Modelling the Interplay of Emotions, Beliefs and Intentions within Collective Decision Making Based on Insights from Social Neuroscience

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Abstract. Collective decision making involves on the one hand individual mental states such as beliefs, emotions and intentions, and on the other hand interaction with others with possibly different mental states. Achieving a satisfactory common group decision on which all agree requires that such mental states are adapted to each other by social interaction. Recent developments in Social Neuroscience have revealed neural mechanisms by which such mutual adaptation can be realised. These mechanisms not only enable intentions to converge to an emerging common decision, but at the same time enable to achieve shared underlying individual beliefs and emotions. This paper presents a computational model for such processes.

Keywords: computational modeling, collective decision making, social neuroscience, mirroring, belief, emotion, intention

1 Introduction

When it comes to group decision making versus individual decision making, it is often said that ‘two heads are better than one’, and ‘the more the merrier’. Combining the individual capabilities in a group setting is often perceived as a benefit for all parties involved. However, deciding as a group comes with substantial challenges, as each group member has autonomous neurological processes, carrying, for example, private mental states such as emotions, beliefs, and intentions, which may seem hard to combine within a group. So, viewed from a distance, group decision making by reaching mutual agreement could be very hard. Yet, quite often coherent decisions are made by groups, and group members even seem to feel good with these decisions. In recent years, this seeming paradox has been resolved by developments in the new area called Social Neuroscience; e.g., [2], [3], [10], [11], [14], [25].

The crux is that after all these private mental states are not so static and isolated as they may seem; they often show high extents of dynamics due to social interaction. In Social Neuroscience neural mechanisms have been discovered that indeed - often in unconscious manners - account for mutual *mirroring* effects between mental states of different persons; e.g., [17], [23], [24]. For example, an emotion expresses itself in a smile which, when observed by another person, automatically triggers certain preparation neurons (also called *mirror neurons*) for smiling within this other person, and consequently generates the same emotion. Similarly, mirroring of intentions and beliefs can be considered.

In this paper group decision making in stressful circumstances (with emergency evacuations as an example) is addressed. Here emotions have an important interaction with the beliefs and intentions involved in a decision making process. A computational model is introduced that not only incorporates mechanisms for mirroring emotions, intentions and beliefs between different persons, but also addresses how within a person beliefs and emotions affect each other, and how they both affect the person’s intentions.

2 Background from Social Neuroscience

Within Neuroscience it has been discovered that certain neurons have a *mirroring function* of (e.g., [9], [17], [18], [20], [21], [22], [23], [24]. In the context of the neural circuits in which they are embedded, these neurons show both a function in preparation for certain actions or bodily changes and a function to mirror similar states of other persons: they are active also when the person observes somebody else intending or performing the action or body change. This includes expressing emotions in body states, such as facial expressions. These neurons and the neural circuits in which they are embedded play an important role in social functioning; (e.g., [9], [17], [23], [24]). When mental states of other persons are mirrored by some of the person's own states, which at the same time play a role in generating their own behaviour, then this provides an effective basic mechanism for how in a social context persons fundamentally affect each other's mental states and behaviour. These discoveries are the basis for an exciting new research area, called Social Neuroscience.

A person's cognitive states usually induce emotions, as described by neurologist Damasio, [6], [7]; for example: 'Even when we somewhat misuse the notion of feeling – as in "I feel I am right about this" or "I feel I cannot agree with you" – we are referring, at least vaguely, to the feeling that accompanies the idea of believing a certain fact or endorsing a certain view. This is because believing and endorsing *cause* a certain emotion to happen.' ([7], p. 93). Damasio's *Somatic Marker Hypothesis*; cf. [1], [5], [7], [8], is a theory on decision making which provides a central role to emotions felt. Within a given context, each represented decision option induces (via an emotional response) a feeling which is used to mark the option. For example, a strongly negative somatic marker linked to a particular option occurs as a strongly negative feeling for that option. Similarly, a positive somatic marker occurs as a positive feeling for that option ([5], pp. 173-174).

