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An Adaptive Emotion Reading Model

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Abstract

This paper focuses on how capabilities to interpret somebody else's emotions can be modelled in an adaptive manner. First a cognitive model to generate emotional states is described. This model involves a recursive body loop: a converging positive feedback loop based on reciprocal causation between body states and emotions felt. By this model emotion reading can be modelled taking into account the Simulation Theory perspective on mindreading as known from the literature, which assumes that the own emotions are involved in reading somebody else's emotions. It is shown how the model was extended to an adaptive model within which a direct connection between a stimulus and the emotion recognition is created, which implies that in principle the observed emotion can be recognised just before it is felt.

Keywords: Theory of Mind; mindreading; adaptive emotion reading; emotion generation; modeling; simulation.

Introduction

From an evolutionary perspective, mindreading (or having a Theory of Mind) in humans and some other kinds of animals has developed for a number of aspects, for example, intention, attention, emotion, knowing (e.g., Baron-Cohen, 1995; Bogdan, 1997; Dennett, 1987; Goldman, 2006; Goldman & Spirada, 2004; Malle, Moses & Baldwin, 2001). Two philosophical perspectives on having a Theory of Mind are Simulation Theory and Theory Theory (Goldman, 2006). In the first perspective it is assumed that mindreading takes place by using the facilities 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. The second perspective is based on reasoning using knowledge about relationships between cognitive states and observed behaviour. An example of such a pattern is: 'I hear that the person says 'ouch!'. Having pain causes saying 'ouch!'. Therefore the person has pain'. The current paper addresses emotion reading from a Simulation Theory perspective: an approach is adopted that involves a person's own emotions in the process of reading the human's emotions.

The concept of 'body loop' as put forward by Damasio (1999) and formalised by Bosse, Jonker and Treur (2008) is used as a point of departure. This perspective distinguishes the (bodily) emotional response to a stimulus from feeling the emotion (sometimes called the emotional feeling), which is caused by sensing the own bodily response. Secondly, an extension of this idea is adopted by assuming that the body loop is not processed once, but in a recursive manner: a converging positive feedback loop based on reciprocal causation between emotional state (with gradually more feeling) and body state (with gradually stronger expression). This cycle is triggered by the stimulus and after an indefinite number of rounds ends up in equilibrium for both states. In this way a model is obtained in which the process of generating an emotional feeling is not only assumed to be carried by neurological structures, but equally well by body states, in a reciprocal causation and convergence process. By Bosse, Memon, and Treur (2008) and Memon and Treur (2008), it was shown that such a recursive body loop model for emotions is an appropriate basis to obtain an emotion reading model from the Simulation Theory perspective. In the current paper it is shown how the model based on a recursive body loop can be extended to obtain an adaptive model for emotion reading. The adaptation creates a shortcut connection from the stimulus (observed facial expression) to the imputed emotion, bypassing the own emotional states. Some simulation results are discussed, and some formally specified dynamic properties of adaptive and non-adaptive emotion reading are shown, and it is discussed how they were verified against simulation traces.

An Emotion Generation Model

The model to generate emotional states for a given stimulus adopts from Damasio (1999) the idea of a 'body loop' and 'as if body loop', but extends this by making these loops recursive. According to the original idea, emotion generation via a body loop roughly proceeds according to the following causal chain:

sensing a stimulus → sensory representation of stimulus →
(preparation for) bodily response → sensing the bodily response →
sensory representation of the bodily response → feeling the emotion

As a variation, an 'as if body loop' uses a causal relation

preparation for bodily response →
sensory representation of the bodily response

as a shortcut in the causal chain. In the model used here an essential addition is that the body loop (or as if body loop) is extended to a recursive (as if) body loop by assuming that the preparation of the bodily response is also affected by the state of feeling the emotion (also called emotional feeling):

feeling the emotion → preparation for bodily response

as an additional causal relation. This idea is supported by the following quote from Damasio (2003, p. 91-92):

'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.'

Both the bodily response and the emotional 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 emotional feeling and body state. Here in each round of the cycle the next body state has a level that is affected by both the level of the stimulus and of the emotional feeling state, and the next level of the emotional feeling is based on the level of the body state. In the more detailed model described 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 0.5 in this case). This implies a pattern of gradual generation (and extinction) of an emotion upon a stimulus.

