An Agent Model for Cognitive and Affective Empathic Understanding of Other Agents[1]

Zulfiqar A. Memon[a,b], Jan Treur[a]

[a]VU University Amsterdam, Agent Systems Research Group
De Boelelaan 1081, 1081 HV Amsterdam
[b]Sukkur Institute of Business Administration (Sukkur IBA)
Air Port Road Sukkur, Sindh, Pakistan
Email: {zamemon, treur }@few.vu.nl
URL: http://www.few.vu.nl/~{zamemon, treur}

Abstract. This paper focuses on modelling capabilities to interpret another person's mind, taking into account both affective and cognitive states. A basic agent model to generate emotional responses and feelings in response to certain stimuli is taken as a point of departure. For the case these stimuli concern observation of another person's body state (e.g., face expressions), emotion reading is achieved, following the Simulation Theory approach to mindreading. Furthermore, by taking (internal) cognitive states instead of stimuli as a source for emotional responses, it is shown how to model the way in which a person associates feelings to cognitive states. Moreover, it is shown how another person can obtain empathic understanding of a person by simulating the way in which feelings are associated to cognitive states. The obtained agent model describes how the empathic agent deals with another agent's cognitive states and the associated feelings, thus not only understanding the other agent's cognitive state but at the same time feeling the accompanying emotion of the other agent.

Keywords: Cognitive agent model, empathic understanding, mindreading

1 Introduction

For effective functioning within a social context, one of the most important issues is to which extent persons have a good understanding of one another. Having understanding of another person often is related to the notion of *mindreading* or having a *Theory of Mind* (ToM). This is a very wide notion, subsuming different aspects or foci of the understanding, and different methods to obtain the understanding. From an evolutionary perspective, mindreading in humans and some other kinds of animals has developed for a number of foci, for example, intention, attention, desire, emotion, knowing, belief; e.g., [1], [6], [9], [17], [18]). Concerning the methods used to obtain a

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Theory of Mind, two philosophical perspectives as described in philosophical literature are Simulation Theory and Theory Theory; e.g., [18]. In the Simulation Theory perspective it is assumed that mindreading takes place by using the facilities (for example, network of causal relations) involving the own cognitive states that are counterparts of the cognitive states attributed to the other person. In the Theory Theory perspective it is assumed that mindreading takes place by reasoning about the other person's mind without using the corresponding facilities. In [9] mindreading models from a Theory Theory perspective have been described for an agent reasoning about another agent's intentions and actions.

For humans, one of the deepest and most fundamental forms of mutual understanding is based on the notion of *empathy*; e.g., [30], [26], [41], [14], [34], [28], [29]. Originally (cf. [35]) the notion of empathy was named by the German word 'einfühlung' which could be translated as 'feeling into'; e.g., [41]. As this word indicates more explicitly, the notion has a strong relation to feeling: *empathic understanding* is a form of understanding which includes (but is not limited to) feeling what the other person feels. This paper not only addresses how a person can be modelled that is able to perform mindreading, but also to have empathic understanding of other persons. A particular challenge here is how to enrich understanding of any cognitive state (such as an attention, belief, desire or intention state) of another person to a form of understanding of this state which includes feeling the same associated emotion as the other person.

One ingredient of the approach developed is a generalisation of Damasio's concept of *body loop* as put forward in [12], [13] and formalised in [8]. This perspective distinguishes the (bodily) emotional response to a stimulus from feeling the emotion, which is caused by sensing the own bodily response. An extension of this idea was obtained by assuming that the body loop is not processed once, as a linear causal chain starting with the stimulus and via the body loop ending up in the feeling, as assumed in [12], [13], [8]. Instead, in [37] a *recursive body loop* was introduced: a converging positive feedback loop based on reciprocal causation between feeling state (with gradually more feeling) and preparation for a body state (with gradually stronger expression). Triggered by a stimulus, after a number of rounds this loop ends up in an equilibrium for both states. Such a recursive loop resolves the wellknown dilemma whether emotions felt cause the prepared response, or, the other way around, the prepared response cause emotions felt. The agent model based on a recursive body loop takes a dynamical system perspective (e.g., [40]) and assumes reciprocal causation.

Two other ingredients that were adopted are the *Simulation Theory* perspective on mindreading (e.g., [18]), and recent neurological findings on preparation neurons with a *mirroring function* (e.g., [27], [39], [45], [43], [44], [46], [48]). As already pointed out above, the Simulation Theory perspective on mindreading assumes that mindreading that focuses on certain mental states and causal network of an observed agent makes use of the same mental states and causal network within the observing agent. The mirroring function of preparation neurons is that they are not only active when a person performs some specific action, but also when he or she observes another person performing the same action.

A nontrivial obstacle for the Simulation Theory perspective on mindreading is what can be called the *reverse causation paradox*. This paradox originates from the often made assumption that the causal relations used by the observed person flow from mental states to actions and body states, whereas the latter is what the observing agent observes. As within the observing agent this observation is the starting point for the simulation process to determine the observed person's mental states, this would be against the direction of the causal relations used. In [18], [21] this paradox was one of the issues encountered. It turns out that to resolve this paradox, a recursive body loop model as exploited here, with its underlying circular causal network involving both the observable body states and the mental states, is an appropriate basis. It provides models for emotion reading and empathic understanding from the Simulation Theory perspective, using the same causal relations in both the observed and observing agent.

In this paper, first the notions of mindreading and empathic understanding are clarified and positioned (Section 2), and the three main ingredients used as a point of departure are briefly introduced: recursive body loops, the Simulation Theory perspective on mindreading, and the mirroring function of preparation neurons (Section 3). In Section 4 the basic agent model for emotion generation based on a recursive body loop, used as a point of departure, is described. Incorporating a mirroring function in preparation states it is shown how this model can be used to model emotion reading from the Simulation Theory perspective. In Section 5 the agent model for empathic understanding is introduced and as an illustration some simulation results for a relatively simple case study are discussed. Section 6 presents a mathematical analysis of the equilibria of the model, which confirms the outcomes of the simulations. Finally, Section 7 is a discussion.

2 On Empathic Understanding

An observed agent's states can have different types of impact on an observing agent's states. In the literature some of these are called empathy. Other examples of such mutual impact are (emotion) contagion and mindreading. In this section the positioning of such types of impact is clarified, and a conceptualisation of empathy as a specific type of impact is provided. In the literature, empathy is described in different manners:

- The ability to put oneself into the mental shoes of another person to understand his or her emotions and feelings [19]
- A complex form of psychological inference in which observation, memory, knowledge, and reasoning are combined to yield insights into the thoughts and feelings of others [30]
- An affective response more appropriate to someone else's situation than to one's own [26]
- An affective response that stems from the apprehension or comprehension of another's emotional state or condition, and which is similar to what the other person is feeling or would be expected to feel in the given situation [16]
- Four criteria of empathy are: (1) presence of an affective state in a person, (2) isomorphism of the person's own and the other person's affective state, (3) elicitation of the person's affective state upon observation or imagination of the other person's affective state, (4) knowledge of the person that the other person's affective state is the source of the person's own affective state ([15], p. 435; [47], p. 974)

Recurring aspects in such descriptions are on the one hand understanding, knowing, having insight in, apprehension or comprehension, and on the other hand feeling the feeling state of the other person. Here the state of the other person may involve emotions felt and/or cognitive states of the person. For the sake of simplicity, below notions such as understanding, having insight in, apprehension, comprehension, are indicated as *understanding*. For example, a person may understand but not feel an emotion felt by another person, or a person may feel but not understand an emotion felt by another person. The latter case means that the person has an emotional activation but does not recognize or label it, like it may happen with the person's own emotional responses (this is a form of emotion contagion). This use of the word understanding (or lack thereof) does not refer to 'knowing why', i.e., the reasons or causes, which is a more enhanced form of understanding.

