Modelling the Role of Cognitive Metaphors in Joint Decision Making

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Abstract—In this paper, a social agent model is presented for the influence of cognitive metaphors on joint decision making processes. The social agent model is based on mechanisms known from cognitive and social neuroscience and cognitive metaphor theory. The model was illustrated in particular for two types of mechanisms that can affect joint decision making in different manners: a cooperative metaphor and a competitive metaphor. By a number of scenarios it was shown how the obtained social agent model can be used to simulate and analyze joint decision processes influenced by cognitive metaphor.

Keywords—metaphor, joint decision making, agent model

I. INTRODUCTION & MOTIVATION

Making decisions together with others is an essential part of human life, especially in social and professional (e.g., politics, trading, personal relationships) context. Choices in such a decision are always influenced by the others. This process is supported by an innate cognitive capability. Understanding and modeling the cognitive basis behind such joint decision-making is a non-trivial research challenge. Recent research from Social Neuroscience provides insight in some of the mechanisms underlying the different elements in joint decision-making processes; (e.g., [1],[5]).

Two core processes were identified as important to model processes of joint decision making: mirror neurons and internal simulation (see [6],[7]). Mirror neurons can prepare the body for a certain action or body change, and also activate upon observing somebody else who is performing or tending to perform this action or body change (e.g., [6],[8]–[11]). Internal simulation is used as a means for prediction of the (expected) effects of a prepared action (e.g., [12],[13]). Furthermore, internal simulation together with mirror neurons in an individual leads to the copying of processes that may take place in an another individual, and facilitate empathic understanding associated to action choices of that individual, but without actually executing those (e.g., [14]–[18]). An interplay of these processes among individuals can lead to the emergence of a joint decision. Additionally, ownership states also play an important role in decision-making process. An important function of an ownership state is that it mainly determines to what extent an individual attributes an action to himself or to another person. Ownership states (i.e., self and other ownership) are used together with prediction of the effects of a prepared action; they can influence whether the action is actually executed, and are the basis for acknowledging authorship of actions [19],[20]. Together, these concepts contribute to mutual empathic understanding between two persons, helping to form a well-founded joint decision. According to [6], a well-founded joint decision occurs when three requirements are met. Firstly, both agents have chosen the same option, secondly, both agents have a good feeling about it, and finally, both agents have empathic understanding of how the other feels about the chosen option.

In addition to the above processes and aspects, still other aspects may influence a joint decision making process. One perspective to explore this is through cognitive metaphor [21–27]. Originally, the theory was that a metaphor only occurs in written or spoken speech. However, according to George Lakoff and Marc Johnson [28] more in general metaphors regularly play an important role in our conceptualization and communication and contribute to a mental image of a current situation. The way we understand many phenomena in our daily lives is metaphorical: one certain mental domain is understood in terms of another mental phenomenon. The function of metaphor is to better understand certain concepts and it is an inevitable part of human thought and reasoning [29]. The cognitive theory on metaphors can be difficult to comprehend because metaphors are deeply and unconsciously engraved in our brain, making them so mundane to us that we do not notice them ourselves. Still, metaphors structure the way we think, how we see the world, and also the way we make decisions together with others. It has been found that the process of human thought through metaphorical associations can unconsciously be affected by bodily changes (see [30]–[32]).

In this paper the influence of cognitive metaphors on joint decision making will be examined by combining the concept of a joint decision making process and a cognitive metaphor together in a computational social agent model. The computational social agent model for joint decision making presented in [6] is taken as a point of departure and extended by incorporating a model for metaphors. Many kinds of metaphors can influence joint decision processes. The introduced model in this paper indicates in a generic manner how they can be incorporated in a model of joint decision making. In addition, it will be shown more specifically how influences of cooperative and competitive metaphors can be modeled in a detailed manner. This will provide a clear
illustration of the influence cognitive metaphors may have in a joint decision making process.

