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 the influence of emotions upon the spread of information into account as well as the influence of information on emotions. The approach is exemplified by means of a case study in the domain of emergency evacuation.

1. 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. [20]), social movements such as political interests and parties (see e.g. [14]), and crowd behavior, as for instance seen in emergency evacuation (see e.g. [18]). 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, both models for the spread of information as well as for the spread of emotions in agent groups have been expressed (see e.g. [22] and [4], [5], [9], respectively).

In the literature, results have been reported that indicate an influence of the emotional state of a person upon the information processing ability (see e.g. [3], [16]). Hence, the emotions that are spread in the group and experienced by the individuals can influence how information spreads in the group and how information is perceived by the individuals. 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], [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 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.

2. An Agent-Based Diffusion Model

In this section the basic agent-based social diffusion model used as a point of departure for this research is introduced. 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:

$$\gamma_{SBA} = \varepsilon_{SB} \cdot \alpha_{SBA} \cdot \delta_{SA} \quad (1)$$

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:

$$\gamma_{SA} = \sum_{B \neq A} \gamma_{SBA} \quad (2)$$

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

$$q_{SA}^* = \sum_{B \neq A} \gamma_{SBA} \cdot q_{SB} / \gamma_{SA} \quad (3)$$

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. This is where the existing absorption and amplification models of emotion contagion merge and are generalized into one more general model of contagion for any state S that both covers absorption and amplification The model to update the value of $q_{SA}(t)$ over time is then expressed as follows:

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

Here the new value of the state is 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 1 summarizes the most important parameters and states within the model.

Table 1. 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

3. 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'

3.1. Theoretical Background

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 theory of Frederickson hints at the effects of emotion on the ability of a person to 'be open' to information. Whereas the models presented in [4], [5] focus on emotion diffusion, 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. On the one hand, 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 [24], [19]. 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 [25]. In [6] it is argued that the media can influence the perception of fear, via the type of information they spread. The authors posit that over-reporting certain types of homicide may affect perceptions of fear; as well, focusing on atypical elements of the crime may further perpetuate false perceptions about offenders and victims. 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.

3.2. 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 2.

Table 2: Example 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"

The intensity of the emotional state of a person will affect his ability to receive information, thereby possibly affecting the value of the individual agent characteristics. In this case the focus is on one type of emotion, namely fear. A high level of emotion contributes to the levels of β_{SA}, η_{SA} and δ_{SA}. However, if fear is low, it should not contribute to the value of the parameters, but they 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:

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

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], [17]. A distinction between amplification values for different types of information is also made, depending on the emotional state fear. The dynamics for the characteristic $\eta_{SA}(t)$ modeling 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:

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

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].

3.3. The Effect of Information upon Emotion

Besides 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:

$$q_{Sfear,A}{}^{*} = \nu\cdot(\textstyle\sum_{B\neq A}\gamma_{SfearBA}\cdot q_{SfearB}/\gamma_{SfearA}) + (1-\nu)\cdot(\textstyle\sum_{Sinfo}\ \omega_{Sinfo,A}\,.(1-p_{SinfoA})\cdot r_{SinfoA}\cdot q_{Sinfo,A}) \quad (8)$$

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.

4. 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. Hereby, the states as shown in Table 2 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:

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

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 3). In the scenarios, the emotional levels have been varied. The influence of information upon emotion has been left out of some scenario 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 4 agents away and the threshold value for fear (τ_{FEAR}) to 0.5.

Table 3. 6 scenarios for diffusion

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

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. 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 cell 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 states and fear and they have the same amplification rate for fear. 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. The translation of this information into actual parameter setting is shown in Table 4. Figure 1 shows the simulation results for scenario 1. The figure should be read as follows: 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}).

Table 4. 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

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 Figure 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. Note that the Figure has been omitted for the sake of brevity, but can be found in Appendix A [1].

