From Mirroring to the Emergence of Shared Understanding and Collective Power

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Abstract. Mirror neurons and internal simulation are core concepts in the new discipline Social Neuroscience. In this paper it is discussed how such neurological concepts can be used to obtain social agent models. It is shown how these agent models can be used to obtain emergence of shared understanding and collective power of groups of agents, both in a cognitive and affective sense.

1 Introduction

In human society in many situations some form of 'sharedness' or 'collectiveness' is experienced, which often covers cognitive as well as affective dimensions. Although this is a very common type of phenomenon, at forehand it is not at all clear how it can emerge. For example, the experience of feeling good being part of a group with a shared understanding and collective action may occur as quite natural. However, as persons in a group are autonomous agents with their own neurological structures and patterns, carrying, for example, their own emotions, beliefs, and intentions, it would be more reasonable to expect that such sharedness and collectiveness is impossible to achieve. Nevertheless, often groups develop coherent views and decisions, and, even more surprisingly, the group members seem to share a good feeling with it. This process depends on possibilities for (informational, motivational and emotional) transfer between individuals, which can be enhanced, for example, by social media.

In recent years new light has been shed on this seeming paradox by developments in neuroscience, in particular, in the new discipline called Social Neuroscience; e.g., [9], [10], [19], [20], [28]. Two interrelated core concepts in this discipline are mirror neurons and internal simulation. Mirror neurons are neurons that not only have the function to prepare for a certain action or body change, but are also activated upon observing somebody else who is performing this action or body change; e.g., [34], [45], [51]. Internal simulation is internal processing that copies processes that may take place in externally, for example, in another individual; e.g., [13], [15], [24], [26], [30].

In this paper, first in Section 2 some core concepts from Social Neuroscience are briefly reviewed. Next, in Section 3 it is discussed how based on them shared understanding can emerge. This covers both cognitive and affective understanding, and in a combined form empathic understanding. In Section 4 it is discussed how collective decisions and actions may emerge, and how such collective actions can be grounded in a shared affective understanding. Section 5 illustrates how such phenomena can be formalised in computational models. Finally, Section 6 is a discussion.

2 Mirror Neurons, Internal Simulation and Social Neuroscience

In this section two core concepts in the discipline of Social Neuroscience are briefly discussed: mirror neurons and internal simulation. Together they realise an individual's mental function of mirroring mental processes of another individual.

2.1 The Discovery of Mirror Neurons

Recently it has been found that in humans a specific type of neurons exists, called *mirror neurons,* which both are active to prepare for certain actions or bodily changes and when such actions or body states are observed in other persons. The discovery of mirror neurons originates from single cell recording experiments with monkeys in Parma in the 1990s. In particular, the focus was on an area in the premotor cortex (F5) known to be involved in the preparation of grasp actions. By accident, and to their own surprise, the researchers discovered that some of the recorded cells were not only firing when the monkey was preparing a grasp action, but also when somebody in the lab was grasping something and the monkey just observed that; cf. [23], [48]; see also [34], [50], [51]. The highly unexpected element was that recognition of observed actions of others involves the subject's preparation for the same type of action. It turned out that in the premotor area F5 about *20%* of the neurons are both active when preparing and when observing the action.

After the discovery of mirror neurons in monkeys it has been hypothesized that similar types of neurons also occur in humans. Indeed, for humans from the usual imaging methods it can be found that in certain premotor areas activity occurs both when an action is observed and when the action is prepared; e.g., [11], [25] based on EEG data; [27], [49] based on PET data, [36] based on fMRI. However, due to limitations in resolution, from such methods it cannot be seen whether the neurons active in action observation are exactly the same neurons that are active in preparing for an action. In principle they could be different neurons in the same area, each with only one function: either observation or preparing. Therefore in the years after the discovery of mirror neurons in monkeys it has been subject to debate whether they also exist in humans; e.g., [31].