The model proposed in this paper can have many possible uses. For example, it could be helpful in the design of human-like virtual agents for simulation-based training, like a virtual agent helping a human in training (group) decision tasks. Another possible use for a more specific task is a virtual agent that helps partners to learn how to make solid joint decisions, or that helps a business to come to a most valuable deal with another business. A model like this is useful in complex simulations of socio-technical systems (e.g., the aviation domain) based on computational models of human behavior for more realistic results. In this paper, first in Section II some of the core concepts used are briefly reviewed. In Section III, the computational social agent model is presented. In Section IV, some of the explored simulation scenarios are discussed. Section V is a discussion and will bring forward some ideas for future research.

II. CORE CONCEPTS: MIRRORING, INTERNAL SIMULATION, OWNERSHIP, AND METAPHORS

The agent model presented here includes a number of cognitive states and processes. The theoretical basis of these states and processes, is discussed in the current section.

A. Mirror neurons

Mirror neurons are fundamental to joint decision making. Mirror neurons are motor neurons that fire when an action is (to be) executed by a subject, but also when the subject observes somebody else performing that action. Observing an action activates the same neural mechanism as preparing for execution of said action [33]. This means that when an action is executed by someone else, this is not just perceived and represented in a sensory manner, also a motor representation occurs in the observers’ mind. Mirror neurons were originally found in monkeys [34], [35], but later studies have proven the existence of a similar mechanism in human beings [8], [36]–[40]. Gallese [33] explains that the mirror neuron areas in one’s brain are responsible for the processes of action execution, action perception, imitation and imagination, with neural links to motor effectors. When an action is executed or imitated, this leads to the excitation of the muscles concerned with that action. When an action is only observed or imagined, the excitation of the muscles does not take place.

B. Process of internal simulation

Internal simulation is another crucial concept in a joint decision making process. This works in combination with mirror neurons. The mirror neuron function makes that a preparation state is activated upon observing an action. As a next step, internal simulation generates a prediction of the (expected) effects of such a prepared action [12], [13].

Emotions and feelings are important elements in human cognition. William James proposed that, after a person receives an input, as a response the body prepares for and executes bodily changes (referred as body-loop) and only then feels an emotion. [41]. In short:

\[
\text{sensory representation} \rightarrow \text{preparation for bodily changes} \rightarrow \text{expressed bodily changes} \rightarrow \text{emotion felt} = \text{based on sensory representation of bodily changes}
\]

Damasio [14], [15] introduced another hypothesis: the as-if body loop. The as-if body loop makes it possible that actual bodily changes in the emotion generation are bypassed by internally simulating the body changes. A person is faced with an input, this input leads to a preparation for bodily changes, and as a form of internal simulation, this leads to a (sensory) representation of a changed body state, causing the emotion that is felt, without actually executing the bodily changes. In addition, Damasio adds that the felt emotion and the preparation for bodily changes mutually affect each other, leading to a cycle.

In combination, mirror neurons and as-if body loops can make feelings and actions of two persons converge. For example, person A gets sensory input of an action that person B (tends to) executes, and of person B’s associated emotion. Then the mirror neurons of person A lead to a preparation state in person A of the action that person B executes and the associated emotion. This, through the as-if body loop, will lead to person A having feelings and preparations that correspond to the action that person B executes and to B’s associated emotion. This mechanism explains how persons affect each other’s decisions and feelings so that convergence can be facilitated [6], [7], [11].

C. Ownership

Differentiating between the actions that are caused by oneself and actions that are caused by others is a vital concept of joint decision making and a requirement for establishing social communication and appropriate interactions. This system of self-other differentiation is important for functions as understanding the meaning of an action and interpreting the meaning of the responsible agent [20], [42]–[44]. Another element, put forward by Moore and Haggard in [19], is the distinction between action ownership based on prediction (prior to execution), and action ownership based on inference after execution of the action (in retrospect). Only when prior to executing an action in the internal simulation process a person attributes the simulated action to himself and predicts the action to have a good outcome, this can result in actual execution of the action. Therefore, prior ownership states play an important role in controlling the actual execution of actions (go/no-go decisions, vetoing). After the execution, the person responsible for executing the action can acknowledge in retrospect the ownership of the action. This acknowledgement is necessary to enable communication of feelings and understanding about an action between people (see [20]).

