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Authors
Memon, Zulfiqar Ali
Treur, Jan

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An Adaptive Integrative Ambient Agent Model to Intervene in the Dynamics of Beliefs and Emotions

Zulfiqar A. Memon [1,2], Jan Treur [1] ({zamemon, treur}@few.vu.nl)
[1] VU University Amsterdam, Department of Artificial Intelligence,
De Boelelaan 1081, 1081 HV Amsterdam, The Netherlands
[2] Sukkur Institute of Business Administration (Sukkur IBA),
Air Port Road Sukkur, Sindh, Pakistan

Abstract

In this paper an adaptive integrative ambient agent model is introduced incorporating estimation of a human's interactive dynamics of believing and feeling. The integrative agent model is equipped with a dynamical model which describes how the strength of a belief depends both on information obtained and emotional responses on the belief. In addition, the agent model integrates an adaptation model to tune parameter values representing personal characteristics. In a simple personalised case it is shown how the ambient agent model is able to assess a person's state and use this assessment to interact in a personalised manner.

Keywords: Integrative agent, believing, feeling, adaptive

Introduction

An important and interesting recent class of applications for software/hardware agents can be found in Ambient Intelligence: the area of ambient or pervasive systems; e.g., (Aarts, Collier, Loenen, Ruyter, 2003; Aarts, Harwig, Schuurmans, 2001; Riva, Vatalaro, Davide, Alcañiz, 2005). One of the more ambitious challenges in this area is to create ambient agents with an appropriate awareness of the (mental) states of humans. Human-aware ambient agent systems can be taken to perform a certain type of mindreading or to possess what in the psychological and philosophical literature is called a Theory of Mind; e.g., (Gärdenfors, 2003; Goldman, 2006). As developed during the evolutionary human history, mindreading addresses different types of mental states, such as intention, attention, belief or emotion states; e.g., see (Gärdenfors, 2003). Inspired by these facilities available in nature, ambient agent models can be developed that have mindreading capabilities for one or some of these types of mental states. However, it is more and more acknowledged that such mental states can be quite dynamic and often interact with each other intensively. To obtain an adequate ambient agent model, dynamical models describing such dynamics and interaction has to be integrated within the agent model.

Human-aware ambient agent systems equipped with the ability to reason about the different types of mental states can be applied in the area of personalised customer relationships and marketing. A recent trend is to dig deeper into the clients' minds and lives. The work reported here focuses on the dynamics and interaction of an individual client's beliefs and emotions and integrates models for these dynamics in an ambient agent model to provide effective intelligent marketing strategies by a better understanding of the cognitive and affective system of the client. In their generation process beliefs trigger emotional responses that result in certain feelings. In a reciprocal manner, the generated feelings affect the belief as well; for some literature on such reciprocal interactions between cognitive and affective astates, see, for example, (Eich, Kihlstrom, Bower, Forgas, and Niedenthal, 2000; Forgas, Goldenberg, and Unkelbach, 2009; Niedenthal, 2007; Schooler and Eich, 2000; Winkielman, Niedenthal, and Oberman, 2009).

In this paper, a computational dynamic model is adopted from (Memon and Treur, 2009) that models the client's reciprocal interaction between feeling and believing. This model is based on neurological theories on the embodiement of emotions as described, for example, in (Damasio, 1994, 1996, 1999, 2004; Winkielman, Niedenthal, and Oberman, 2009). More specifically, in accordance with, for example (Damasio, 1999, 2004), for feeling the emotion associated to a belief a converging recursive body loop is assumed. A second converging feedback loop introduced in the model, inspired the Somatic Marker Hypothesis (Damasio, 1994, 1996), involves the interaction back from the feeling to the belief.

This dynamical model is integrated within an ambient agent model to enable the agent to assess the strength of the belief and feeling, and to intervene when desired. As a personal characteristic represented by a parameter indicating a bias of the belief in a positive or negative direction, is hard to determine at forehand, the ambient agent is equipped with an adaptation model to adjust the value of this parameter over time. This results in an adaptive integrative agent model that learns to estimate the human's belief and feeling better and better over time.