Recently the existence of mirror neurons in humans has found support in single cell experiments with epilepsy patients undergoing pre-surgical evaluation of the foci of epilepsy; cf. [21], [43]; see also [34], pp. 201-203; [35], [38]. In these experiments for 14 patients, the activity of approximately 500 neurons was recorded; they were located in three sectors of the mesial frontal cortex (the ventral and dorsal sectors of the anterior cingulate cortex and the pre-supplementary motor cortex (SMA)/SMA proper complex). The subjects were tested both for hand-grasping actions and for emotional face expressions. Some of the main findings were that neurons with mirror neuron properties were found in all sites in the mesial frontal cortex where recording took place, in total for approximately *12%* of all recorded neurons; about half of them related to hand-grasping, and the other half to emotional face expressions; cf. [35].

2.2 Super Mirror Neurons for Control and Self-Other Distinction

Due to the multiple functions of mirror neurons, the functional meaning of activation of them (e.g., preparing or observing an action, or both) in principle is context-dependent. The context determines in which cases their activation is meant to lead to actual execution of the action (e.g., in self-initiated action performance, or imitation), and in which cases it is not (e.g., in action observation). A specific subset of mirror neurons has been found, called *super mirror neurons* that seem to be able to indicate such a context and play a role in the control of actual execution of a prepared action. These neurons are suggested to exert control by allowing or suppressing action execution, and/or by suppressing preparation states. More details on super mirror neurons can be found in [7], [35], and [34], pp. 196-203.

In the single cell recording experiments with epileptic patients mentioned above, also cells were found that are active when the person prepares an own action that is executed, but shut down when the action is only observed. This has led to the hypothesis that these cells may be involved in the functional distinction between a preparation state activated in order to actually perform the action, a preparation state activated to interpret an observed action (or both, in case of imitation). In [34], pp. 201-202 it is also described that some of such cells are sensitive to a specific person, so that the action can be attributed to the specific person that was observed: self-other distinction; see also [7].

2.3 Mirroring: Mirror Neuron Activation and Internal Simulation

Activation states of mirror neurons are important not by themselves, but because they play a crucial role in an important mental function: *mirroring* mental processes of other persons by *internal simulation*. How mirroring relates to internal processes involving emotions and feelings may ask for some further explanation. A classical view on emotions is that based on some sensory input due to internal processing emotions are felt, and based on that they are expressed in some body state; e.g., a face expression:

> sensory representation → felt emotion → preparation for bodily changes →
> expressed bodily changes = expressed emotion

James [37] claimed a different direction of causality (see also [17], pp. 114-116):

> sensory representation → preparation for bodily changes → expressed bodily changes →
> emotion felt = based on sensory representation of (sensed) bodily changes

The perspective of James assumes that a *body loop* is used to generate an emotion. Damasio made an important further step by introducing the possibility of an *as-if body loop* bypassing (the need for) actually expressed bodily changes (cf. [13], pp. 155-158; see also [15], pp. 79-80; [16], [17]):

> sensory representation → preparation for bodily changes = emotional response →
> emotion felt = based on sensory representation of (simulated) bodily changes

An as-if body loop describes an *internal simulation* of the bodily processes, without actually affecting the body, comparable to simulation in order to perform, for example, prediction, mindreading or imagination; e.g., [2], [24], [26], [30]; see also [6], [29] for computational accounts. The feelings generated in this way play an important role in valuing predicted or imagined effects of actions (in relation to amygdala activations; see, e.g., [42], [44]). Note that, in contrast to James [37], Damasio [13] distinguishes an emotion (or emotional response) from a feeling (or felt emotion). The emotion and feeling in principle mutually affect each other in a bidirectional manner: an as-if body loop usually occurs in a cyclic form by assuming that the emotion felt in turn affects the prepared bodily changes; see, for example, in ([16], pp. 91-92; [17], pp. 119-122):

emotion felt = based on sensory representation of (simulated) bodily changes →
preparation for bodily changes = emotional response

This provides a cyclic process that (for a constant environment) can lead to equilibrium states for both, as shown, for example, in [6] by a computational model. From a more general viewpoint, as-if body loops as introduced in [13] contribute:

(1) sensory input directly affects preparation states, after which further internal processing takes place (in line with, e.g., [37])
(2) the notion of internal simulation (in line with, e.g., [2], [30]).

