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:

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

Here $\varepsilon_{SB}$ is the personal characteristic expressiveness of the sender (agent $B$) for $S$, $\delta_{SA}$ the personal characteristic openness of the receiver (agent $A$) for $S$, and $\alpha_{SBA}$ 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 \( \gamma_{SA} \) from the group towards agent \( A \) is calculated:

\[
\gamma_{SA} = \sum_{B \neq A} \gamma_{SB} \tag{2}
\]

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

\[
q_{SA}^* = \sum_{B \neq A} \gamma_{SB} \cdot \frac{q_{SB}}{\gamma_{SA}} \tag{3}
\]

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 \( \eta_{SA} \) to absorb or to amplify the level of a state and the bias \( \beta_{SA} \) 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:

\[
q_{SA}(t + \Delta t) = q_{SA}(t) + \gamma_{SA} \left( \eta_{SA}(1 - (1 - \beta_{SA}) q_{SA}(t)) - \gamma_{SA} q_{SA}(t) \right) \Delta t \tag{4}
\]

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>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q_{SA} )</td>
<td>level for state ( S ) for agent ( A )</td>
</tr>
<tr>
<td>( \delta_{SA} )</td>
<td>extent to which agent ( A ) expresses state ( S )</td>
</tr>
<tr>
<td>( \eta_{SA} )</td>
<td>tendency of agent ( A ) to absorb or amplify state ( S )</td>
</tr>
<tr>
<td>( \beta_{SA} )</td>
<td>positive or negative bias of agent ( A ) on state ( S )</td>
</tr>
<tr>
<td>( \alpha_{SB} )</td>
<td>channel strength for state ( S ) from sender ( B ) to receiver ( A )</td>
</tr>
<tr>
<td>( \gamma_{SB} )</td>
<td>contagion strength for state ( S ) from sender ( B ) to receiver ( A )</td>
</tr>
</tbody>
</table>

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 $\delta_{SA}$, $\eta_{SA}$ and $\beta_{SA}$ 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 $\xi_{SA}$, $\eta_{SA}$, $\beta_{SA}$ and interaction characteristic $\alpha_{BA}$. 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>
<thead>
<tr>
<th>relevance for survival ($\tau$) [0-1]</th>
<th>positivity of information ($p$) [0-1]</th>
<th>types of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>“Local authorities have been informed”</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>“All rear exits are obstructed”</td>
<td></td>
</tr>
</tbody>
</table>

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 $\beta_{SA}$, $\eta_{SA}$ and $\delta_{SA}$. 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:

$$\delta_{SA}(t+\Delta t) = \delta_{SA}(t) + \mu(1/1+e^{\beta_{SA} q_{SA} r_{SA} p_{SA}} - \delta_{SA}(t)) \cdot \Delta t$$

(5)

If $q_{SA} r_{SA} p_{SA}$ is lower than threshold $\tau$ (on the interval $[0,1]$), it will not contribute to the value of $\delta_{SA}$. If $q_{SA} r_{SA} p_{SA}$ has a value above $\tau$, 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 formulæ, $\mu$ 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 $\delta_{SA}(t)$ modeling the amplification or absorption of informational state $S$ are described as follows:

$$\eta_{SA}(t+\Delta t) = \eta_{SA}(t) + \mu(1/1+e^{\beta_{SA} q_{SA} r_{SA} p_{SA}} - \eta_{SA}(t)) \cdot \Delta t$$

(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:

$$\beta_{SA}(t+\Delta t) = \beta_{SA}(t) + \mu(1/1+e^{\beta_{SA} q_{SA} r_{SA} p_{SA}} - \beta_{SA}(t) \cdot \Delta t$$

(7)

Again, the bias is not influenced by fear if its value is low. In case fear is high, $\beta_{SA}$ 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:

$$q_{SA} = q_{SA} \cdot \gamma_{SA} \cdot \gamma_{SA} = (1 - \gamma_{SA}) \cdot \gamma_{SA} + \gamma_{SA} \cdot \gamma_{SA}$$

(8)

Here the influence depends on the impact from the emotion fear by others (the first factor, with weight $\gamma$) 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 $\alpha_{SA}$ has been made dependent upon the distance:

$$\alpha_{SA} = 1 - (1/(1+e^{\beta_{SA}}))$$

(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 ($\tau$).

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 ($\tau_{FEAR}$) to 0.5.

### Table 3. 6 scenarios for diffusion

<table>
<thead>
<tr>
<th>Initial settings</th>
<th>emotion ↔ information</th>
<th>emotion ↔ information</th>
</tr>
</thead>
<tbody>
<tr>
<td>high fear levels</td>
<td>scenario 1</td>
<td>scenario 4</td>
</tr>
<tr>
<td>low fear levels</td>
<td>scenario 2</td>
<td>scenario 5</td>
</tr>
<tr>
<td>mixed fear levels</td>
<td>scenario 3</td>
<td>scenario 6</td>
</tr>
</tbody>
</table>

Scenarios 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 noticed 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 ($q_{HL}$), row 4 of highly relevant, negative information ($q_{LL}$) and row 5 shows values for the state of low relevant, negative information ($q_{LL}$).