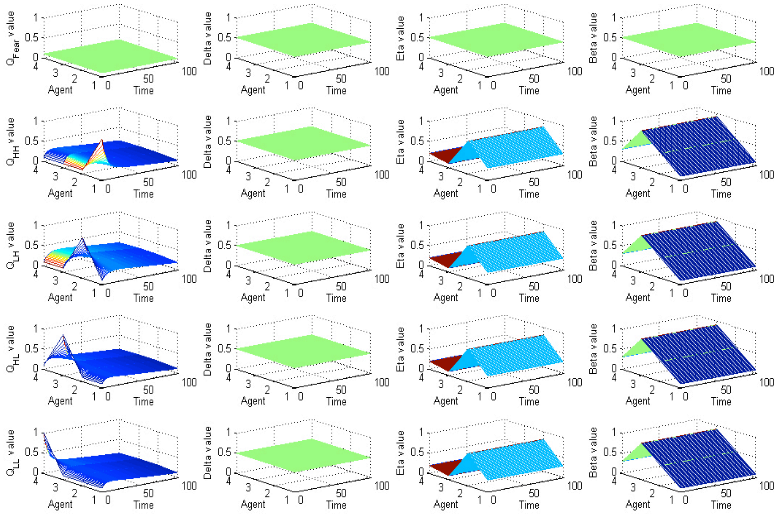

Figure 1. Simulation results of scenario 1

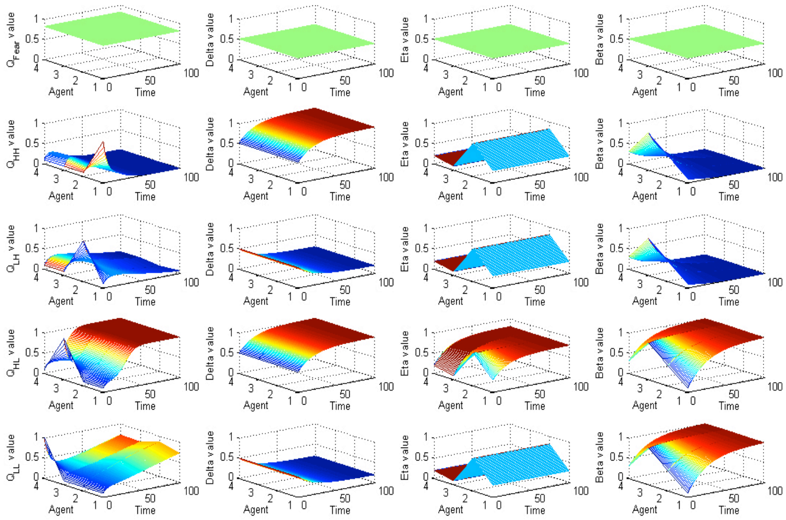

Figure 2. Simulation results of scenario 2

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 v 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), the q-values will only be discussed. They are displayed in Figure 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, agent3 and agent4 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 agent1 and agent2. 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.

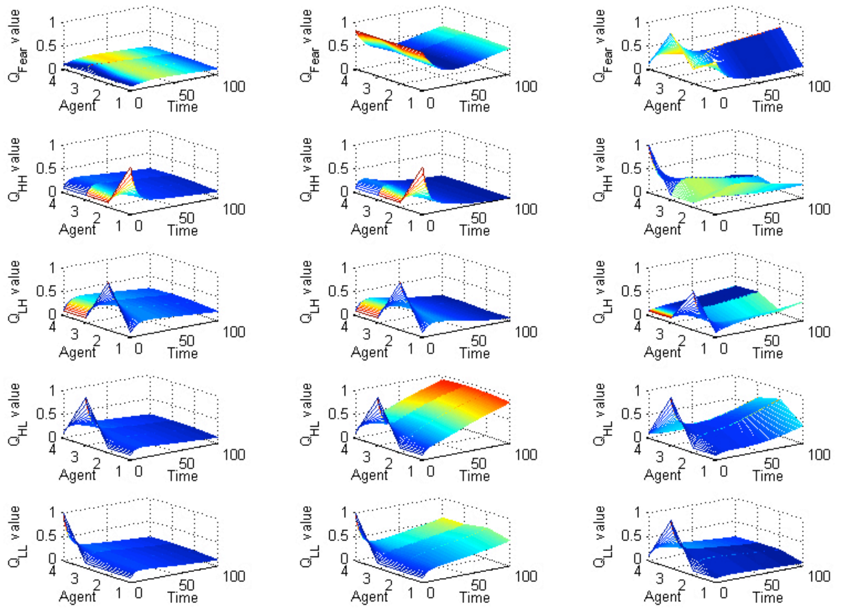

Figure 3. The Q-values for scenario 4 (leftmost column), 5 (center column), and 6 (rightmost column)

5. 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.

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 5):

- $q_{fear,A} < \tau$ 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 5. 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.

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 6.

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 below 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 2). The equilibrium equation $1-(1-q_{SfearA}{*})\cdot(1-q_{SfearA}) = q_{SfearA}$ is equivalent to

$1 - q_{SfearA} = (1-q_{SfearA}^*) \cdot (1- q_{SfearA})$

which is equivalent to $q_{SfearA} = 1$ or $q_{SfearA}^* = 0$, and q_{SfearA} any value. As all terms in the double sum expression for $q_{Sfear,A}^*$ are nonnegative, assuming $0 < \nu_{SfearA} < 1$, the condition $q_{SfearA}^* = 0$ represents *full absense of negative group impact* on A. It is equivalent to $\gamma_{SfearBA} \cdot q_{SfearB} = 0$ for all $B \neq A$, and $\omega_{SinfoA} \cdot (1 - p_{SinfoA}) \cdot r_{SinfoA} \cdot q_{Sinfo,A}^* = 0$ for all *Sinfo* which are equivalent to $q_{SfearB} = 0$ for all $B \neq A$, with $\gamma_{SfearBA} \neq 0$, and $q_{Sinfo,A}^* = 0$ for all *Sinfo* with $\omega_{SinfoA} \neq 0$, $p_{SinfoA} \neq 1$ and $r_{SinfoA} \neq 0$. As $q_{Sinfo,A}^* = \sum_{B \neq A} \gamma_{SinfoBA} \cdot q_{Sinfo,B} / \gamma_{SinfoA}$, these are equivalent to $q_{SfearB} = 0$ for all $B \neq A$, with $\gamma_{SfearBA} \neq 0$, and $q_{Sinfo,B} = 0$ for all *Sinfo* with $\omega_{SinfoA} \neq 0$, $p_{SinfoA} \neq 1$ and $r_{SinfoA} \neq 0$ and all $B \neq A$ with $\gamma_{SinfoBA} \neq 0$.