Here (1) breaks with the tradition that there is a standard order of processing sensing – internal processing – preparation for action, and (2) allows for involving body representations in internal processes without actually having to change any body state. As mirror neurons make that some specific sensory input (an observed person) directly links to related preparation states, just like (1) above, it fits quite well in the perspective based on as-if body loops. In this way mirroring is a process that fully integrates mirror neuron activation states in the ongoing internal processes based on as-if loops; see also [17], pp. 102-104. As this happens mostly in an unconscious manner, mirroring imposes limitations on the freedom for individuals to have their own personal emotions, beliefs, intentions, and actions.

2.4 Development of the Discipline Social Neuroscience

Above it has been pointed out how states of other persons lead to activation of some of a person's coresponding own states that at the same time play a crucial role in the person's feelings and actions. This provides an effective mechanism for how observed actions and feelings and own actions and feelings are tuned to each other. This mechanism explains how in a social context persons fundamentally affect each other's personal actions and states, including feelings. Given these implications, the discovery of mirror neurons and how they play their role in mirroring processes is considered a crucial step for the further development of the disciplines of social cognition and social psychology, by providing a biological basis for many social phenomena.

Many examples of social phenomena now can be related to mirroring, for example: social diffusion or contagion of personal states such as opinions or emotions; empathic understanding; group formation, group cohesion, collective decision making. Based on these developments, and their wide applicability the new discipline Social Neuroscience has shown a fast development; e.g., [9], [10], [19], [20], [28]. The impact of this discipline is very wide, as it is considered to cover the concept of social reality (e.g., [8]), spiritual and religious experience (e.g., [52]), and collective consciousness or global empathy and its role in the future evolution (e.g., [12], [47]). In the next two sections it will be discussed how different types of shared understanding and collective power can emerge based on the mirroring function.

3 The Emergence of Shared Understanding

Understanding can occur in different forms. An agent can have an understanding of a world state by generating and maintaining a internal cognitive state in relation to it (e.g., one or more beliefs about it). This can be distinguished as a *cognitive* type of *understanding*. An agent can also form and maintain an internal affective state in relation to a world state (e.g., a specific emotion or feeling associated to it). Such a form of understanding can be distinguished as an *affective* type of *understanding*. An important role of this type of understanding is that it provides a basis for *experiencing* in the understanding. Affective and cognitive understanding are often related to each other. Any cognitive state triggers an associated emotional response which based on an as-if body loop activates a sensory representation of a body state which is the basis of the related feeling (e.g., [13], [15], [16], [17]); see also Section 2. Assuming similar neural architectures, the associated emotion is generated in an observing agent just like it is in an observed agent. In this way, mirroring is a mechanism to obtain shared understanding integrating cognitive and affective aspects.

A second way of distinguishing different types of understanding is by considering that the concerning world state can be either an *agent-external* world state or an *agent-internal* world state. For example, having beliefs about another agent's emotions, beliefs or goals is of the second, agent-internal type, whereas having beliefs about the weather is of the first type. These two dimensions of distinctions introduced above can be applied to *shared* understanding of an agent B with an agent A, from which a matrix results as illustrated in Table 1with different examples.

Table 1 Examples of different types of shared understanding

	Agent-internal	*Agent-external*
Shared cognitive understanding	• having beliefs about agent A's beliefs, intentions or goals • sharing goals for an internal agent state	• sharing beliefs with agent A about an external world state • sharing goals for an external world state
Shared affective understanding	• feeling the same as agent A is feeling about an agent state	• sharing a good or bad feeling about an external world state
Shared cognitive and affective understanding	• believing that agent A feels bad • believing X and feeling Y, and believing that agent A also believes X and feels Y	• sharing a belief or goal and feeling • sharing a belief and a feeling that intention X will achieve goal Y

3.1 The Emergence of Shared Understanding for Agent-External States

An agent's understanding of the external world in the form of a collection of beliefs is sometimes called the agent's world model. This can be considered a cognitive world model. More general, shared understanding of an external world state can involve:

- a *shared cognitive world model* (e.g., sharing beliefs about an external world state)
- a *shared affective world model* (e.g., sharing feelings about an external world state)
- a combined *shared cognitive-affective world model* (e.g., sharing both)

An example of the last item is sharing a belief that climate change has some serious effects and sharing a bad feeling about that, or sharing a belief that a new iPad will come out soon and sharing a good feeling about that. Obtaining such shared understanding of the external world may make use of different means. Individual information gathering can play a role, but also verbal and nonverbal interaction between agents. If some external world state is considered by agents, both verbal and nonverbal expressions are input for mirroring processes. These mirroring processes affect, for example, both the strength by which something is believed about this state, and the strength of the feeling associated to it. Thus both cognitive and affective shared understanding can develop, based on (mostly unconscious) mirroring processes.

3.2 The Emergence of Shared Understanding for Agent-Internal States

A second type of understanding concerns states that are internal for one of the agents. For such understanding different terms are used; e.g., mindreading, Theory of Mind (ToM), empathy, or more specific terms such as emotion or intention recognition; e.g., [20], [26], [46]. Also here understanding may be limited to cognitive understanding; for example, believing that another person has the intention to go out for a dinner, or feels depressed. However, for humans also an affective type of mutual understanding is common, usually combined with some form of cognitive understanding. One of the most fundamental forms of mutual understanding is indicated by the notion of *empathy*; e.g., see [18], [20], [34], [46], [53], [54], [57]. Originally by Lipps [40] the notion was named by the German word 'einfühlung' which could be translated as 'feeling into'; e.g., [46]. As this word indicates more explicitly, the notion of empathy has a strong relation to feeling: *empathic understanding* includes experiencing what the other person feels, but also believing that the experienced feeling is felt by the other person, based on self-other distinction (a form of super mirroring). Therefore empathic understanding can be considered a form of combined affective and cognitive understanding; see also [53], [54]. As an example, in [57], and [18], p. 435, the following four criteria of empathy of *B* for *A* are formulated:

(1) Presence of an affective state in a person *B*
(2) Isomorphism of *B*'s own and *A*'s affective state
(3) Elicitation of the *B*'s affective state upon observation or imagination of *A*'s affective state
(4) Knowledge of *B* that *A*'s affective state is the source of the *B*'s own affective state

The understanding indeed is both affective (1) and cognitive (4), but in this case it concerns in particular an affective state and not a cognitive state of the other person. Therefore it can be called *affective-focused empathy*. In contrast, to indicate affective and cognitive understanding of another agent's cognitive state (e.g., a belief) the term *cognitive-focused empathy* may be used. The term (*full) empathy* can be used to indicate combined cognitive-affective understanding of both cognitive and (associated) affective states of another agent. Note that empathy always involves feelings, so this is also the case, for example, in cognitive-focused empathy. However, in case of full empathy these feelings are related to the other person (using self-other distinction), and in case of purely cognitive-focused empathy the feelings are experienced but not related to the other person (for example, due to impaired self-other distinction). Table 2 illustrates these types of understanding for agent *B* having understanding of states of agent *A*. That mirroring (together with super mirroring) provides a basic mechanism involved in the creation of empathic understanding has much support in the recent literature; e.g., [22], [53], [54], [57], and [34], pp. 106-129.

Table 2: Examples of different types of Theory of Mind and empathy of agent B w.r.t. agent A

Agent A **Agent B**	*Affective states*	*Cognitive states*	*Affective and cognitive states*
Affective understanding	Feeling but not having a belief for *A*'s emotion (*emotion contagion*)	Feeling but not having a belief for *A*'s belief	Feeling but not having a belief for *A*'s emotion and belief
Cognitive understanding	Having a belief but no feeling for *A*'s emotion (*affective-focused ToM*)	Having a belief but no feeling for *A*'s belief (*cognitive-focused ToM*)	Having a belief but no feeling for *A*'s emotion and belief (*ToM*)
Affective and cognitive understanding	Having both a belief and feeling for *A*'s emotion (*affective-focused empathy*)	Having both a belief and feeling for *A*'s belief (*cognitive-focused empathy*)	Having a belief and feeling for *A*'s belief and feeling (*empathy*)

4 The Emergence of Collective Power

Each individual can exert a certain amount and direction of power by his or her actions, depending on personal characteristics and states. In a situation where such powers are exerted in different directions by multiple individuals, they can easily annihilate each other, or result in a kind of Brownian motion where particles move back and forth but do not change place much. In cases that the individual momenta represented by the individual powers and their directions, have an arbitrary distribution over a population, no serious collective momentum will emerge.