To illustrate the model, the following example scenario is used. A person (client) develops strong (false) beliefs due to strong negative feelings (of insecurity) about a product offered by the bank, for example, buying bonds or shares. The ambient agent estimates the level of belief and feeling of the client related to this insecurity. When the client becomes too insecure, i.e., the emotion level goes above certain threshold, the ambient agent can take measures in order to achieve a reduction of the insecure feeling, e.g., by providing information that makes the client feel more secure.

In this paper, first in Section 2 the dynamical model for the interaction between belief and feeling is described. In Section 3 the ambient agent model is described which integrates the dynamical model. Section 4 describes the parameter adaptation model integrated within the agent. Section 5 presents some simulation results. Finally, Section 6 is a discussion.

Belief and Emotion

In this section a computational model for the interaction between believing and feeling is briefly discussed, as adopted from (Memon and Treur, 2009). As any mental state in a person, a belief state induces emotions felt within this person, as described by Damasio (1999; 2004, p. 93):

belief $\rightarrow$ preparation for bodily response $\rightarrow$ bodily response $\rightarrow$ sensing the bodily response $\rightarrow$ sensory representation of the bodily response $\rightarrow$ feeling

As a variation, an 'as if body loop' uses a direct causal relation: preparation for the bodily response $\rightarrow$ sensory representation of the bodily response; as a shortcut in the causal chain. 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 the emotion: feeling $\rightarrow$ preparation for the bodily response; as an additional causal relation. Within the model used in this paper both the bodily response and the feeling are assigned a level, expressed by a number; for example, the strength of a smile and the extent of happiness.

Although beliefs in an idealised rational agent might only depend on informational sources, real life persons may, for example, have a more optimistic or pessimistic character and affect their beliefs accordingly. To model this a causal relation: feeling $\rightarrow$ belief; is added. Therefore two recursive loops result, as shown in Figure 1. From a neurological perspective the existence of a connection from feeling to belief may be considered plausible, as this may be developed based on a general Hebbian learning mechanism (Hebb, 1949; Bi and Poo, 2001) that strengthens connections between neurons that are activated simultaneously. Another type of support for a connection from feeling to belief can be found in Damasio's Somatic Marker Hypothesis; cf. (Damasio, 1994, 1996; Bechara and Damasio, 2004; Damasio, 2004). This is a theory on decision making which provides a central role to emotions felt. Each decision option induces (via an emotional response) a feeling which is used to mark the option. Usually the Somatic Marker Hypothesis is applied to provide endorsements or valuations for options for a person's actions. However, it may be considered plausible that such a mechanism is applicable to valuations of internal states such as beliefs as well.

The hybrid dynamic modelling language LEADSTO used subsumes qualitative and quantitative causal relationships, and dynamical systems; cf. (Bosse, Jonker, Meij and Treur, 2007). Within LEADSTO the temporal relation a $\twoheadrightarrow$ 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. A dedicated software environment is available to support specification and simulation.

An overview of the model for believing and feeling is depicted in Figure 1. Note that the precise numerical relations between the indicated variables V shown are not expressed in this picture. The detailed specification of the model can be found in (Memon and Treur, 2009).

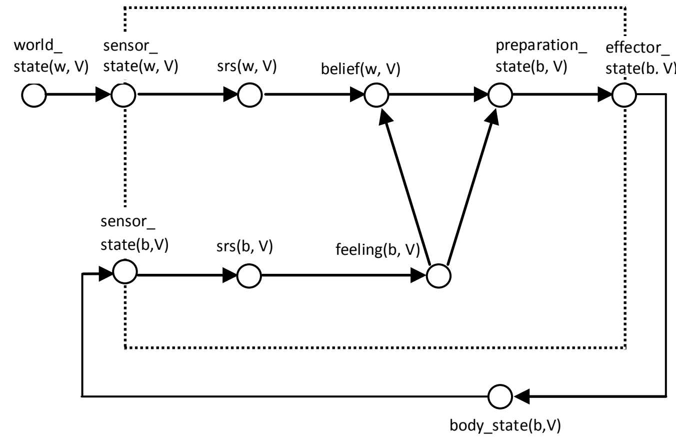

Figure 1: Dynamical model for belief and feeling

As an example, the dynamic property for the process for belief generation is described. The level for the belief is calculated based on a function $g(\beta, V_1, V_2)$ of the original levels, where β is the personal characteristic (with values from *0* to *1*) indicating positive or negatieve bias for the belief.