In the description of the detailed cognitive model the temporal relation a →→ 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 language (called LEADSTO) both logical and numerical calculations can be specified, and a dedicated software environment is available to support specification and simulation; for details see (Bosse, Jonker, Meij, & Treur, 2007). The specification (both informally and formally) of the model for emotion generation based on a recursive body loop is as follows.

LP1 Sensing a stimulus
If stimulus s occurs then a sensor state for s will occur.
s →→ sensor_state(s)

LP2 Generating a sensory representation of a stimulus
If a sensor state for s occurs, then a sensory representation for s will occur.
sensor_state(s) →→ srs(s)

LP3 From sensory representation and emotion to preparation[1]
If a sensory representation for s occurs and emotion e has level v,
then preparation state for facial expression f will occur with level (1+v)/2.
srs(s) & emotion(e, v) →→ preparation_state(f, (1+v)/2)
If no sensory representation for s occurs and emotion e has level v,
then preparation state for facial expression f will occur with level v/2.
not srs(s) & emotion(e, v) →→ preparation_state(f, v/2)

LP4 From preparation to body modification
If preparation state for facial expression f occurs with level v,
then the face is modified to express f with level v.
preparation_state(f, v) →→ effector_state(f, v)

LP5 From body modification to modified body
If the face is modified to express f with level v,
then the face will have expression f with level v.
effector_state(f, v) →→ own_face(f, v)

LP6 Sensing a body state
If facial expression f with level v occurs,
then this facial expression is sensed.
own_face(f, v) →→ sensor_state(f, v)

LP7 Generating a sensory representation of a body state
If facial expression f of level v is sensed, then a sensory representation for facial expression f with level v will occur.
sensor_state(f, v) →→ srs(f, v)

[1] Here, it is assumed that the relative effects of both antecedents are the same. However, the formula (1+v)/2 can as well be replaced by the more generic formula w1+w2*v with weights w1 and w2. Such an extension also enables the modeller to distinguish different types of emotions (e.g., fear may develop faster than happiness).

LP8 From sensory representation of body state to emotion
If a sensory representation for facial expression f with level v occurs,
then emotion e is felt with level v.
srs(f, v) →→ emotion(e, v)

LP9 Imputation
If a certain emotion e is felt, with level ≥ th and a sensory representation for s occurs, then emotion e will imputed to s. Here, th is a (constant) threshold for imputation of emotion. In the simulations shown, th is assumed 0.95.
srs(s) & emotion(e, v) & v≥th →→ imputation(s, e)

In the imputation state, the experienced emotion e is related to the stimulus s, which triggers 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 by Damasio (1999) is called a state of conscious feeling also plays this role. This state that relates an emotion felt to any triggering stimulus will play an important role in the emotion reading process.