These distinctions can be used more generally to obtain a form of classification of different types of mindreading that are possible. More specifically, mindreading can address three types of states of an observed person:

(a) Emotions felt by the person
(b) Cognitive states (e.g., attention states, desire, intention, belief states)
(c) Both emotion states and cognitive states

Moreover, this not only applies to a person who is observed but also to a person performing the observing. In particular, a person can understand or feel another person's state, or both. Given this, mindreading of another person's state can take three forms:

(1) Feeling the state of another person without understanding it
(2) Understanding the state of another person without feeling it
(3) Both understanding and feeling the state of another person

As the other person's state may involve emotions felt and/or cognitive states, the combination of these provides the matrix of possibilities as shown in Table 1.

Here row (1) covers *contagion* cases in which by the observed agent feelings within the observing agent are generated, but the observing agent only feels them and has no understanding of the states of the observed agent and their relation to the observing agent's feelings. For example, the possibility indicated as type (1a), 'feeling but not understanding another person's emotion', is a case of *emotion contagion* as often occurs in the interaction between persons (e.g., [23]). Here the emotion felt by one person is only mirrorred in the emotion felt in the other person. Some may describe this as a form of (emotional) empathy, but below the standard for the concept empathy will be put a bit higher.

Observed person ***Observing person***	*Other person's emotions felt* (a)	*Other person's cognitive states* (b)	*Other person's emotions felt and cognitive states* (c)
Feeling but not understanding (1)	Feeling but not understanding another person's emotion	Feeling but not understanding another person's belief, desire, intention, attention, …	Feeling but not understanding another person's emotions and cognitive states
Understanding but not feeling	Understanding but not feeling another person's emotion	Understanding but not feeling another person's belief, desire, intention,	Understanding but not feeling another person's emotions and

(2)		attention, …	cognitive states
Both understanding and feeling (3)	Understanding and feeling another person's emotion	Understanding and feeling another person's belief, desire, intention, attention, …	Understanding and feeling another person's emotions and cognitive states

Table 1: Different types of mutual impact of agent states

In Table 1, row (2) covers cases where the observing person understands certain states of the observed person but does not feel anything in relation to that. These can be considered cases of *mindreading*. A specific case is type (2c): 'understanding but not feeling another person's emotions and cognitive states'. This is a case that is often assumed to occur in psychopaths who have well-developed skills in mindreading and apply them to their victims thereby serving their own interest, but do not mirror the feelings of their victims (cf. [42], pp. 159-165; [5]). Yet other specific cases are type (2b) which subsumes classicical cases described by the Theory Theory perspective on mindreading (e.g., [18], [9]), and type (2a) that subsumes approaches based on dedicated emotion recognition methods, for example, from facial expressions; e.g., [38].

Within the literature, cases that fall in row (3) of Table 1 are often related to empathy; therefore this row (3) is considered here as a most general or *weak notion of empathy*. Some of the descriptions of the notion of empathy (e.g., in the informal approaches from [19], [26], [16], quoted above) concentrate on feelings and mirroring them, which can be described as being of type (3a), although sometimes more emphasis is on feeling than on understanding; without understanding it would be of type (1a) which in fact is considered here emotion contagion and not empathy. In ([15], p. 435), and ([47], p. 974) four criteria of empathy are used: (1) presence of an affective state in a person, (2) isomorphism of the person's own and the other person's affective state, (3) elicitation of the person's affective state upon observation or imagination of the other person's affective state, (4) knowledge of the person that the other person's affective state is the source of the person's own affective state. As only affective states are considered, this also classifies as type (3a), or emotional empathy. The basic agent model for emotion reading from a Simulation Theory perspective described in Section 4 and used as a starting point for the agent model introduced in Section 5 is also of type (3a).

In addition to feelings, other descriptions in the literature explicitly involve thoughts as well, of both the observed and observing person (e.g., [30]), which makes them subsumed by type (3c). This type (3c) can be considered as the *strong notion of empathy*. In Section 5 below this more extended (and challenging) notion of empathy is taken as the aim for the agent model introduced. Here an extra aspect is that feelings and cognitive states are interrelated: usually any cognitive state of a person (for example, a belief, desire, intention or attention state) induces or goes together with a certain emotion state. For example, a belief that something bad is to happen, may relate to feeling fear, or the belief that something good has happened may relate to feeling happiness. Another example of such a relationship is the role of cognitive elements (for example, certain thoughts) in the development, persistence and recurrence of mood disorders such as depressions; e.g., [31].

3 Recursive Body Loops, Mirroring and Simulation Theory

In this section the three main ingredients used are briefly introduced: recursive body loops, the mirroring function of preparation states, and the Simulation Theory perspective on mindreading.

3.1 Recursive Body Loops

The approach developed here adopts from [12], [13] the idea of a 'body loop' and 'as if body loop', in a recursive form. According to the original idea, a body loop roughly proceeds according to the following causal chain; see [12], [13], [8]:

> sensing a stimulus → sensory representation of stimulus → preparation for bodily response
> → sensing the body modification → sensory representation of the body modification
> → feeling

In the approach taken as a point of departure here (adopted from [37]) an essential addition is that the body loop (or as if body loop) is extended to a *recursive body loop* (or *recursive as if body loop*) by assuming that the preparation of the bodily response is also affected by the state of feeling:

> feeling → preparation for bodily response

as an additional causal relation. Such recursiveness is also assumed by [13], as he notices that what is felt by sensing is actually a body state which is an internal object, under control of the person:

> 'The brain has a direct means to respond to the object as feelings unfold because the object at the origin is inside the body, rather than external to it. The brain can act directly on the very object it is perceiving. It can do so by modifying the state of the object, or by altering the transmission of signals from it. The object at the origin on the one hand, and the brain map of that object on the other, can influence each other in a sort of reverberative process that is not to be found, for example, in the perception of an external object.' (…) 'In other words, feelings are not a passive perception or a flash in time, especially not in the case of feelings of joy and sorrow. For a while after an occasion of such feelings begins – for seconds or for minutes – there is a dynamic engagement of the body, almost certainly in a repeated fashion, and a subsequent dynamic variation of the perception. We perceive a series of transitions. We sense an interplay, a give and take.' ([13], pp. 91-92)

Thus the obtained model is based on reciprocal causation relations between feeling and (preparations for) body states, as roughly shown in Fig. 1.

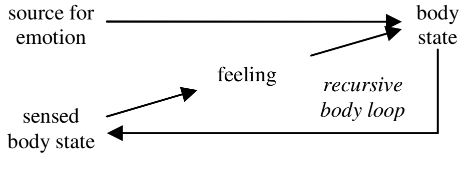

Fig. 1: Recursive body loop induced by a source for emotion (external stimulus or internal cognitive state)

Here the source of the emotion can be an external stimulus as in the causal chain described above, but, as further discussed below, also any internal cognitive state. In the approach presented here both the bodily response and the feeling are assigned a level or gradation, expressed by a number, which is assumed dynamic. The causal cycle is modelled as a positive feedback loop, triggered by the stimulus and converging to a certain level of feeling and body state preparation. Here in each round of the cycle the next body state preparation has a level that is affected by both the levels of the stimulus and the feeling state, and the next level of the feeling is based on the level of the body state preparation. In the more detailed model described in Sections 4 and 5 below, the combined effect of the levels of the stimulus and the emotional state on the body state is modelled as a weighted sum (with equal weights).

