Chapter 10
Work Together or Fight Together: Modeling Adaptive Cooperative and Competitive Metaphors as Mental Models for Joint Decision Making

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Abstract In this chapter, joint decision making processes are studied and the role of cognitive metaphors as mental models in them. A second-order self-modeling network model is introduced based on mechanisms known from cognitive and social neuroscience and cognitive metaphor and mental model literature. The cognitive metaphors were modeled as specific forms of mental models providing a form of modulation within the joint decision making process. The model addresses not only the use of these mental models in the decision making, but also their Hebbian learning and the control over the learning. The obtained self-modeling network model was applied to two types of metaphors that 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 self-modeling network model can be used to simulate and analyze joint decision processes and how they are influenced by such cognitive metaphors.

Keywords Metaphor · Mental model · Joint decision making · Self-modeling network model · Second-order adaptive

10.1 Introduction

Joint decision-making is a complex process involving cognitive, affective, and social elements. Mechanisms underlying joint decision-making processes have been described within the area of Social Neuroscience; e.g., Cacioppo and Berntson (2005), Decety and Cacioppo (2010), Demiral et al. (2016), Harmon-Jones and Winkielman (2007), Herrera et al. (1997), Hasson et al. (2012), Kato et al. (2016),

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Liepelt et al. (2016), Ruissen and De Bruijn (2015), Stenzel and Liepelt (2016). Mirror neurons and internal simulation play an important role in these mechanisms; see also Treur (2011a), Duell and Treur (2012). Mirror neurons activate both to prepare the body for a certain action or body change, and upon observing somebody else who is performing or tending to perform this action or body change; e.g., Iacoboni (2008a, b), Pineda (2009), Rizzolatti and Sinigaglia (2008). Internal simulation is used as a means for prediction of the (expected) effects of a prepared action; e.g., Haggard (2008), Wolpert (1997). Internal simulation triggered by mirror neuron activations is a form of mirroring which in a sense copies processes that may or do take place within an another individual; e.g., (Damasio 1999, 1994; Gallese and Goldman 1998; Goldman 2006; Hesslow 2002). This form of mirroring is a basis for empathic understanding of another person and his or her preferred decision option choices and as a contagion effect also influences the own preferred options.

Also ownership states play an important role in decision-making processes. An ownership state in general determines to what extent an individual attributes an action to him or herself or to another person and are the basis for acknowledging authorship of actions. They also are used (together with prediction of the effects of a prepared action) to decide on whether a considered action is actually executed; e.g., Moore and Haggard (2008), Treur (2012). The mental processes as described contribute to mutual empathic understanding between two persons, which is an important element of a well-founded joint decision. According to Treur (2011a), a well-founded joint decision has three main elements: both persons have chosen the same option, both have a good feeling about it, and both have empathic understanding of how the other feels about the chosen option. Ideally, based on their dynamic interplay, all mental processes described above together may lead to an emerging well-founded joint decision. However, as these three criteria define a relatively high standard for well-foundedness, in practical situations there are many possibilities for failure of a joint decision on one or more of the three criteria for one or both of the persons, as analysed in detail in Duell and Treur (2012).

In addition to the mental processes described above, still some other factors play an important role in a joint decision making process, for example, the cognitive metaphors used by Cardillo et al. (2012), Carroll and Thomas (1982), Kuang (2003), Leary (1994), Ponterotto (2012), Romero and Soria (2005). According to Lakoff and Johnson (2003) metaphors usually play an important role in our mental image of a situation. Cognitive metaphors are a mode of thought, that is automatically and unconsciously applied in our brains and are an inevitable part of human thought (Lakoff 1993). They 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 metaphorical associations can unconsciously be affected by bodily changes; see Barsalou (2008, Landau et al. (2010), Williams et al. (2009).

In this chapter the role of cognitive metaphors in joint decision making will be explored in more detail by considering a metaphor as a form of a mental model (Abdel-Raheem 2020; Al-Azr 2020; Craik 1943; Gentner and Stevens 1983; Furlough and Gillan 2018; Palmunen et al. 2021; Van Ments and Treur 2021b; Williams 2018):

- which modulates our mental decision making processes
- which is strengthened or weakened by learning
- over which control is exerted

Joint decision making processes and the use of a cognitive metaphor in them will be modeled in an integrative manner by a second-order adaptive self-modeling network model. The computational model for joint decision making presented in (Treur 2011a) is taken as a point of departure for the joint decision making processes and extended by incorporating an adaptive model for metaphors and their learning and control, with some inspiration from (Van Ments et al. 2015) where nonadaptive metaphors were considered. In particular, *cooperative* and *competitive* metaphors and their influence on joint decision making will be addressed.

In this chapter, in Sect. 10.2 some relevant concepts used are briefly summarised and in Sect. 10.3 the self-modeling network modeling approach used is briefly explained. In Sect. 10.4, the designed second-order adaptive self-modeling network model is introduced. Section 10.5 illustrates the model by a simulation scenario. Finally, Sect. 10.6 is a discussion. In the Appendix section the full specification of the introduced network model is included.

10.2 Background Knowledge

In this section some of the background knowledge underlying the network model introduced in Sect. 10.3 is briefly discussed.

10.2.1 Mirror Neurons and Internal Simulation

Mirror neurons are crucial for social processes such as joint decision making. Mirror neurons are neurons that fire both when an action is (to be) executed by a person, and when the person observes somebody else performing that action: observing an action activates the same neural mechanisms as preparing for execution of that action; e.g., (Gallese 2009). 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 (Gallese et al. 1996; Rizzolatti et al. 1996; Iacoboni et al. 2005), but later studies have found similar mechanism in humans (Iacoboni 2008a, b; Fried et al. 2011; Mukamel et al. 2010; Keysers and Gazzola 2010). For example, according to Gallese (2009) 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. In case an action is executed or imitated, this leads to the excitation of the muscles for that action. In case an action is only observed or imagined, the excitation of these muscles does not happen.

Internal simulation works together with mirror neurons. The mirror neuron function makes that upon observing an action a preparation state for the same action is activated. Upon this activation, internal simulation generates a prediction of the expected effect of the prepared action (Haggard 2008; Wolpert 1997). This also applies to preparations for emotional responses. James (1884) proposed that, after a person receives an input, as a response the body prepares for and executes bodily changes (referred to as *body-loop*) and only after that feels an emotion. Damasio (1994, 1999) introduced the *as-if body loop* that makes it possible that actual bodily changes are bypassed by internal simulation of these bodily changes. This means that a person gets some stimulus as input, which in turn 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; the latter sensory representation leads to 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 create contagion that makes that feelings and actions of two persons converge. For example, person A gets sensory input that person B tends to execute a certain action, and person B's associated emotion. By the mirroring, person A activates a preparation state of the same action and also of the associated emotion. This, through internal simulation by the as-if body loop, will lead to person A having feelings and preparations that correspond to the action that person B tends to execute and to B's associated emotion. This mechanism explains how persons affect each other's decisions and feelings so that convergence can occur: e.g., Treur (2011a, b).

10.2.2 Ownership and Empathic Understanding

The concept self-other differentiation and differentiating between the actions that are caused by oneself and actions that are caused by others are important for joint decision making (Brass and Spengler 2009; Farrer and Frith 2002; Fourneret et al. 2002; Jeannerod et al. 2003; Schwabe and Blanke 2007; Treur 2012). In addition, as described by Moore and Haggard (2008), there is a distinction between action ownership based on prediction (prior to execution), and action ownership based on inference after execution of the action (in retrospect). When prior to executing an action, the internal simulation of the considered action by a person predicts the action to have a good outcome, this can result in self-ownership and based on that in actual execution of the action. Therefore, prior ownership states play an important role in decision making on 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.

In DeVignemont and Singer (2006, p. 435) the following criteria 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
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 person *A*, so that the other person *B* can notice it, then this contributes an *empathic nonverbal response* of *A* to *B*, whereas communication of *A* of the emotion to *B* (i.e., *A* communicates 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 *A* to *B*; see also Treur (2011b, c).

10.2.3 Cognitive Metaphors as Mental Models

According to cognitive metaphor theory, our brain maps knowledge of known concepts onto new ones to comprehend new situations (Gentner 1983; Gentner and Stevens 1983; Gentner and Markman 1997; Vosniadou and Ortony 1989). This also occurs in analogical reasoning: a mapping between two domains, called the source (or base) and the target (or topic) (Gentner 1983; Gentner and Stevens 1983), based on an number of features or characteristics the base and the topic have in common. Consider for example as a metaphor the sentence '*That person is poison*'. Literally, this does not make sense; a human being is not a venomous object. However, this sentence can be recognized as a cognitive metaphor, with 'person' as the topic and 'poison' as the source. This might lead to conceiving this person as something that kills, injures, or impairs an organism and is something destructive or harmful. As also indicated in Gentner and Stevens (1983) and Gentner and Gentner (1983), metaphors can be addressed as a specific type of mental models.

As described by El Refaie (2003), metaphors can change the way a person thinks about a situation, as constant repetition of using a particular metaphor will strengthen it by learning mechanisms and lead to our unconscious acceptance of that metaphor as a normal way of seeing that situation; e.g., see Barsalou (2008), Landau et al. (2010), Williams et al. (2009). Moreover, many studies have found that a person's actions are subconsciously influenced by the automated activation of motives (Bargh et al. 2001; Bargh and Morsella 2008). This applies in particular, to the concepts and motives playing a role in joint decision making process, including all underlying processes. All these are strongly affected by our metaphorical image of the situation. In this chapter, this influence of cognitive metaphor on the joint decision making process will be explored for two types of metaphors: a cooperative metaphor (joint decision making as working together) and a competitive metaphor (joint decision making as fighting together).