4.1 The Emergence of Collective Action Based on Mirroring

To obtain emergence of collective power, the individual momenta should converge to a similar direction so that a collective momentum can result. To obtain this, within groups of agents, shared agent states can emerge (by mirroring) that in an anticipatory sense relate to action, and by which collective power can be developed. Types of internal states relating to action are intentions or preparations. They can be seen as tendencies to perform a specific action; the emergence of shared preparations by mirroring may be quite effective in this sense. Such a process may play an important role in emerging collective decision making: a mirroring process may achieve that a specific preparation option gets a high activation level for all individuals in a group.

4.2 The Role of Feelings and Valuing in the Emergence of Collective Action

Usually in the individual process of action selection, before a prepared action comes in focus to be executed, an internal simulation to predict the effects of the action takes place: the action is simulated based on prediction links, and in particular for the associated affective effects, based on as-if body loops that predict the body state which is the basis of the related feeling (e.g., [13], [15], [16], [17]). Based on these predicted effects a valuation of the action takes place, which may involve or even be mainly based on the associated affective state, as, for example, described in [1], [13], [14], [16], [42], [44]. The idea here is that by an as-if body loop each option (prepared action) induces a simulated effect including a feeling which is used to value the option. For example, when a negative feeling and value is induced by a particular option, it provides a negative assessment of that option, whereas a positive feeling and value provides a positive assessment. The decision for executing a prepared action is based on the most positive assessment for it.

This process of simulating effects of prepared actions not only takes place for preparations of self-generated actions, but also for intentions or actions from other persons that are observed. In this way by the mirroring process not only a form of action or intention recognition takes place in the form of activation of corresponding own preparation states by mirror neurons, but in addition also the (predicted) effects are simulated, including the affective effects. This provides an emotionally grounded form of understanding of the observed intention or action, including its valuing, which is shared with the observed agent; see also [17], pp. 102-104.

Given the important role of the feeling states associated to preparations of actions, it may be unrealistic to expect that a common action can be strong when the individual feelings and valuations about such an action have much variation over a group. To achieve emergence of strong collective action, also a shared feeling and valuation for this action has to develop: also mirroring of the associated emotions has to play an important role. When this is achieved, the collective action has a solid shared emotional grounding: the group members do not only intend to perform that action collectively, but they also share a good feeling about it. In this process social media can play an important facilitating role in that (1) they dramatically strengthen the connections between large numbers of individuals, and (2) they do not only support transfer of, for example, beliefs and intentions as such, but also associated emotions reinforcing them, thus making the transfer double effective.

5 Computational Models for Social Agents

In this section, the processes discussed above are illustrated by (pointers to) examples of computational models. For example, in [6] and [39] it is shown how mirroring plays a role in emotion recognition. Examples with both mirroring and super mirroring functions can be found in [29], [58], [59]. In [29] it is shown how depending on the context represented by super mirror states, activation of a preparation state has a function in either execution, recognition, imagination or imitation of an action. In [58] it is shown how super mirror states play a role in regulation of different forms of social response patterns, and in [59] in prior and retrospective ownership states for an action.

Computational models for the emergence of shared understanding of agent-external states can be found, for example, in [4] where a computational model for converging emotion spirals (e.g., of fear) is described. In [32] a computational model for cognitive states (beliefs), and affective states (fear) with respect to the external world (in mutual relation) is described which shows how for such combined cases shared understanding emerges. Computational models that have been developed for different types of shared understanding of agent-internal states based on a mirroring mechanism, can be found, for example, in [6] and [58] for affective-focused empathic understanding and social responses, and in [41] for full empathic understanding.

