Modeling Super Mirroring Functionality in Action Execution, Imagination, Mirroring, and Imitation

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Abstract. In this paper a cognitive agent model is presented that models multiple functions of preparation states: mirroring an observed action, imitation of an action, or imagining an action. The model incorporates a super mirroring function enabling the agent to keep track of the context of a mental process: mirroring another agent, imitation of another agent, action imagination, or own action performance. These cognitive functions have been adopted from informal descriptions of mirror neuron and super mirror neuron functions in neurological literature. Example simulations are presented that illustrate the model.

Keywords Cognitive model, super mirror neurons, imitation, imagination.

1 Introduction

Within an agent's internal neurological processes, sensory representations of stimuli usually lead to preparations for responses. Recent neurological findings reveal that so called 'preparation' neurons have multiple functions; preparing for an action to be executed is only one of these functions. For example, preparation of actions may play a role in imagination, or in interpreting an observed action. In these cases, actual execution of the prepared action is suppressed. This multi-tasking aspect of preparation states, which from an evolutionary perspective can be viewed as an economic use of available resources, entails a fundamental problem concerning the representational content of such neurons. Apparently, activation of such neurons by itself has no unambiguous meaning; it is strongly context-dependent. A way out of this problem of multi-interpretability of preparation neurons is obtained when suitable forms of context can be defined. Indeed this is what is assumed to happen at the neurological level (e.g., [8], pp. 196-203, [11]), based on what are called super mirror neurons. These are neurons which were found to have a function in allowing or suppressing action execution after preparation has taken place.

This paper presents a cognitive agent model displaying the (re)use of preparation states in the processes of imagining, imitating or mirroring an action. It is shown that the use of a context provides the agent with the capability of differentiating between the different uses of the same preparation state. In Section 2 the main principles adopted are discussed. In Section 3 the cognitive agent model is described in more detail. Section 4 illustrates the functioning of the model by showing simulation results for different contexts, and Section 5 addresses a mathematical analysis. Finally, Section 6 provides a discussion.

2 Principles Adopted

This paper presents a model with four different functions for the preparation of the same action. The shared representation of action preparations in these four cases is supported in the literature by the concepts of *inner simulation* (cf. Hesslow, 2002), the as-if body loop (cf. [3, 4]) and mirroring (cf. [8, 12, 15]). Preparations for responses can lead to further mental processing via an *as-if action execution loop* from preparation state to sensory representation of the expected outcome; cf. [6]. When inner simulation is combined with the inhibition of action execution, a preparation for an action can be used to simulate the results of an action as if it were actually executed; the concept of inner simulation supports a role for preparation neurons in imagination. Such sensory representations of expected outcomes induce preparation states for a specific bodily reaction to this outcome. According to Damasio (e.g., [3, 4]) a bodily reaction can be viewed as an emotional response; sensing changes in the body state lead to feeling these emotions (*body loop*). However, the preparation for a bodily reaction can also directly lead to a sensory representation of the bodily reaction without the bodily reaction actually taking place (*as-if body loop*). For the cognitive agent model presented here, the following causal chain is assumed; see [3, 4, 6]:

sensory representation of stimulus → preparation for response →
sensory representation of expected outcome → preparation for body reaction →
sensory representation of body state.

This causal chain is extended to a recursive loop by assuming that the preparation for the response is also affected by the level of feeling the emotion associated to the expected outcome of the response:

sensory representation of body state → preparation for response

Within the agent model presented in this paper, states are assigned a quantitative (activation) level. The positive feedback loops between preparation states for responses and their associated body states, and the sensory representations of expected outcomes are triggered by a sensory representation of a stimulus and converge to a certain level of feeling and preparation.