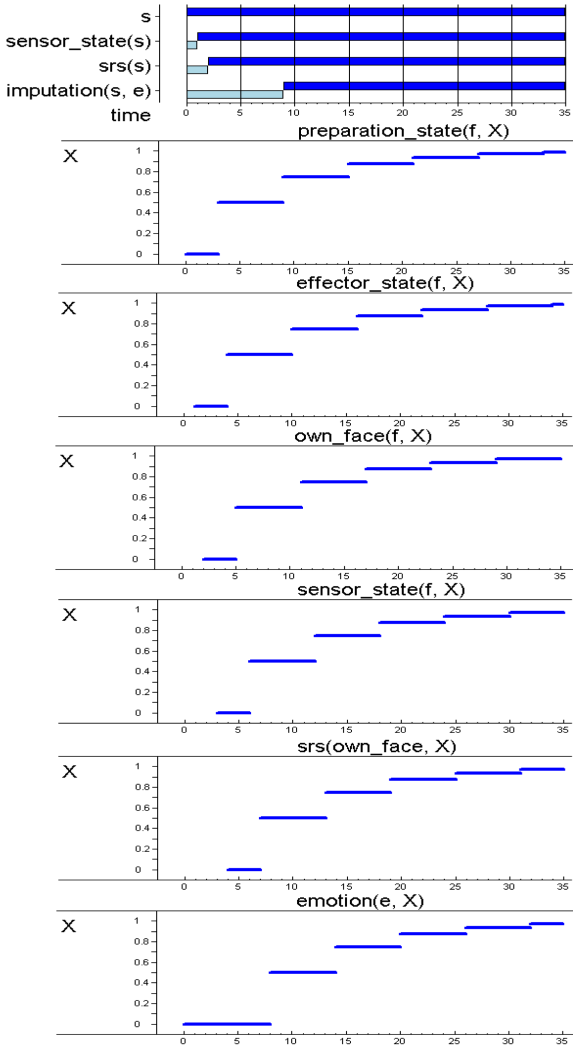

Figure 1: Example simulation of emotion generation

Instead of a recursive body loop, a variation of the model as described can be made to model a ‘recursive as if body loop’; see (Damasio, 1999) for evidence for a causal relation between preparation state and sensory representation. This can be incorporated by replacing the temporal relations LP4, LP5. LP6, LP7 by the following:

LP4* From preparation to sensory representation of body state
If preparation state for facial expression f occurs with level v, then a sensory representation for facial expression f with level v will occur.
preparation_state(f, v) $\twoheadrightarrow$ srs(f, v)

Based on the model, a number of simulations have been performed; for an example, see Figure 1 (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 s, sensor_state(s), srs(s), imputation(s, e) 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 points 9 and further. The graphs show how the recursive body loop approximates converging states both for emotion and facial expression.

Emotion Reading

Based on the model for emotion generation presented in the previous section, in this section a model for emotion reading (for the Simulation Theory perspective) is discussed. Such a model for emotion reading should essentially be based on a model to generate the own emotions. Indeed, the model presented in the previous section can be specialised in a rather 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 facial expression f of another person is considered: s = othersface(f). Indeed there is strong evidence that (already from an age of 1 hour) sensing somebody else’s facial expression leads (within about 300 milliseconds) to preparing for and showing the same facial expression (Goldman & Sripada, 2004, pp. 129-130). 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 just shows an example of behaviour based on emotion reading.

LP10 Communication preparation
If emotion e is imputed to s, then a related communication is prepared
imputation(e, s) $\twoheadrightarrow$ preparation_state(say(your emotion is e))

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

The model described in the previous section has been extended by the above two temporal relations in LEADSTO format, and used for simulation. An example simulation trace was obtained that for a large part coincides with the one shown in Figure 1 (with the other person’s facial expression f as the stimulus), with an extension as shown in Figure 2. Here also the time delays within the additional temporal LEADSTO relations were taken one time unit.

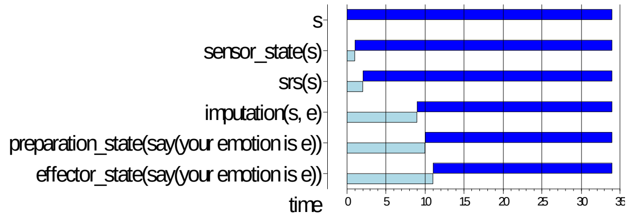

Figure 2: Trace extension for emotion reading

Adaptive Emotion Reading

As a next step, the model for emotion reading is extended by a facility to learn a direct connection between the stimulus (the other face) and the emotion imputation. Such a connection creates an emotion reading process that in principle bypasses the generation of the own emotion. The learning principle to achieve such an adaptation process is inspired by the well-known learning principle at a neurological level that connected neurons that are frequently activated simultaneously strengthen their connecting synapse (e.g., Gleitman, 1999). In an analogous manner, within the model presented here an extra state is included that represents the sensitivity of a direct connection between the sensory representation of the stimulus (the other face) and the emotion imputation. If this sensitivity is high, the imputation will directly follow the sensory representation of the stimulus, as is expressed by the following temporal relationship.

LP12 Imputation shortcut
If the imputation sensitivity is high and a sensory representation for s occurs, then emotion e will imputed to s.
srs(s) & srs_stimulus_imputation_sensitivity(high)
$\twoheadrightarrow$ imputation(s, e)

The adaptation process itself and the persistence of the sensitivity level is described by the following relationships.