D. Empathic response

In [45], p. 435 the following criteria for empathy are expressed for a person (S) having a state of empathy for another person (B): (1) presence of an affective state in the person, (2) isomorphism of the person’s own and the other person’s affective state, (3) elicitation of the person’s affective state upon observation or imagination of the other person’s affective state, and (4) knowledge of the person that the other person’s affective state is the source of the person’s own
Affective state. Assuming true, faithful bodily (nonverbal) and verbal expression, the following reformulation can be made to obtain criteria for an empathic response to another person. If the prepared body state is actually expressed by $S$, so that the other agent $B$ can notice it, then this contributes an empathic nonverbal response of $S$ to $B$, whereas communication of $S$ of the emotion to $B$ (i.e., $S$ is communicating that $B$ has this emotion) is considered an empathic verbal response. The bodily expression of an observed emotion together with such a communication to $B$ occurring at the same time is considered a full empathic response of $S$ to $B$.

E. Cognitive metaphors

A person may encounter many unknown situations; the brain somehow has to make sense of them. According to cognitive metaphor theory, our brain maps knowledge of known concepts onto new ones to comprehend new situations [46–48]. This is also referred to as analogy making: a mapping between two domains, called the source (or base) and the target (or topic) [46, 47], based on a number of features or characteristics the base and the topic have in common. Consider for example as a metaphor the sentence “That woman is poison”.

Metaphor theory, our brain maps knowledge of known concepts to create new concepts in order to make sense of them. However, this sentence can be recognized as a cognitive metaphor, with ‘woman’ as the topic and ‘poison’ as the source. This might lead to conceiving said woman as something that kills, injures, or impairs an organism and is something destructive or harmful.

As described by El Refaie [49], metaphors can change the way we think about a situation, as constant repetition of particular metaphors will lead to our unconscious acceptance of that particular metaphor as a normal way of seeing that situation. Thereby, a metaphor subconsciously constructs how we perceive concepts (see [30–32]). Furthermore, several studies have shown that our actions are subconsciously influenced by the automated activation of motives [50, 51]. In particular, the concepts and motives playing a role in joint decision making process, including all underlying processes, are influenced by our metaphorical image of the situation. Therefore, cognitive metaphors strongly affect the way humans make decisions with each other. In this paper, the influence of cognitive metaphor on the joint decision making process will be examined and illustrated, specifically for two categories of metaphors: a cooperative metaphor and a competitive metaphor. For example, if a person uses the metaphor ‘war’ to make a decision, he will unconsciously experience the decision making process as a form of war, attacking the opponent and defending his own points. This will lead to a competitive mind set and an outcome with one winner and one loser. However, if a person uses a friendlier metaphor for the decision process, for instance ‘art dance’, this will lead to a cooperative mind set. If a person uses this mindset in the joint decision making process, he or she will aim at creating something together with the partner, leading to a joint outcome.

III. A COMPUTATIONAL DYNAMIC SOCIAL AGENT MODEL FOR JOINT DECISION MAKING WITH METAPHORS

A neurologically inspired social agent model is presented that integrates the role of metaphors in joint decision making. It adopts elements of previously developed models, in particular models on joint decision making processes [6] and ownership [20]. Based on these elements and the knowledge about cognitive metaphors as discussed, an integrative social agent model was created that focuses on the influence of cognitive metaphor in joint decision making processes. For a graphical overview of the model, see Fig. 1 and for its abbreviations, see Table 1. The graphical overview incorporates several states (circles) and their dynamics as processes (arrows). This model represents the cognitive behavior of one agent (Self: $S$) and it observes the actions and emotions of another agent (agent B) in the process of joint decision making.