For example, if a person uses the metaphor of fighting or war to make a decision, he or she will unconsciously conceptualise and experience the decision making process as a form of fight, attacking the opponent and defending his or herself. This will lead to a competitive mindset, often leading to an outcome with one winner and one loser which will not satisfy the high standard of a well-founded joint decision (Treur 2011a): one of the persons will feel good and the other one will feel bad and there will be limited or no mutual empathic understanding.

However, if a person uses a less competitive metaphor for the decision process, for instance 'art dance', this will lead to a more cooperative mindset. If a person uses this mindset in the joint decision making process, he or she will aim at creating something together with the other person, with a higher chance of leading to a joint outcome satisfying the high standard of a well-founded joint decision (Treur 2011a): a joint decision about which both have a good feeling and both empathically understand each other.

In this chapter these uses of metaphors as mental models (Abdel-Raheem 2020; Al-Azr 2020; Craik 1943; Gentner and Stevens 1983; Furlough and Gillan 2018; Palmunen et al. 2021; Williams 2018) will be addressed. Like mental models in general, metaphors can be applied, can be adaptive by involving learning and revision, and can be controlled. These different aspects of metaphors as mental models as pointed out for mental models in general in Van Ments and Treur (2021b) will be addressed in the adaptive self-modeling network model introduced in Sect. 10.4. Before that, in Sect. 10.3 a brief overview of the self-modeling network modeling approach used is provided.

10.3 The Self-modeling Network Modeling Approach Used

In this section, the network-oriented modeling approach based on self-modeling networks used from Treur (2020a, b) is briefly summarised.

10.3.1 Network States and Network Characteristics

The following is a crucial distinction for network models:

- Network *characteristics* (such as connection weights and excitability thresholds) have values (their strengths) and determine (e.g., cognitive) processes and behaviour in an implicit, automatic manner. They can be considered to provide an *embodiment view* on the network.

- Network *states* (such as sensor states, sensory representation states, preparation states, emotion states) have values (their activation levels) and are explicit representations that may be accessible for network states or a person and can be handled or manipulated explicitly. They can be considered to provide an *informational view* on the network.

Following Treur (2016, 2020b), a temporal-causal network model is characterised by the following types of network characteristics (here X and Y denote nodes of the network, also called states, which have values $X(t)$ and $Y(t)$ over time t):

- **Connectivity characteristics**
  Connections from a state X to a state Y and their *weights* $\boldsymbol{\omega}_{X,Y}$
- **Aggregation characteristics**
  For any state Y, some *combination function* $\mathbf{c}_Y(V_1, \ldots, V_k)$ defines the aggregation $\mathbf{c}_Y(\boldsymbol{\omega}_{X_1,Y}X_1(t), \ldots, \boldsymbol{\omega}_{X_k,Y}X_k(t))$ that is applied to the *single impacts* $V_i = \boldsymbol{\omega}_{X_i,Y}X_i(t)$ on Y from its incoming connections from states $X_1, \ldots, X_k$.
- **Timing characteristics**
  Each state Y has a *speed factor* $\boldsymbol{\eta}_Y$ defining how fast it changes for given impact.

The following standard difference equation used for simulation purposes and also for analysis incorporate these network characteristics $\boldsymbol{\omega}_{X,Y}$, $\mathbf{c}_Y(..)$, $\boldsymbol{\eta}_Y$ in a numerical format:

$$Y(t + \Delta t) = Y(t) + \boldsymbol{\eta}_Y\left[\mathbf{c}_Y\left(\boldsymbol{\omega}_{X_1,Y}X_1(t), \cdots, \boldsymbol{\omega}_{X_k,Y}X_k(t)\right) - Y(t)\right]\Delta t \qquad (10.1)$$

for any state Y and where X_1 to X_k are the states from which Y gets its incoming connections. Here the overall combination function $\mathbf{c}_Y(..)$ for state Y is the weighted average of one or more available basic combination functions $\mathbf{c}_j(..)$ by specified weights $\boldsymbol{\gamma}_{j,Y}$ and parameters $\boldsymbol{\pi}_{1,j,Y}, \boldsymbol{\pi}_{2,j,Y}$ of $\mathbf{c}_j(..)$ for Y:

$$\mathbf{c}_Y(V_1, \ldots, V_k) = \frac{\boldsymbol{\gamma}_{1,Y}\mathbf{c}_1(V_1, \ldots, V_k) + \cdots + \boldsymbol{\gamma}_{m,Y}\mathbf{c}_m(V_1, \ldots, V_k)}{\boldsymbol{\gamma}_{1,Y} + \cdots + \boldsymbol{\gamma}_{m,Y}} \qquad (10.2)$$

Table 10.1 lists some of these basic combination functions: these are the ones used in this chapter. Such Eqs. (10.1), (10.2) and the formulae for the combination functions shown in Table 10.1 are hidden in the dedicated software environment; see (Treur 2020b), Chap. 9 or (Treur and Van Ments 2022), Chap. 17. Within the software environment described there, a large number of around 45 useful basic combination functions are included in a combination function library. The above concepts enable to design network models and their dynamics in a declarative manner, based on mathematically defined functions and relations. How it works is that the network characteristics $\boldsymbol{\omega}_{X,Y}$, $\boldsymbol{\gamma}_{j,Y}$, $\boldsymbol{\pi}_{1,j,Y}, \boldsymbol{\pi}_{2,j,Y}$, $\boldsymbol{\eta}_Y$ that define the design of the network model, are (formatted in a standard table format) given as input to the dedicated software environment, and hidden within this environment the difference Eqs. (10.1) are executed for all states, thus generating simulation graphs as output.

Table. 10.1 Basic combination functions from the library used in the model presented here

	Notation	Formula	Parameters
Advanced logistic sum	$\mathbf{alogistic}_{\sigma,\tau}(V_1, \ldots, V_k)$	$\left[\frac{1}{1+e^{-\sigma(V_1+\cdots+V_k-\tau)}} - \frac{1}{1+e^{\sigma\tau}}\right](1+e^{-\sigma\tau})$	Steepness $\sigma > 0$ Excitability threshold τ
Hebbian learning	$\mathbf{hebb}_{\mu}(V_1, V_2, W)$	$V_1 V_2(1 - W) + \mu W$	Persistence parameter μ
Step modulo	$\mathbf{stepmod}_{\rho,\delta}(V)$	For time t value 0 if t mod $\rho < \delta$, else 1	Repetition interval ρ Duration interval δ
Scale mapping	$\mathbf{scalemap}_{\upsilon,\lambda}(V)$	$\lambda + (\upsilon - \lambda)\, V$	Lower bound λ Upper bound υ

10.3.2 Self-models Representing Network Characteristics by Network States

The self-modeling network modeling approach is inspired by the more general idea of self-referencing or 'Mise en abyme', sometimes also called 'the Droste-effect' after the famous Dutch chocolate brand who uses this effect in packaging and advertising of their products since 1904. This effect occurs when within artwork a small copy of the same artwork is included. This can be applied graphically in paintings or photographs, or in sculptures. Also, it is sometimes used within literature (story-within-the-story), theater (theater-within-the-theater), or movies (movie-within-the-movie). This idea is applied to network models as follows. As indicated in Sect. 10.3.1, 'network characteristics' and 'network states' are two distinct concepts for a network. Self-modeling is a way to relate these distinct concepts to each other in an interesting and useful way:

- A *self-model* is making the implicit network characteristics (such as connection weights and excitability thresholds) explicit by adding states for these characteristics; thus the network gets an internal self-model of part of the network structure of itself.
- In this way, different self-modeling levels can be created where network characteristics from one level relate to explicit network states at a next level. By iteration, an arbitrary number of self-modeling levels can be modeled, covering *second-order* or *higher-order effects*.

Adding a self-model for a temporal-causal network is done in the way that for some of the states Y of the base network and some of the network structure characteristics for connectivity, aggregation and timing (in particular, some from $\boldsymbol{\omega}_{X,Y}$, $\boldsymbol{\gamma}_{i,Y}$, $\boldsymbol{\pi}_{i,j,Y}$, $\boldsymbol{\eta}_Y$), additional network states $\mathbf{W}_{X,Y}$, $\mathbf{C}_{i,Y}$, $\mathbf{P}_{i,j,Y}$, $\mathbf{H}_Y$ (self-model states) are introduced:

(a) **Connectivity self-model**

- Self-model states $\mathbf{W}_{X_i,Y}\mathbf{W}_{Xi,Y}$ are added representing connectivity characteristics, in particular connection weights $\boldsymbol{\omega}_{X_i,Y}$

(b) **Aggregation self-model**

- Self-model states $\mathbf{C}_{j,Y}$ are added representing aggregation characteristics, in particular combination function weights $\boldsymbol{\gamma}_{i,Y}$
- Self-model states $\mathbf{P}_{i,j,Y}$ are added representing aggregation characteristics, in particular combination function parameters $\boldsymbol{\pi}_{i,j,Y}$

(c) **Timing self-model**

- Self-model states $\mathbf{H}_Y$ are added representing timing characteristics, in particular speed factors $\boldsymbol{\eta}_Y$

The notations $\mathbf{W}_{X,Y}$, $\mathbf{C}_{i,Y}$, $\mathbf{P}_{i,j,Y}$, $\mathbf{H}_Y$ for the self-model states indicate the referencing relation with respect to the characteristics $\boldsymbol{\omega}_{X,Y}$, $\boldsymbol{\gamma}_{i,Y}$, $\boldsymbol{\pi}_{i,j,Y}$, $\boldsymbol{\eta}_Y$: here **W** refers to $\boldsymbol{\omega}$, **C** refers to $\boldsymbol{\gamma}$, **P** refers to $\boldsymbol{\pi}$, and **H** refers to $\boldsymbol{\eta}$, respectively. In a 3D graphical format, these self-model states are depicted in a separate plane above a base plane for the base network, as will be illustrated in Sect. 10.4. For the processing, these self-model states define the dynamics of state Y in a canonical manner according to Eqs. (10.1) whereby $\boldsymbol{\omega}_{X,Y}$, $\boldsymbol{\gamma}_{i,Y}$, $\boldsymbol{\pi}_{i,j,Y}$, $\boldsymbol{\eta}_Y$ are replaced by the state values $\mathbf{W}_{X,Y}(t)$, $\mathbf{C}_{i,Y}(t)$, $\mathbf{P}_{i,j,Y}(t)$, $\mathbf{H}_Y(t)$ of states $\mathbf{W}_{X,Y}$, $\mathbf{C}_{i,Y}$, $\mathbf{P}_{i,j,Y}$, $\mathbf{H}_Y$ at time t, respectively.