In Figure 1 an overview of the interplay of the different states within the model for collective decision making is shown. It is assumed that at the individual level the strength of an intention for a certain decision option depends on the person's beliefs (*cognitive responding*) and emotions (*somatic marking*) in relation to that option. Moreover, it is assumed that beliefs may generate certain emotions (*affective responding*), for example of fear, that in turn may affect the strength of beliefs (*affective biasing*). Note that it is assumed that these latter emotions are independent of the different decision options.

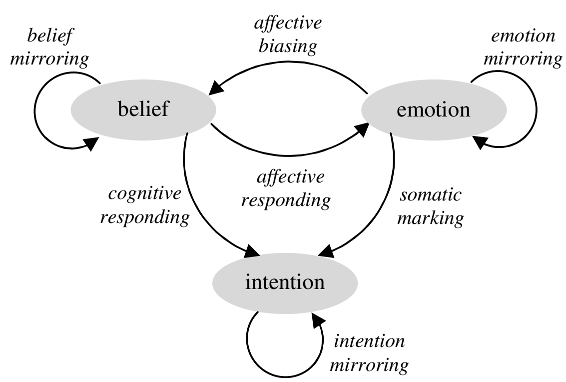

Figure 1 The interplay of beliefs, emotions and intentions in social context

Given this, to obtain collectiveness of the decision making a mirroring mechanism as briefly described above is used in three different ways; see also Figure 1:

- *mirroring of emotions* is a mechanism for how fear and emotions felt in different individuals about a certain considered decision option mutually affect each other,
- *mirroring of beliefs* is a mechanism transfering information on the extent to which different individuals believe certain information
- *mirroring of intentions* is a mechanism transfering information between individuals on the strength of action tendencies (e.g., [13], p.70) for certain decision options

These mechanisms describe not only how over time the individual decision intentions of group members may converge to a common group intention, but also how this relates to a basis of shared beliefs and shared emotions developed within the group. Indeed, the computational model introduced in Sections 3 and 4 shows these types of patterns, as illustrated in Section 5.

3 A Computational Model for Mirroring of Mental States

A main building block of the computational model is a general model describing at an abstract level the mirroring of a given mental state *S* (for example, an emotion, belief or intention). This is based upon the model that was also used as a generic building block in [15], [16]. An important element is the contagion strength γ_{SBA} from person *B* to person *A* in a group. This denotes how much the state *S* of *A* is influenced by the state *S* of *B*. It is defined by $\gamma_{SBA} = \varepsilon_{SB}\ \alpha_{SBA}\ \delta_{SA}$ (1). Here, ε_{SB} is the personal characteristic *expressiveness* of the sender *B* for *S*, δ_{SA} the personal characteristic *openness* of the receiver *A* for *S*, and α_{SBA} the interaction characteristic *channel strength* for *S* from sender *B* to receiver *A*. In order to determine the level q_{SA} of state *S* in an agent *A*, the following calculations are performed. First, the overall contagion strength γ_{SA} from the group towards agent *A* is calculated: $\gamma_{SA} = \Sigma_{B\neq A}\ \gamma_{SBA}$ (2). This value is used to determine the weighed impact $q_{SA}*$ of all the other agents upon state *S* of agent *A*:

$$q_{SA}* = \Sigma_{B\neq A}\ \gamma_{SBA}\ q_{SB} / \gamma_{SA} \qquad (3)$$

Two additional personal characteristics determine how much this external influence actually changes state *S* of agent *A*, namely the tendency η_{SA} to absorb or to amplify the level of a state and the bias β_{SA} towards increasing or reducing impact for the value of the state.

$$q_{SA}(t+\Delta t) = q_{SA}(t) + \gamma_{SA}\ [f(q_{SA}*(t), q_{SA}(t)) - q_{SA}(t)]\ \Delta t \qquad (4)$$

where the combination function $f(q_{SA}*(t), q_{SA}(t))$ used was taken as:

$$f(q_{SA}*(t), q_{SA}(t)) = \eta_{SA}\ [\ \beta_{SA}\ (1 - (1 - q_{SA}*(t))(1 - q_{SA}(t))) + (1-\beta_{SA})\ q_{SA}*(t)\ q_{SA}(t)\ ] + (1 - \eta_{SA})\ q_{SA}*(t)$$

