteristics $\beta_{Sinfo,A}$ and $\eta_{Sinfo,A}$ can be determined as shown in Table V. Moreover, as above it can be shown that β_{SinfoA} is attracted by the value $1-p_{SinfoA}$, and $\eta_{Sinfo\ A}(t)$ is attracted by the value $q_{fear,A}(t)$, so they both are stable.

B. *Analysis of $q_{Sfear,A}(t)$*

The fear state is described by

$$dq_{SfearA}(t)/\,dt = \gamma_A\cdot[\eta_{SfearA}\cdot(\beta_{SfearA}\cdot(1-(1-q_{SfearA}{}^*)\cdot(1-q_{SfearA}))\ +$$
$$(1-\beta_{SfearA})\cdot q_{SfearA}{}^*\cdot q_{SfearA})\ +$$
$$(1-\eta_{SfearA})\cdot q_{SfearA}{}^* - q_{SfearA}]$$

Then the equilibrium equations becomes:

$$\eta_{SfearA}\cdot(\beta_{SfearA}\cdot(1-(1-q_{SfearA}{}^*)\cdot(1-q_{SfearA}))\ +$$
$$(1-\beta_{SfearA})\cdot q_{SfearA}{}^*\cdot q_{SfearA}) + (1-\eta_{SfearA})\cdot q_{SfearA}{}^* \;=\; q_{SfearA}$$

In general the equation is too complex to be solved symbolically, but for some cases it can be solved; see Table V (lower part).

C. *Special case $\eta_{SfearA} = 1$ and $\beta_{SfearA} = 1$*

This case concerns an amplifying agent for fear with an increasing orientation. For this case the analysis shows that there is a strong tendency for q_{SfearA} to reach value 1. It will only not reach 1 if there are extreme circumstances that there is full absence of negative group impact: none of the other group members transfer any bad information or fear (see Table V).

TABLE V. EQUILIBRIUM VALUES. UPPER: VALUES FOR $Q_{fear,A}$. LOWER: VALUES FOR $\delta_{Sinfo\ A}$, $B_{Sinfo\ A}$, η_{Sinfo}

	$q_{fear,A} = 0$	$0 < q_{SfearA} < 1$	$q_{fear,A} = 1$
$\eta_{SfearA}=1\ \ \beta_{SfearA}=1$	any value < 1 for q_{SfearA} iff there is full absence of negative group impact		$q_{fear,A} = 1$
$\eta_{SfearA}=1\ \ \beta_{SfearA}=0$	$q_{fear,A} = 0$	any value > 0 for q_{SfearA} iff there is full presence of negative group impact	
$\eta_{SfearA} = 0$	$q_{fear,A} = 0$, and there is full absence of negative group impact	$q_{SfearA}{}^* = q_{SfearA}$	$q_{fear,A} = 1$, and there is full presence of negative group impact

	$q_{fear,A} = 1$	$\tau \leq q_{SfearA} < 1$	$q_{SfearA} < \tau$
$\delta_{Sinfo\ A}$	$\delta_{Sinfo,A} = r_{Sinfo\ A}$	$\delta_{Sinfo,A} = 1-(1-r_{Sinfo\ A})\ q_{fear,A}$	any value for $\delta_{Sinfo,A}$
$\beta_{Sinfo\ A}$	any value for $\beta_{Sinfo\ A}$	$\beta_{Sinfo\ A} = 1-p_{Sinfo\ A}$	any value for $\beta_{Sinfo\ A}$
$\eta_{Sinfo\ A}$	$r_{Sinfo\ A} > 0$ and $p_{Sinfo\ A} < 1$ and $\eta_{Sinfo\ A} = q_{fear,A}$	any value for $\eta_{Sinfo\ A}$	

D. Special case $\eta_{SfearA} = 1$ and $\beta_{SfearA} = 0$

This case concerns an amplifying agent for fear with a decreasing orientation. For this case the analysis shows that there is a strong tendency for q_{SfearA} to reach value 0. It will only not reach 0 if there are extreme circumstances in the sense that there is full presence of negative group impact: all other group members do transfer bad information and fear. See Table V.

E. Special case $\eta_{SfearA} = 0$

This case concerns an absorbing agent for fear. For this case the analysis shows that there is a strong tendency for q_{SfearA} to reach some value between 0 and 1. It will only reach 0 or 1 if there are extreme circumstances that not any of the other group members does transfer any bad information or fear, or if all of them transfer both in a maximal sense. The value reached between 0 and 1 is some form of average of the values of the other group members.

F. Equilibria for q_{SfearA}

The equilibrium equation: $q_{SfearA}* = q_{SfearA}$. For the cases $q_{SfearA}* = q_{SfearA} = 0$ and $q_{SfearA}* = q_{SfearA} = 1$ the terms of the double summation for $q_{SfearA}*$ can be handled as above, thus providing the conditions as depicted in Table V.