LP13 Imputation sensitivity adaptation
If the imputation sensitivity is sen1 and a sensory representation for s occurs and an imputation occurs, then the imputation sensitivity is the value sen2 next to sen1.
srs(s) & imputation(s, e) &
srs_stimulus_imputation_sensitivity(sen1) &
next_value(sen1, sen2)
$\twoheadrightarrow$ srs_stimulus_imputation_sensitivity(sen2)

LP14 Imputation sensitivity persistence
If the imputation sensitivity is sen1 and no increase occurs, then it will remain the same.
srs_stimulus_imputation_sensitivity(sen1) &
next_value(sen1, sen2) &
not srs_stimulus_imputation_sensitivity(sen2)
$\twoheadrightarrow$ srs_stimulus_imputation_sensitivity(sen1)
srs_stimulus_imputation_sensitivity(high)
$\twoheadrightarrow$ srs_stimulus_imputation_sensitivity(high)

Adaptive Simulation

Based on the model for adaptive emotion reading presented in the previous section, a number of simulations have been performed; for an example, see Figure 3. In this figure, the imputation sensitivity state has initial value set to low, represented by srs_stimulus_imputation_sensitivity(low) in the upper part. The adaptation phase consists of two trials, where as soon as the person imputes emotion e to the target stimulus s (which is the observation of the other person's face), the imputation sensitivity level goes up, i.e., from low to medium to high, in accordance with the temporal relationship LP13 described above. Note that the sensitivity state keeps its value in the adaptation phase until the person (again) imputes emotion e to target, as described by temporal relationship LP14, but retains its final value, i.e. high, after the adaptation phase of two trials.

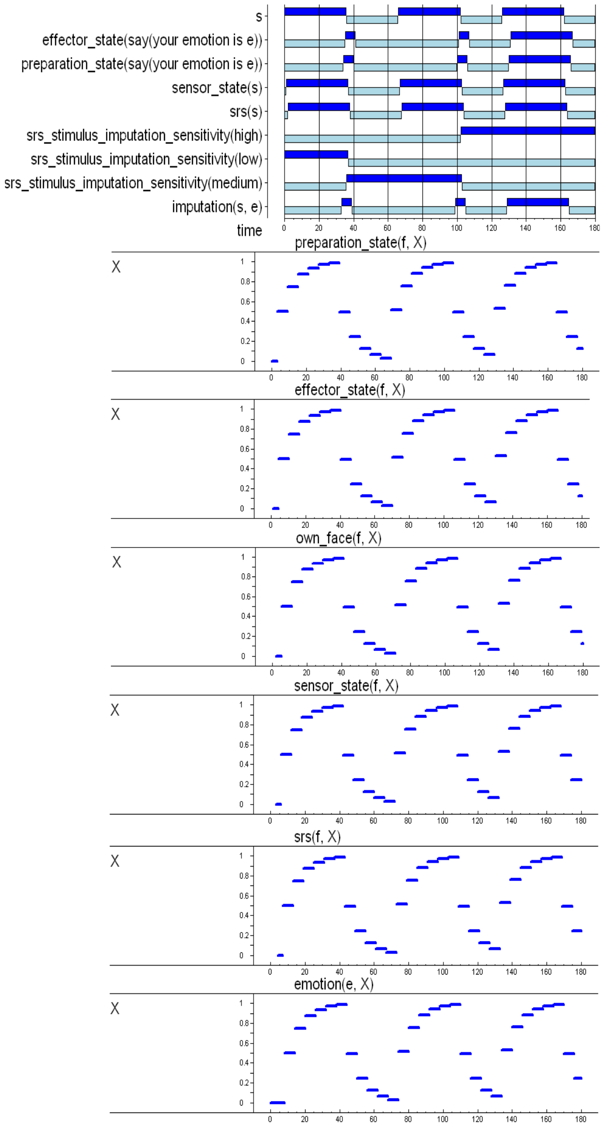

Figure 3: Simulation results for adaptive emotion reading

Note in the lower part of Figure 3, the values of other state properties gradually increase as the person observes the stimulus, following the recursive feedback loop discussed in Section 3. These values sharply decrease as the person stops observing the stimulus, as described by the temporal relationship LP3 in Section 3. After the adaptation phase, and with the imputation sensitivity at high, the person imputes emotion e to the target stimulus directly after occurrence of the sensory representation of the stimulus, as shown in the third trial in the upper part of Figure 3. Note here that even though the person has adapted to impute emotion e to the target directly after the stimulus, the other state property values continue to increase in the third trial as the person receives the stimulus; this is because the adaptation phase creates a connection between the sensory representation of the stimulus and emotion imputation without eliminating the recursive feedback loop altogether.