### Table 4. Parameter settings for scenario 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$Q_{FEAR}$</th>
<th>$Q_{HH}$</th>
<th>$Q_{HL}$</th>
<th>$Q_{LL}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 (init Q)</td>
<td>0.1</td>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>A2 (init Q)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>A3 (init Q)</td>
<td>0.1</td>
<td>0.1</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>A4 (init Q)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>A1 ($\delta$)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>A2 ($\delta$)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>A3 ($\delta$)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>A4 ($\delta$)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>A1 ($\eta$)</td>
<td>0.5</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>A2 ($\eta$)</td>
<td>0.5</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>A3 ($\eta$)</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>A4 ($\eta$)</td>
<td>0.5</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>A1 ($\phi$)</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>A2 ($\phi$)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>A3 ($\phi$)</td>
<td>0.5</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>A4 ($\phi$)</td>
<td>0.5</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

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].
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 \( q_{HH} \), \( q_{HL} \), \( q_{LH} \) 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 \( q \)-values increase slightly for all agents due to availability of information. However, just as the information levels decay, the \( q \)-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 \( q \)-levels first decreases and then increases 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 \( q \)-levels. Looking at the simulation results of scenario 6 two main observations can be made. First, the \( q \)-levels 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, \( q \)-levels are reduced as the agents obtain more positive information and soon after increases when the obtained information has a less positive content.
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 δ_{sinfo,A}(t), β_{sinfo,A}(t) and η_{sinfo,A}(t)**

The openness δ_{sinfo,A} is described in differential equation format by

\[ d \delta_{sinfo,A}(t)/dt = μ_{sinfo,A} \left((1+e^{-δ_{sinfo,A}}) - 1\right). \]

It is assumed that μ_{sinfo,A} > 0. First of all, it follows that when q_{fear,A} < r, then always dδ_{sinfo,A}(t)/dt = 0, so for these cases any value for δ_{sinfo,A} is an equilibrium. Next, assuming q_{fear,A} ≥ r, it holds

\[
\begin{align*}
\delta_{sinfo,A} &\mbox{ is in equilibrium if } \\
(1 - (1-r_{sinfo,A})q_{fear,A} - \delta_{sinfo,A}) &\mbox{ = 0 if } \\
\delta_{sinfo,A} &\mbox{ is strictly increasing if } \\
(1 - (1-r_{sinfo,A})q_{fear,A} - \delta_{sinfo,A}) &> 0 if \\
\delta_{sinfo,A} &\mbox{ is strictly decreasing if } \\
(1 - (1-r_{sinfo,A})q_{fear,A} - \delta_{sinfo,A}) &< 0 if
\end{align*}
\]

From this the following equilibrium values can be determined (see also Table 5):

• q_{fear,A} < r and any value for δ_{sinfo,A} or
• q_{fear,A} ≥ r and δ_{sinfo,A} = 1 - (1-r_{sinfo,A})q_{fear,A}

For example, q_{fear,A} = 1 → δ_{sinfo,A}(t) = r_{sinfo,A} and r_{sinfo,A} = 1 and q_{fear,A} ≥ r ⇒ δ_{sinfo,A} = 1. The following monotonicity conditions hold for q_{fear,A}(t) ≥ r

\[ δ_{sinfo,A}(t) \mbox{ is strictly increasing if } \]

These conditions show that δ_{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 δ_{sinfo,A}(t).

Similarly the equilibrium values of the characteristics β_{sinfo,A} and η_{sinfo,A} can be determined as shown in Table 5. Moreover, as above it can be shown that β_{sinfo,A} is attracted by the value 1 - p_{sinfo,A}, and η_{sinfo,A}(t) is attracted by the value q_{fear,A}(t), so they both are stable.

**Analysis of q_{sinfo,A}(t)**

The fear state is described by

\[ dq_{sinfo,A}(t)/dt = γ_{A} \left(\eta_{sinfo,A} \cdot (1-q_{sinfo,A}) \cdot (1-q_{sinfo,A}) + (1-β_{sinfo,A}) \cdot q_{sinfo,A} \cdot q_{sinfo,A} + (1 - γ_{sinfo,A} \cdot q_{sinfo,A} \cdot q_{sinfo,A}) \right). \]

Then the equilibrium equations become:

\[ η_{sinfo,A} \cdot (β_{sinfo,A} \cdot (1 - (1-q_{sinfo,A}) \cdot (1-q_{sinfo,A}) + (1 - γ_{sinfo,A} \cdot q_{sinfo,A} \cdot q_{sinfo,A}) + (1 - γ_{sinfo,A} \cdot q_{sinfo,A} \cdot q_{sinfo,A}) \cdot q_{sinfo,A} = q_{sinfo,A}. \]

In general the equation is too complex to be solved symbolically, but for some cases it can be solved; see Table 6.