By (4) the new value for the state *S* at time $t + \Delta t$ is calculated from the old value at *t*, plus the change of the value based upon the transfer by mirroring. This change is defined as the multiplication of the overall contagion strength γ_{SA} times the difference of a combination function of $q_{SA}*$ and q_{SA} with q_{SA}. The combination function used has a component for amplification (after $\eta_{SA}(t)$) and one for absorption. The amplification component depends on the tendency of the person towards more positive (part multiplied by $\beta_{SA}(t)$ or negative (part of equation multiplied by $1-\beta_{SA}(t)$ side). Table 1 summarizes the most important parameters and states within this general model.

Table 1. Parameters and states

q_{SA}	level for state *S* for person *A*
ε_{SA}	extent to which person *A* expresses state *S*
δ_{SA}	extent to which person *A* is open to state *S*
η_{SA}	tendency of person *A* to absorb or amplify state *S*
β_{SA}	positive or negative bias of person *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*

4 A Computational Model for the Interplay of Beliefs, Emotions and Intentions

This section describes a computational model for the interplay of emotions, beliefs and intentions in a group of persons in the context of collective decision making. In this model the general model described in Section 3 is specialised for three different types of mental states *S*, namely beliefs, emotions, and intentions. In principle this a large number of variants of equation (4) above for all persons *A* in a group and all states *S*, indicated by *belief(X)*, *fear*, *emotion(O)*, *intention(O)* for information *X* and options *O*. However, in addition, at the individual level interactions between these different states are modelled, as depicted in Figure 1; see also Table 2 for a brief explanation of all interactions in the model. This means that the model obtained by forming specialisations of the generic model from Section 3 is modified in order to incorporate the internal interactions between the different types of states. For example, as can be seen in Table 2, the effect of beliefs on fear of a person has to be combined with the effect of fear of other group members on the own fear. This will be explained in more detail in the remainder of this section.

Table 2 The different types of processes in the model

from S	to S'	type	description
belief(X)	*fear*	internal	affective response on information; for example, on threads and possibilities to escape
emotion(O) *fear*	*emotion(O)* *fear*	interaction	emotion mirroring by nonverbal and verbal interaction; for example, fear contagion
fear	*belief(X)*	internal	affective biasing; for example, adapting openness, amplification extent and orientation
belief(X)	*belief(X)*	interaction	belief mirroring by nonverbal and verbal interaction; for example, of information on threads and options to escape
belief(X)	*intention(O)*	internal	cognitive response on information; for example, aiming for an exit that is believed to be reachable
emotion(O)	*intention(O)*	internal	somatic marking of intention options; for example, giving options that feel bad a low valuation
intention(O)	*intention(O)*	interaction	intention mirroring by nonverbal and verbal interaction; for example, of tendency to go in a certain direction

4.1 The Effect of Emotions on Beliefs

To model the effect of emotions on information diffusion, below the personal characteristics δ_{SA}, η_{SA} and β_{SA} for a belief state $S = belief(X)$ are not assumed constant, but are instead modeled in a dynamic manner, depending on emotions. Personal characteristics $\varepsilon_{belief(X)A}$, $\delta_{belief(X)A}$, $\eta_{belief(X)A}$, $\beta_{belief(X)A}$ and interaction characteristic $\alpha_{belief(X)BA}$ are parameters in the model as described in Section 3. One additional category is introduced here, namely informational state characteristics r_{XA} denoting how relevant, and p_{XA} denoting how positive information X is for person A. An assumption made for the model is that the intensity of the fear state of a person will affect his ability to receive information, by affecting the value of the individual person characteristics; in particular, a high level of fear affects $\beta_{belief(X)A}$, $\eta_{belief(X)A}$ and $\delta_{belief(X)A}$. First the effect of fear upon the openness for a belief *belief(X)* (characterized by a relevance r_{XA} of information X for A) is expressed:

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

If $q_{fear,A}$ is lower than threshold τ (on the interval [0,1]), it will not contribute to the value of $\delta_{belief(X)A}$. 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 [11], [19]. A distinction between amplification values for different types of information is also made, depending on the emotional state fear. The dynamics for the characteristic $\eta_{belief(X)A}(t)$ modeling the amplification or absorption of *belief(X)* are described as follows:

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

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 [4] on how emotion can result in selective processing of emotion-relevant information.