LP3 Generating a belief for a feeling and a sensory representation

If a sensory representation for w with level V_1 occurs,
and the associated feeling of b with level V_2 occurs
and the belief for w has level V_3
and β_1 is the person's orientation for believing
and γ_1 is the person's flexibility for beliefs
then a belief for w with level $V_3 + \gamma_1 (g(\beta_1, V_1, V_2)-V_3) \Delta t$ will occur.

has_state(human, srs(w, V_1)) &
has_state(human, feeling(b, V_2)) &
has_state(human, belief(w, V_3))
$\twoheadrightarrow$ has_state(human, belief(w, $V_3 + \gamma_1 (g(\beta_1, V_1,V_2) - V_3) \Delta t$)

For the function $g(\beta, V_1, V_2)$ the following was taken:

$$g(\beta, V_1, V_2) = \beta(1-(1-V_1)(1-V_2)) + (1-\beta)V_1V_2$$

Dynamic property LP4 describes the emotional response to a belief in the form of the preparation for a specific bodily reaction. This dynamic property uses the same combination model based on $g(\beta, V_1, V_2)$ as above.

LP4 From belief and feeling to preparation of a body state

If belief w with level V_1 occurs
and feeling the associated body state b has level V_2
and the preparation state for b has level V_3
and β_2 is the person's orientation for emotional response
and γ_2 is the person's flexibility for bodily responses
then preparation state for body state b will occur with level $V_3 + \gamma_2 (g(\beta_2, V_1, V_2)-V_3) \Delta t$.

has_state(human, belief(w, V_1)) &
has_state(human, feeling(b, V_2)) &
has_state(human, preparation(b, V_3))
$\twoheadrightarrow$ has_state(human, preparation(b, $V_3+\gamma_2 (g(\beta_2, V_1, V_2)-V_3) \Delta t$)

The Ambient Agent Model

Within the integrative ambient agent model, the model for the dynamics of belief and feeling is embedded in order to enable the agent to reason about this process, and to assess the person's beliefs and feelings. In psychology, this capability is often referred to as mindreading or Theory of Mind (e.g., Gärdenfors, 2003). The embedding uses the format that the causal relationships of the model described in

Section 2 above are transformed into relationships for beliefs of the ambient agent on mental states of the person. In order to achieve this, the idea of recursive modelling is used; e.g., (Marsella, Pynadath and Read, 2004). This means that the beliefs that agents have about each other are represented in a nested manner. Each mental state is parameterized with the name of the agent considered, thus creating concepts like

has_state(human, feeling(b, 0.5))
has_state(AA, performed(add_pos_info))

In addition, a number of meta-representations are introduced. For example, has_state(AA, belief(has_state(human, feeling(b, 0.7)))) states that the ambient agent (AA) believes that the human has a feeling level of *0.7* for b. The following are the resulting agent local properties (ALP) that specify the processes within the ambient agent. The first property specifies how the agent AA observes that the human senses external information.

ALP1 Observing the human's sensing external information
If the human senses external information,
then the ambient agent AA will observe this.

has_state(human, sensor_state(externalinfo, V))
→ has_state(AA, observed(
has_state(human, sensor_state(externalinfo, V))))

ALP2 Generating a belief for the human's sensing
If the ambient agent AA observes that the human senses an external information,
then it will generate a belief on it.

has_state(AA, observed(
has_state(human, sensor_state(externalinfo, V))))
→ has_state(AA, belief(
has_state(human, sensor_state(externalinfo, V))))

ALP3 Generating a belief for a sensory representation
If AA believes that the human senses external information,
then it will generate a belief that the human will have a sensory representation for this.

has_state(AA, belief(
has_state(human, sensor_state(externalinfo, V))))
→ has_state(AA, belief(has_state(human, srs(externalinfo, V))))