A question that may arise from the distinctions made in Section 2 is whether it is possible to feel a state of another person which by itself is not a feeling, for example, a belief state. An answer to this involves the way in which any cognitive state in a person induces emotions felt within this person, as described by Damasio ([12], [13]); e.g.:

> '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. As far as I can fathom, few if any exceptions of any object or event, actually present or recalled from memory, are ever neutral in emotional terms. Through either innate design or by learning, we react to most, perhaps all, objects with emotions, however weak, and subsequent feelings, however feeble.' ([13], p. 93)

From this perspective, if any cognitive state of an observed person is mirrorred within an observing person, by an (assumingly) similar mechanism the feeling associated to that cognitive state can be generated within the observing person as well. In principle, this can even happen for the case where the observed person has a damaged neural structure causing that this associated feeling is not generated. In this case the observing person can feel the other person's state, whereas the person him or herself does not feel it. For example, if such a person believes he or she has won a lottery, he or she may not feel happiness about it, whereas an observing agent may mirror such a belief and based on that may generate the accompanying feeling of happiness. In some more detail, for this situation emotion generation via a body loop roughly proceeds according to the following causal chain; see [12], [13]:

> having a cognitive state → preparation for the induced bodily response →
> induced body modification → sensing the body modification →
> sensory representation of the body modification → feeling

Again, as a variation, an 'as if body loop' uses a direct causal relation from preparation to sensory representation of body state, as a shortcut in the causal chain, and the body loop (or as if body loop) is extended to a recursive (as if) body loop by adding an additional causal relation from the state of feeling to the preparation of the bodily response.

3.2 The Mirroring Function of Preparation States

The idea of a recursive body loop combines quite well with recent neurological findings on mirror neurons (e.g., [27], [39], [43], [46]). Mirror neurons are preparation neurons with a special additional function, called a *mirroring function*: they are active not only when a person performs a specific action, but also when the person observes somebody else performing this action. For example, there is strong evidence that (already from an age of 1 hour) sensing somebody else's face expression leads (within about 300 milliseconds) to preparing for and showing the same face expression ([18], pp. 129-130).

The idea is that these neurons play an important role in social functioning and in (empathic) understanding of others; (e.g., [27], [46]). The discovery of mirror neurons is considered a crucial step for the further development of the discipline of social cognition, comparable to the role the discovery of DNA has played for biology, as it provides a neurological basis for many social phenomena; cf. [27].

Combined with the perspective of a recursive body loop, the mirroring function of preparation neurons provides an additional ingredient that explains how an observed emotional response of another person (via the person's body state; e.g., a face expression), via the activation of preparation for the same response within the observing person due to its mirroring function, triggers the recursive body loop which subsequently leads to a corresponding feeling within the observing person.

3.3 The Simulation Theory Perspective on Mindreading

The idea of a body loop together with the mindreading function of preparation states forms an adequate basis for modelling mindreading from the Simulation Theory perspective in philosophy (e.g., [18]). The Simulation Theory perspective assumes that mindreading uses the network of causal relations involving the own cognitive states that are counterparts of the cognitive states attributed to the other person. For example, the state of feeling pain oneself is used in the process to determine whether the other person has pain. This means that the own network is used to simulate the process of the other person; a similar simulation perspective can be used to explain imagination; see [24].

In contrast, the Theory Theory perspective is based on reasoning using knowledge about relationships between cognitive states and observed behaviour. An example of such a pattern based on causal knowledge of the observing person about the observed person is: 'I hear that she says 'ouch!'. I know that having pain causes saying 'ouch!'. Therefore she has pain'.

In ([18], pp. 124-132), a number of possible informal emotion reading models from the Simulation Theory perspective are sketched and discussed. When a mental state is assumed to cause the observed person's body states and actions, and observing the latter is the starting point, a main challenge to be addressed is to solve what can be called the *paradox of reverse causation*: how to simulate a process which in principle has the reverse order compared to the causal relations used in the simulation.

For his model 1, to resolve this paradox, a 'generate and test process' for emotional states was assumed, where on the basis of a hypothesized emotional state an own facial expression is generated, and this is compared to the observed facial expression of the other person. In the assessment of this model, the unspecified hypothesis generation process for a given observed face was considered as a less satisfactory aspect. Models 2 and 3 discussed in [18] are based on a notion of what he called 'reverse simulation'. This means that for the causal relation from emotional state to (the preparation of) a facial expression which is used to generate the own facial expressions, also a reverse relation from prepared own facial expression to emotional state is assumed, which is used for the mind reading process. A point of discussion concerning these two models is that it is difficult to fit them to the Simulation Theory perspective: whereas the emotional states and facial expression (preparation) states used for mindreading are the same as used for the own emotions and facial expressions, the causal relations between them used in the two cases are not the same. Model 4 is based on a so-called 'mirroring process', where a correlation between the emotional state of the other person and the corresponding own emotional state is assumed, based on a certain causal chain between the two. However, the relation of such a causal chain with the causal relations used to generate the own emotional states and facial expressions is not made clear, so it is still hard to claim that it fits in the Simulation Theory perspective.

The approach adopted from [37] in the current paper has drawn some inspiration from the four models sketched (but not formalised) in [18], as briefly discussed above. The recursive body loop (or as if body loop) introduced here addresses the problems of model 1, as it can be viewed as an efficient and converging way of generating and testing hypotheses for the emotional states, where the (as if) body loop takes care of the generation process. Moreover, it solves the problems of models 2 and 3, as the causal chain used from facial expression to emotional state is not a reverse simulation, but just the circular causal chain (body loop) via the body state which is used for generating the own responses and feeling states as well. Finally, compared to model 4, the models put forward here can be viewed as an efficient manner to obtain a mirroring process between the emotional state of the other person on the own emotional state, based on the machinery available for the own emotional states.

A mental process within the observing person based on a recursive body loop and a mirroring function of preparation states can be used as a form of simulation of the mental process within the observed person, and therefore coheres well with the Simulation Theory perspective on mindreading. Thus the combination of ideas briefly discussed in this section (recursive body loop, mirroring function of preparation neurons, and Simulation Theory) fits together quite well and forms the basis of the modelling approach presented here.

4 A Basic Agent Model for Emotion Generation and Imputation

In this section a basic agent model to generate emotions and feeling for a given stimulus is introduced. This model is a dynamical system style model (e.g., Port and van Gelder, 1995) and was adopted from [37] and can be classified as being of type (3a) in Table 1. The agent model is based on the Simulation Theory perspective (e.g., [18]), and is inspired by recent neurological findings on mirror neurons (e.g., [27]). It is shown how in this model the emotion felt by an observed person is mirrorred in the observing person and can be imputed by the observing person to the observed person.

In the description of the detailed agent model the temporal relation $a \rightarrow b$ denotes that when a state property a occurs, then after a certain time delay (which for each relation instance can be specified as any positive real number), state property b will occur. In this hybrid dynamical modelling language (called LEADSTO) both logical and numerical (dynamical systems) calculations can be specified, and a dedicated software environment is available to support specification and simulation; for more details see [7]).

First a general agent model is discussed of the case where any stimulus leads to an induced emotional response which is felt, and imputed to the stimulus. Next it is discussed how, when this stimulus is an observed body state (for example, a face expression) of another person expressing that person's emotion, then the same emotion is felt by the observing person and imputed to this person.

4.1 Generating Emotional Responses and Feelings by a Recursive Body Loop

The specification (both informally and formally) of the model for emotion generation based on a recursive body loop is as follows, as also shown by arrows between nodes in Fig. 2; here labels LP1, … at the arrows refer to local properties specified below in detail. Capitals are used for variables and lower case letters for instances. First a general pattern from world states to sensory representations of them is described. Note that it is assumed that only the observable part of the world is included in the model.

LP1 Sensing a world state
If world state property *W* occurs of level *V*
then a sensor state for *W* of level *V* will occur.
world_state(W, V) ↠ sensor_state(W, V)

LP2 Generating a sensory representation for a sensed world state
If a sensor state for world state property *W* with level *V* occurs,
then a sensory representation for *W* with level *V* will occur.
sensor_state(W, V) ↠ srs(W, V)

The above two properties are assumed to hold for all instances of the variables *W* and *V*. In contrast, note that the following property applies to a specific instance *s* and a specific instance *b*, which indicates the emotional response to this specific *s*.