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

$$\beta_{belief(X)A}(t+\Delta t) = \beta_{belief(X)A}(t) + \mu\cdot(1/(1+e^{\sigma(q_{fear,A}(t) - \tau)}))\cdot(1-q_{belief(X)A}(t))\cdot((\zeta_A\cdot p_{XA} + (1-\zeta_A)\cdot(1-p_{XA})) - \beta_{belief(X)A}(t))\cdot\Delta t \qquad (7)$$

Parameter τ is a number between *0* and *1* and represents a threshold for q_{fear}: when $q_{\text{fear}} > \tau$, then $q_{fear,A}$ has an influence on the bias $\beta_{belief(X)A}(t)$. Parameter ζ_A is a personality characteristic; if $\zeta_A = 1$, represents a person who is optimistic when he/she has a lot of fear: positive information will be strengthened more and negative information will be weakened more. The reverse happens when $\zeta_A = 0$, this represents a person who is more 'pessimistic' when experiencing fear: negative information will be strengthened and positive information will be weakened. Both personality characteristics seem to exist in people: a bias towards the negative side of information in case of experiencing a high level of fear, corresponds with the narrowing hypothesis from Frederickson's broaden-and-build theory in [12]. The reverse personality characteristic of being able to 'stay optimistic' under pressure is a personality characteristic that is found in leaders. These dynamically changing 'parameters' $\delta_{belief(X)A}(t)$, $\eta_{belief(X)A}(t)$, $\beta_{belief(X)A}(t)$ are used in the equation describing the dynamics of the belief state *belief(X)*:

$$q_{belief(X)A}(t+\Delta t) = q_{belief(X)A}(t) + \gamma_{belief(X)A}(t)\,[\, f(q_{belief(X)A}{}^*(t), q_{belief(X)A}(t)) - q_{belief(X)A}(t)]\,\Delta t \qquad (4)$$

where the combination function $f(q_{SA}{}^*(t), q_{SA}(t))$ used is taken in a dynamic manner as:

$$f(q_{belief(X)A}{}^*(t), q_{belief(X)A}(t)) = \eta_{belief(X)A}(t)\,[\,\beta_{belief(X)A}(t)\,(1-(1-q_{belief(X)A}{}^*(t))(1-q_{belief(X)A}(t))) + (1-\beta_{belief(X)A}(t))\,q_{belief(X)A}{}^*(t)\,q_{belief(X)A}(t)\,] + (1-\eta_{belief(X)A}(t))\,q_{belief(X)A}{}^*(t)$$

Note that since it depends on $\delta_{belief(X)A}(t)$, also $\gamma_{belief(X)A}(t)$ becomes dynamic.

4.2 The Effect of Beliefs on Emotions in the Dynamics of Fear

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:

$$q_{fear,A}{}^*(t) = \nu_A \cdot (\Sigma_{B\neq A}\, \gamma_{fearBA} \cdot q_{fearB} / \gamma_{fearA}) + (1-\nu_A)\cdot(\Sigma_X\ \omega_{X,fear,A} \cdot (1-p_{XA})\cdot r_{XA}\cdot q_{belief(X)A}) \qquad (8)$$