An example of a connectivity self-model state is $\mathbf{W}_{X,Y}$, representing connection weight $\boldsymbol{\omega}_{X,Y}$. This will be applied in Sect. 10.4.2.1 to the connections of a mental model for a metaphor. Similarly, self-model states $\mathbf{H}_Y$ can be added that refer to the speed factor $\boldsymbol{\eta}_Y$ of Y.

As the outcome of the addition of a self-model to a network model is again a network model itself, this construction can easily be applied iteratively to obtain multiple orders of self-models. This will be applied in Sect. 10.4.2.2 by adding second-order self-model states $\mathbf{H}_{\mathbf{W}_{X,Y}}$ representing the adaptive speed factors (i.e., adaptive learning rates in this case) for all first-order self-model states $\mathbf{W}_{X,Y}$ which in turn represent the adaptive connection weights $\boldsymbol{\omega}_{X,Y}$ of the considered mental model.

10.4 The Second-Order Adaptive Network Model

In this section, a social neuroscience-inspired controlled adaptive network model is presented that integrates the role of metaphors as mental models in joint decision making. It adopts elements of previously developed models, in particular models on joint decision making processes and ownership (Treur 2011a, 2012). Based on these elements and the background knowledge discussed in Sect. 10.2, an adaptive network model was designed addressing the influence of an adaptive cognitive metaphor in joint decision making processes. First, in Sect. 10.4.1 the base level of the model is discussed. Then in Sect. 10.4.2 the applied first- and second-order adaptation principles are discussed in how they were modeled by first- and second-order self-models that were added to the base level network.

10.4.1 The Base Model for Metaphors in Joint Decision Making

For a graphical overview of the connectivity of the network model for one person *A* and joint decision making with another person *B*, see Fig. 10.1 in 2D for the base level network. Later on in Sect. 10.4.2, the self-models for learning and control are shown in a 3D graphical representation.

10.4.1.1 The Joint Decision Making in the Base Model

For an overview of the states used for one person *A*, see Table 10.2 for the base level states in the pink area (the first-order self-model states in the blue area and the second-order self-model states in the purple area will be discussed in Sect. 10.4.2). The model uses four world states ws:

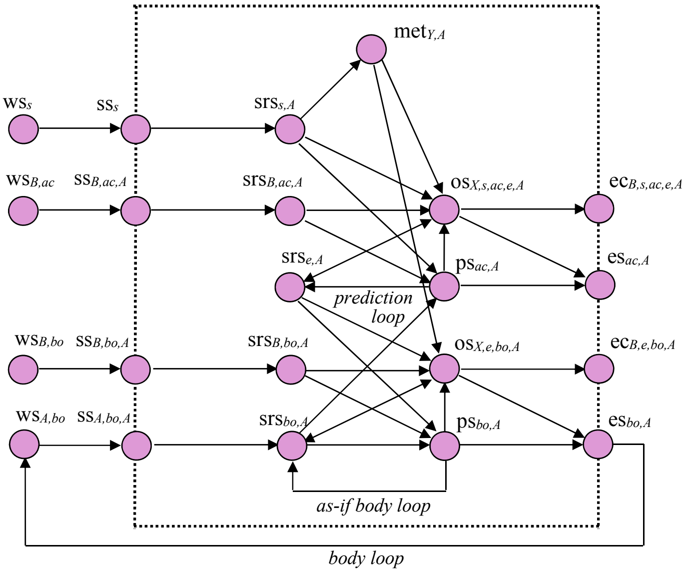

Fig. 10.1 Connectivity of the base network in graphical 2D representation with a person *A*'s model for joint decision making with another person *B* and the role of a metaphor in it. The variable *X* in the two ownership states actually has two instantiations: $X = A$ and $X = B$; both occur in the model. Moreover, there can be multiple metaphors met$_Y$ in the model where *Y* gets multiple instantiations, in the considered simulation scenarios there are two specific ones: cooperative and competitive

ws_s for stimulus *s*.
$\text{ws}_{A,ac}$ for action *ac* any person *A* tends to do and can be observed by any other person.
$\text{ws}_{A,bo}$ for the body state of any person *A* feeling *bo* for action effect *e* of *A* and can be observed by any other person.

As can be seen in Fig. 10.1, these input world states have connections to corresponding sensor states, $\text{ss}_{s,A}$, $\text{ss}_{B,ac,A}$, $\text{ss}_{B,bo,A}$, and $\text{ss}_{bo,A}$, and these in turn to sensory representation states $\text{srs}_{s,A}$, $\text{srs}_{B,ac,A}$, $\text{srs}_{B,bo,A}$, and $\text{srs}_{bo,A}$ will be used for own body state representation $\text{srs}_{A,bo,A}$. The example scenario used is as follows. At a given point in time two persons observe a stimulus *s* for a context where joint decision making about some action *ac* is needed, which in any person *A* triggers a causal pathway from $\text{ws}_{s,A}$ to $\text{ss}_{s,A}$ to $\text{srs}_{s,A}$. The latter sensory representation state of stimulus *s*, partially activates a preparation state $\text{ps}_{ac,A}$ for possibly deciding for action *ac*. This option can correspond to a habitual response of that person upon the stimulus. For such a (partially) activated $\text{ps}_{ac,A}$ state an assesment and decision process is needed to decide whether or not to go for the action. Following Damasio (1994, 1999) this makes use of an internal simulation process (based on a *prediction loop*) to generate a sensory representation state srs_e to predict the effect *e* of the considered action *ac* and associate an emotional response preparation state $\text{ps}_{bo,A}$ for emotion *bo* to this predicted effect. Both via a *body loop* and via an *as-if body loop* this emotional response preparation state $\text{ps}_{bo,A}$ generates a feeling state $\text{fs}_{bo,A}$, which in turn affects preparation state $\text{ps}_{ac,A}$: a positive associated feeling strengthens the preparation for the action, which in turn also positively affects the self-ownership state $\text{os}_{A,s,ac,e,A}$ of *A* for the action *ac* with predicted effect *e*. This self-ownership strengthens a decision for execution of *ac* and may make *A* (tend to) go for *ac*.

A similar model can be made for the other agent *B*, where in Fig. 10.1 and Table 10.1 the person names *A* and *B* have to be swapped, and for all states an extra indication for the agent *A* or *B* itself has to be added as subscript (see also the Appendix section). The two models for *A* and *B* obtained in this way are connected to each other as shown in Fig. 10.2. Note that for the sake of simplicity only the nonverbal interaction is fully modelled. How the interaction by verbal communication from the ec states is received by the other person is left out of the model (Table 10.2).

For the sake of simplicity this model does not include the differentiation of prior and retrospective states; for more information on this distinction, see (Treur 2012). While the decision process is developing, each person *A* also starts to execute basic indications of its (to be) executed action *ac* through partial activation of the execution state $\text{es}_{ac,A}$. As this is in the context of joint decision making, this generates signs of the preferred choice of each person which will be observed by the other person. Therefore, any person *A* observes that the other person *B* tends to perform action *ac* through its observed world state $\text{ss}_{B,ac,A}$, leading to a sensory representation state $\text{srs}_{B,ac,A}$. At this point a mirror neuron function of preparation state $\text{ps}_{ac,A}$ is used in the model. By this, sensory representation state $\text{srs}_{B,ac,A}$ affects $\text{ps}_{ac,A}$. In this way observing the other person *B* affects person *A*'s corresponding states and preparations, making that the feelings and decisions of both persons may be tuned to each