ALP4 From sensory representation and feeling to belief
If AA believes that the human has a sensory representation for external information with level V_1
and AA believes that the human has feeling b with level V_2,
and the belief for w has level V_3
and β_1 is the person's estimated orientation for emotional response
and γ_1 is the person's flexibility for bodily responses
then it will generate the belief that the human's belief with level $V_3+\gamma_1$ (g(β_1, V_1, V_2)-V_3) Δt will occur

has_state(AA, belief(
has_state(human, srs(externalinfo, V1)))) &
has_state(AA, belief(has_state(human, feeling(b, V2)))) &
has_state(AA, belief(has_state(human, belief(w, V3))))
→ has_state(AA, belief(has_state(human,
belief(w, $V_3+\gamma_1$ (g(β_1, V_1, V_2)-V_3) Δt))))

ALP5 From belief and feeling to preparation of a body state
If AA believes that the human has a belief for w with level V_1
and AA believes that the human has feeling b with level V_2,
and the preparation for body state b has level V_3
and β_2 is the person's orientation for emotional response
and γ_2 is the person's flexibility for bodily responses
then it will generate the belief that the human's preparation state for body state b will occur with level $V_3+\gamma_2\ (g(\beta_2, V_1, V_2)-V_3)\ \Delta t$.

has_state(AA, belief(has_state(human, belief(w, V1)))) &
has_state(AA, belief(has_state(human, feeling(b, V2))))
has_state(AA, belief(has_state(human, preparation(b, V3)))) &
→ has_state(AA, belief(has_state(human,
preparation(b, $V_3+\gamma_2$ (g(β_2, V_1, V_2)-V_3) Δt))))

ALP6 From preparation to body modification
If AA believes that the human's preparation state for body state b with level *V* occurred,
then it will believe that the human's body state will have level *V*.

has_state(AA, belief(has_state(human, preparation(b, V))))
→ has_state(AA, belief(has_state(human, effector_state(b, V))))

ALP7 From body modification to modified body
If AA believes that the human's body is modified with level *V*,
then it will believe that the human's body is showing b with level *V*.

has_state(AA, belief(has_state(human, effector_state(b, V))))
→ has_state(AA, belief(has_state(human, body_state(b, V))))

ALP8 Sensing a body state
If AA believes that the human's body is showing b with level *V*,
then it will believe that the human will sense this body state.

has_state(AA, belief(has_state(human, body_state(b, V)))) →
has_state(AA, belief(has_state(human, sensor_state(b, V))))

ALP9 Generating a sensory representation of a body state
If AA believes that the human has sensed body state b with level *V*,
then it will believe that the human has a sensory representation for body state b with level *V*.

has_state(AA, belief(has_state(human, sensor_state(b, V))))
→ has_state(AA, belief(has_state(human, srs(b, V))))

ALP10 From sensory representation of body state to feeling
If AA believes that the human has a sensory representation for body state b with level *V*,
then it will believe that the human has feeling b with level *V*.

has_state(AA, belief(has_state(human, srs(b, V))))
→ has_state(AA, belief(has_state(human, feeling(b, V))))

In addition, a number of other rules have been established to model the behaviour of the human and the ambient agent, and its effect on the world:

ALP11 Intervention by the Ambient Agent
If AA believes that the human has feeling b with level *V* which is higher than a certain threshold th1,
then it will add some positive information to the external environment

has_state(AA, belief(has_state(human, feeling(b, V)))) & V ≥ th1
→ has_state(AA, performed(add_pos_info))

ALP12 Effect of intervention in the world
As long as AA does not add some positive information to the external environment,
then positive information will remain 0.

not has_state(AA, performed(add_pos_info))
→ added_pos_info(0)

As soon as AA adds some positive information to the external environment, it will be available in the environment.

has_state(AA, performed(add_pos_info))
→ added_pos_info(0.2)

The Adaptation Model

Characteristics of a human, used as parameters in a dynamical model (such as the β used in the belief generation in the model described above) are often not easy to determine at forehand, and can only be given to the agent as initial beliefs. This section describes a method by which an agent is able to adapt these beliefs concerning human characteristics to the real characteristics. Using the dynamical model with parameter values as represented by these initial beliefs, the agent predicts the human belief and feeling state, up to a certain time point. When at that time point, for example by observation, information is obtained about the real value of this belief or feeling state, this is used as input for the adaptation process. The agent adjusts the belief on the human characteristic, to reduce the difference between predicted and real value.