The discovery of mirror neurons has revealed that preparation states for own actions may also be used in the recognition of actions of others (e.g., [8]). Mirror neurons are motor neurons that fire not only when an action is performed, but also when the same action is observed. So when the stimulus is an observed action, then a preparation state for that action is created and through the as-if action execution loop and the as-if body loop the expected outcome and the feelings associated with that action are recognised. The existence of mirror neurons provides support for the role of preparation neurons in action recognition through mirroring, and in imitation. When the preparation state has a mirroring function or is created through imagination, the prepared action will not be executed. Therefore in the step from preparation to actual response, in addition to the preparation level another factor has to be taken into account. Within neurological literature such as [8], pp. 196-203, and [11], such a factor is assumed to be realised by a specific type of mirror neurons, called *super mirror neurons* [8] to keep track of the context in which a mental process takes place. In single cell recording experiments with epileptic patients [11], neurons were found that are active when the person prepares an own action to be executed, but shut down when the action is only observed, which suggests that these cells may be involved in the distinction between a self-generated preparation state and a preparation state generated through observation of an action [8]. In [8], pp. 201-202, it is also described that certain cells are sensitive to a specific person, so that in the case of an observed action, this action can also be attributed to the specific person that was observed.

Within the cognitive agent model presented in the next section, the functions of super mirror neurons have been incorporated in focus states, generated by processing of available (sensory) context information. For the case modeled, this focus can refer to the person her or himself, observing another person's action, imitating an action, or imagination of performing an action. When the focus is on action execution or imitation, this has a positive effect on performing the action. When the focus is on imagination, or recognizing another person's action, it has a suppressing effect. In the latter case the preparations and related feeling generated through simulation can be used to attribute them to that person.

3 Specification of the Cognitive Agent Model

To formalise the agent model, the hybrid dynamic modeling language LEADSTO has been used; cf. [1]. Within LEADSTO the dynamic property $a \rightarrow_D b$ denotes that when a state property a occurs, then after a certain time delay (specified as any positive real number D), state property b will occur. This D will be taken as the time step Δt, and not be mentioned explicitly. Both logical and quantitative calculations can be specified, and a software environment is available to support specification and simulation.

Fig. 1 shows a graphical representation of the agent model. In this figure, the circles represent state properties. Occurrence of one or more state properties at a certain point in time can lead to the occurrence of another state property at the next point in time, as represented by the labeled arrows. The state properties in this model contain variables. The state property sensor_state(c[,a]) represents the sensing of a context. Variable c denotes the specific context and optional variable a denotes the agent to which the action preparation state to be generated should be attributed (in the case of mirroring or imitation, the action preparation should be attributed to another agent). State property srs(c[,a]) represents the sensory representation that is generated for a sensed context. Again, variable c denotes the specific context and optional variable a denotes the agent to which the to be generated action preparation state should be attributed. State property focus(c[,a]) represents a focus state for a specific context and agent (optional) that is generated in response to a sensory representation of a context. State property attribution(b,V,a) represents the attribution of a body state b that was generated with strength V to agent a. Such an attribution state is created in case of mirroring or imitation. State properties sensor_state(s,V) and srs(s,V) represent the sensing and the generation of a sensory representation of a stimulus s that is sensed with strength V. When another agent is being mirrored or imitated, the stimulus needs to be transformed before it can be translated into the preparation for an action. For example when the agent is imitating another agent who is lifting a box, then the sensed stimulus will be another agent lifting a box. In order to be able to generate the same action, lifting a box, the agent will imagine himself being at the location of the other agent and seeing a box in front of him. This state is represented by state property transformed_stimulus(s,V), where variable s may have an instanstiation (e.g., 'box') different from s in state property srs(s,V) (e.g., 'agent a lifting a box').