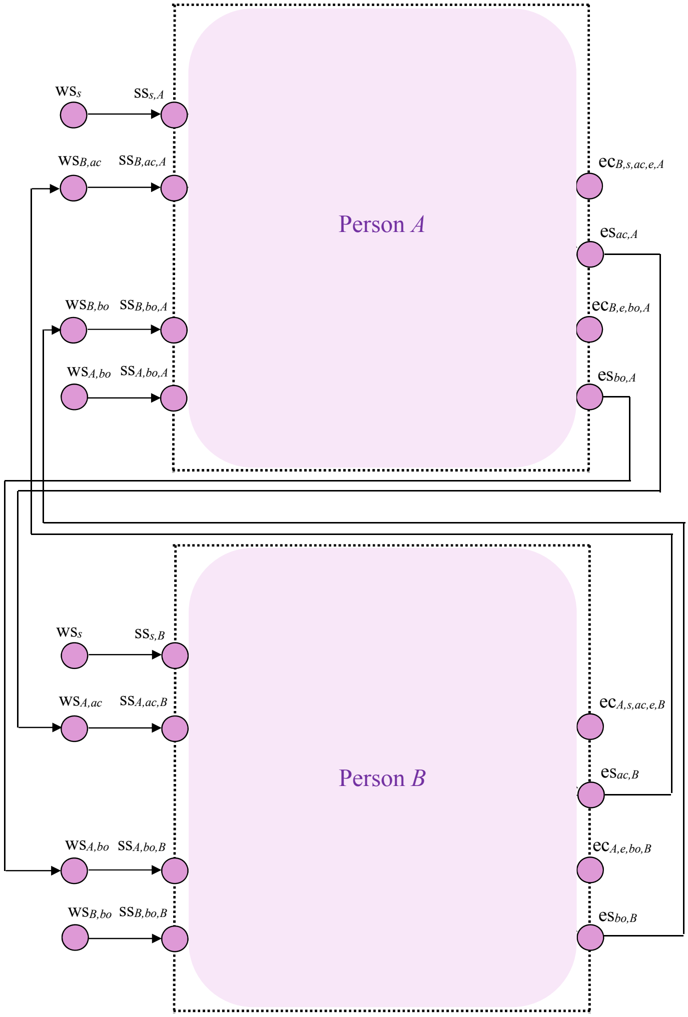

Fig. 10.2 Connectivity for the nonverbal interactions between the two persons *A* and *B*

other. Moreover, the persons differentiate the self's (person *A*) and other's (person *B*) ownership represented within person *A* by ownership states $os_{A,s,ac,e,A}$ and $os_{B,s,ac,e,A}$, respectively. Furthermore any self-ownership state $os_{A,s,ac,e,A}$ suppresses $srs_{e,A}$ after deciding to go for action *ac*. This is important for the separation of effects of action prediction and action execution as highlighted in Moore and Haggard 2008). Due to this it is expected to have a dip in the sensory representation and feeling in-between predictive representation and inferential representation (Aron 2007; Blakemore et al. 2000).

Table 10.2 Overview of the states

Explanation		
ws_s	Stimulus *s* in the world	Base level
$ws_{A,ac}$	*A* tending to do action *ac*	
$ws_{A,bo}$	Body state *bo* of *A*	
$ss_{s,A}$	Sensing stimulus *s* by *A*	
$ss_{B,ac,A}$	Sensing by *A* of *B* tending to do action *ac*	
$ss_{B,bo,A}$	Sensing by *A* of body state *bo* of *B*	
$ss_{A,bo,A}$	Sensing own body state *bo* of *A*	
$srs_{s,A}$	Sensory representation state of *A* for stimulus *s*	
$srs_{e,A}$	Sensory representation state of *A* for action effect *e* of *ac*	
$srs_{B,ac,A}$	Sensory representation state of *A* for *B* tending to do action *ac*	
$srs_{B,bo,A}$	Sensory representation state of *A* for body state *bo* of *B*	
$srs_{A,bo,A}$	Sensory representation state of *A* for own body state *bo* of *A*	
$ps_{ac,A}$	Preparation state of *A* for action *ac*	
$ps_{bo,A}$	Preparation state of *A* for emotional response *bo*	
$os_{B,s,ac,e,A}$	Ownership state of *A* for doing action *ac* in the context of *B*, *s* and *e*	
$os_{B,e,bo,A}$	Ownership state of *A* for emotion *bo* in the context of *B* and *e*	
$ec_{B,s,ac,e,A}$	Communication from *A* to *B* of action *ac* in the context of *B*, *s* and *e*	
$ec_{B,e,bo,A}$	Communication from *A* to *B* of emotion *bo* in the context of *B* and *e*	
$met_{Y,A}$	Metaphor *Y* activation state of *A*	
$\mathbf{W}_{srs_{s,A}, met_{Y,A}}$	Representation of the weight of the connection from $srs_{s,A}$ to $met_{Y,A}$	First-order Self-model level
$\mathbf{W}_{met_{Y,A}, os_{A,s,ac,e,A}}$	Representation of the weight of the connection from $met_{Y,A}$ to $os_{B,s,ac,e,A}$	
$\mathbf{W}_{met_{Y,A}, os_{A,e,bo,A}}$	Representation of the weight of the connection from $met_{Y,A}$ to $os_{B,e,bo,A}$	
$\mathbf{H}_{\mathbf{W}_{srs_{s,A}, met_{Y,A}}}$	Representation of the speed factor (learning rate) of weight representation $\mathbf{W}_{srs_{s,A}, met_{Y,A}}$ for the connection from $srs_{s,A}$ to $met_{X,A}$	Second-order Self-model level

In this model, it is assumed that a person will not perform an action spontaneously but starts to slowly provide signs of deciding. In line with a person *A*'s initial preparation of action *ac*, it will add activation to $srs_{e,A}$. This will lead to emotions associated to the predicted effects of action *ac*: the person prepares for expressing emotions for effect representation $srs_{e,A}$ through $ps_{bo,A}$. Each emotion is evaluated through the process of internal simulation (by the as-if body loop in Fig. 10.1) and the person experiences its associated feeling (without executing it) and in parallel develops the self-ownership of the emotion indicated by body state *bo* and effect *e*: $os_{A,e,bo,A}$. Similar to the action *ac*, persons start to share the signs of their emotion through execution state: $es_{bo,A}$. As the same process is developing inside the other person *B*, person *A* can see the emotions of person *B* through $ss_{B,bo,A}$ and represent this by $srs_{B,bo,A}$. Also in this case through a mirror neuron function it also effects on $ps_{bo,A}$ and leads to develop $os_{A,e,bo,A}$. Furthermore, the ownership state $os_{A,e,bo,A}$ also suppresses $srs_{bo,A}$ after going for *bo* (Moore and Haggard 2008) as explained for $os_{A,s,ac,e,A}$.

10.4.1.2 How the Joint Decision Making is Modulated by a Mental Model for a Metaphor

A metaphor is considered here as a specific type of mental model that modulates the mental processes for joint decision making. In the model, activation of such a mental model for a metaphor Y by any person A is represented by a metaphor state named $\text{met}_{Y,A}$ and its activation. In a generic manner there are two sides for the (functional) role that characterizes a metaphor state $\text{met}_{Y,A}$ within the causal chains of mental processes:

1. how is it affected by certain states (via incoming arrows and pathways to the metaphor state $\text{met}_{Y,A}$)
2. how does it affect other states and processes (via the outgoing arrows and pathways from the metaphor state $\text{met}_{Y,A}$)

The antecedent side (1) of this characterization of a metaphor state $\text{met}_{Y,A}$ specifies to which situations it applies. Through this it is determined in which situations a given metaphor becomes activated. This is modeled here by a connection from context representation state $\text{srs}_{s,A}$ to the metaphor state $\text{met}_{Y,A}$. Once a metaphor has become active, it affects other states and processes. This is the second, consequent part (2) of the characterization of a specific metaphor state $\text{met}_{Y,A}$. For a given metaphor, this is modeled by specifying connections with certain (person-specific) weights from the metaphor state $\text{met}_{Y,A}$ 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 $\text{met}_{Y,A}$ of person A influences the own self-ownership states $\text{os}_{A,s,ac,e,A}$ and $\text{os}_{A,e,bo,A}$ for actions and feelings. In this way, through these ownership states, the metaphor state $\text{met}_{Y,A}$ has influence on whether a person goes for the action or not: it performs a form of modulation of these ownership states.

Summarising, based on the above, metaphors Y are modeled at the base level as mental models that consists of (see the darker shaded area in Fig. 10.3):

- one or more metaphor states $\text{met}_{Y,A}$
- mutual connections with negative weights between different metaphor states that are assumed to be mutually exclusive
- a connection from context representation state $\text{srs}_{s,A}$ to each metaphor state $\text{met}_{Y,A}$

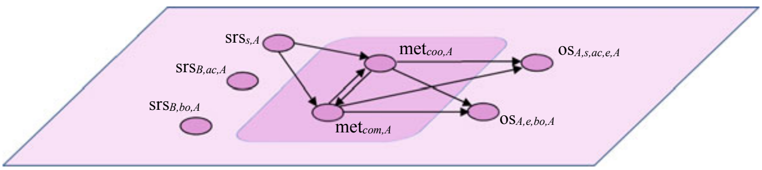

Fig. 10.3 Graphical 3D representation displaying the base mental model for the metaphors with the metaphor states $\text{met}_{coo,A}$ and $\text{met}_{com,A}$ and their incoming activation and outgoing effect connections at the base level and mutual connections to suppress each other

- two connections from each metaphor state $\mathrm{met}_{Y,A}$ to self-ownership states $\mathrm{os}_{A,s,ac,e,A}$ and $\mathrm{os}_{A,e,bo,A}$ for action *ac* and feeling *bo*

The specific metaphors *Y* used as illustration in this chapter are the cooperative metaphor and the competitive metaphor (indicated by *coo* and *com*, respectively). The negative mutual connections create a winner-takes-it-all competition between them by which it can be modeled that they exclude each other.

Both metaphors share as a characteristic that they only apply to a context in which another person *B* is present with whom a joint decision has to be made. This is what is modeled here by the link from context representation state $\mathrm{srs}_{s,A}$ to the metaphor state $\mathrm{met}_{Y,A}$. The context stimulus *s* and strengths of this connection can be different for different persons, thus also expressing personal characteristics of a person, and can also be different for the cooperative and the competitive metaphor. Also the outgoing connections will usually have different weights for different persons, different metaphors and different circumstances. For the sake of sufficient flexibility and adaptivity, in the model introduced here all these incoming and outgoing connections to and from metaphor state met_Y are adaptive; this will be discussed in Sect. 10.4.2.

10.4.2 Modeling First- and Second-Order Self-models for Adaptation and Control

In this section it is discussed how the mental models representing the considered metaphors are made adaptive and how control is exerted over this adaptation. This is done based on first- and second-order self-models for these mental models, as described in Sect. 10.3.2. These first-order and second-order self-models are graphically depicted in 3D in Fig. 10.4 (extending Fig. 10.3) by the two (blue and purple) planes above the (pink) base plane.