For reasonable adjustments, information is required on how a change in parameter value affects the difference between predicted and real value of the variable that is considered; this is called the sensitivity of the variable value for the parameter value. The *sensitivity* S of variable X (e.g., the belief or feeling level) for parameter P (e.g., the β used in belief generation) is the number such that a change ΔP in the value of parameter P will lead to a change ΔX in X which is (approximately) proportional to ΔP with S as proportion factor: $\Delta X = S\ \Delta P$. This is an approximation which is more accurate when the Δ's are taken small. To determine a sensitivity S the following approximation method is used. A small change ΔP in the parameter is used to make an additional prediction for X, and based on the resulting difference ΔX found in the two predicted values for X, by $S_{X,P} = \Delta X / \Delta P$ the sensitivity S can be estimated. Once the sensitivity and a deviation ΔX between estimated and observed level have been determined, the value W of the parameter P is adjusted by ΔP in the following manner (with α the adaptation speed):

$$\Delta P = \alpha * (1 - W) * (-\Delta X / S_{X,P}) \quad \text{if } -\Delta X / S_{X,P} \geq 0$$

$$\Delta P = \alpha * W * (-\Delta X / S_{X,P}) \quad \text{if } -\Delta X / S_{X,P} \leq 0$$

This has been specified in LEADSTO-format as follows.

ALP13 Calculating change ΔX in predicted belief X

If AA believes that the human has a sensory representation for external information with level V_1
and AA believes that the human has feeling b with level V_2,
and AA believes that the predicted belief for w has level V_3
and β_1 is the person's estimated orientation for emotional response
and γ_1 is the person's flexibility for bodily responses
and the change to be made in person's estimated β_1 is V_4
then it will generate the predicted belief for w with level $V_3+\gamma_1\ (g(\beta_1+V_4, V_1, V_2)-V_3)\ \Delta t$

```
has_state(AA, belief(as_state(human,srs(externalinfo, V1)))) &
has_state(AA, belief(has_state(human, feeling(b, V2)))) &
has_state(AA, belief(predicted_belief(w, V3)))
→ has_state(AA, belief(
      predicted_belief(w, V3+γ1 (g(β1+V4, V1, V2)-V3) Δt ))))
```

ALP14 Generating sensitivity

If AA believes that the predicted belief for w has level V_1
and AA believes that the human has a belief for w with level V_2
and the change to be made in person's estimated β_1 is V_3
then AA will generate the belief for sensitivity by $(V1 - V2)/V3$

```
has_state(AA, belief(predicted_belief(w, V1))) &
has_state(AA, belief(has_state(human, belief(w, V2))))
→ has_state(AA, belief(sensitivity, (V1 – V2) / V3))
```

ALP15 Calculating deviation

If AA believes that the human has a belief for w with level V_1
and AA believes that the observed human belief is V_2
then AA will generate the belief that the deviation between estimated and observed belief is $(V1 - V2)$

```
has_state(AA, belief(has_state(human, belief(w, V1)))) &
has_state(AA, belief(observed_human_belief, V2))
→ has_state(AA, belief(deviation, V1 – V2))
```

ALP16 Adapt estimated beta

If AA believes the estimated beta is V_1
and AA believes that the deviation between estimated and observed belief is V_2
and AA believes that the sensitivity is V_3
and $-V_2 / V_3 > 0$
and α is the adaptation speed
then AA will generate the belief in an estimated beta with level $(\alpha * (1 - V1) * (-V1 / V3) + V1)$

```
has_state(AA, belief(estimated_beta(V1))) &
has_state(AA, belief(deviation, V2)) &
has_state(AA, belief(sensitivity, V3)) &
- V2 / V3 > 0
→ has_state(AA,
      belief(estimated_beta(α * (1 - V1)* (-V1 / V3) + V1)))
```