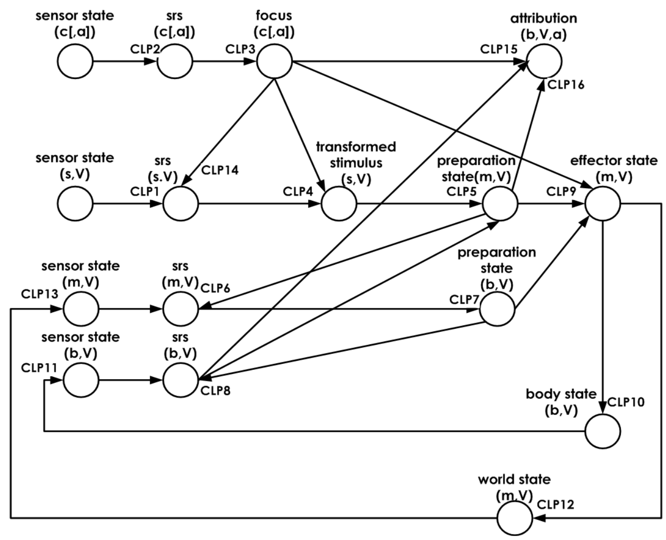

Fig. 1. Overview of the cognitive agent model

State property preparation_state(m,V) represents the state in which execution of motor plan m with strength V is prepared. State property effector_state(m,V) represents the actual execution of motor plan m with strength V. State properties sensor_state(m,V), srs(m,V), sensor_state(b,V) and srs(b,V) represent the sensing and sensory representation of execution of motor plan m with strenght V, and the sensing and sensory representation of body state b with strength V respectively. The occurrence of a sensory representation of a motor plan being executed leads to the preparation for the occurrence of a specific body state. This is denoted by state property preparation_state(b,V), with b being this specific body state and V the strength of the preparation. Finally, body_state(b,V) and world_state(m,V) represent the externally observable occurrence of a body state b with strength V and the observable execution of motor plan m with strength V respectively.

The dynamic properties, or temporal relations between these state properties are denoted by the labelled arrows in Figure 1. Dynamic properties CLP1 and CLP4 describe perception of a stimulus and its transformation.

CLP1 Generating a sensory representation for a sensed stimulus
if stimulus s is sensed with strength *V*
then a sensory representation for s with strength *V* will occur
sensor_state(s,V) → srs(s,V)

A sensory representation of stimulus s1 is transformed to a stimulus s2 when the observed stimulus is a person performing an action and the focus is to imitate or mirror this person, as was described above for the case of imitating another agent who is lifting a box. In the case of imitation or mirroring, the agent needs to imagine that he is 'standing in the shoes' of the agent that he is imitating or mirroring. Indeed neurological evidence has been found in support of this hypothesis that humans mentally displace themselves such that they literally put themselves in the shoes of the other, when they imitate or mirror the behavior of another person [10]. When the focus is to perform a self-initiated action or to imagine an action, then the stimulus is not transformed.

CLP4 Generating a transformed representation of the stimulus

if a sensory representation of stimulus s1 occurs with strength *V*
and the focus state is imitate or to mirror agent a's behavior
and transformation of stimulus s1 from the third person perspective to the first person perspective results in stimulus s2
then a transformed stimulus s2 will occur with strength *V*

srs(s1,V) & (focus(imitation,a) or focus{mirroring,a)) → transformed_stimulus(s2,V)

if a sensory representation of stimulus s occurs with strength *V*
and the focus state is to execute a self-initiated action or to imagine an action
then transformed stimulus s will occur with strength *V*

srs(s,V) & (focus(action_execution) or focus(imagination)) → transformed_stimulus(s,V)

Properties CLP5 and CLP9 define how stimulus s leads to a response in the form of the preparation and execution of a motor plan m. A preparation state for a specific motor plan is created or updated based on the transformed stimulus representation, the current state of feeling and the current state of preparation.

CLP5 Generating a preparation state

if transformed stimulus representation s occurs with strength V_1
and sensory representation for body state b occurs with strength V_2
and the current preparation state for motor plan m has strength V_3
then the updated preparation state for m has strength $V_3 + \gamma(h(\beta, \omega_1, \omega_2, V_1, V_2) - V_3)\,\Delta t$

transformed_stimulus(s,V1) & srs(b,V2) & preparation_state(m,V3)
→ preparation_state(m,V3+γ(h(β,ω1, ω2,V1,V2)-V3)Δt)

The level of preparation V_3 is updated based on a function $h(\beta, \omega_1, \omega_2, V_1, V_2)$ of the levels of strength of the stimulus and body state associated with motor plan m, defined as follows:

$$h(\beta, \omega_1, \omega_2, V_1, V_2) = \beta(1-(1-\omega_1 V_1)(1-\omega_2 V_2)) + (1-\beta)\,\omega_1\omega_2 V_1 V_2$$