10.4.2.1 The First-Order Adaptation Principles Used

The first-order self-model models how the incoming and outgoing connections to and from the metaphor states adapt over time. The weights of these connections are represented by the **W**-states in the middle (blue) plane in Fig. 10.4. For the **W**-states $\mathbf{W}_{\mathrm{srs}_{s,A},\mathrm{met}_{Y,A}}$ for the incoming connections of the metaphor states, the well-known hebbian learning adaptation principle (Hebb 1949) is applied, in a simplified form stated as:

Hebbian Learning adaptation principle

What fires together, wires together (Shatz 1992)

This principle makes that when a metaphor is triggered more often, over time it gets stronger incoming connections from $\mathrm{srs}_{s,A}$ and therefore stronger and faster

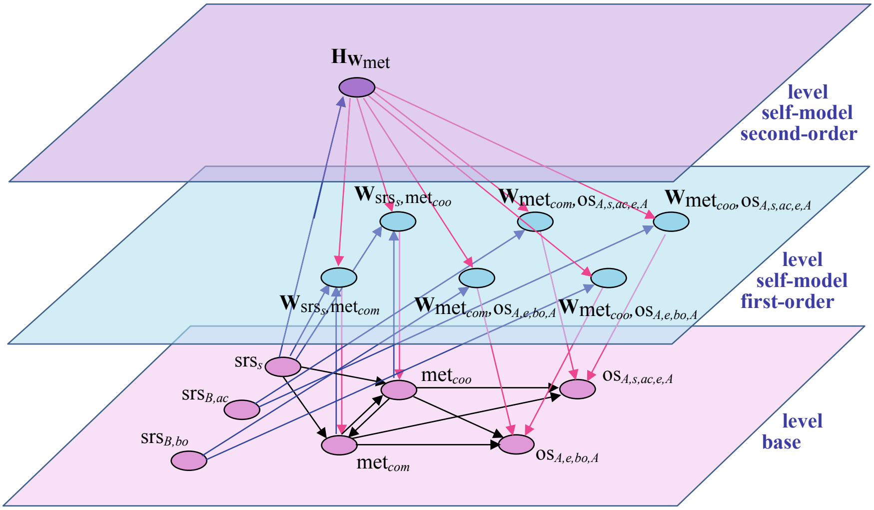

Fig. 10.4 Connectivity of part of the second-order adaptive network in graphical 3D representation displaying the mental models for the metaphors with their activation and effect connections at the base level, their learning at the first-order self-model level and the control of the learning at the second-order self-model level

activations when it is applicable. This principle uses two links from the connected base states $\text{srs}_{s,A}$ and $\text{met}_{Y,A}$ to state $\mathbf{W}_{\text{srs}_{s,A},\text{met}_{Y,A}}$ and also a link from $\mathbf{W}_{\text{srs}_{s,A},\text{met}_{Y,A}}$ to itself. The combination function used for hebbian learning is $\mathbf{hebb}_{\mu}$**(..)** as shown in Sect. 10.3.1 in Table 10.1.

The **W**-states for the outgoing connections from the metaphor states determine the effect of the metaphor states on the self-owner states. The way in which the cooperative and competitive metaphor states have effects on the decision making according to an adaptation principle for self-ownership characteristics can be stated as:

Self-Ownership Modulation adaptation principle

(a) For a cooperative approach, make that self-ownership is strengthened if the other person tends to go for the action and is weakened if the other person tends not to go for it.
(b) For a competitive approach, make that self-ownership is weakened if the other person tends to go for the action and is strengthened if the other person tends not to go for it.

These adaptive effects are modeled by the adaptive connections from the metaphor states to the self-ownership states $\text{os}_{A,s,ac,e,A}$ or $\text{os}_{A,e,bo,A}$ in such a way that some (usually relatively modest) modulation takes place of the activation of these self-ownership states as follows:

(a) A cooperative metaphor state $\text{met}_{coo,A}$ increases activation of the self-ownership states $\text{os}_{A,s,ac,e,A}$ or $\text{os}_{A,e,bo,A}$ if the other person *B* tends to go for *ac* or *bo* and decreases activation of $\text{os}_{A,s,ac,e,A}$ or $\text{os}_{A,e,bo,A}$ if *B* tends not to go for *ac* or *bo*
(b) A competitive metaphor state $\text{met}_{com,A}$ decreases activation of the self-ownership states $\text{os}_{A,s,ac,e,A}$ or $\text{os}_{A,e,bo,A}$ if the other person *B* tends to go for *ac* or *bo* and increases activation of $\text{os}_{A,s,ac,e,A}$ or $\text{os}_{A,e,bo,A}$ if *B* tends not to go for *ac* or *bo*

By these effects a person will emphasize more the own preferred decision using a competitive metaphor and less using a cooperative metaphor. The self-ownership states will have a strong effect on the activation of $\text{es}_{ac,A}$ and $\text{es}_{bo,A}$ (in addition to the influence from the preparation states). For the first-order self-model **W**-states representing the outgoing connections of metaphor states, network characteristics are used that indeed realise (a) and (b) of the above adaptation principle. This is achieved firstly for connectivity by using incoming connections from $\text{srs}_{B,ac,A}$ or $\text{srs}_{B,bo,A}$ to the **W**-states $\mathbf{W}_{\text{met}_{Y,A},\text{os}_{A,s,ac,e,A}}$ or $\mathbf{W}_{\text{met}_{Y,A},\text{os}_{A,e,bo,A}}$ (the upward blue arrows in Fig. 10.4). Secondly, for aggregation, by using the combination function $\mathbf{scalemap}_{\lambda,\upsilon}\mathbf{(..)}$ for these **W**-states, the scale [0, 1] for activation of $\text{srs}_{B,ac,A}$ or $\text{srs}_{B,bo,A}$ is linearly mapped (for some relatively small number $\delta > 0$) on the scale $[-\delta, \delta]$ for activation of $\mathbf{W}_{\text{met}_{Y,A},\text{os}_{A,s,ac,e,A}}$ or $\mathbf{W}_{\text{met}_{Y,A},\text{os}_{A,e,bo,A}}$. This parameter $\delta > 0$ in principle can be small but for specific types of persons, for stronger forms of modulation also can get values up to 1. For the two cases, this works out as follows:

(a) For the cooperative case of $\mathbf{W}_{\text{met}_{coo,A},\text{os}_{A,s,ac,e,A}}$ or $\mathbf{W}_{\text{met}_{coo,A},\text{os}_{A,e,bo,A}}$ the linear scale mapping to the interval $[-\delta, \delta]$ is *monotonically increasing*; this goes as follows:

- activation values <0.5 of $\text{srs}_{B,ac,A}$ or $\text{srs}_{B,bo,A}$ (indicating a tendency of *B* not to go for action *ac*) are mapped onto negative activation values for $\mathbf{W}_{\text{met}_{coo,A},\text{os}_{A,s,ac,e,A}}$ or $\mathbf{W}_{\text{met}_{coo,A},\text{os}_{A,e,bo,A}}$ in the range $[-\delta, 0]$
- activation values >0.5 of $\text{srs}_{B,ac,A}$ or $\text{srs}_{B,bo,A}$ (indicating a tendency of *B* to go for action *ac*) are mapped onto positive activation values for $\mathbf{W}_{\text{met}_{coo,A},\text{os}_{A,s,ac,e,A}}$ or $\mathbf{W}_{\text{met}_{coo,A},\text{os}_{A,e,bo,A}}$ in the range $[0, \delta]$.

As a result, person *A*'s self-ownership states will be (slightly) decreased if the other person *B* tends to not go for *ac* and (slightly) increased if *B* tends to go for *ac*, which indeed is in line with (a) above.

(b) For the competitive case of $\mathbf{W}_{\text{met}_{com},\text{os}_{A,s,ac,e,A}}$ or $\mathbf{W}_{\text{met}_{com,A},\text{os}_{A,e,bo,A}}$ the linear scale mapping onto the interval $[-\delta, \delta]$ is *monotonically decreasing*; this goes as follows:

- activation values <0.5 of $\text{srs}_{B,ac,A}$ or $\text{srs}_{B,bo,A}$ (indicating a tendency of *B* not to go for action *ac*) are mapped onto positive activation values for $\mathbf{W}_{\text{met}_{com,A},\text{os}_{A,s,ac,e,A}}$ or $\mathbf{W}_{\text{met}_{com,A},\text{os}_{A,e,bo,A}}$ in the range $[0, \delta]$.
- activation values > 0.5 of $\text{srs}_{B,ac,A}$ or $\text{srs}_{B,bo,A}$ (indicating a tendency of *B* to go for action *ac*) are mapped onto negative activation values for $\mathbf{W}_{\text{met}_{com,A},\text{os}_{A,s,ac,e,A}}$ or $\mathbf{W}_{\text{met}_{com,A},\text{os}_{A,e,bo,A}}$ in the range $[-\delta, 0]$.

As a result, person *A*'s self-ownership states will be (slightly) increased if the other person *B* tends to not go for *ac* and (slightly) decreased if *B* tends to go for *ac*, which indeed is in line with (b) above.