5.1 A Generic Contagion Model

As a further illustration, first a model is briefly described where a person's internal states are fully determined by other persons' states, and not by other internal processes (taken from [4]). This model describes at an abstract level the mirroring of any given mental state S (for example, an emotion or intention). An important element is the contagion strength γ_{SBA} for S from person B to person A. This indicates the strength by which the state S of A is affected by the state S of B. It depends on characteristics of the two persons: how expressive B is, how open A is, and how strong the connection from B to A is. In the model it is defined by

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

Here, ε_{SB} is the *expressiveness* of B for S, δ_{SA} the *openness* of A for S, and α_{SBA} the *channel strength* for S from B to A. The level q_{SA} of state S in agent A (with values in the interval $[0, 1]$) over time is determined as follows. The overall contagion strength γ_{SA} from the rest of the group towards agent A is $\gamma_{SA} = \Sigma_{B\neq A}\ \gamma_{SBA}$. The aggregated impact $q_{SA}{*}$ of all these agents upon state S of agent A is:

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

Given these, the dynamics of the level of state S in A are modelled by:

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

where $f(X, Y)$ is a combination function, which can be taken, for example, as:

$$f(X, Y)\ = \alpha X + (1-\alpha)Y \qquad \text{(absorption, no bias)}$$
$$f(X, Y)\ = \beta_{SA}\ (1 - (1 - X)(1 - Y)) + (1-\beta_{SA})\ XY \qquad \text{(amplification, bias } \beta_{SA})$$

The parameter β_{SA} with values between 0 and 1 indicates a bias towards increasing (upward, $\beta_{SA} > 0.5$) or reducing (downward, $\beta_{SA} < 0.5$) the impact for the value of the state S of A. Some example simulations for levels of an emotion state S using the latter combination function are shown in Fig. 1 for three agents a, b, c (taken from [4]). When there are no biases (i.e., all $\beta_{SA} = 0.5$), then a shared level emerges which is a weighted average of the individual initial values; an example of this is shown in Fig. 1(a). The way in which these initial values are weighted depends on the openness, expressiveness and channel parameters. If one of the group members is a charismatic leader figure, with very high expressiveness ε and very low openness δ, then this person's initial state will dominate in the emerging shared state, for example, as thought for persons like Lech Wałęsa, Winston Churchill, Adolph Hitler, Martin Luther King Jr, Fidel Castro, Mahatma Gandhi. Persons with high openness and low expressivity are considered to be followers, persons with low openness and expressiveness loners. Social media can play an important role because they increase the channel strengths α between individuals for, for example, beliefs and intentions, and also for the associated emotions. In Fig. 1(b) a situation is shown where biases play a role; here the emerging shared emotion level is higher than any of the initial individual values. Note that the bias of agent b is downward (value $0.3 < 0.5$), which indeed for this agent leads to a downward trend first; this trend is changing after time point 2, due to the impact of othyer, as by then the other agents' emotion levels have substantially increased.

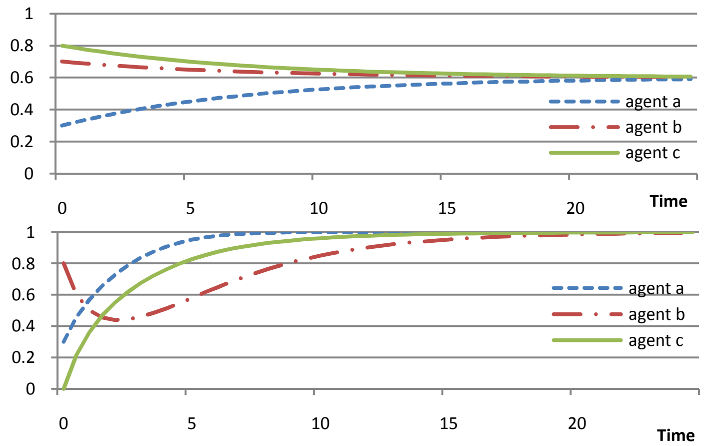

Fig. 1: Emerging shared emotion states depending on bias values
(a) Not biased: all $\beta_A = 0.5$ (b) Biased: $\beta_a = 1$, $\beta_b = 0.3$, $\beta_c = 0.8$