LP3 From sensory representation and feeling to preparation
If a sensory representation for *s* occurs with level *1*
and body state *b* is felt with level *V*,
then preparation state for body state *b* will occur with level *(1+V)/2*.
srs(s, 1) & feeling(b, V) ↠ preparation_state(b, (1+V)/2)

Note that here the impact of the sensory representation of s (assumed to have level *1*) and the feeling of b (level *V*) is combined, expressed as *(1+V)/2*. Next the general recursive body loop is modelled, by properties LP4 to LP8 as follows. These properties are assumed to hold for all instances of the variables *B* and *V*.

LP4 From preparation to body modification
If preparation state for body state *B* occurs with level *V*,
then the body state is modified to express *B* with level *V*.
preparation_state(B, V) ↠ effector_state(B, V)

LP5 From body modification to modified body
If the body state is modified to express *B* with level *V*,

then the body state will have expression *B* with level *V*.
effector_state(B, V) ↠ body_state(B, V)

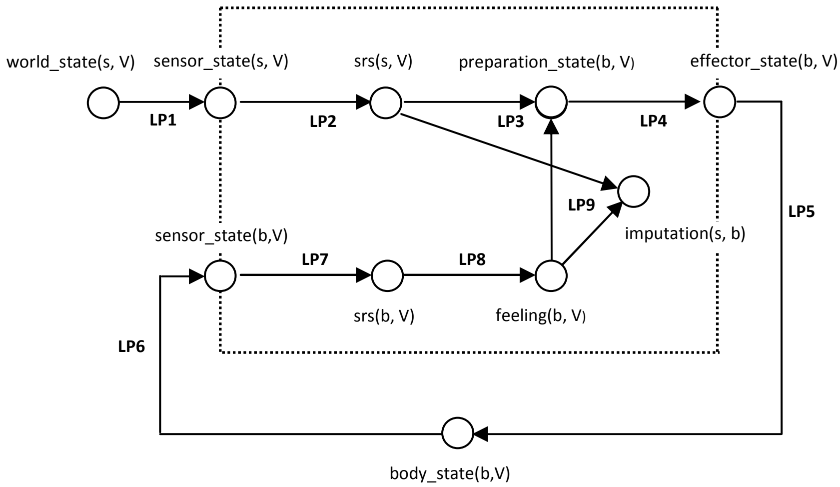

Fig. 2: Agent model for emotion generation and imputation

LP6 Sensing a body state
If body state *B* with level V occurs,
then this body state is sensed.
body_state(B, V) ↠ sensor_state(B, V)

LP7 Generating a sensory representation of a body state
If body state *B* of level *V* is sensed,
then a sensory representation for body state *B* with level *V* will occur.
sensor_state(B, V) ↠ srs(B, V)

LP8 From sensory representation of body state to feeling
If a sensory representation for body state *B* with level *V* occurs,
then *B* is felt with level *V*.
srs(B, V) ↠ feeling(B, V)

In the imputation state, the emotion b felt, is related to the stimulus s, that triggered the emotion generation process. Note that this state makes sense in general, for any type of stimulus s, as usually a person does not only feel an emotion, but also has an awareness of what causes an emotion; what in (Damasio, 1999) is called a state of conscious feeling also plays this role.

LP9 Imputation
If a certain emotion *b* is felt, with level *V≥ 0.5* and a sensory representation for *s* occurs,
then emotion *b* will imputed to *s*.
srs(s, 1) & feeling(Bb, V) & V≥0.5 ↠ imputation(s, b)

4.2 Incorporating a Mirroring Function to Enable Simulation and Mindreading

An agent model for emotion reading from the Simulation Theory perspective should essentially be based on a model to generate the own emotions. Indeed, the model presented in the previous section can be used in a quite straightforward manner to enable emotion reading. The main step is that the stimulus s that triggers the emotional process, which until now was left open, is instantiated with the body state of another person, to make it specific, a face expression f of another person is considered: s = othersface(f). Based on the assumption that a preparation state (for a similar own face expression) exists that by some connection is triggered by this observation, the model described above will immediately start to perform simulation of the observed person's internal process, and through this performs mindreading. The assumption that such a connection between an observed face expression and preparation for a similar own face expression exists (either innate or resulting from learning) has found a wide support in the literature, starting, for example, from very young children responding to a smile of their parents by their own smile; see also (Iacoboni, 2008).

Using the model, a number of simulations have been performed; for an example, see Fig. 3 (here the time delays within the temporal LEADSTO relations were taken 1 time unit). In this figure, where time is on the horizontal axis, the upper part shows the time periods in which the binary logical state properties world_state(s), sensor_state(s), srs(s), imputation(s, f) hold (indicated by the dark lines): respectively from time point 0, 1, 2 and 9. Below this part for the other state properties values for the different time periods are shown (by the dark lines). For example, the preparation state for f has value *0.5* at time point 3, which is increased to *0.75* and further at time point 9 and further. The graphs show how the recursive body loop approximates converging states both for feeling and face expression: value *1* for both.

The model extended by the above two temporal relations in LEADSTO format, was used for simulation as well. An example simulation trace was obtained that for a large part coincides with the one shown in Fig. 2 (with the other person's face expression f as the stimulus), with an extension as shown in Fig. 4. Here also the time delays within the additional temporal LEADSTO relations were taken one time unit. Where relevant, initial values were taken *0*.

Furthermore, for the sake of illustration, following the emotion imputation, a communication about it is prepared and performed. This extension is not essential for the emotion reading capability, but shows an example of behavior based on emotion reading.

LP10 Communication preparation
If emotion *B* is imputed to *S*,
then a related communication is prepared
imputation(B, S) $\rightarrow\!\!\rightarrow$ preparation_state(say(your emotion is B))

LP11 Communication
If a communication is prepared,
then this communication will be performed.
preparation_state(say(your emotion is B)) $\rightarrow\!\!\rightarrow$ effector_state(say(your emotion is B))