VI. DISCUSSION AND CONCLUSION

In this paper, a model has been presented for social diffusion which incorporates the effect of emotions upon the spreading of information as well as the effect of information upon emotions. This work has been inspired by a number of theories and observations as found in literature (cf. [2], [6], [7], [10], [15], [20]). The model focuses on emotion contagion, which has been shown to occur in many cases varying from emotions in small groups to panicking crowds (cf. [2]). Previous emotion contagion models that focus on groups have been used as a point of departure (cf. [4], [5], [9]). The model has been evaluated by a case study in the domain of emergency evacuations, and was shown to exhibit the patterns that could be expected based upon the literature. The mathematical analysis of the model has shown the equilibria of the model. An agent-based approach was used that differs from the approach of the computational models from social science named above ([18], [13], [16]), which model the complex spread of innovations as diffusion that is asymmetric in time, irreversible, and nondeterministic.

As part of future work it will be considered to model how mood can affect (systematic) information processing, for example in case of a depression. In [8] such mechanisms are discussed. Other ideas for future work consist of extending the current model for multiple emotions affecting each other and information as well and vice versa.

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REFERENCES

[1] Appendix A http://www.cs.vu.nl/~mhoogen/social-diffusion/AppendixA.pdf

[2] Barsade, S.G.: The ripple effect: Emotional contagion and its influence on group behavior. Administrative Science Quarterly, 47(4), 2002, 644-675.

[3] Bodenhausen, G.V., Sheppard, L., & Kramer, G.: Negative affect and social judgment: The differential impact of anger and sadness. *European Journal of Social Psychology, 24,* 1994, 45-62.

[4] Bosse, T., Duell, R., Memon, Z.A., Treur, J., Wal, C.N. van der.: A Multi-agent Model for Mutual Absorption of Emotions. In: Otamendi, J., et al. (eds.) Proceedings of the 23rd European Conference on Modelling and Simulation, ECMS'2009, 2009, pp. 212-218.

[5] Bosse, T., Duell, R., Memon, Z.A., Treur, J., and Wal, C.N. van der, A Multi-Agent Model for Emotion Contagion Spirals Integrated within a Supporting Ambient Agent Model. In: Yang, J.-J. et al. (eds.), *Proceedings of PRIMA'09*. Lecture Notes in Artificial Intelligence, vol. 5925. Springer Verlag, 2009, pp. 48–67.

[6] Boulahanis, J., Heltsley, M. Perceived Fears: The Reporting Patterns of Juvenile Homicide in Chicago Newspapers *Criminal Justice Policy Review,* 15(132), 2004.

[7] Chen, E., Lewin, M., & Craske, M. Effects of state anxiety on selective processing of threatening information. *Cognition and Emotion, 10*, 1996, pp. 225-240.

[8] Côté, S. Reconciling the feelings-as-information and hedonic contingency models of how mood influences systematic information processing. *J. of Applied Soc. Psychology,* 35(8), 2005, pp.1656–1679.

[9] Duell, R., Memon, Z.A., Treur, J., Wal, C.N. van der.: An Ambient Agent Model for Group Emotion Support. In: Proc. of the Third Intern. Conf. on Affective Computing and Intelligent Interaction, ACII'09. IEEE Computer Society Press, 2009, pp. 550--557.

[10] Frederickson, B.L. The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. American Psychologist, 56, 2001, pp. 218-226.

[11] Frederickson, B.L., and Branigan, C. Positive Emotions broaden the scope of attention and thought-action repertoires. Cognition and Emotion. 19(3), 2005, pp. 313-332.

[12] Friedman, H., Riggio, R. Effect of Individual Differences in Nonverbal Expressiveness on Transmission of Emotion. Journal of Nonverbal Behavior, 6(2), 1981.

[13] Hedström, Peter, Rickard Sandell and Charlotta Stern.: Mesolevel Networks and the Diffusion of Social Movements: The Case of the Swedish Social Democratic Party, American J. of Sociology, 106 (1), 2000, pp. 145-172.

[14] Nabi, R.L. Anger, fear, uncertainty, and attitudes: A test of the cognitive-functional model. *Communication Monographs*, *69*, 2002, pp. 204-216.

[15] Nabi, R.L. Exploring the framing effects of emotion: Do discrete emotions differentiallly influence information accessibility, information seeking, and policy preference? Communication Research, 30 (224), 2003, pp. 224-247.

[16] Pan, X., Han, C., Dauber, K., Law,K.: Human and social behaviour in computational modeling and analysis of egress. Automation in Construction 15(4), 2006, pp. 448-461.

[17] Patrick, C., Cuthbert, B., and Lang, P. Emotion in the Criminal Psychopath: Fear Image Processing. *Journal of Abnormal Psychology*, 103(3), 1994, pp. 523-534.

[18] Rogers, E.: Diffusion of Innovations. Free Press, New York, 1983.

[19] Soui, M, Ghédira, K, Hammadi, S. Proposal of Personalized Multimodal Information Diffusion System, Proc. of the 1st Intern. Conf. on ICT & Accessibility, ICTA'2007, 2007, pp. 219-224.

[20] Witte, K. Allen, M. A Meta-Analysis of Fear Appeals: Implications for Effective Public Health Campaigns. Health Educ Behav, 27(5), 2000, pp. 591-615.