5.2 Integration of Mirroring in Other Internal Processes

The generic model described above applies to any internal state *S*, but does not describe any interplay between different internal states yet. In more realistic cases such an interplay also contributes to the levels of the states, and therefore the impact of other internal states *S′* on a given state *S* has to be integrated with the impact of mirroring on *S*. For example, Fig. 2 shows an internal model where a certain cognitive state (for example, a sensory representation or belief) has both a cognitive and affective impact on a person's emotions and preparations. Usually such impacts also have feedback loops; an example of this is an as-if body loop (see Section 2). Therefore, often an internal model consists of a number of cycles, for example, as shown in Fig. 2. In processing, these loops may converge to some equilibrium, when impact from outside is not changing too fast.

An integration of such an internal model with external impact by mirroring can be obtained as follows: to update $q_{SA}(t)$ for a state *S*, the levels $q_{S'A}(t)$ for the other states *S′* are taken into account. A general way to do this is by a combination function *f* that both takes into account the aggregated mirroring impact $q_{SA}{*}(t)$ and the values $q_{S'A}(t)$ for all (relevant) internal states $S' \neq S$. A relatively simple way to define such a combination function is by a weighted average of all these impacts:

$$q_{SA}{**}(t) = \lambda_{SA}\, q_{SA}{*}(t) + \Sigma_{S' \neq S}\, \lambda_{S'A}\ q_{S'A}(t) \qquad \text{with } \Sigma_{S'}\, \lambda_{S'A} = 1$$

and then in the dynamic update model for $q_{SA}(t)$ described above in the combination function $f(X, Y)$ use this $q_{SA}{**}(t)$ instead of $q_{SA}{*}(t)$. This way of combination was used in the computational model for emotion-grounded collective decision making described in [32], based on the principles discussed in Section 4 above. In this case mirroring was applied to both emotion and intention states for any option *O*:

- *mirroring of emotions* as a mechanism for how emotions felt about a certain considered decision option *O* in different individuals mutually affect each other
- *mirroring of intentions* as a mechanism for how strengths of intentions (action tendencies) for a certain decision option *O* in different individuals affect each other

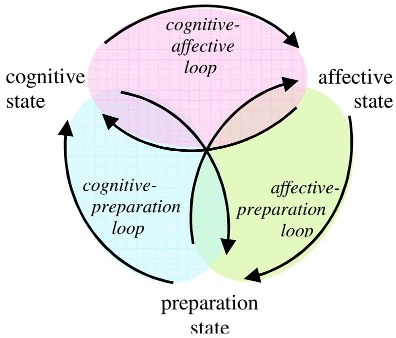

Fig. 2. Example of a more complex internal model

In the model not only intentions of others, but also a person's emotions affect the person's own intentions (the arrow from affective state to preparation state in Fig. 2). In updating $q_{SA}(t)$ for an intention state *S* relating to an option *O*, the intention states of others for *O* and the values for the emotion state *S'* for *O* were taken into account, and aggregated using the approach indicated above. In simulations in most cases not only a collective decision for an intention was emerging, but also a shared underlying feeling. For more details and simulation results, see [32]. Examples of exceptions occur when group members have no openness for others, or are not connected to others.

5.3 The Interplay of Intentions, Beliefs and Emotions

An example of a more complex computational model is the collective decision making model ASCRIBE addressing an interplay of beliefs, intentions, and emotions (Agent-based Social Contagion Regarding Intentions, Beliefs and Emotions; cf. [33]); see Fig. 3. The internal model used here instantiates part of the general picture of Fig. 2. Beliefs instantiate the cognitive, emotions the affective, and intentions the preparation states. In this specific internal model it is assumed that an individual's 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 these latter emotion impacts are independent of specific decision options (e.g., a general fear level). Mirroring was used in three different forms (the dotted arrows in Fig. 3): of emotions (both fear and emotions felt about a certain decision option *O*), of beliefs, and of intentions (for a certain decision option *O*). In the model for the dynamics of intentions, the impact from mirroring is combined with impact from the emotion states and impact from beliefs, in a similar manner as described above. The same applies, for example, to the impact of beliefs on the emotion state. However, in this model also a different type of combination of mirroring and internal processes takes place, involving impact of fear states to beliefs: it is assumed that some of the parameters, for example, for biases and openness with respect to beliefs are affected by fear levels. For more details of this model and example simulations, see [33]; in [5] an application to a real world crowd behaviour case is presented.