A similar explanation can be given for the effects of a metaphor on the ownership states concerning the associated emotion *bo.*

10.4.2.2 The Second-Order Adaptation Principle Used

Within the second-order self-model, a second-order adaptation principle known from neuroscience literature (Robinson et al. 2016) is applied that relates the adaptation speed for the first-order self-model to stimulus exposure:

Exposure Accelerates Adaptation Speed adaptation principle

Adaptation accelerates with increasing stimulus exposure (Robinson et al. 2016)

Note that this essentially indicates a monotonically increasing relation or function from the level of stimulus exposure to the adaptation speed. The adaptation speed of the **W**-states is represented in the second-order self-model by the $\mathbf{H_W}$-states; note that in the introduced model they are not differentiated but unified by one **H**-state per person, and applied to all **W**-states (see the six downward pink arrows in Fig. 10.4). The positive upward links from the stimulus representation state $\text{srs}_{s,A}$ to an $\mathbf{H_W}$-state and the monotonically increasing combination function $\mathbf{alogistic}_{\sigma,\tau}\mathbf{(..)}$ used for the $\mathbf{H_W}$-state, take care that these $\mathbf{H_W}$-states indeed monotonically increase with increasing activation of $\text{srs}_{s,A}$.

10.5 Simulation of an Example Scenario

In this section the model is illustrated by an example scenario for two persons *A* and *B* where *A* develops a cooperative metaphor and *B* a competitive metaphor. This choice was achieved by making a slight difference in the persistence parameter $\boldsymbol{\mu}$ for the learning of these metaphors (persistence values 0.99 for the dominating metaphors in comparison to values 0.95 for the other metaphors; see the role matrix **mcfp** in the Appendix section). In Fig. 10.5, the stimulus for context *s* occurs from time 100 to 200 and recurs from 300 to 400. From the given context *s*, initially *A* tends not to go for action *ac* (the weight of the connection from $\text{srs}_{s,A}$ to $\text{ps}_{ac,A}$ is not 1 but 0.4; see the role matrix **mcw** in the Appendix section) whereas *B* tends to go for it. This can be seen from 100 to 160, where

- the thin blue line indicates *B*'s preparation state $\text{ps}_{ac,B}$ for *ac*
- the thin green line the predicted effect $\text{srs}_{e,B}$ of action *ac*
- and the thin red line the emotional response $\text{ps}_{bo,B}$ that *B* has for *ac*

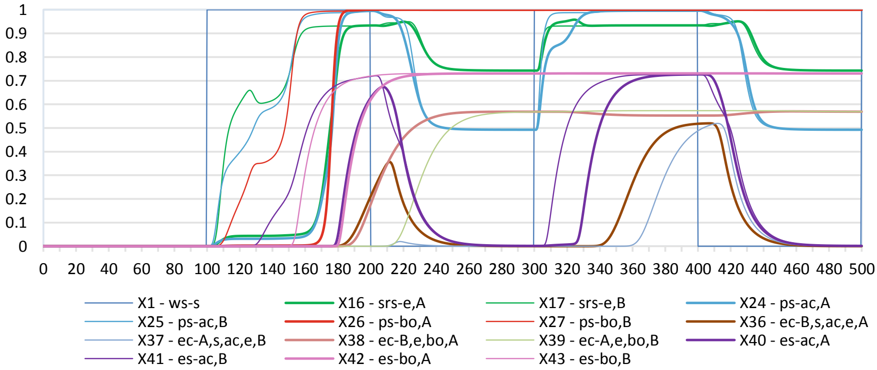

Fig. 10.5 Example simulation: the preparation states, execution states and communication states

All three reach levels above 0.9 after time 150. In contrast, the corresponding states $\text{ps}_{ac,A}$, $\text{srs}_{e,A}$, $\text{ps}_{bo,A}$ for *A* as depicted by the thicker blue, green and red line, stay below 0.05 until time 160. After time 160 these values also get substantially higher to above 0.9. This happens because *A* shows cooperative behaviour and after around time 130, person *B* shows by $\text{es}_{ac,B}$ the tendency to go for action *ac* (the thin purple line) and after time 150 by $\text{es}_{bo,B}$ person *B* shows to have a positive emotion *bo* about it (the thin pink line). Then, after around time 180, also *A* shows (by the thicker purple line) a tendency to go for action *ac*, and (by the ticker pink line) a tendency for a positive emotion *bo* about it. The thicker dark brown line that comes up around time 190 indicates the very modest and short empathic response of *A* to *B*'s tendency for *ac* and the thicker light brown line that also comes up from around 190 shows the empathic response of *A* to *B*'s emotion. Finally, the thin light light green line that comes up after time 210 shows the empathic response of *B* to *A*'s emotion. At the same time it is seen that *B* shows practically not any empathic response of *A*'s tendency to go for action *ac* (values around time 220 staying below 0.02).

However, when stimulus *s* occurs again between time 300 and 400, the process is a bit different. Now *A* is faster in going for *ac* and having a positive emotion *bo* about it. Then, finally *B* does not only show empathic response of *A*'s emotion, but also on *A*'s tendency to go for *ac* (the blue-grey line peaking just above 0.5 between time 410 and 420). These differences between the two episodes relate to the adaptive elements in the process that are not displayed in Figs. 10.5 but in 10.6. In Fig. 10.6 it is illustrated how the adaptation works, the control of the adaptation, their influence on the metaphor activations, and in turn the influence of the metaphors on the ownership states. The following can be seen:

- the thicker green line indicates adaptation control states $\mathbf{H}_{\mathbf{W}_{A,met}}$ and $\mathbf{H}_{\mathbf{W}_{B,met}}$ for both persons.

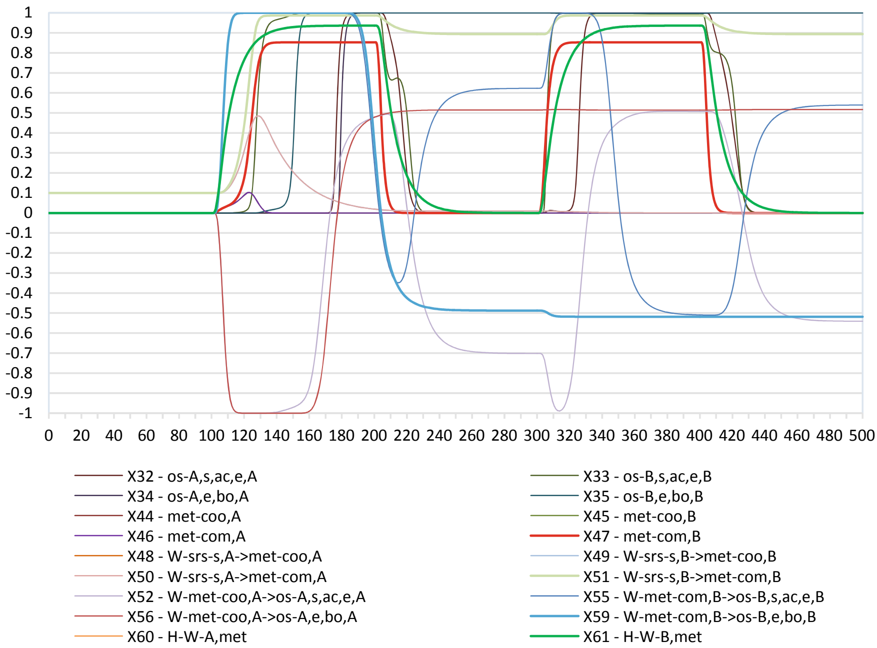

Fig. 10.6 Example simulation of the scenario of Fig. 10.5: the metaphor states and self-ownership states and all **W**-states and $\mathbf{H}_{\mathbf{W}}$-states for adaptation and control

- the thicker light green line displays the **W**-states $\mathbf{W}_{\text{srs}_{s,A},\text{met}_{coo,A}}$ and $\mathbf{W}_{\text{srs}_{s,B},\text{met}_{com,B}}$ (starting at value 0.1) for the adaptive weights of the connections from $\text{srs}_{s,A}$ to $\text{met}_{coo,A}$ and from $\text{srs}_{s,B}$ to $\text{met}_{com,B}$.
- the thicker red line indicates both metaphor activation states $\text{met}_{coo,A}$ and $\text{met}_{com,B}$. They clearly win the competition with the alternative metaphors $\text{met}_{com,A}$ and $\text{met}_{coo,B}$, that show a peak value around 0.1 between time 120 and 130 and then go down.
- the thicker light blue line displays the **W**-state for an adaptive weight of a connection from a metaphor state to an ownership state; for example, $\mathbf{W}_{\text{met}_{com,B},\text{os}_{B,e,bo,B}}$ representing the weight of the connection from $\text{met}_{com,B}$ to $\text{os}_{B,e,bo,B}$. This functions as upward (positive value of $\mathbf{W}_{\text{met}_{com,B},\text{os}_{B,e,bo,B}}$) or downward (negative value of $\mathbf{W}_{\text{met}_{com,B},\text{os}_{B,e,bo,B}}$) modulation of self-ownership state $\text{os}_{B,e,bo,B}$. In Fig. 10.6 there are four of such **W**-states for the outgoing connections from the (activated) metaphor states $\text{met}_{coo,A}$ and $\text{met}_{com,B}$; note that they are the states that show negative values at some point in time (which depends on the specific circumstances at that time point during the decision making).

It is shown that the metaphors only become fully activated after a time duration of 30 time units within the first stimulus interval of 100 time units. Therefore, in Fig. 10.5 it can be noticed that the process adaptively changes within that time period. As in the second episode from time 300 to 400, the metaphor is immediately activated based on the learnt and persisting connections, that shows different behaviour, enabling finally *B* to come with a stronger empathic response to person *A*, for example.