Parameter β models a person's characteristic for emotional response (from *0* as weakest response to *1* as strongest response): in the loop in which the strength of the preparation state for m is iteratively updated, β determines to what degree the strength of the preparation state for m is amplified (here $0 \leq \beta \leq 1$, which keeps the strenght within [*0*,*1*]). Parameter γ describes the rate of growth of the update function and parameters ω1 and ω2 provide an option for differential weighting of strenghts of the stimulus and the associated feeling in the update process. This function is also used in the update process of the strength of sensory representations of the outcome of an action (CLP6) and the body state resulting from an action (CLP8). Furthermore it is used in a slightly adapted manner in the update process of preparations for body states (CLP7) and it is used to determine the strenght of an effector state of motor plan m by combining the strenghts of the preparation m and associated body state b (CLP9). The strength of the effector state for m is determined by a combination of the strengths of the preparation state for m (V_1) and the preparation state for b (V_2). An effector state only occurs when the focus is self-performed action or imitation.

CLP9 From preparation of action and preparation of body to action

if a preparation state for motor plan m occurs with strength V_1
and a preparation state for body state b occurs with strength V_2

and the focus is self-performed action or imitation
then an effector state for m occurs with strength $h(\beta, \omega_1, \omega_2, V_1, V_2)$
preparation_state(m,V1) & preparation_state(b,V2) &
(focus(action_execution) or focus(imitation,a)) → effector_state(m, h(β,ω1, ω2,V1,V2))

If motor plan m is executed, CLP10 and CLP11 describe how this leads to a feeling of the changes in the body state through the body loop [3]. The body state is first changed through property CLP10. The body state is then sensed through CLP11.

CLP10 From effector state to body state
if an effector state for motor plan m occurs with strength V
then a body state b will occur with strength V
effector_state(m,V) → body_state(b,V)

CLP11 Sensing a body state
if body state b occurs with strength V
then b will be sensed with strength V
body_state(b,V) → sensor_state(b,V)

However, even before a motor plan is executed, its predicted outcome already leads to a feeling through the as-if body loop [3] described by properties CLP6, CLP7 and CLP8. In response to a preparation state for motor plan m, a sensory representation of the predicted sensory outcome of m is formed (CLP6). This leads to a preparation state for the body state b associated with motor plan m (CLP7).

CLP6 Generating a sensory representation of a response outcome
if a preparation state for motor plan m occurs with strength V_1
and action m is sensed in the world with strength V_2
and the current sensory representation for m has strength V_3
then the updated sensory representation for m has strength $V_3 + \gamma(h(\beta, \omega_1, \omega_2, V_1, V_2) - V_3) \Delta t$
preparation_state(m,V1) & sensor_state(m,V2) & srs(m,V3) → srs(m, V3+γ(h(β,ω1, ω2,V1,V2)-V3)Δt)

The strength of the preparation of body state b associated with motor plan m is updated with rate γ. Again, β represents the orientation for emotional response.

CLP7 Generating a preparation of a body state
if a sensory representation of motor plan m occurs with strength V_1
and the current preparation state for body state b has strength V_2
then the updated preparation state for b has strength $V_2 + \gamma(\omega_1 V_1 - V_2) \Delta t$
srs(m,V1) & preparation_state(b,V2) → preparation_state(b, V2+γ(ω1V1 - V2)Δt)

Property CLP8 describes the update of the strength of a sensory representation for body state b, based on the strengths of the preparation state for b, the sensor state for b and the current strength of the sensory representation for b in a similar manner as described above for CLP5.

CLP8 Generating a sensory representation of the body state
if a preparation state for body state b occurs with strength V_1
and body state b is sensed with strength V_2
and the current sensory representation of b has strength V_3
then the updated sensory representation of b has strength $V_3 + \gamma(h(\beta, \omega_1, \omega_2, V_1, V_2) - V_3) \Delta t$
preparation_state(b,V1) & sensor_state(b,V2) & srs(b,V3) → srs(b, V3+γ(h(β,ω1, ω2,V1,V2)-V3)Δt)

This preparation state can directly lead to a sensory representation of the changed body state (CLP8) as opposed to the indirect path from an effector state of m resulting in a sensory representation of the changed body state through the real sensation (CLP11) of an actual change in the body state (CLP10).