If AA believes estimated beta is V_1
and AA believes that the deviation between estimated and observed belief is V_2
and AA believes that the sensitivity is V_3
and $-V_2 / V_3 \leq 0$
and α is the adaptation speed
then AA will generate the belief in an estimated beta with level $(\alpha * V1 * (-V1 / V3) + V1)$

```
has_state(AA, belief(estimated_beta(V1))) &
has_state(AA, belief(deviation, V2)) &
has_state(AA, belief(sensitivity, V3)) &
- V2 / V3 <= 0
→ has_state(AA, belief(estimated_beta(α * V1 * (-V1 / V3) + V1)))
```

Simulation Results

Based on the model described in the previous section, a number of simulations have been performed within the LEADSTO simulation environment (Bosse, Jonker, Meij and Treur, 2007). The model was tested in a small scenario, involving an ambient agent and a human (indicated by AA and human, respectively). The agent model was equipped with the model to estimate human's emotion level. The central emotion used in the scenario is insecurity for the particular product, as discussed in Section 1. In order to simulate this, every now and then certain events take place, which influence the level of insecurity of the human either positively (e.g., some good news about the product published in a newspaper) or negatively (e.g., some friend informed him about his own past bad experience with that product). To model this behavior, the following property has been used:

ALP17 Generating a sensor state for external information

If a sensor state of external information of level V_1 occurs
and the ambient agent has added some positive information V_2, has flexibility η
and some positive information V_3
and some negative information V_4 is present from the environment,
then the human will sense external information with level $(V_1 - \eta * (V_2 + V_3) * V_1 + \eta * V_4 * (1 - V_1))$.

```
has_state(human, sensor_state(externalinfo, V1)) &
added_pos_info(V2) &
flexibility(η) &
positive_externalinfo(V3) &
negative_externalinfo(V4)
→ has_state(human, sensor_state(
      externalinfo, (V1-η*(V2+V3)* V1+η*V4*(1-V1))))
```

Here positive_externalinfo and negative_externalinfo represent the positive and negative events that are occurring randomly in the environment which influence the insecurity level of the human. For the example simulations the probability for the positive events to occur has been taken *0.8* and for negative events to occur is *0.3*. The main goal of the ambient agent is to estimate the level of insecurity of the human. To this end, it starts with some initial values of the human's belief and feeling levels, and then keeps on updating this, using the strategies explained earlier. him some positive information about the product). When it is estimated that the human becomes too (unreasonably) insecure, the ambient agent can take measures to calm him down (e.g., informing

Some example simulation traces (under different but fixed parameter settings) are illustrated in Figures 2 and 3 (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, added_pos_info. Below this part, quantitative information is provided about the human's actual belief and feeling level, and the ambient agent AA's estimation of this belief and feeling level, respectively. Values for these levels for the different time periods are shown by the dark lines. Note that only a selection of the relevant state properties is shown.

The first trace (see Figure 2), shows a situation in which the estimated β (*0.95*) is substantially higher than the real β (*0.7*), as indicated in the upper part of Figure 2. As shown in the figure, the ambient agent AA estimates the level of emotion of the human too high so that it is too early in adding the positive information indicated in the upper part by state property: has_state(AA, performed(add_pos_info)), at time point 52.