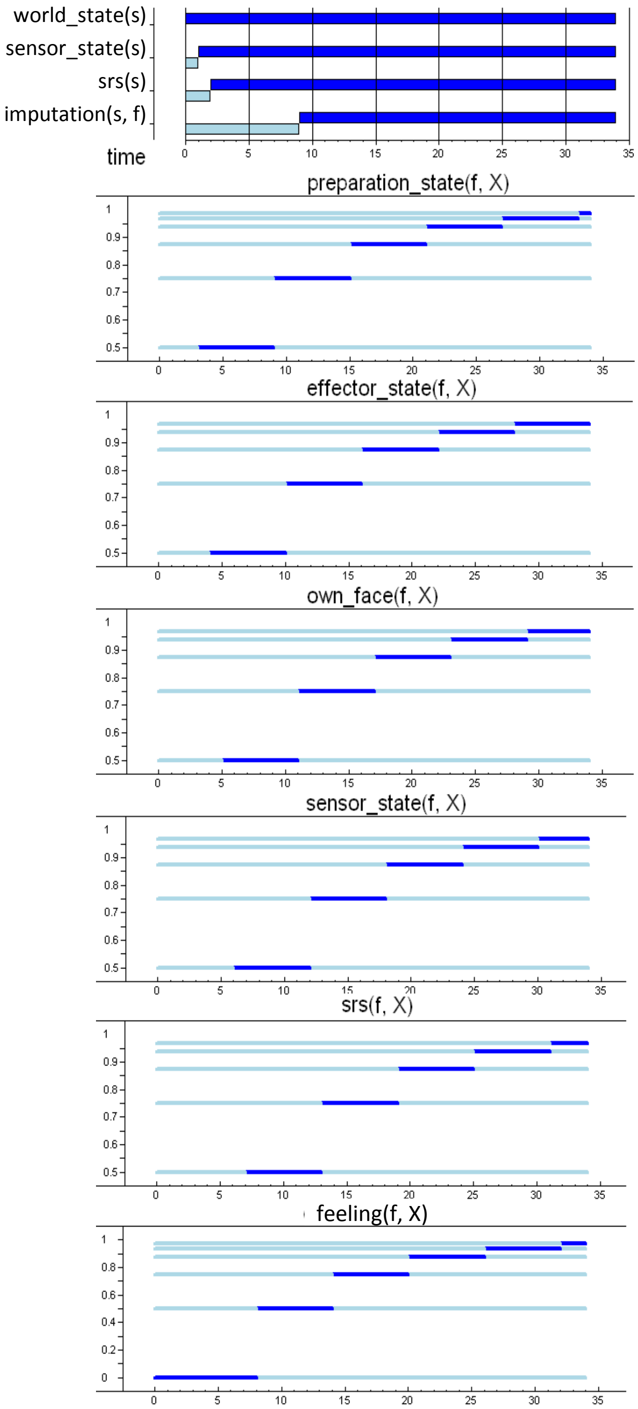

Fig. 3: Simulation trace for emotional responses and feelings based on a recursive body loop

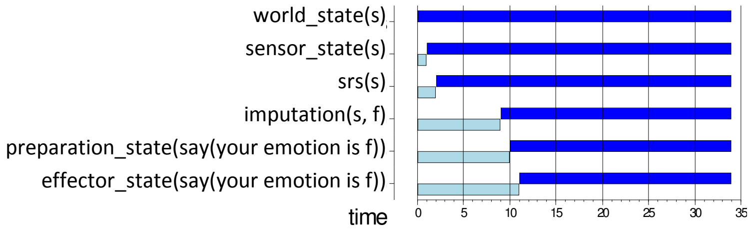

Fig. 4: Simulation trace extension for emotion reading

5 An Agent Model for Empathic Understanding

The agent model for empathic understanding (of type (3c) in Table 1) presented in this section is also based on the Simulation Theory perspective; cf. [18]. According to this perspective empathic understanding is obtained by the observing agent by activating the same own mental states as the observed agent, thereby using similar mechanisms as those used by the observed agent. Therefore, a first step is the design of the basic mechanisms to generate a cognitive state (here a belief state was chosen), and to generate the associated feelings. These basic mechanisms will be used by both agents.

A lottery scenario is used to illustrate the model. Agent A observes both his own lot number and the winning number and creates the corresponding beliefs; as the number in both beliefs is the same, from these the belief that the lottery was won is generated, which leads to an associated feeling of happiness. By communication, agent B hears from agent A about the own lot number and the winning number. From this he simulates the process in agent A thus entering an empathic understanding process in which he generates both the belief about the lottery won and the associated feeling. For an overview of the model for agent A, see Fig. 5. An overview of the model of agent B is depicted in Fig. 6. These pictures also show representations from the detailed specifications explained below. The detailed specification (both informally and formally) of the agent model for empathic understanding is presented below. Here capitals are used for (assumed universally quantified) variables, e.g. 'B', whereas small letters represents an instance of that variable, e.g. 'b'. All aspects have been formalized numerically by numbers in the interval [0, 1].

5.1 An Agent Model for Emotional Responses and Feelings for the Lottery Case

First the part is presented that describes the basic mechanisms to generate a belief state (on winning the lottery) and the associated feeling (of happiness). These are used by both the observed and observing agent. The first dynamic property addressing how properties of the world state can be sensed is LP1 as also used in Section 4.

LP1 Sensing a world state
If world state property *W* occurs of level *V*
then a sensor state for *W* of level *V* will occur.
world_state(W, V) ↠ sensor_state(W, V)

For this case this dynamic property is used by agent A to observe both the own number and the winning number (see Fig. 5); to this end the variable W is instantiated by own_number(x) and winning_number(x). Note that communications are also considered world facts; LP1 is used by agent B by instantiating W for communications indicated as communicated_by_to(I, agentA, agentB). From this sensory representations and beliefs are generated according to the next two dynamic properties LP2 and LP3. Note that also for these the variable W is instantiated as before. By LP2 a sensory representation is created.

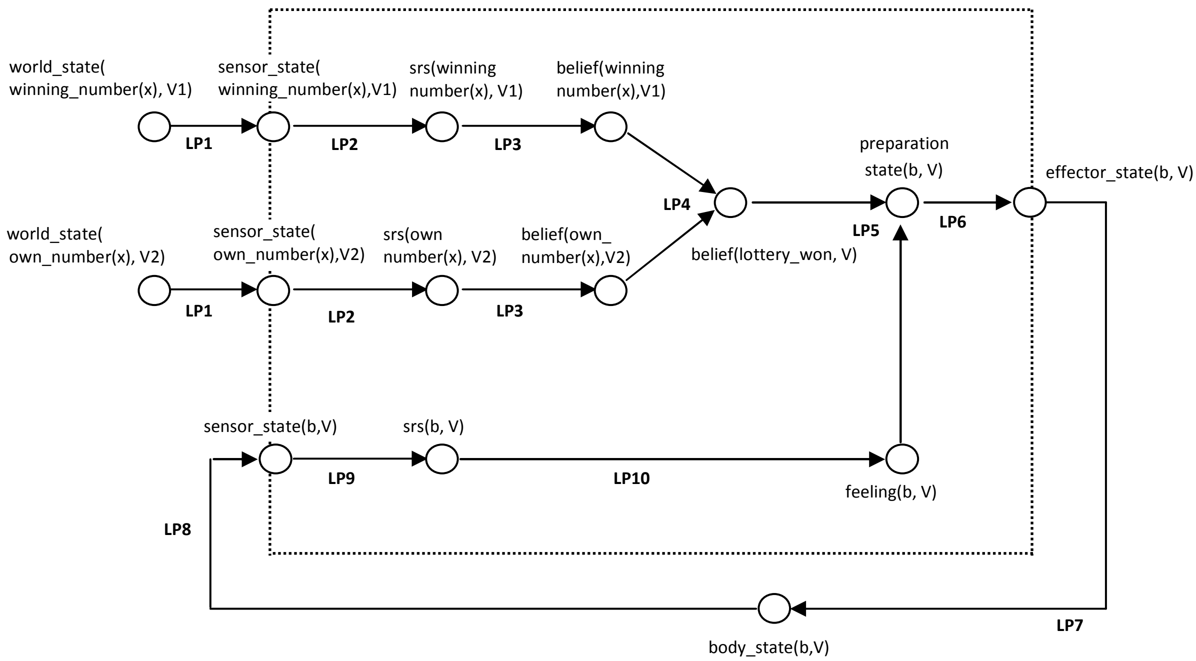

Fig. 5: Overview of the agent model for the observed person A

The generation of beliefs based on observations goes via a sensory representation as follows.

LP2 Generating a sensory representation for a sensed world state
If a sensor state for world state property *W* with level *V* occurs,
then a sensory representation for *W* with level *V* will occur.
sensor_state(W, V) ↠ srs(W, V)

LP3 Generating a belief state for a sensory representation
If a sensory representation for *W* with level *V* occurs,
then a belief for *W* with level *V* will occur.
srs(W, V) ↠ belief(W, V)

Dynamic property LP4 describes how the beliefs based on observations are used to infer a belief that the lottery was won.

LP4 Generating a belief on winning the lottery
If a belief with level *V1* occurs that *X* is the main price winning number of the lottery
and a belief with level *V2* occurs that *X* is the number of the own lot
then a belief with level *0.5V1+0.5V2* will occur that the main price of the lottery was won
belief(winning_number(X), V1) & belief(own_number(X), V2) ↠ belief(lottery_won, 0.5V1+0.5V2)

The emotional response to this belief is the preparation for a specific bodily reaction b, as expressed in dynamic property LP5.