Verification of Properties

To verify whether the overall behaviour of the model is according to expectations, some hypotheses (in terms of logical dynamic properties) have been identified, formally specified, and verified for simulation traces. These properties express proper emotion reading, and some of them are meant to distinguish emotion reading in a situation before adaptation and after adaptation. In particular, before an accomplished adaptation process, upon occurrence of a stimulus, first the emotion has to be felt before the emotion reading takes place. After an adaptation process, the emotion reading takes place before the emotion is felt and therefore it will take place faster.

The modelling approach for temporal expressions is based on the Temporal Trace Language TTL (cf. Bosse, Jonker, Meij, Sharpanskykh & Treur, 2009). This reified temporal predicate logical language supports formal specification and analysis of dynamic properties, covering both qualitative and quantitative aspects. TTL is built on atoms referring to states, time points and traces. A *state* of a process for (state) ontology Ont is an assignment of truth values to the set of ground atoms in the ontology. The set of all possible states for ontology Ont is denoted by STATES(Ont). To describe sequences of states, a fixed *time frame* T is assumed which is linearly ordered. A *trace* γ over state ontology Ont and time frame T is a mapping γ : T $\rightarrow$ STATES(Ont), i.e., a sequence of states γ_t (t $\in$ T) in STATES(Ont). The set of *dynamic properties* DYNPROP(Ont) is the set of temporal statements that can be formulated with respect to traces based on the state ontology Ont in the following manner. Given a trace γ over state ontology Ont, the state in γ at time point t is denoted by state(γ, t). These states can be related to state properties via state(γ, t) |= p which denotes that state property p (from sort SPROP(Ont)) holds in trace γ at time t. Based on these statements, dynamic properties can be formulated in a sorted first-order predicate logic, using quantifiers over time and traces and the usual first-order logical connectives such as $\neg$, $\wedge$, $\vee$, $\Rightarrow$,

$\forall$, $\exists$. A special software environment has been developed for TTL, featuring a Property Editor for building TTL properties and a Checking Tool that enables formal verification of such properties against a set of traces.

Using the TTL environment, the following Global Properties (GP's) have been identified, formalised and automatically verified (first an abbreviation is introduced to count how often a state holds in a certain time period):

Abbreviations

state_holds_times_between(S:SPROP,0,tb,te:TIME,γ:TRACE) $\equiv$
$\neg$ [$\exists$t1:TIME tb<t1<te & state(γ, t1) |= S]

state_holds_times_between(S:SPROP,n+1,tb,te:TIME,γ:TRACE) $\equiv$
$\exists$t1:TIME tb<t1<te & state(γ, t1) |= S &
$\neg$[$\exists$t2:TIME tb<t2<t1 & state(γ, t2) |= S] &
state_holds_times_between(S, n, t1, te, γ)

GP1a Input-Output Correlation Timing

In trace γ, if at time point t1 the person perceives a facial expression of another person, then within time duration D this leads to communication about the person's emotional state.

GP1a(t1:TIME, γ:TRACE, D:REAL) $\equiv$
state(γ, t1) |= othersface(f) $\Rightarrow$
[$\exists$t2:TIME t1<t2<t1+D &
state(γ, t2) |= effector_state(your emotion is e)]

This first property checks whether the process of responding (verbally) to the stimulus is performed correctly. As could be expected, this property indeed turned out to hold for any t1. In the situation before learning, it holds for D=36, and after learning it holds already for D=6.

GP1b Input-Output Correlation During Learning

If in trace γ between tb and te the person perceives a facial expression of another person for n (different) time points, then within time duration D this leads to communication about the person's emotional state.

GP1b(tb, te:TIME, n:INTEGER, γ:TRACE, D:REAL) $\equiv$
state_holds_times_between(othersface(f), n, tb, te, γ) $\Rightarrow$
[$\exists$t:TIME te<t<te+D &
state(γ, t) |= effector_state(your emotion is e)]

This property also holds for all time points, and for n=3 and D=6: in all situations that the person perceived the stimulus three times, this resulted in a response within 6 time points.

GP2 Successful Associative Learning

If in trace γ between tb and te state property S1 and S2 hold together for n (different) time points, then eventually a relation between these states will be learned.

GP2(tb, te:TIME, n:INTEGER, γ:TRACE) $\equiv$
$\forall$S1,S2:SPROP
state_holds_times_between(S1$\wedge$S2, n, tb, te, γ) $\Rightarrow$
[$\exists$t:TIME $\exists$w:REAL te<t<te+D &
state(γ, t) |= sensitivity_for_relation_between(w, S1,S2) & w>δ]

This property holds for n=2 (and for D=1), which confirms that the associative learning is directly successful after two trials. Note that here δ is a certain sensitivity threshold, which can be considered to depend on n. Thus, an example instance of sensitivity_for_relation_between(w, S1, S2) could be the predicate srs_stimulus_imputation_sensitivity(high).