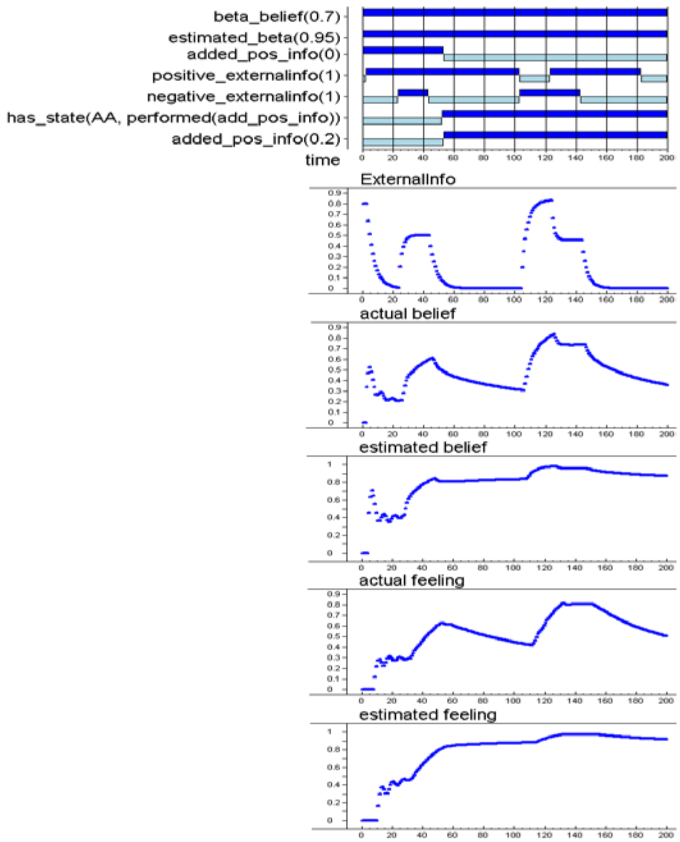

Figure 2: Simulation 1: the estimated β is higher than the real β

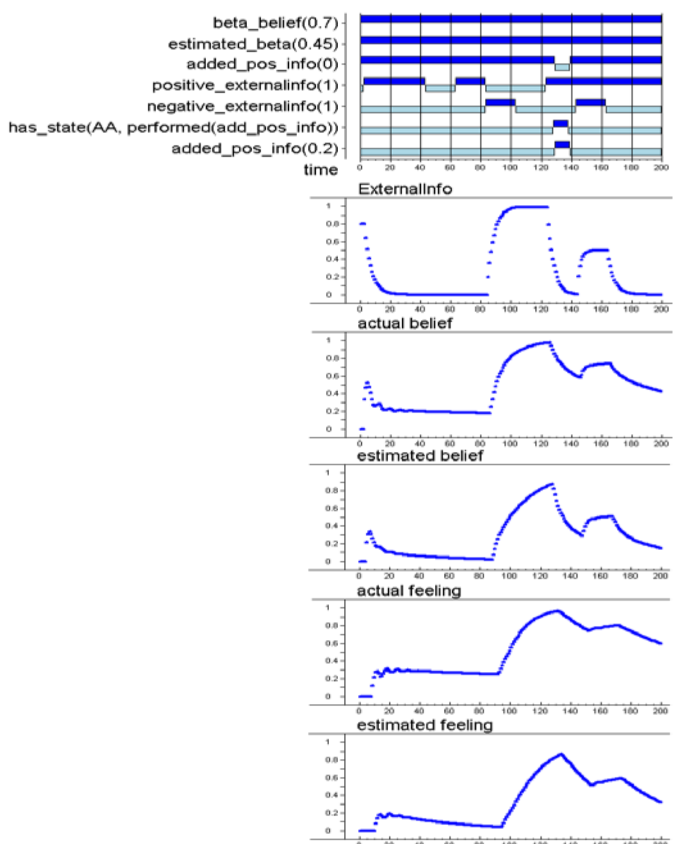

Figure 3: Simulation 2: the estimated β is lower than the real β

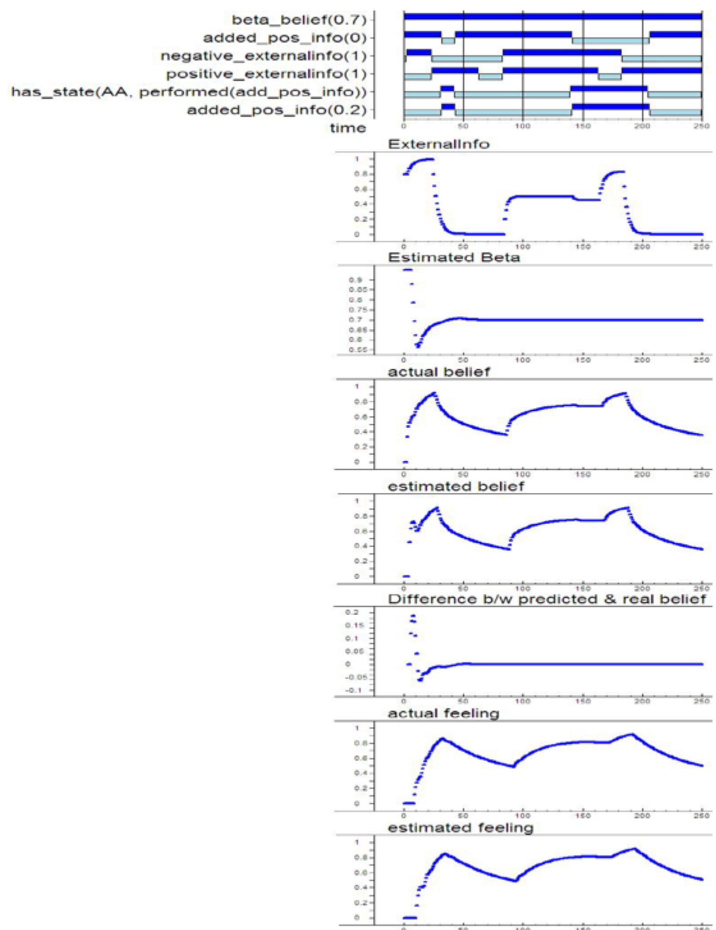

Figure 4: Simulation 3: the estimated β is adapted and approximates the real β

The second trace (see Figure 3) shows a situation in which the estimated β (*0.45*) is substantially lower than the real β (*0.7*), as indicated in the upper part of the Figure 3. As shown in the figure, the ambient agent AA estimates the level of emotion of the human much too low, so that it is too late in adding the positive information, indicated in the upper part by state property: has_state(AA, performed(add_pos_info)), at time point 128. This is too late, because, as shown in the actual emotion graph below, the human's emotion level has gone too high already at time point 118.

In Figure 4 a simulation trace is shown where the parameter β is adapted to the person. Here the initial value of β is too high (*0.95*) compared to the actual value (*0.7*). To compensate for that, the adaptation model first reduces the estimated value to below *0.6*, after which it almost monotonically approximates the real value *0.7*.

Discussion

To function in a knowledgeable manner, ambient agents (e.g., Aarts, Collier, Loenen, Ruyter, 2003; Aarts, Harwig, Schuurmans, 2001; Riva, Vatalaro, Davide, Alcañiz, 2005) need a model of the humans they are supporting. Such a model enables them to perform a form of mindreading (e.g., Gärdenfors, 2003; Goldman, 2006). The ambient agent model presented here focuses on mindreading concerning the interaction between beliefs and emotions, based on