LP5 From belief that lottery was won and feeling to preparation of a specific body state
If a belief that the lottery was won with level *V1* occurs and feeling body state b has level *V2*,
then preparation state for body state *b* will occur with level *0.5V1+0.5V2*.
belief(lottery_won, V1) & feeling(b, V2) ↠ preparation_state(b, 0.5V1+0.5V2)

Dynamic properties LP6 to LP10 describe the body loop for this case, as before in Section 4.

LP6 From preparation to effector state for body modification
If preparation state for body state *B* occurs with level *V*,
then the effector state for body state *B* with level *V* will occur.
preparation_state(B, V) ↠ effector_state(B, V)

LP7 From effector state to modified body
If the effector state for body state *B* with level *V* occurs,
then the body state *B* with level *V* will occur.
effector_state(B, V) ↠ body_state(B, V)

LP8 Sensing a body state
If body state *B* with level *V* occurs,
then this body state *B* with level *V* will be sensed.
body_state(B, V) ↠ sensor_state(B, V)

LP9 Generating a sensory representation of a body state
If body state *B* with level *V* is sensed,
then a sensory representation for body state *B* with level *V* will occur.
sensor_state(B, V) ↠ srs(B, V)

LP10 From sensory representation of body state to feeling
If a sensory representation for body state *B* with level *V* occurs,
then *B* is felt with level *V*.
srs(B, V) ↠ feeling(B, V)

5.2 An Agent Model for Empathic Understanding for the Lottery Case

Above the part of the model was shown that is used by both the observed and observing agent. Next the part of the model is discussed that is particularly involved in the empathic understanding process. This part of the model is used within the observing agent; see Fig. 6. First the communication from the other agent is related to the own beliefs.

LP11 Affecting own beliefs by communicated information
If in agent B a sensory representation with level *V* occurs that agent A communicated world fact *W*,
then a belief with level *V* for this world fact will occur.
srs(communicated_by_to (W, agentA, agentB), V) ↠ belief(W, V)

Next it is shown how the imputation process takes place for a belief. Here, *th* is a (constant) threshold for imputation. In the simulations shown, th is assumed 0.95 as an example.

LP12 Imputation of a belief
If a belief that the lottery was won with level *V1≥ th* occurs
and a belief occurs with level *V2≥th* that the own number was communicated by agentA,
and a belief occurs with level *V3≥th* that the winning number was communicated by agentA,
then the belief that the lottery was won will imputed.
belief(lottery_won, V1) &
belief(communicated_by_to(own_number(X1), agentA, agentB), V2) &
belief(communicated_by_to(winning_number(X2), agentA, agentB), V3) &
V1≥th & V2≥th & V3≥th
↠ imputation(belief(lottery_won), agentA)

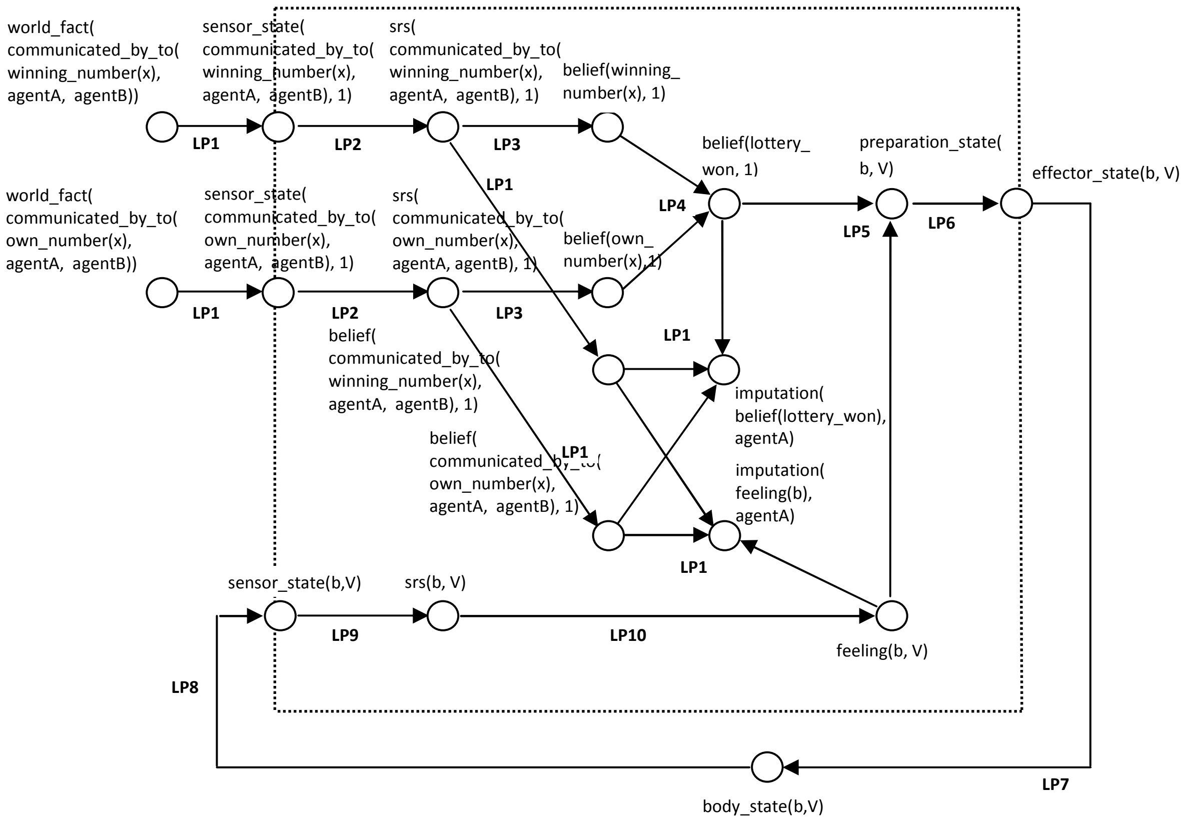

Fig. 6: Overview of the agent model for empathic understanding by the observing person B