Here the influence depends on the impact from the emotion fear by others (the first factor, with weight ν_A) in combination with the influence of the belief present within the person. In this case, information has an increasing effect on fear if it is relevant and non positive. This $q_{fear,A}{}^*(t)$ is used in the equation describing the dynamics of fear:

$$q_{fearA}(t+\Delta t) = q_{fearA}(t) + \gamma_{fearA}\,[\,f(q_{fearA}{}^*(t), q_{fearA}(t)) - q_{fearA}(t)]\,\Delta t$$

with

$$f(q_{fearA}{}^*(t), q_{fearA}(t)) = \eta_{fearA}\,[\,\beta_{fearA}\,(1-(1-q_{fearA}{}^*(t))(1-q_{fearA}(t))) + (1-\beta_{fearA})\,q_{SA}{}^*(t)\,q_{SA}(t)\,] + (1-\eta_{fearA})\,q_{fearA}{}^*(t)$$

4.3 The Effects of Beliefs and Emotions on Intentions

The abstract model for mirroring described above applies to emotion, belief and intention states *S* for an option *O* or the situation in general, but does not describe any interplay for intentions yet. Taking the Somatic Marker Hypothesis on decision making as a point of departure, not only intentions of others, but also own emotions affect the own intentions. To incorporate such an interaction, the basic model is extended as follows: to update $q_{intention(O)A}$ for an intention state *S* relating to an option *O*, both the intention states of others for *O* and the $q_{emotion(O)A}(t)$ values for the emotion state *S'* for *O* are taken into account. These intention and emotion states *S* and *S'* for option *O* are denoted by *OI* and *OE*, respectively:

Level of fear of person *A*:	$q_{fearA}(t)$
Level of emotion for option *O* of person *A*:	$q_{emotion(O)A}(t)$
Level of intention indication for option *O* of person *A:*	$q_{intention(O)A}(t)$
Level of belief supporting option *O* of person *A*:	$q_{beliefsfor(O)A}(t)$

Here $q_{beliefsfor(O)A}(t)$ denotes to aggregated support for option *O* by beliefs of *A*; it is defined as

$$q_{beliefsfor(O)A}(t) = \Sigma_X\ \omega_{XOA}\, q_{belief(X)A} / \Sigma_X\ \omega_{XOA}$$

where ω_{XOA} indicates how supportive information *X* is for option *O*. The combination of the own (positive) emotion level and the rest of the group's aggregated intention is made by a weighted average of the two:

$$q_{intention(O)A}{}^{**}(t) = (\omega_{OIA1}/\omega_{OIEBA})\,q_{intention(O)A}{}^*(t) + (\omega_{OEA2}/\omega_{OIEBA})\,q_{emotion(O)A}(t) + (\omega_{OBA2}/\omega_{OIEBA})\,q_{beliefsfor(O)A}(t)$$

$$\gamma_{intention(O)A}{}^* = \omega_{OIEBA}\ \gamma_{intention(O)A}$$

where ω_{OIA1}, ω_{OBA2} and ω_{OEA2} are the weights for the contributions of the group intention impact (by mirroring), the own emotion impact (by somatic marking), and the own belief impact on the intention of *A* for *O*, respectively, and

$$\omega_{OIEBA} = \omega_{OIA1} + \omega_{OEA2} + \omega_{OBA2}$$

The combination of the own belief level and the rest of the group's aggregated emotion for a certain option O is made by a weighted average of the two

$$q_{emotion(O)A}^{**}(t) = (\omega_{OEA1}/\omega_{OEBA})\, q_{emotion(O)A}^{*}(t) + (\omega_{OBA1}/\omega_{OEBA})\, q_{beliefsfor(O)A}(t) \quad (8)$$

$$\gamma_{emotion(O)A}^{*} = \omega_{OEBA}\, \gamma_{emotion(O)A} \quad (9)$$

where ω_{OEA1} *and* ω_{OBA1} are the weights for the contributions of the group emotion impact (by mirroring), the own belief impact on the emotion of *A* for *O*, respectively, and $\omega_{OEBA}=\omega_{OEA1}+\omega_{OBA1}$. Then the overall model for the dynamics of emotions and intentions for options becomes:

$$q_{emotion(O)A}(t + \Delta t) = q_{emotion(O)A}(t) + \gamma_{intention(O)A}^{*} [\eta_{emotion(O)A} (\beta_{emotion(O)A} (1 - (1-q_{emotion(O)A}^{**}(t))(1-q_{emotion(O)A}(t))) + (1-\beta_{emotion(O)A})\, q_{emotion(O)A}^{**}(t)\, q_{emotion(O)A}(t)) + (1 - \eta_{emotion(O)A})\, q_{emotion(O)A}^{**}(t) - q_{emotion(O)A}(t)] \cdot \Delta t$$

$$q_{intention(O)A}(t + \Delta t) = q_{intention(O)A}(t) + \gamma_{intention(O)A}^{*} [\eta_{intention(O)A} (\beta_{intention(O)A} (1 - (1-q_{intention(O)A}^{**}(t))(1-q_{intention(O)A}(t))) + (1-\beta_{intention(O)A})\, q_{intention(O)A}^{**}(t)\, q_{intention(O)A}(t)) + (1 - \eta_{intention(O)A})\, q_{intention(O)A}^{**}(t) - q_{intention(O)A}(t)] \cdot \Delta t$$

5 Simulation Results

In this section, the results of a case study will be presented. The goal of the case study was to investigate if the computational model can simulate the interplay of emotions, intentions and beliefs, as described in neuroscientific, social and psychological literature. The computational model was implemented in Matlab in the context of an evacuation scenario (see Appendix A† for the complete Matlab specification).

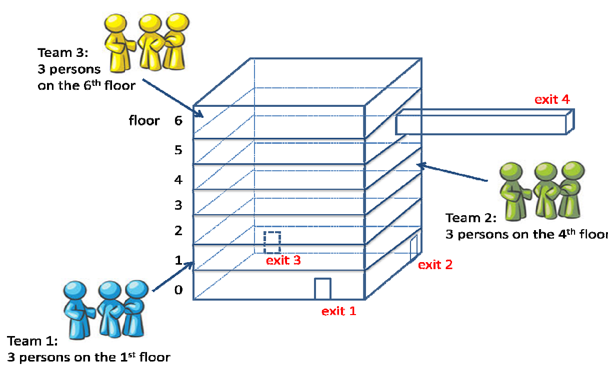

Fig. 1. The location of 3 teams in a building of 6 floors with 4 exits

The example scenario is expressed as follows: at the end of a working day in an office, the fire alarm goes off and all the persons that are in the building need to evacuate immediately. At the time of the alarm, 3 teams of each 3 people are present on different floors, as can be seen in Figure 1**.** Persons can communicate with each other when they are on the same floor, or they can communicate to each other through their personal device. Communication through such personal devices can only occur in case the distance is 3 floors or less. The building has 4 emergency exits. If an exit is accessible, the information is rated as 'positive' information, if not accessible then the information is rated 'not positive. According to the model, $p = 1$ and $p = 0$ are given as values to these two messages. The messages are always modeled as relevant for survival, $r = 1$.

In the scenario, the three persons located at the top initially know that exit 4 is available (with a belief of *1*), whereas the three persons on the middle floor do not have any strong beliefs about an emergency exit. The three at the first floor have beliefs of strength *1* concerning exit 1 and 2 (whereby the first one concerns a negative piece of information, namely that the exit is blocked and the second concerns positive information: the exit is accessible). Furthermore, a belief of strength *0* is present concerning exit 3. Besides these values, all other values are set to *0.5* with respect to the beliefs to indicate that they know the exits are there but do not know specifically whether the exit is accessible or not. Moreover, the intentions of all agents are initially set to *0* and the emotions to *0, 1, 0*, and *1* for exit 1, 2, 3, and 4

† http://www.cs.vu.nl/~mhoogen/social-diffusion/AppendixA-ICONIP10.pdf

respectively (since exit 1 and exit 3 represent negative information, the emotion for that option is not positive). Finally, for the emotion of fear the agents at the first floor have no fear, at the middle floor they have maximum fear, and at the top floor medium fear is present. Furthermore, the initial belief about the situation itself is *0.5*. Regarding all the parameter setting as described before: each agent has the same initial set of parameters, and these can be found in the Matlab specification as shown in appendix A.