neurological theories that address this interaction. A belief usually triggers an emotional response and may also depend on this emotional response, as, for example, shown in literature such as (Eich et al., 2000; Forgas et al., 2009; Niedenthal, 2007; Schooler and Eich, 2000).

The ambient agent model presented uses a computational model of this interaction, adopted from (Memon and Treur, 2009). For feeling the emotion, based on elements taken from (Damasio, 1999, 2004; Bosse, Jonker and Treur, 2008), a converging recursive body loop is included in the model. As a second loop the model includes a feedback loop for the interaction between feeling and belief. The causal relation from feeling to belief in this second loop was inspired by the Somatic Marker Hypothesis described in (Damasio, 1994, 1996; Bechara and Damasio, 2004), and may also be justified by a Hebbian learning principle (cf. Hebb, 1949; Bi and Poo, 2001). Both the strength of the belief and of the feeling emerge as a result of the dynamic pattern generated by the two loops.

The adaptive integrative agent model equipped with the dynamical model for the dynamics of belief and feeling was specified in the hybrid dynamic modelling language LEADSTO, and simulations were performed in its software environment; cf. (Bosse, Jonker, Meij, and Treur, 2007). An adaptation model was integrated within the agent to be able to tune beliefs on the human's characteristics used as parameters in the dynamical model to the real characteristics. Here feedback can be used when at times the human reveals his or her belief or feeling. To evaluate the ambient agent model in human experiments is left to future work.

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