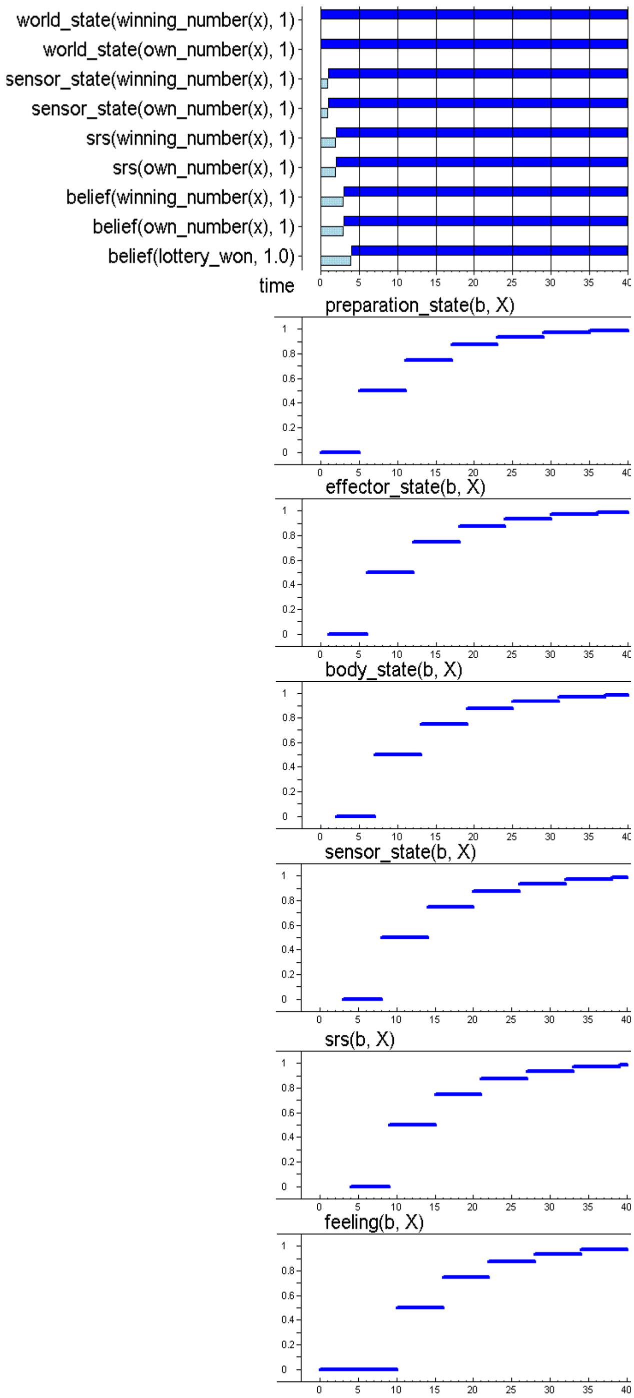

Fig. 7: Example simulation trace for the observed person

Finally, feelings are imputed in the following manner.

LP13 Imputation of a feeling
If a certain body state *B* is felt, with level *V1≥ th*
and a belief occurs with level *V2≥th* that the own number was communicated by agentA,
and a belief occurs with level *V3≥th* that the winning number was communicated by agentA,
then feeling *B* will imputed.

```
feeling(B, V1) &
belief(communicated_by_to(own_number(X1), agentA, agentB), V2) &
belief(communicated_by_to(winning_number(X2), agentA, agentB), V3) &
V1≥th & V2≥th & V3≥th
→ imputation(feeling(B), agentA)
```

5.3 Example Simulation Results for Empathic Understanding in the Lottery Case

Based on the model described in the previous section, a number of simulations have been performed. Some example simulation traces are included in this section as an illustration; see Fig. 7 and Fig. 8 (here the time delays within the temporal LEADSTO relations were taken 1 time unit). In all of these figures, where time is on the horizontal axis, the upper part shows the time periods, in which the binary logical state properties hold (indicated by the dark lines); for example,

```
world_state(winning_number(X), 1)
belief(lottery_won, 1.0)
imputation(feeling(b), agentA)
```

Below this part, quantitative information for the other state properties values for the different time periods are shown (by the dark lines). For example, in Fig. 7, the preparation state for b has value 0.5 at time point 6 which increased to 0.75 at time point 12 and so forth. The graphs show how the recursive body loop approximates a state for feeling with value 1. Notice that in all lower 6 traces i.e. from preparation state to feeling state, the states are activated based on temporal delay between them, i.e. preparation state has activation level '0' at time point 0, the successor state effector state has activation level '0' at time point 1 and so on.

Fig. 7 shows the simulation for the observed agent based on the basic mechanisms to generate a belief state and to generate the associated feeling as described in the previous section (from LP1 to LP10). As shown in Fig. 7 (upper part), the observed agent A notices his own number and the winning number from the world state, shown by the state properties

```
sensor_state(own_number(X), 1)
sensor_state(winning_number(X), 1)
```

respectively. It then generates the belief that he has won the lottery by comparing the two numbers shown by the state property

```
belief(lottery_won(X), 1.0)
```

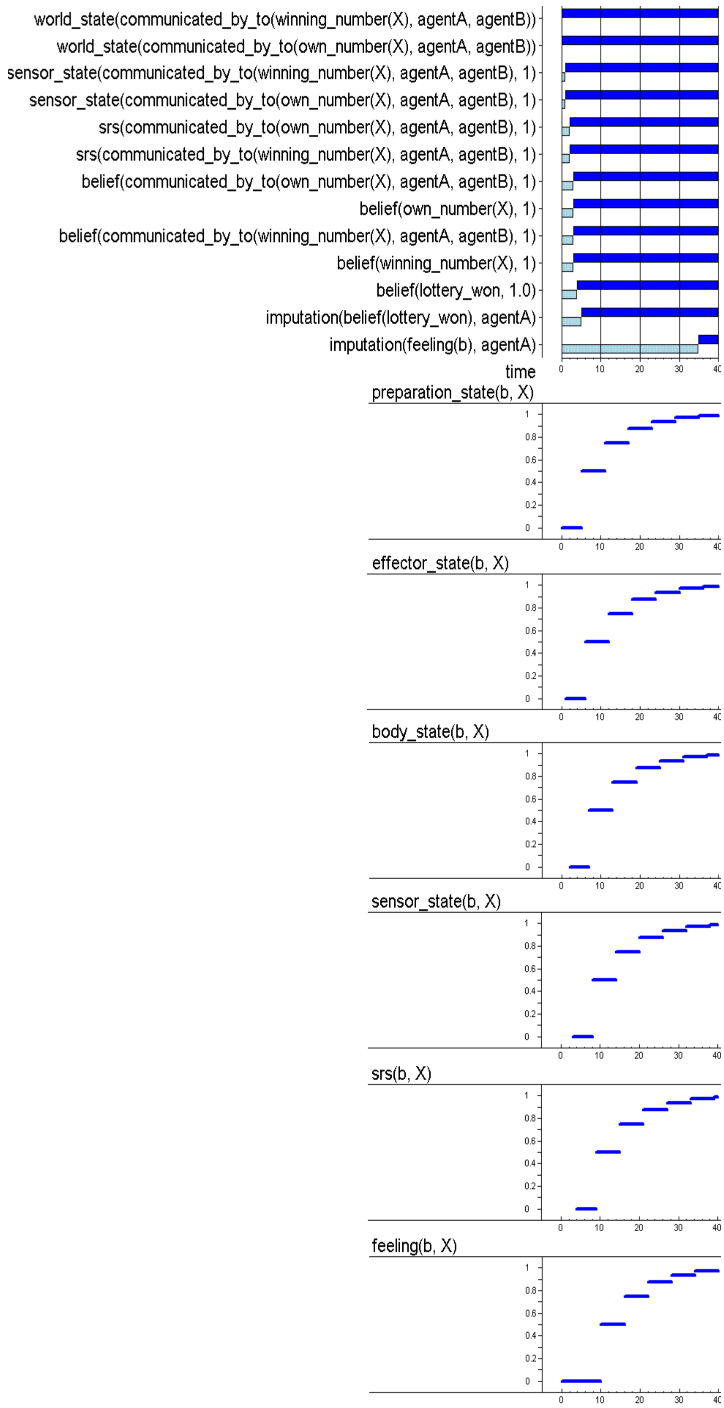

Fig. 8: Example simulation trace for the observing agent

The lower part of Fig. 7 shows the values of the various activation levels over time. Here it is shown that the recursive body loop results in an approximation of convergent activation levels for the states that relate to the feeling and the body state, among others.

Fig. 8 shows a simulation trace for the observing agent, depicting the empathic understanding process described in the previous section (in particular using LP11 to LP13, but also using LP1 to LP10 for the underlying basic mechanism). Here it is shown (in the upper part of the Fig. 8) that agent A (observed agent) communicates his own number and winning number to the agent B (observing agent), shown by the state properties

sensor_state(communicated_by_to(own_number(X), agentA, agentB), 1)
sensor_state(communicated_by_to(winning_number(X), agentA, agentB), 1)

respectively. Stepping in the shoes of agent A, then agent B (the observing agent) generates its own beliefs about the lot numbers and about winning lottery belief (which mirror the beliefs of agent A), as shown by the state property

belief(lottery_won, 1.0)

Later agent B imputes this belief (at time point 5) to agent A as shown by state property

imputation(belief(lottery_won), agentA).