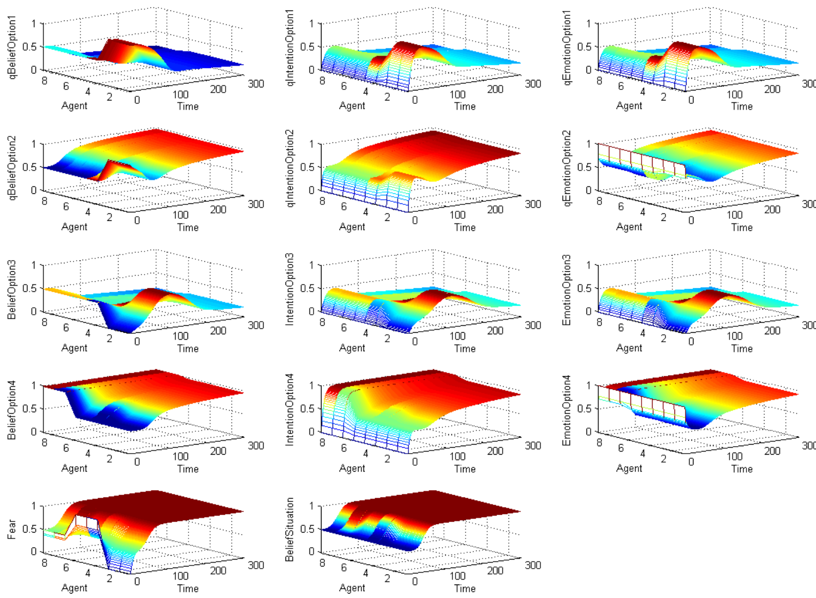

Fig. 2. Simulation results for the example scenario

Figure 2 shows the change of the values of the beliefs, intentions, and emotions. The top four columns represent the values related to the four exits. Here, the values for the agents during the simulation runs are shown. Furthermore, at the bottom row the amount of fear and the judgment of the entire situation are shown. It can be seen that fear spreads quickly, resulting in a very negative judgment of the situation by all agents. For exit 1 the belief about the exit being congested eventually stabilizes at a relatively low value due to the fact that no human has a good feeling for that option (although in the beginning the emotions are slightly pulled upwards as well as the intention, due to the very strong belief of the three agents at the first floor). For exits 2 and 4 a very strong belief occurs rapidly for all agents as well as a very strong intention and the positive emotions also remain high. Finally, for exit 3 the agents at the first floor get a slightly stronger belief, intention, and emotion due to the fact that the other agents have a belief with value 0.5 about the exit. Eventually however, the values return to a rather low value again due to the fact that the others have lowered their value again.

6 Discussion

This paper has presented a computational model for collective decision making based on neural mechanisms revealed by recent developments in Social Neuroscience; e.g., [2], [3], [10], [11], [14], [25]. These mechanisms explain how mutual adaptation of individual mental states can be realised by social interaction. They not only enable intentions to converge to an emerging common decision, but at the same time enable to achieve shared underlying individual beliefs and emotions. Therefore a situation can be achieved in which a common decision is made that for each individual is considered in agreement with the own beliefs and feelings. More specifically, this model for collective design making involves on the one hand individual beliefs, emotions and intentions, and on the other hand interaction with others involving mirroring of such mental states; e.g., [17], [23], [24]. As shown in Figure 1 and in Table 2, the model involves seven types of interations: three types of mirroring interactions between different persons, and within each person four types of interactions between the individual mental states.

In earlier work presented in [15] a simpler model for decision making was introduced in which only decision options and emotions associated to them, and their mutual interaction play a role, and no fear, nor interactions with beliefs. This model covers only three of the seven types of interaction of the currently presented model. The overlap is mainly in the somatic marking of intentions for decision options. In [16] a model was introduced in which only emotions and information and their mutual interaction play a role, and no decision making. The equations for the dynamics of δ, η, and β were adopted from this paper.

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