Basic elements in the joint decision making model

The model uses five world states (WS) as inputs: stimulus $s$: WS($s$), action $a$ of agent B: WS($B, a$), effect $e$ of self action $a$: WS($e$), feeling $b$ associated to action effect $e$ of Agent B: WS($b$), and feeling $b$ associated to self action effect $e$: WS($b$). In Fig. 1 it has used subscript letter ‘i’ for features: $a$, $e$, and $b$; that indicates the $i^{th}$ instance of that feature. Therefore, through this model it is possible to have multiple action options through a single stimulus. The input world states WS($s$), WS($B, a$), WS($e$), WS($B, b$), and WS($b$) lead to sensor states SS($s$), SS($B, a$), SS($e$), SS($B, b$), and SS($b$), and subsequently to sensory representation states SR($s$), SR($B, a$), SR($e$), SR($B, b$), and SR($b$), respectively.

From the dynamic perspective, at a given point in time two or more agents receive/observe a stimulus $s$. This leads to a causal chain WS($s$) to SS($s$) to SR($s$). Having sensory representation of the stimulus $s$, each agent individually prepares for possible options through preparation states PS($a$) for executing action $a$; these options may correspond to the habitual responses upon the stimulus. Having represented PS($a$) states a decision or selection process is needed to decide which option to select. For this, the internal simulation process is used (following Damasio): without executing the action options through the body loop, each option is internally

![Fig. 1. A graphical overview of the social agent model](image-url)
provides a basis for evaluation of each option. In the model, prior and retrospective states; for more information on this.

S’s feelings and decisions of both agents to be tuned to each other, execution state ES(a).

execution state ES(a), for its action selection. Note that for the sake of simplicity this model does not include the differentiation of prior and retrospective states; for more information on this distinction, see [20]. While this action selection process is developing, the agent starts to execute basic indications of its (to be) selected option a_i through partial activation of its execution state ES(a_i). As this is in the context of joint decision making, the preferred signs of choices of each agent will be observed by the other agents (for the simplicity of explanation only two agents are considered). Therefore, the agent S observes that the other agent B tends to perform action a_i through its observed world state WS(B, a_i), leading to a sensory representation state SR(B, a_i). At this point of time the mirror neurons are used in this model. It is assumed that through the relevant mirror neuron function of preparation state PS(a_i), sensory representation state SR(B, a_i) affects PS(a_i). In this way observing the other agent B affects agent S’s corresponding states and preparations, leading to the feelings and decisions of both agents to be tuned to each other, as discussed in the previous section. Moreover, the agents differentiate the self and other (agent B’s) ownership and start to develop other-ownership states OS(B, s, a_i, e_i). Furthermore any ownership state OS(X, s, a_i, e_i) suppresses SR(e_i) after executing action a_i. This is important for the separation of effects of action prediction and execution as highlighted in [19]. Due to this it is expected to have a dip in the sensory representation and feeling in-between predictive representation and inferential representation [53], [54].

In this model, it is assumed that an agent will not perform an action spontaneously but starts to slowly provide signs of execution and develop or suppress it over time more and more strongly. In line with the agent’s initial preparation of action a_i, it will add activation to SR(e_i). This will lead to emotions associated to the predicted effects of action a_i; the agent prepares for expressing emotions for effect representation SR(e_i) through PS(b_i). Each emotion is evaluated through the process of internal simulation (by the as-if body loop in Fig. 1) and the agent experiences its associated feeling (without executing it) and in parallel develops the self-ownership of the emotion indicated by body state b_i and effect e_i; OS(S, e_i, b_i). For mutually exclusive options, the state PS(b_i) also includes a self suppressive link as explained for PS(a_i).

Similar to the action a_i, agents start to share the signs of their emotion through execution state: ES(b_i). As the same process is developing inside the other agent B, agent S can see the emotions of agent B through WS(B, b_i) and represent this by SR(B, b_i). Through the mirror neuron function it also affects on PS(b_i) and leads to develop OS(B, e_i, b_i) (as explained for SR(B, a_i)). Furthermore the ownership state OS(X, e_i, b_i) also suppresses SR(b_i) after executing b_i [19] as explained for the OS(S, e_i, b_i).