The actual outcome of the execution of motor plan m is observed through CLP12 and CLP13. The execution of an action changes the world in which the agent is acting throught CLP12.

CLP12 From effector state to world state
if an effector state for motor plan m occurs with strength *V*
then this action m will occur in the world with strength *V*
effector_state(m,V) → world_state(m,V)

These changes in the world can then again be observed throught CLP13.

CLP13 Sensing outcome of a motor plan
if action m occurs in the world with strength *V*
then m will be sensed with strength *V*
world_state(m,V) → sensor_state(m,V)

Finally, properties CLP2, CLP3, CLP4, CLP9, CLP14, CLP15, and CLP16 describe how a focus state arises. First the context of the action preparation is sensed. A context can consist of a self-performed action, imagination of an action, imitation of another agent, or mirroring another agent. In case of imitation or mirroring, the context also indicates which agent is imitated or mirrored (indicated below by rectangular braces). This leads to a sensory representation of the context (CLP2). This sensory representation leads to a focus state of either performing, imagining, imitating or mirroring an action (CLP3).

CLP2 Generating a sensory representation for a sensed context
if context c is sensed [and implies agency to agent a]
then a sensory representation for c [with agency a] will occur
sensor_state(c[,a]) → srs(c[,a])

A sensory representation of a context leads to a focus state of either self-performed action, imagination, imitation or mirroring.

CLP3 From sensory representation of a context to focus state
if a sensory representation of a context c occurs [with agency a]
then a focus state for c [with agency a] will occur
srs(c[,a]) → focus(c[,a])

In case of imitating or mirroring the identity of the agent that is to be imitated or mirrorred is also added to the focus state. This focus state can have several different effects. In the case of imagining an action, the focus state is responsible for activating a sensory representation of a stimulus that is not really there (CLP14, see [6]). When the focus is imagination, then a sensory representation of a stimulus is created.

CLP14 Imagining a stimulus
if the focus is imagination
then a sensory representation of imagined stimulus s will occur with strength *1*
focus(imagination) → srs(s,1)

In the case of imitating or mirroring of another agent, the focus state is responsible for enabling transformation of a sensory representation of a stimulus from a third person perspective to a first person perspective (CLP4, see [10]). In the case of action execution or imitation, the focus state is responsible for the creation of an effector state (CLP9), while in the case of imagining or mirroring, its responsibility is to inhibit the creation of an effector state. Finally, through CLP15 and CLP16, the focus state leads to the attribution of the preparation for an action (CLP16) and the corresponding feelings (CLP15) to the self or to another agent, according to the context. In case of imitation, the action and associated feeling are attributed to the self as well as to the other agent.

CLP15 Attribution of a feeling
if a sensory representation of body state b occurs with strength *V*
and the focus is self-performed action, imagination or imitation
then the feeling of b with strength *V* is attributed to the self
srs(b,V) & (focus(action_execution) or focus(imagination) or focus(imitation,a)) → attribution(b,V,self)

if a sensory representation of body state b occurs with strength *V*
and the focus is imitation or mirroring of agent a's behavior
then the feeling of b with strength *V* is attributed to agent a
srs(b,V) & (focus(imitation,a) or focus(mirroring,a)) → attribution(b,V,a)

CLP16 Attribution of an action
if a sensory representation of action m occurs with strength *V*
and the focus is self-performed action, imagination or imitation
then action m with strength *V* is attributed to the self
srs(m,V) & (focus(action_execution) or focus(imagination) or focus(imitation,a)) → attribution(m,V,self)
if a sensory representation of action m occurs with strength *V*
and the focus is imitation or mirroring of agent a's behavior
then action m with strength *V* is attributed to the self as well as to agent a
srs(m,V) & (focus(imitation,a) or focus(mirroring,a)) → attribution(m,V,a)