As shown in the figure, after generating the associated feeling, agent B also imputes this feeling to agent A, shown by the state property

imputation(feeling(b), agentA)

at time point 35.

6 Mathematical Analysis

In this section it is analysed what the equibria of the proposed model are. The following equilibrium equations ELP1 to ELP13 can be obtained from the dynamic properties LP1 to LP13. Here, for example, *sensor_state(W)* denotes the equilibrium value for the sensor state for *W*, and the same for the other states; moreover, for binary logical states expressions such as

imputation(belief(lottery_won), agentA)

have the value *1* indicating that it is true and *0* that it is false. With these notations, the equilibrium equations are:

ELP1 *sensor_state(W) = world_state(W)*

ELP2 *srs(W) = sensor_state(W)*

ELP3 *belief(W) = srs(W)*

ELP4 *belief(lottery_won) = 0.5 belief(winning_number(X)) + 0.5 belief(own_number(X))*

ELP5 *preparation_state(b) = 0.5 belief(lottery_won) + 0.5 feeling(b)*
ELP6 *effector_state(B) = preparation_state(B)*
ELP7 *body_state(B) = effector_state(B)*
ELP8 *sensor_state(B) = body_state(B)*
ELP9 *srs(B) = sensor_state(B)*
ELP10 *feeling(B) = srs(B)*
ELP11 *belief(W) = srs(communicated_by_to (W, agentA, agentB))*
ELP12 *belief(lottery_won) ≥ th &*
belief(communicated_by_to(own_number(X1), agentA, agentB)) ≥ th &
belief(communicated_by_to(winning_number(X2), agentA, agentB)) ≥ th
⇒ imputation(belief(lottery_won), agentA) = 1
ELP13 *feeling(B) ≥ th &*
belief(communicated_by_to(own_number(X1), agentA, agentB))≥ th &
belief(communicated_by_to(winning_number(X2), agentA, agentB)) ≥ th
⇒ imputation(feeling(B), agentA) = 1

Moreover, the environment context provides:

EC *world_state(communicated_by_to(own_number(X), agentA, agentB)) = 1*
world_state(communicated_by_to(winning_number(X), agentA, agentB)) = 1

From this via ELP1 to ELP3 and ELP11 it follows that

belief(communicated_by_to(own_number(X), agentA, agentB)) = 1
belief(communicated_by_to(winning_number(X), agentA, agentB)) = 1

belief(own_number(X)) = 1
belief(winning_number(X)) = 1

By LP4 it follows

belief(lottery_won) = 1

and by ELP5 this provides

ELP14 *preparation_state(b) = 0.5+ 0.5 feeling(b)*

From ELP6 to ELP10 it follows

ELP15 *preparation_state(b) = effector_state(b) = body_state(b) =*
sensor_state(b) = srs(b) = feeling(b)

From ELP14 and ELP the following equation in *feeling(b)* is obtained (which corresponds to the loop in the model):

feeling(b) = 0.5+ 0.5 feeling(b)

From this it follows

$$feeling(b) = 1$$

and by ELP15, the other values in ELP15 are *1* too.

Finally, from ELP12 and ELP13 it follows

$$imputation(belief(lottery\_won), agentA) = 1$$
$$imputation(feeling(B), agentA) = 1$$

This mathematical analysis confirms the outcomes of the simulations in the previous section.

7 Discussion

In the literature on automated emotion recognition, a person's observations of another person's body state, for example, facial expressions, are used as a basis. Here, a specific emotion recognition process can be modelled in the form of a classification process of facial expressions in terms of a set of possible emotions; see, for example, [38]. Indeed, a model based on such a classification procedure is able to perform emotion recognition. However, within such an approach the imputed emotions will not have any relationship to a person's own emotions. The basic agent model for emotion reading used in the current paper as a point of departure (adopted from [37]; see also the extended [11] combines the person's own emotion generation with the emotion reading process as also claimed by the Simulation Theory perspective on mindreading, e.g., [18], [21]. According to this perspective mindreading is performed by the observing agent in a simulative manner by activating the same mental states as the observed agent; see also [24]. This assumption is recently getting more and more support by empirical results, for example, concerning the discovery of the mirror neuron system; e.g., [43], [29], [27], [28], [20], [39].

For an agent observing another agent, having an empathic understanding of the observed agent is considered different from just mindreading. Mindreading as such can focus on certain aspects such as emotion, desire, belief, intention, or attention states (e.g., [17]). A characteristic of an empathic response is that the response does not only include that the observing agent understands the mental state of the observed agent, but also feels the associated feeling. In this paper it was shown how the presented agent model is capable of understanding other agents in an empathic way. The dynamical systems style (cf. [40]) agent model describes how the empathic agent does not only understand another agent's mental state but at the same time feels the accompanying emotion. This agent model for empathic understanding proposed was based on two main assumptions:

(1) The observing agent performs mindreading using the same mental states as the observed agent
(2) Both agents have a similar mechanism to associate feelings to a given mental state

Concerning assumption (1), to obtain a form of mindreading for which the observing agent generates the same mental state, the Simulation Theory perspective was followed; cf. [18]. Concerning assumption (2), to this end a computational model of Damasio [12], [13]'s informal theory about the generation of emotion and feeling was exploited. This theory assumes a neural mechanism that involves changes in an agent's sensed body state, triggered by a certain mental state. Assuming that the observed agent and the observing agent indeed have a similar mechanism for this, makes it possible that for a given mental state the observing agent generates the same feeling as the observed agent.

Especially in relation to assumption (2) it can be questioned to which extent the mechanisms to associate feelings to a given mental state are always the same for two persons. As it may be considered plausible that basically the mechanisms are similar, it is not difficult to imagine that both due to innate and learned individual differences, the empathic reaction may be limited in extent. Indeed, it is often reported that identical twins have a much higher level of mutual empathy than any two persons which are not identical twins. Moreover, it is also often considered that more empathy is shown between two persons when they have had similar experiences in life. Nevertheless, a certain extent of empathy still seems possible between persons which are not genetically identical and have not exactly the same experiences. It is an interesting challenge for future research to develop the introduced model for empathy further by introducing parameters by which such individual differences can be expressed, and for which some notion of extent to which empathy occurs can be defined.

In a wide literature, the role of emotions in virtual agents in general is addressed; e.g., [2], [22], [49]. Usually these approaches are not specifically related to empathic responses, and often use body or face expressions as a way of presentation, and not as a more biologically grounded basis for the emotion as in the neurological perspective of [12], [13], which was adopted in the current paper. The importance of computational models for 'caring' agents in a virtual context showing empathy has also been recognized in the literature; see, for example [33], [3], [4], [36]. The presented cognitive agent model differs from such existing models in that it is grounded in recent insights from neuroscience, especially the theories of Damasio [12], [13]. Other models described in the literature related to empathy usually only address more limited forms of empathy (see Section 2 and Table 1), for example:

- emotion recognition (e.g., [38], [18]), or
- recognition of some cognitive state (e.g., [9]), or
- contagion of emotions; (e.g., [23]).

As far as the authors know the model proposed here is unique in the sense that it combines both understanding and (associated) feeling of another person's states, and takes into account the way in which (other) mental states induce feelings both for the observing and the observed person in an isomorphic manner.

A limitation of the approach adopted in the current paper, is the mechanism by which it deals with 'imputation' state. In this paper, the imputation state has been worked out in a simplified manner, by using an executable rule. The current paper did not discuss about the issue of what will happen if 'imputation' did not occur or what will be the result of the 'imputation' state based on the available psychological literature. These issues have been left to future work. Future work will also address a more extensive evaluation and assessment of the models and thereby will explore more variations, for example, of different scenarios with different extents of similarity between the persons, and different values of its parameters such as the threshold value and the weight factors, for example in the generation of the preparation and the belief which were now taken *0.95* and *0.5* respectively.

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