The integration of metaphors in the model

In a generic manner there are two sides for the (functional) role that characterizes a metaphor within the causal chains of mental processes: (1) how is it affected by certain states, and (2) how does it affect other states and processes.

Side (1) of a characterization of a metaphor specifies to which situations it applies. Through this it is determined in which situations a given metaphor becomes activated. This works according to a process of analogy making (see [46], [47]). This is modeled by considering a number of characteristics or features of a situation and match this to characteristics or features of the metaphor. If a match occurs, the metaphor will become active, else it will remain inactive. So, any given metaphor is characterized by such a set of characteristics or features. The strength of the matching process also involves personal characteristics of the agent. For a given situation one agent may match it strongly to one specific metaphor, whereas another agent may match it more strongly to an alternative metaphor for the same situation. In this way individual differences occur. In general the characteristics of the situation are internally represented by a set of sensory representations SR(w_1), …SR(w_n), for example, formed on the basis of observations SS(w_1), …SS(w_n) of the situation. For a specific agent the matching of these characteristics to a metaphor state Met(m) is modeled by the agent-specific strengths of the connections from these sensory representation states SR(w_1), …SR(w_n) to the metaphor state Met(m). The case of the specific metaphors relevant for joint decision making the relevant characteristics in the first place include the fact that there are other agents involved, and secondly, that there are different action options to consider.
Once a metaphor has become active, it affects other states and processes. This is the second part (2) of the characterization of a specific metaphor. For a given metaphor, this is modeled by specifying connections with certain (agent-specific) weights from the metaphor state to other states. For the case of the specific metaphors relevant for joint decision making such connections are to the states relevant in the joint decision making process. In this case a metaphor state of agent S influences the ownership states for action options and feelins. This way, through the ownership states, the metaphor state has influence on whether an action option is chosen or not.

The specific metaphors used as illustration in this paper are the cooperative metaphor and the competitive metaphor. Both metaphors share as a characteristic that they only apply when another person is present and play a role in some form of joint decision making in which different options are considered. So, to specify to which situations these metaphors apply (1) connections from sensory representation states SR(β, ..) are used, in particular:

1. Sensory representation states SR(β, a) and SR(b, b) activate cooperative and competitive metaphor states Met(cco) and Met(com).

The strengths of these connections can be different between different agents, and also different between the cooperative and the competitive metaphor, thus also expressing personal characteristics of an agent.

The way in which the cooperative and competitive metaphor states have effects (2) on the decision making is as follows. These effects are modeled by connections from the metaphor states to ownership states OS(X, ..) in such a way that:

2a. A cooperative metaphor state Met(cco) suppresses self ownership states OS(S, ...).

2b. A competitive metaphor state Met(com) strengthens self ownership states OS(S, ...).

By these effects an agent tends more to keep the own preferred option using a cooperative metaphor and less using a competitive metaphor.

Due to the processes as explained the agent will (strongly) execute an action ai, and emotion bi through the body loop. For the execution of ES(ai) and ES(bi) only self-ownership states will have effect, in addition to the preparation states. Finally the agent acknowledges authority for the executed action and communicates about the effects and emotions of the executed action through EC(X, s, a, e) and EC(X, e, b).

Dynamics of the model

Having a cognitive model, it is important to translate it into a computational format to obtain simulation results. For this purpose, the model was compiled as proposed in [55] to simulate scenarios. Connections between state properties (the arrows in Fig. 1) have weights ωk, as indicated in Table II. In this table a weight ωk has a value between -1 and +1 and may depend on the specific stimulus s, action a, effect e, and/or emotion b involved. By varying these connection strengths, different possibilities for the repertoire offered by the model can be realized and can be aligned with considered scenarios and personal characteristics of agents. Usually weights are assumed to be nonnegative, except for inhibiting connections.