4 Simulation Results

Using the supporting LEADSTO software environment, for the formally specified model a number of simulations were run. The resulting simulation traces visualise the state properties of the model over time; e.g., see Figure 2. Time is depicted at the horizontal axis. The visualisation using bars indicates of the different state properties whether they are true or false at every time point. The graphs indicate for state properties containing a quantitative variable, the development of the (real) value of this variable over time. Four example simulation results will be briefly discussed to demonstrate the ability of the agent model to display self-performed action, action imagination, imitation and mirroring. As a scenario, the lifting of a box was considered. For all scenario's shown β was set to *1* (maximal emotional response), γ was set to *0.2* (moderate rate of change), and ω_1 and ω_2 were both set to *1* (equal weighing of both factors considered in the function *h*). Furthermore, the step size Δt was set to *1*. The strength of the stimuli (box and a person lifting a box) were both set to *0.5*. Figure 2 shows simulation traces for two example simulations.

Self-performed action In the simulation results for the self-performed action of lifting a box first the stimulus - the box - is perceived by the agent: sensor_state(box, 0.5) is true from time point 0 up to time point 100. Then a sensory representation is formed; srs(box, 0.5) becomes true after 1 time step. Since the context is a self-performed action, the stimulus does not need to be transformed, therefore the transformed stimulus is equal to the sensory representation of the observed stimulus: transformed_stim(box, 0.5). Development takes place of the strengths of feeling srs(b,V), preparation for the motor plan preparation_state(m,V), preparation for the bodily response preparation_state(b,V), the effector state for the motor plan effector_state(m,V) and the attribution of the action and the feeling to the self, attribution(m,V,self) and attribution(b,V,self) respectively. The simulation shows that not only does a preparation state for a motor plan arise, but the effector state also obtains a strenght > 0. A little later in time, the preparation state for a bodily response arises (the as-if body loop, [3, 4]). The preparation of a body state leads to the development of a feeling (srs(b,V)), the actual occurrence of the body state contributes to the strength of the feeling. The action (motor plan m) as well as the feeling (body state b) are attributed to the self.