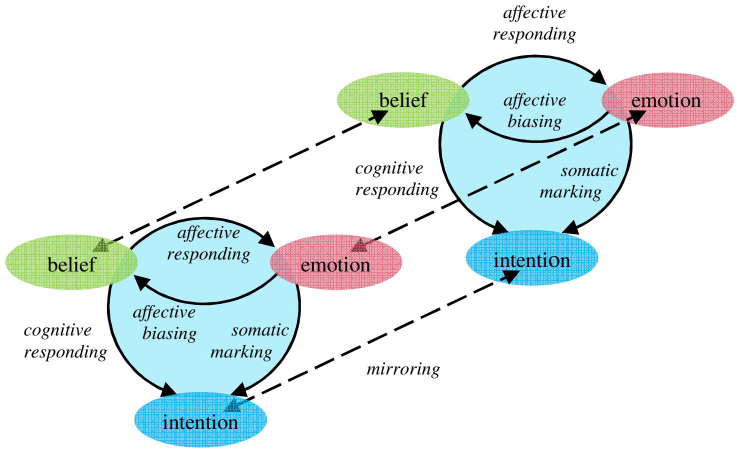

Fig. 3. Threefold mirroring integrated with internal interplay of beliefs, emotions and intentions

6 Discussion

In this paper it was discussed how mechanisms from the new discipline Social Neuroscience can be exploited to obtain social agent models, covering both cognitive and affective processes, and their interaction. Core mechanisms used are mirror neurons and internal simulation. Mirror neurons are certain neurons that are activated due to observation of another agent having a corresponding state; e.g., [34], [45], [51]. Internal simulation is further internal processing copying a process within another person; e.g., [13], [15], [24], [26], [30]. It was shown how such agent models can be used to perform simulation and analysis of the emergence of shared understanding of a group of agents. Furthermore, it was shown how such agent models can be used to perform simulation and analysis of the emergence of collective power of a group of agents. This was addressed both in a cognitive or affective or combined sense, so that not only the group members together go for a collective action, but they also share the experience of a good feeling about it, which gives the collective action a solid emotional grounding. It was discussed how such processes depend on the connection strengths between persons, which are strengthened, for example, by social media.

The obtained agent models were specified as internal models at the cognitive and affective level, and often involve loops between different internal states. However, under certain assumptions such internal models can be abstracted to behavioural model providing more efficient processing, which is important especially when larger numbers of agents are simulated; for more details; for example, see [55], [56].

The perspective put forward in this paper has a number of possible application areas. In the first place it can be used to analyse human social processes in groups, crowds or in societies as a whole. The application to crowd behaviour in emergency situations addressed in [5] is an example of such an application. Other cases address, for example, collective decision making, the construction of social reality (e.g., [8]), the development of collective consciousness (e.g., [12]), and global empathy enabling to solve global problems such as climate change (e.g., [47]), or spiritual and religious experience (e.g., [52]).

A second area of application addresses groups of agents that partly consist of human agents and partly of devices, such as smartphones, and use of social media. For such mixed groups it can not only be analysed what patterns may emerge, but also the design of these devices and media can be an aim, in order to create a situation that the right types of patterns emerge, for example, with safe evacuation as a consequence.

A third area of application concerns a close empathic interaction between a human and a device. The importance of computational models in a virtual context for 'caring' agents showing empathy has also been well-recognized in the literature; see, for example [3]. As a fourth area of application team formation can be addressed. In this area it may be analysed in what way the above perspective provides possibilities that differ compared to already existing approaches.

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