### TABLE II. OVERVIEW OF THE CONNECTIONS AND THEIR WEIGHTS

<table>
<thead>
<tr>
<th>from states</th>
<th>to state</th>
<th>weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES(ai)</td>
<td>WS(e)</td>
<td>0</td>
</tr>
<tr>
<td>ES(bi)</td>
<td>WS(bi)</td>
<td>0</td>
</tr>
<tr>
<td>WS(s)</td>
<td>SS(s)</td>
<td>0</td>
</tr>
<tr>
<td>WSI(β, a)</td>
<td>SS(β, a)</td>
<td>0</td>
</tr>
<tr>
<td>WS(bi)</td>
<td>SS(bi)</td>
<td>0</td>
</tr>
<tr>
<td>SS(e)</td>
<td>SR(s)</td>
<td>0</td>
</tr>
<tr>
<td>SS(β, a)</td>
<td>SR(β, a)</td>
<td>0</td>
</tr>
<tr>
<td>SS(e, b)</td>
<td>SR(e, b)</td>
<td>0</td>
</tr>
<tr>
<td>SS(β, a, e)</td>
<td>SR(β, a, e)</td>
<td>0</td>
</tr>
<tr>
<td>SS(β, a, e)</td>
<td>SR(β, a, e)</td>
<td>0</td>
</tr>
<tr>
<td>OS(S, s, a, e)</td>
<td>ES(ai)</td>
<td>0</td>
</tr>
<tr>
<td>OS(S, e, b)</td>
<td>ES(bi)</td>
<td>0</td>
</tr>
<tr>
<td>OS(X, s, a, e)</td>
<td>EC(X, s, a, e)</td>
<td>0</td>
</tr>
<tr>
<td>OS(X, e, b)</td>
<td>EC(X, e, b)</td>
<td>0</td>
</tr>
</tbody>
</table>

The dynamics of the model depends on the values of each of these weights (together with other parameters).

Local Properties in LEADSTO (see [56]) specify the update dynamics of the activation value of the ‘to state’ based on the activation levels of the ‘from states’. For the dynamics of each local property a LEADSTO formalisation was made. Each state includes an additional parameter called speed factor υ, indicating the speed by which an activation level is updated upon received input from other states to the state ‘i’. Two different speed values are used as fast and slow: fast value is for internal states and slow value is for external states (the states inside the dotted black block are considered as internal states). Activation of a state depends on multiple other states that are directly attached to it. Therefore incoming activation levels from other states are combined to some aggregated input and affect the activation level according to a differential equation as in (1) below. For each state a continuous logistic threshold function is used as in equation (2), where σ is the steepness, and τ the threshold value. When the aggregated input is negative (3) is used. To achieve the temporal behavior of each state as a dynamical system, a difference equation is used in the form of equation (4) (where Δt is the time step size).

\[
\frac{dy_i}{dt} = y_i \left( f \left( \sum_{k=1}^{n} \omega_k y_k \right) - y_i \right) - y_i 
\]

\[
f(X) = \frac{1}{1 + e^{-\sigma(X-\tau)}} 
\]

\[
y_i(t + \Delta t) = y_i(t) + \left[ f \left( \sigma, \tau, \sum_{k=1}^{n} \omega_k y_k \right) - y_i(t) \right] \Delta t
\]

IV. SIMULATION OF EXAMPLE SCENARIOS

The model presented in Section III was validated by simulating a large number of example scenarios based on

1 http://www.few.vu.nl/~dte220/IAT2015_LEADSTO.pdf
V. DISCUSSION

In this paper, the influence of cognitive metaphor on joint decision making processes was examined using a social agent model. The social agent model presented in this paper was based on mechanisms for joint decision making known from social neuroscience and on cognitive metaphor theory [21], [28], [29], [49], [60], [61]. These are two concepts that have not been combined in a computational model before. Among the core mechanisms adopted are mirror neurons [6], [8-11], internal simulation [6], [14-19], and ownership states [6], [20], [42-44]. In the model, the integration of cognitive metaphor in joint decision making was addressed in general, but illustrated for a cooperative and competitive metaphor state in particular. The metaphor states are activated by the activation of certain sensory representations. In turn the metaphor states affect the agent’s ownership states and thus a decision to perform an action or not.

http://www.few.vu.nl/~dte220/IAT2015_xmlFiles.zip
processes influenced by cognitive metaphor. The outcomes of the different situations currently simulated already show that metaphors have an influence on the joint decision making process, the model still needs to be tested with more scenarios, for example with different metaphors.