10.6 Discussion

In this chapter, a self-modeling network model for the influence of a cognitive metaphor used as mental model (Al-Azr 2020; Craik 1943; Gentner and Stevens 1983; Furlough and Gillan 2018; Palmunen et al. 2021) on joint decision making processes was presented. This chapter is based on material from Van Ments and Treur (2021a). The introduced network model is based on mechanisms for joint decision making known from social neuroscience such as (Cacioppo and Berntson 2005; Decety and Cacioppo 2010; Demiral et al. 2016; Harmon-Jones and Winkielman 2007; Herrera et al. 1997; Hasson et al. 2012; Kato et al. 2016; Liepelt et al. 2016; Ruissen and De Bruijn 2015; Stenzel and Liepelt 2016) and literature on cognitive metaphor theory (Gentner and Gentner 1983; Leary 1994; Lakoff 1993; Lakoff and Johnson 2003; Refaie 2003; Lee and Schwarz 2014). Different concepts and mechanisms from cognitive and social neuroscience have been adopted, such as mirror neurons (Iacoboni 2008; Pineda 2009; Rizzolatti and Sinigaglia 2008), internal simulation (Damasio 1994, 1999; Gallese and Goldman 1998; Goldman 2006; Hesslow 2002), and ownership states (Farrer and Frith 2002; Jeannerod et al. 2003; Schwabe and Blanke 2007). The model focused on cooperative and competitive metaphors and their adaptation, in particular the way in which they are adaptively activated and how they adaptively affect self-ownership states.

Concerning the base joint decision making process, the current chapter adopted the model described in Treur (2011a), like also, for example, Van Ments et al. (2015) did. However, in the current chapter the focus is on three substantial additions that were made in comparison to Treur (2011a):

1. adding the role of a cognitive metaphor in a joint decision process by modeling the metaphor as an internal *mental model* (Abdel-Raheem 2020; Craik 1943; Furlough and Gillan 2018; Williams 2018) according to the cognitive architecture for mental models proposed in Van Ments and Treur (2021b)
2. incorporating *plasticity* (Hebb 1949) by making the decision process adaptive via adaptation of this mental model through learning
3. incorporating *metaplasticity* (Abraham and Bear 1996; Robinson et al. 2016) by adding control over the adaptation.

Here (2) and (3) are completely new for joint decision making, and for (1), following Van Ments and Treur (2021b) the mental model for the metaphor introduced here is different from the metaphor model used in Van Ments et al. (2015): although in both cases mental states are used for a metaphor, the incoming connections for these mental states are different (and are also adaptive and controlled) here and now model context-dependency of metaphor activation. Finally, in contrast to the previously published models as mentioned, the current model was designed and implemented using the more advanced self-modeling network modeling approach and its software environment introduced in Treur (2020b).

For further development, also plasticity of intrinsic excitability (Chandra and Barkai 2018; Debanne et al. 2019) may be considered as an alternative or in addition to Hebbian learning for plasticity of connection weights as considered here.

10.7 Appendix: Specification of the Network Model by Role Matrices

Role matrices provide a compact standardised and structured table format that can be used to specify the network characteristics $\boldsymbol{\omega}_{X,Y}$, $\boldsymbol{\gamma}_{j,Y}$, $\boldsymbol{\pi}_{i,j,Y}$, $\boldsymbol{\eta}_Y$ that define a design of a (self-modeling) network model. As discussed in Sect. 10.3, the three types of characteristics are:

Connectivity specified in role matrices **mb** (for base connections $X \rightarrow Y$) and **mcw** (for connection weights $\boldsymbol{\omega}_{X,Y}$); see Fig. 10.7

Aggregation specified by role matrices **mcfw** (for combination function weights $\boldsymbol{\gamma}_{j,Y}$) and **mcfp** (for combination function parameters $\boldsymbol{\pi}_{i,j,Y}$); see Fig. 10.8

Timing specified by role matrix **ms** (for speed factors $\boldsymbol{\eta}_Y$); see Fig. 10.9.

The yellow highlighted values in role matrices **mcw** and **mcfp** are specific values used for the example simulation discussed in Sect. 10.5. First, in Table 10.3 an overview is given of all states. Role matrices have rows for all of the states in the network model, indicated by the state names X_i on the left side (which is also followed by a more informative name).

For *connectivity* characteristics, in role matrix **mb**, depicted in Fig. 10.7, in each row it is listed which are the states X_j from which X_i has incoming connections. For example in the 24th row it is indicated that state X_{24} (which is also named $ps_{ac,A}$) has incoming connections from states X_{14}, X_{18}, and X_{22} (which are also named $srs_{s,A}$, $srs_{B,ac,A}$, and $srs_{A,bo,A}$). In role matrix mcw, also depicted in Fig. 10.7 for each of these connections weights are specified in the corresponding cell. For example, in the 24th row, in the first column it is indicated that the connection weight from X_{14} (also named $srs_{s,A}$) to X_{24} (also named $ps_{ac,A}$) is 0.4. In this way, a compact overview is obtained for all connection weights $\boldsymbol{\omega}_{X,Y}$ of the network model. Note that in some of the cells of **mcw** no numbers are specified but state names X_k. This is the way in which it is indicated that that X_k is a self-model state which plays the role of the connection weight of the cell in which it is specified. In a computational sense, this means that at any time in computations the value of that state is used for the concerning connection weight. So, this makes the adaptation of the connection weights happen.

Similarly, for *aggregation* characteristics, in role matrix **mcfw** the combination function weights are specified. It can be seen in Fig. 10.8 that all states X_2 to X_{47} and also X_{60} and X_{61} have combination function weight 1 (only) for the combination

Table. 10.3 Overview of all states

state	explanation
X_1 ws_s	Stimulus *s* in the world
X_2 $ws_{A,ac}$	*A* tending to do action *ac*
X_3 $ws_{B,ac}$	*B* tending to do action *ac*
X_4 $ws_{A,bo}$	Body state *bo* of *A*
X_5 $ws_{B,bo}$	Body state *bo* of *B*
X_6 $ss_{s,A}$	Sensing stimulus *s* by person *A*
X_7 $ss_{s,B}$	Sensing stimulus *s* by person *B*
X_8 $ss_{B,ac,A}$	Sensing *B* tending to do action *ac* as experienced by person *A*
X_9 $ss_{A,ac,B}$	Sensing *A* tending to do action *ac* as experienced by person *B*
X_{10} $ss_{B,bo,A}$	Sensing body state *bo* of *B* as experienced by person *A*
X_{11} $ss_{A,bo,B}$	Sensing body state *bo* of *A* as experienced by person *B*
X_{12} $ss_{A,bo,A}$	Sensing own body state *bo* of *A* as experienced by person *A*
X_{13} $ss_{B,bo,B}$	Sensing own body state *bo* of *B* as experienced by person *B*
X_{14} $srs_{s,A}$	Sensory representation state for stimulus *s* by person *A*
X_{15} $srs_{s,B}$	Sensory representation state for stimulus *s* by person *B*
X_{16} $srs_{e,A}$	Sensory representation state for action effect *e* by person *A*
X_{17} $srs_{e,B}$	Sensory representation state for action effect *e* by person *B*
X_{18} $srs_{B,ac,A}$	Sensory representation state for *B* tending to do action *ac* perceived by person *A*
X_{19} $srs_{A,ac,B}$	Sensory representation state for *A* tending to do action *ac* perceived by person *B*
X_{20} $srs_{B,bo,A}$	Sensory representation state for body state *bo* of *B* by person *A*
X_{21} $srs_{A,bo,B}$	Sensory representation state for body state *bo* of *A* by person *B*
X_{22} $srs_{A,bo,A}$	Sensory representation state for own body state *bo* of *A* by person *A*
X_{23} $srs_{B,bo,B}$	Sensory representation state for own body state *bo* of *B* by person *B*
X_{24} $ps_{ac,A}$	Preparation state for action *ac* by person *A*
X_{25} $ps_{ac,B}$	Preparation state for action *ac* by person *B*
X_{26} $ps_{bo,A}$	Preparation state for emotional response *bo* by person *A*
X_{27} $ps_{bo,B}$	Preparation state for emotional response *bo* by person *B*
X_{28} $os_{B,s,ac,e,A}$	Other - Ownership state for doing action *ac* in the context of *B*, *s* and *e* by person *A*
X_{29} $os_{A,s,ac,e,B}$	Other - Ownership state for doing action *ac* in the context of *A*, *s* and *e* by person *B*
X_{30} $os_{B,e,bo,A}$	Other - Ownership state for emotion *bo* in the context of *B* and *e* by person *A*
X_{31} $os_{A,e,bo,B}$	Other - Ownership state for emotion *bo* in the context of *A* and *e* by person *B*
X_{32} $os_{A,s,ac,e,A}$	Self-Ownership state for doing action *ac* in the context of *A*, *s* and *e* by person *A*
X_{33} $os_{B,s,ac,e,B}$	Self-Ownership state for doing action *ac* in the context of *B*, *s* and *e* by person *B*
X_{34} $os_{A,e,bo,A}$	Self-Ownership state for emotion *bo* in the context of *A* and *e* by person *A*
X_{35} $os_{B,e,bo,B}$	Self-Ownership state for emotion *bo* in the context of *B* and *e* by person *B*
X_{36} $ec_{B,s,ac,e,A}$	Communication of action *ac* in the context of *B*, *s* and *e* by person *A*
X_{37} $ec_{A,s,ac,e,B}$	Communication of action *ac* in the context of *A*, *s* and *e* by person *B*
X_{38} $ec_{B,e,bo,A}$	Communication of emotion *bo* in the context of *B* and *e* by person *A*
X_{39} $ec_{A,e,bo,B}$	Communication of emotion *bo* in the context of *A* and *e* by person *B*
X_{40} $es_{ac,A}$	Action execution of action *ac* by person *A*
X_{41} $es_{ac,B}$	Action execution of action *ac* by person *B*
X_{42} $es_{bo,A}$	Execution state of body state *bo* by person *A*
X_{43} $es_{bo,B}$	Execution state of body state *bo* by person *B*
X_{44} $met_{coo,A}$	Cooperative metaphor activation state for person *A*
X_{45} $met_{coo,B}$	Cooperative metaphor activation state for person *B*
X_{46} $met_{com,A}$	Competitive metaphor activation state for person *A*
X_{47} $met_{com,B}$	Competitive metaphor activation state for person *B*
X_{48} $\mathbf{W}_{srs_{s,A},met_{coo,A}}$	Representation of the weight of the connection from $srs_{s,A}$ to $met_{coo,A}$
X_{49} $\mathbf{W}_{srs_{s,B},met_{coo,B}}$	Representation of the weight of the connection from $srs_{s,B}$ to $met_{coo,B}$
X_{50} $\mathbf{W}_{srs_{s,A},met_{com,A}}$	Representation of the weight of the connection from $srs_{s,A}$ to $met_{com,A}$
X_{51} $\mathbf{W}_{srs_{s,B},met_{com,B}}$	Representation of the weight of the connection from $srs_{s,B}$ to $met_{com,B}$
X_{52} $\mathbf{W}_{met_{coo,A},os_{A,s,ac,e,A}}$	Representation of the weight of the connection from $met_{coo,A}$ to $os_{A,s,ac,e,A}$
X_{53} $\mathbf{W}_{met_{coo,B},os_{B,s,ac,e,B}}$	Representation of the weight of the connection from $met_{coo,B}$ to $os_{B,s,ac,e,B}$
X_{54} $\mathbf{W}_{met_{com,A},os_{A,s,ac,e,A}}$	Representation of the weight of the connection from $met_{com,A}$ to $os_{A,s,ac,e,A}$
X_{55} $\mathbf{W}_{met_{com,B},os_{B,s,ac,e,B}}$	Representation of the weight of the connection from $met_{com,B}$ to $os_{B,s,ac,e,B}$
X_{56} $\mathbf{W}_{met_{coo,B},os_{A,e,bo,A}}$	Representation of the weight of the connection from $met_{coo,A}$ to $os_{A,e,bo,A}$
X_{57} $\mathbf{W}_{met_{coo,B},os_{B,e,bo,B}}$	Representation of the weight of the connection from $met_{coo,B}$ to $os_{B,e,bo,B}$
X_{58} $\mathbf{W}_{met_{com,B},os_{A,e,bo,A}}$	Representation of the weight of the connection from $met_{com,A}$ to $os_{A,e,bo,A}$
X_{59} $\mathbf{W}_{met_{com,B},os_{B,e,bo,B}}$	Representation of the weight of the connection from $met_{com,B}$ to $os_{B,e,bo,B}$
X_{60} $\mathbf{H}_{\mathbf{W}_{A,met}}$	Representation state for the metaphor adaptation speed of person *A*
X_{61} $\mathbf{H}_{\mathbf{W}_{B,met}}$	Representation state for the metaphor adaptation speed of person *B*