Note that q_{SfearA} is strictly decreasing iff

$1 - (1-q_{SfearA}^*) \cdot (1-q_{SfearA}) < q_{SfearA}$ iff

$1 - q_{SfearA} < (1-q_{SfearA}^*) \cdot (1-q_{SfearA})$ iff

$q_{SfearA} < 1$ and $1- q_{SfearA}^* > 1$ iff

$q_{SfearA} < 1$ and $q_{SfearA}^* < 0$

As this is impossible, a strictly decreasing q_{SfearA} is never possible for this combination of parameter values. Therefore in all cases where there is no equilibrium q_{SfearA} will strictly increase.

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 below 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 2. The equilibrium equation $q_{SfearA}^* q_{SfearA} = q_{SfearA}$ is equivalent to $q_{SfearA} = 0$ or q_{SfearA} has any value, and $q_{SfearA}^* = 1$. The latter case $q_{SfearA}^* = 1$ represents *full presence of negative group impact*. It is equivalent to $q_{SfearB} = 1$ for all $B \neq A$ with $\gamma_{SfearBA} \neq 0$, and $(1 - p_{SinfoA}) \cdot r_{SinfoA} \cdot q_{Sinfo,A}^* = 1$ for all *Sinfo* with $\omega_{SinfoA} \neq 0$. Again, since $q_{Sinfo,A}^* = \sum_{B \neq A} \gamma_{SinfoBA} \cdot q_{Sinfo,B} / \gamma_{SinfoA}$ this is equivalent to $q_{SfearB} =t 1$ for all $B \neq A$ with $\gamma_{SfearBA} \neq 0$, and $q_{Sinfo,B} = 1$ and $p_{SinfoA} = 0$ and $r_{SinfoA} = 1$ for all $B \neq A$ and *Sinfo* with $\gamma_{SinfoBA} \neq 0$ and $\omega_{SinfoA} \neq 0$. Note that q_{SfearA} is strictly increasing iff $q_{SfearA}^* q_{SfearA} > q_{SfearA}$. As this is impossible a strictly increasing q_{SfearA} is never possible for this combination of parameter values. Therefore in all cases where there is no equilibrium q_{SfearA} will strictly decrease.

Special case $\eta_{SfearA} = 0$ This case concerns an absorbing agent for fear. For this case the analysis below 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.

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 2 below.

6. Discussion

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 model has been inspired by a number of theories and observations as found in literature (i.e. [2], [6], [7], [10], [17], [24], [25]). 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.

The approach used in this work is an agent-based approach that differs from the approach of the computational models from social science named above [20], [14], [18]. These computational models differ from the model presented here, in the way that they model the complex spread of innovations as diffusion that is asymmetric in time, irreversible, and nondeterministic. The model presented in this paper models the continuous spread of different types of emotions and information among the group members over time, which can have many patterns in it and is reversible in time.

Table 5 Overview of cases of equilibrium values for $\delta_{Sinfo\ A}$, $\beta_{Sinfo\ A}$, $\eta_{Sinfo\ A}$

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

Table 6 Overview of cases of equilibrium values for $q_{fear,A}$

	$q_{fear,A} = 0$	$0 < q_{SfearA} < 1$	$q_{fear,A} = 1$
$\eta_{SfearA}=1$ $\beta_{SfearA}=1$	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

The current model has also been inspired by previous emotion contagion models that focus on the spread of emotion in groups (cf. [4], [5], [9]). The process of emotion contagion, in which a group member influences the emotions of another group member (and vice versa), through the conscious or unconscious induction of emotion states [21], is a primary mechanism through which individual emotions create a collective emotion. This process has been described as an inclination to mimic the gestural behavior of others, to "synchronize facial expression, utterances and attitudes" [13]. Emotion contagion has been shown to occur in many cases varying from emotions in small groups to panicking crowds; see [2], [15] and [23].

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] mechanisms by which mood may affect (systematic) information processing are discussed. Mood differs from emotion in that it is not so much elicited by a particular stimulus, but mood operates more on the background and can affect a wide range of actions and thoughts. Other ideas for future work consist of extending the current model for multiple emotions affecting each other and information as well and vice versa.

7. References

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

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