The presented model could have many possible uses. For example, it could be helpful in the design of human-like virtual agents for simulation based training, like a virtual agent helping a human in training (group) decision tasks. Another possible use for a more specific task is a virtual agent that helps partners as a mediator how to learn how to make solid joint decisions. This scenario shows more activation of ES of a and b; mutual empathic understanding exists, a solid joint decision has been formed. For agent A, the lower prediction loop leads to less execution of all actions. For agent B, the lower prediction strength leads to a more competitive effect: a; and b; execute stronger, a; and b; execute less strong.

Both agents execute their own preferred action and feeling and no mutual empathic understanding exists, a solid joint decision has been formed. In comparison to this configuration with stronger prediction link, there is less gap between the executed actions, e.g. the difference in strength in execution of a; and b; and a; and b;. Also the ES states are less steep with a weaker prediction link.

Both agents execute action a; and body state b; Mutual empathic understanding exists, a solid joint decision has been formed. In comparison to this configuration with stronger prediction link, there is less gap between the executed actions, e.g. the difference in strength in execution of a; and b; and a; and b;. Also the ES states are less steep with a weaker prediction link.

It was shown how a social agent model can be used to simulate and analyze different scenarios for joint decision processes influenced by cognitive metaphor. The outcomes were shown for several possible scenarios. Although the outcomes of the different situations currently simulated already show that metaphors have an influence on the joint decision making process, the model still needs to be tested with more scenarios, for example with different metaphors.

In an extension of this research several options could be considered. For example, the current model could be adapted to enable the use of multiple metaphors. Furthermore, the way that metaphors are activated in the model could be extended by including other external influences in the activation process. Finally, the influence of disorders on the use of metaphor in decision making would be an interesting concept to examine further.