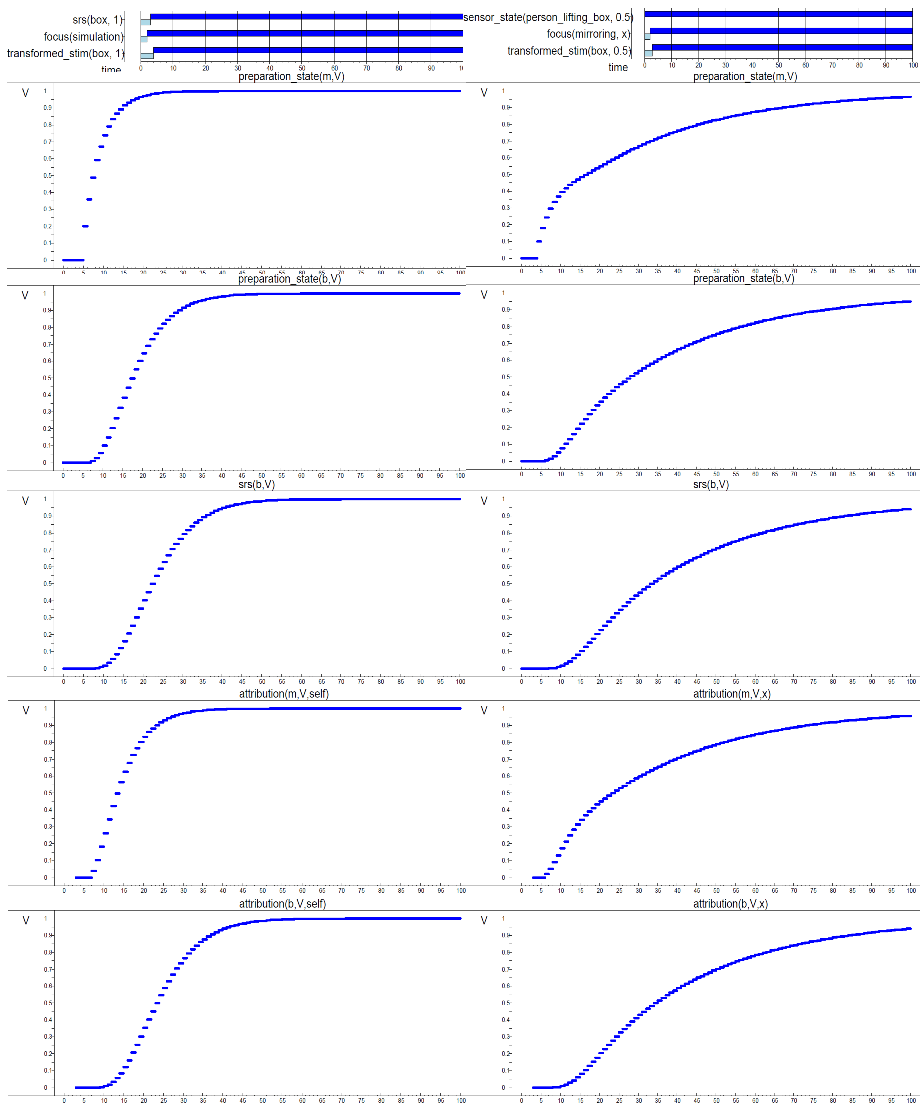

Fig. 2: Simulation traces: (a) imagination (left hand side) and (b) mirroring (right hand side)

Action imagination The simulation results for the imagination of the action of lifting a box (Figure 2(a)) show that the sensory representation for the stimulus (box) is formed in the absence of a sensor state for the stimulus. Furthermore, even though the preparation state for m reaches the same level as that in the scenario of self-performed action, the formation of an effector state is prevented by the context of imagination; the value of variable *V* in state property effector_state(m,V) remains 0.

Imitation The simulation results for the imitation of the action of lifting a box show that the sensed stimulus of a person lifting a box is transformed to a first person perspective: a representation of the box. State property sensor_state(person_lifting_box, 0.5) is transformed to state property transformed_stim(box, 0.5). Furthermore, it is shown that the focus state contains not only the context of imitation, but also the identity of the agent to be imitated (agent x): focus(imitation, x). Consequently, the action is attributed to the self, as well as to agent x.

Mirroring The simulation results for the scenario of mirroring agent x's action of lifting a box (Figure 2(b)) show that again, the stimulus is transformed to a first person perspective and the action and feeling are attributed to agent x. Furthermore, the activation of an effector state for m is prevented by the context of mirroring. Therefore, in the case of mirroring there is no change in the body state b, since the action is not executed. Therefore, the development of the strengths of the preparation states and the associated feeling is slower. In the scenario of imagination there is also an absence of action execution.

5 Mathematical Analysis

In the example simulations discussed above it was shown that for a time period with a constant environment, the strengths of sensory representations, preparations, body states and feelings reach a stable equilibrium. By a mathematical analysis it can be addressed which types of equilibria are possible. To this end equations for equilibria were determined from the dynamical model equations. Here:

$ts(X, t)$	the level of the transformed sensory representation of X
$p(X, t)$	the level of the preparation of X
$srs(X, t)$	the level the sensory representation of X
$e(X, t)$	the level of the effector state for X
$ss(X, t)$	the level of the sensor state for X (for simplicity assumed 0 or 1)

The following equation models the transformed stimulus:

$$ts(w2, t) = 1 - (1-ss(w1, t))\,(1-ss(imagination, t))\,(1-ss(action, t))$$

Note that this is 1 when one of the external factors $ss(w1, t)$, $ss(imagination, t)$ and $ss(action, t)$ is 1, and 0 otherwise. The dynamical model specifications can be expressed as differential equations as follows.

$$\frac{dp(m,t)}{dt} = \gamma(\beta(1\text{-}(1\text{-}ts(w2, t))(1\text{-}srs(b, t))) + (1\text{-}\beta)ts(w2, t)srs(b, t) - p(m, t))$$

$$\frac{de(m,t)}{dt} = \gamma[(\beta(1\text{-}(1\text{-}p(m, t))(1\text{-}srs(w3, t)) + (1\text{-}\beta)p(m, t)srs(w3, t)]\; [1 - (1 - ss(imitation, t))\,(1 - ss(action, t))\,] - e(m, t))$$

$$\frac{dsrs(w3,t)}{dt} = \gamma(\beta(1\text{-}(1\text{-}p(a, t))(1\text{-}e(a, t))) + (1\text{-}\beta)p(a, t)e(a, t) - srs(w3, t))$$

$$\frac{dsrs(b,t)}{dt} = \gamma(\beta(1-(1-srs(w3, t))(1-e(m, t))) + (1-\beta)\, srs(w3, t)e(m, t) - srs(b, t))$$