**Special case η_{sinfo,A} = 1 and β_{sinfo,A} = 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_{sinfo,A} 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_{sinfo,A}) \cdot (1-q_{sinfo,A}) = q_{sinfo,A} is equivalent to
which is equivalent to \( q_{\text{fear}} = 1 \) or \( q_{\text{fear}} = 0 \), and \( q_{\text{fear}} \) any value. As all terms in the double sum expression for \( q_{\text{fear}} \) are nonnegative, assuming \( 0 < v_{\text{fear}} < 1 \), the condition \( q_{\text{fear}} = 0 \) represents full absence of negative group impact on \( A \). It is equivalent to \( v_{\text{fear}}BA \cdot v_{\text{fear}}B = 0 \) for all \( B \neq A \), and \( \omega q_{\text{info},A} \cdot (1 - p q_{\text{info},A}) \cdot v_{\text{info},A} \cdot r q_{\text{info},A} = 0 \) for all \( \text{info} \) which are equivalent to \( q_{\text{fear}} = 0 \) for all \( B \neq A \), with \( v_{\text{fear}}B \neq 0, \omega q_{\text{info},A} \neq 0, p q_{\text{info},A} \neq 1 \) and \( r q_{\text{info},A} \neq 0 \). As \( q_{\text{info},A} = \sum B \omega q_{\text{info},B} \cdot q_{\text{fear},B} / S_{\text{info},B} \), these are equivalent to \( q_{\text{fear}} = 0 \) for all \( B \neq A \), with \( v_{\text{fear}}B \neq 0 \), and \( q_{\text{info},B} = 0 \) for all \( \text{info} \) with \( \omega q_{\text{info},A} \neq 0 \), \( p q_{\text{info},A} \neq 1 \) and \( r q_{\text{info},A} \neq 0 \).

Note that \( q_{\text{fear}} \) is strictly decreasing iff
\[
1 - (1 - q_{\text{fear}}) \cdot (1 - q_{\text{fear}}^* - q_{\text{fear}}) \quad \text{iff}
1 - q_{\text{fear}} < (1 - q_{\text{fear}}) \cdot (1 - q_{\text{fear}}^*) \quad \text{iff}
q_{\text{fear}} < 1 \quad \text{iff}
q_{\text{fear}} < 1 \quad \text{and} \quad q_{\text{fear}}^* < 0
\]

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

**Special case \( q_{\text{fear}} = 1 \)** This case concerns an amplifying agent for fear. For this case the analysis below shows that there is a strong tendency for \( q_{\text{fear}} \) 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 \( q_{\text{fear}} \)**

The equilibrium equation \( q_{\text{fear}} = \sum B \omega q_{\text{info},B} \cdot q_{\text{fear},B} / S_{\text{info},B} \) for the cases \( q_{\text{fear}} = q_{\text{fear}} = 0 \) and \( q_{\text{fear}} = q_{\text{fear}} = 1 \) the terms of the double summation for \( q_{\text{fear}} \) 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 \( \delta q_{\text{info},A} \), \( \beta q_{\text{fear},A} \), \( \eta q_{\text{info},A} \)

<table>
<thead>
<tr>
<th>( \delta q_{\text{info},A} )</th>
<th>( \beta q_{\text{fear},A} )</th>
<th>( \eta q_{\text{info},A} )</th>
<th>( \delta q_{\text{info},A} )</th>
<th>( \eta q_{\text{info},A} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \delta q_{\text{info},A} &gt; 0 ) and ( \beta q_{\text{fear},A} &lt; 1 )</td>
<td>( \beta q_{\text{fear},A} = 1 - \beta q_{\text{fear},A} )</td>
<td>any value for ( \eta q_{\text{info},A} )</td>
<td>any value for ( \delta q_{\text{info},A} )</td>
<td>any value for ( \eta q_{\text{info},A} )</td>
</tr>
<tr>
<td>( \delta q_{\text{info},A} = 0 ) or ( \beta q_{\text{fear},A} = 1 ) and ( \eta q_{\text{info},A} = \eta q_{\text{info},A} )</td>
<td>( \beta q_{\text{fear},A} = 1 - \beta q_{\text{fear},A} )</td>
<td>any value for ( \beta q_{\text{fear},A} )</td>
<td>any value for ( \delta q_{\text{info},A} )</td>
<td>any value for ( \eta q_{\text{info},A} )</td>
</tr>
</tbody>
</table>
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