Table III. Summary of Simulation Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Nr</th>
<th>Agent</th>
<th>Metaphor configuration</th>
<th>Connection weights used</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted metaphor</td>
<td>1a</td>
<td>A</td>
<td>Comp</td>
<td>1</td>
<td>Both agents execute their own preferred action and feeling and no mutual empathic understanding exists. No solid joint decision has been formed.</td>
</tr>
<tr>
<td>SR(B,X) → Met(m)</td>
<td>Xe[a,b]</td>
<td></td>
<td>B</td>
<td>Comp</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1b</td>
<td>A</td>
<td>Coop</td>
<td>1</td>
<td>Both agents execute action a; and body state b;. Mutual empathic understanding exists, a solid joint decision has been formed. The process took longer than in the competitive scenario, because it takes time for agent A to switch his action preference from a; to a;</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Coop</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted mirroring</td>
<td>2a</td>
<td>A</td>
<td>Coop</td>
<td>1</td>
<td>Here, finally both agents execute a; and b;. Mutual empathic understanding exists, and so does a solid joint decision. This scenario shows more activation of ES of a; and b; than when the strength of the mirroring process (i.e., the link from SR(B,a;) to PS(a;) is weaker. Even though agent B is competitive, the more sensitive mirroring leads to a higher activation of the action a; that agent A originally prefers, leading to agent A mirroring this process of agent B and thus also executing a; more (same for body state b;).</td>
</tr>
<tr>
<td>SR(B,X) → PS(X)</td>
<td>Xe[a,b]</td>
<td></td>
<td>B</td>
<td>Comp</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2b</td>
<td>A</td>
<td>Comp</td>
<td>0.5</td>
<td>Both agents are competitive and have an impaired mirroring process, meaning that they are less influenced by the actions of the other. The scenario has the same outcome as ‘1a’; however, for both agents their preferred action is executed more strongly and the other action has even less activation.</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Comp</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted prediction link</td>
<td>3a</td>
<td>A</td>
<td>Coop</td>
<td>0.3,0.2</td>
<td>Both agents execute action a; and body state b;. Mutual empathic understanding exists, a solid joint decision has been formed. In comparison to this configuration with stronger prediction link, there is less gap between the executed actions, e.g. the difference in strength in execution of a; and b; and a; and b; is stronger as-if body loop. Also the ES states are less steep with a weaker prediction link.</td>
</tr>
<tr>
<td>PS(a;) → SR(a;)</td>
<td></td>
<td></td>
<td>B</td>
<td>Comp</td>
<td>0.3,0.6</td>
</tr>
<tr>
<td></td>
<td>3b</td>
<td>A</td>
<td>Coop</td>
<td>0.3,0.2</td>
<td>Both agents execute action a; and body state b;. Mutual empathic understanding exists, a solid joint decision has been formed. For agent A, the lower prediction loop leads to less execution of all actions. For agent B, the lower prediction strength leads to a more competitive effect: a; and b; execute stronger, a; and b; execute less strong.</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Comp</td>
<td>0.3,0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted as-if body loop</td>
<td>4a</td>
<td>A</td>
<td>Comp</td>
<td>0.4,0.3</td>
<td>Both agents executed their own preferred action and feeling and no mutual empathic understanding exists, no solid joint decision has been formed. Compared to a stronger as-if body loop, the agents act more competitive, e.g. they execute their own preferred action more and the other action less strongly than with a stronger as-if body loop.</td>
</tr>
<tr>
<td>PS(b;) → SR(b;)</td>
<td></td>
<td></td>
<td>B</td>
<td>Comp</td>
<td>0.3,0.6</td>
</tr>
<tr>
<td></td>
<td>4b</td>
<td>A</td>
<td>Comp</td>
<td>0.5,0.3</td>
<td>Both agents execute action a; and body state b;. Mutual empathic understanding exists, a solid joint decision has been formed. Preparation states, execution states en communication states are a lot less steep, making the decision making process slower.</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Comp</td>
<td>0.3,0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted metaphor effect</td>
<td>5a</td>
<td>A</td>
<td>Coop</td>
<td>0.4,-0.4; 0.4,-0.4; -0.2,0.2; -0.2,0.2</td>
<td>Both agents execute action a; and body state b;. Mutual empathic understanding exists, a solid joint decision has been formed. Comparing this scenario with a stronger connection between metaphor and ownership: for both agents, all other ownership states develop less strongly, self ownership states develop stronger due to less influence of cooperative metaphor. Due to this, it takes longer before both agents’ actions and feelings converge, than with a normal ownership state; the ES, EC graphs are less steep.</td>
</tr>
<tr>
<td>Met(y)</td>
<td>→ OS(X,e,a)</td>
<td></td>
<td>B</td>
<td>Coop</td>
<td>0.4,-0.4; 0.4,-0.4; -0.2,0.2; -0.2,0.2</td>
</tr>
<tr>
<td></td>
<td>5b</td>
<td>A</td>
<td>Comp</td>
<td>0.8,-0.9; 0.8,-0.9; -0.5,0.5; -0.5,0.5;</td>
<td>Both agents execute their own preferred action and feeling and no mutual empathic understanding exists, no solid joint decision has been formed. In comparison with a weaker connection between metaphor and ownership state, for each agent, all self ownership states develop stronger, other ownership states develop less strong due to more influence of the competitive metaphor. In this scenario, the decisions are formed more quickly (even though not joined), and the agents are more competitive, e.g. they execute their own preferred action more strongly and the other action less strongly than with a weaker metaphor-ownership connection.</td>
</tr>
<tr>
<td>OS(X,e,b)</td>
<td>Xe[B,S]</td>
<td></td>
<td>B</td>
<td>Comp</td>
<td>0.8,-0.9; 0.8,-0.9; -0.5,0.5; -0.5,0.5</td>
</tr>
</tbody>
</table>

REFERENCES