To obtain equations for equilibria, constant values for all variables are assumed (also the ones that are used as inputs). Then in all of the equations the reference to time t can be left out, and in addition the derivatives can be replaced by 0. Assuming γ nonzero, this leads to four equations in $srs(b)$, $p(m)$, $srs(w3)$, $e(m)$, with externally determined $ss(c)$ and $ts(w2)$. For the case that $\beta = 1$, the following equations result

$$ts(w2) = 1 - (1-ss(w1))\,(1-ss(imagination))\,(1-ss(action)) \quad (0)$$
$$(1-(1-ts(w2))(1-srs(b))) - p(m) = 0 \quad (1)$$
$$(1-(1-p(m)(1-srs(w3)))\ \ [1 - (1-ss(imitation))\,(1-ss(action))\,] - e(m) = 0 \quad (2)$$
$$(1-(1-p(m))(1-e(m))) - srs(w2) = 0 \quad (3)$$
$$(1-(1-srs(w3))(1-e(m))) - srs(b) = 0 \quad (4)$$

When both $\beta = 1$ and $ts(w2) = 1$, this results in the following:

$$ss(w1) = 1 \ \text{ or } \ ss(imagination) = 1 \ \text{ or } \ ss(action) = 1 \quad (0)$$
$$p(m) = 1 \quad (1)$$
$$e(m) = [1 - (1 - ss(imitation))\,(1 - ss(action))\,] \quad (2)$$
$$srs(w3) = 1 \quad (3)$$
$$srs(b) = 1 \quad (4)$$

This case is shown in the example traces in Figure 2.

6 Discussion

The cognitive agent model presented in this paper incorporates both a mirroring function and a super mirror function of preparation states. The mirroring function enables the agent to recognize actions of other agents, while experiencing feelings associated to these actions. The super mirroring function provides a control layer; it enables the agent to determine and keep track of the context of its mental processing, such as action imagination, mirroring another agent, imitation of another agent or own action execution. Depending on the context, the super mirroring function suppresses or stimulates the actual performance of a prepared action. When this super mirroring function is not well-developed this may lead to deviations in functioning, such as imperfect self-other distinction as occurs in variants of autism, or uncontrolled impulses to imitate what is observed (for example, after watching anti-social or violent actions on TV).

The cognitive functions involved have been adopted, abstracted, and formalised from mirror neuron and super mirror neuron functions informally described in neurological literature such as [6, 8, 15, 12, 11]. The cognitive agent model has been formally specified in the hybrid temporal modeling language LEADSTO [1], and has been analysed mathematically. In example simulations it was shown that preparation states for actions can be used not only for actual preparation of a to be executed action, but that such a preparation state can also be used to internally simulate the effects of the execution of an action (as in mirroring or imagination). The sensing of the context of an action and the creation of a focus state is the process that eventually leads to the differentiation between the different uses of the same preparation state. This focus state influences perception of the stimulus and execution of the action.

Furthermore the focus state is also responsible for attribution of the effects of the preparation state to the correct agent.

The resulting cognitive agent model functions according to the Simulation Theory perspective on mindreading (e.g., [5]), the simulation perspective on imagination [6], and perspectives on imitation [7, 13, 14], which all assume that the own sensory representations, feelings and preparation states are used in reading another agent's actions and emotions, in imagination of actions and emotions, and in imitation. Thus it provides an economically designed generic agent model unifying different modes of mental processing. It has a high extent of flexibility, as it can easily switch between the different modes of mental processing. Due to this flexibility and its economical design, this model may provide a basis for extension to models that build on these forms of action preparation and execution, for example, to induce empathy reactions or to infer intentions of the mirrored agent.

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