GP3a Emotion reading with own feeling

In trace γ, if at time point t1 a stimulus occurs, then there is a point in time that the emotion is recognised whereas it is felt as well.

GP3a(t1:TIME, γ:TRACE) $\equiv$
state(γ, t1) |= othersface(f) $\Rightarrow$
$\exists$t2:TIME, v:REAL [t1<t2<t1+D & v>th &
state(γ, t2) |= effector_state(your emotion is e) &
state(γ, t2) |= emotion(e, v)]

GP3b Emotion reading without own feeling

In trace γ, if at time point t1 a stimulus occurs, then there is a point in time that the emotion is recognised whereas it is not felt (yet).

GP3b(t1:TIME, γ:TRACE) $\equiv$
state(γ, t1) |= othersface(f) $\Rightarrow$
$\exists$t2:TIME, v:REAL [t1<t2<t1+D & v$\leq$0.1 &
state(γ, t2) |= effector_state(your emotion is e) &
state(γ, t2) |= emotion(e, v)]

These properties can be used to distinguish the phase when the person performs emotion reading with an experienced emotion from the phase without an experienced emotion. Checks pointed out that the second phase is entered at time point 126. To conclude, although not proven exhaustively, the above checks have pointed out that the model satisfies a number of relevant expected properties. In addition, they allow the modeller to fine-tune the precise temporal aspects of the simulated emotion reading process.

Discussion

A person's observations of another person's body, for example facial expressions, are used by the person as a basis for emotion recognition. Here, a specific emotion recognition process can be modelled in the form of a prespecified classification process of facial expressions in terms of a set of possible emotions; see, e.g., (Cohen, Garg & Huang, 2000; Malle, Moses & Baldwin, 2001; Pantic & Rothkrantz, 1997 & 2000). 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 model for emotion reading presented in the current paper combines the person's own emotion generation with the emotion reading process as also claimed by the Simulation Theory perspective on mindreading, (e.g., Goldman, 2006; Goldman & Sripada, 2004). In addition, adaptive facilities within the model allow the person to learn a direct classification without involving the own emotions.

In (Goldman, 2006, pp. 124-132), a number of possible emotion reading models from the Simulation Theory perspective are sketched and discussed. For his model 1, 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 hypothesis generation process for a given observed face was considered as less satisfactory. Models 2 and 3 discussed by Goldman (2006) are based on a notion of '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 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.

The approach adopted in the current paper has drawn some inspiration from the four models sketched (but not formalised) by Goldman (2006), 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. Moreover, it solves the problems of models 2 and 3, as the causal chain from facial expression to emotional state is not a reverse simulation, but just the causal chain via the body state which is used for generating the own emotional feelings 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.

Models for emotion reading by a person can be of two types: either they make use of the own emotion states of the person, or they are independent of them. In principle models according to the Simulation Theory perspective are of the first type, whereas models according to the Theory Theory perspective or based on a specific classification procedure can be of the second type. In (Bosse, Memon, & Treur, 2008) a non-adaptive cognitive model for emotion reading is described based on a recursive body loop according to the Simulation Theory perspective. Moreover, it is shown how this model can be used by an ambient software agent in order to estimate a person's emotion level. This software agent is adaptive in the sense that at run-time the parameter in the emotion reading model can be tuned to the person. By Memon and Treur (2008) it is shown how this non-adaptive model according to the Simulation Theory perspective can be related to a biological (neurological) model. In contrast to the above models, the current paper addresses a cognitive model for emotion reading which itself is adaptive. This adaptivity allows the model to gradually incorporate relations that bypass the own emotion states, and thus at run-time provides a model for emotion reading independent of the own emotion state. As this learnt pathway bypasses the own emotion generation process, and its body-related part, it may be faster. Moreover, as own emotions are not involved anymore, it may be argued that the learnt model for emotion reading by itself is not a model from the Simulation Theory perspective, whereas the model for the learning process to obtain this model is. As a final remark, it may be considered that the learnt model (or part of) is innate, and is only further tuned by the learning process.

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