	mb base connectivity	1	2	3	4	5	6	mcw connection weights	1	2	3	4	5	6
X_{1}	ws_{s}	X_{1}							1					
X_{2}	$ws_{A,ac}$	X_{40}							1					
X_{3}	$ws_{B,ac}$	X_{41}							1					
X_{4}	$ws_{A,bo}$	X_{42}							1					
X_{5}	$ws_{B,bo}$	X_{43}							1					
X_{6}	$ss_{s,A}$	X_{1}							1					
X_{7}	$ss_{s,B}$	X_{1}							1					
X_{8}	$ss_{B,ac,A}$	X_{3}							1					
X_{9}	$ss_{A,ac,B}$	X_{2}							1					
X_{10}	$ss_{B,bo,A}$	X_{5}							1					
X_{11}	$ss_{A,bo,B}$	X_{4}							1					
X_{12}	$ss_{A,bo,A}$	X_{4}							1					
X_{13}	$ss_{B,bo,B}$	X_{5}							1					
X_{14}	$srs_{s,A}$	X_{6}							1					
X_{15}	$srs_{s,B}$	X_{7}							1					
X_{16}	$srs_{e,A}$	X_{24}	X_{32}						1	-0.2				
X_{17}	$srs_{e,B}$	X_{25}	X_{33}						1	-0.2				
X_{18}	$srs_{B,ac,A}$	X_{8}							1					
X_{19}	$srs_{A,ac,B}$	X_{9}							1					
X_{20}	$srs_{B,bo,A}$	X_{10}							1					
X_{21}	$srs_{A,bo,B}$	X_{11}							1					
X_{22}	$srs_{A,bo,A}$	X_{12}	X_{26}						1	1				
X_{23}	$srs_{B,bo,B}$	X_{13}	X_{27}						1	1				
X_{24}	$ps_{ac,A}$	X_{14}	X_{18}	X_{22}					0.4	1	1			
X_{25}	$ps_{ac,B}$	X_{15}	X_{19}	X_{23}					1	1	1			
X_{26}	$ps_{bo,A}$	X_{16}	X_{20}	X_{22}					1	1	1			
X_{27}	$ps_{bo,B}$	X_{17}	X_{21}	X_{23}					1	1	1			
X_{28}	$os_{B,s,ac,e,A}$	X_{18}							1					
X_{29}	$os_{A,s,ac,e,B}$	X_{19}							1					
X_{30}	$os_{B,e,bo,A}$	X_{20}							1					
X_{31}	$os_{A,e,bo,B}$	X_{21}							1					
X_{32}	$os_{A,s,ac,e,A}$	X_{44}	X_{46}	X_{14}	X_{18}	X_{16}	X_{24}		X_{52}	X_{54}	1	1	1	1
X_{33}	$os_{B,s,ac,e,B}$	X_{45}	X_{47}	X_{15}	X_{19}	X_{17}	X_{25}		X_{53}	X_{55}	1	1	1	1
X_{34}	$os_{A,e,bo,A}$	X_{44}	X_{46}	X_{16}	X_{20}	X_{22}	X_{26}		X_{56}	X_{58}	1	1	1	1
X_{35}	$os_{B,e,bo,B}$	X_{45}	X_{47}	X_{17}	X_{21}	X_{23}	X_{27}		X_{57}	X_{59}	1	1	1	1
X_{36}	$ec_{B,s,ac,e,A}$	X_{28}							1					
X_{37}	$ec_{A,s,ac,e,B}$	X_{29}							1					
X_{38}	$ec_{B,e,bo,A}$	X_{30}							1					
X_{39}	$ec_{A,e,bo,B}$	X_{31}							1	1				
X_{40}	$es_{ac,A}$	X_{32}	X_{24}						1	1				
X_{41}	$es_{ac,B}$	X_{33}	X_{25}						1	1				
X_{42}	$es_{bo,A}$	X_{34}	X_{26}						1	1				
X_{43}	$es_{bo,B}$	X_{35}	X_{27}						1	1				
X_{44}	$met_{coo,A}$	X_{14}	X_{46}						X_{48}	-0.5				
X_{45}	$met_{coo,B}$	X_{15}	X_{47}						X_{49}	-0.5				
X_{46}	$met_{com,A}$	X_{14}	X_{44}						X_{50}	-0.5				
X_{47}	$met_{com,B}$	X_{15}	X_{45}						X_{51}	-0.5				
X_{48}	$\mathbf{W}_{srs_{s,A},met_{coo,A}}$	X_{14}	X_{44}	X_{48}					1	1	1			
X_{49}	$\mathbf{W}_{srs_{s,B},met_{coo,B}}$	X_{15}	X_{45}	X_{49}					1	1	1			
X_{50}	$\mathbf{W}_{srs_{s,A},met_{com,A}}$	X_{14}	X_{46}	X_{50}					1	1	1			
X_{51}	$\mathbf{W}_{srs_{s,B},met_{com,B}}$	X_{15}	X_{47}	X_{51}					1	1	1			
X_{52}	$\mathbf{W}_{met_{coo,A},os_{A,s,ac,e,A}}$	X_{18}							1					
X_{53}	$\mathbf{W}_{met_{coo,B},os_{B,s,ac,e,B}}$	X_{19}							1					
X_{54}	$\mathbf{W}_{met_{com,A},os_{A,s,ac,e,A}}$	X_{18}							1					
X_{55}	$\mathbf{W}_{met_{com,B},os_{B,s,ac,e,B}}$	X_{19}							1					
X_{56}	$\mathbf{W}_{met_{coo,B},os_{A,e,bo,A}}$	X_{20}							1					
X_{57}	$\mathbf{W}_{met_{coo,B},os_{B,e,bo,B}}$	X_{21}							1					
X_{58}	$\mathbf{W}_{met_{com,B},os_{A,e,bo,A}}$	X_{20}							1					
X_{59}	$\mathbf{W}_{met_{com,B},os_{B,e,bo,B}}$	X_{21}							1					
X_{60}	$\mathbf{Hw}_{A,met}$	X_{14}							1					
X_{61}	$\mathbf{Hw}_{B,met}$	X_{15}							1					

Fig. 10.7 Connectivity role matrices **mb** (for base connections) and **mcw** (for connection weights)

function $\mathbf{alogistic}_{\sigma,\tau}(..)$, which means that that function is used for aggregation for all of these states. In addition, in role matrix **mcfp** the parameters for the combination functions are specified. For example, it is indicated in row 24 that state X_{24} uses the logistic sum function with parameters 5 (for steepness $\boldsymbol{\sigma}$) and 1 (for threshold $\boldsymbol{\tau}$).

	mcfw combination function weights	1 alogistic	2 hebbian	3 scale-map	4 step-mod	mcfp combination function parameters	1 alogistic σ	τ	2 hebbian μ	3 scale-map λ	υ	4 step-mod ρ	δ
X_1	ws_s				1							200	100
X_2	$ws_{A,ac}$	1					5	0.5					
X_3	$ws_{B,ac}$	1					5	0.5					
X_4	$ws_{A,bo}$	1					5	0.5					
X_5	$ws_{B,bo}$	1					5	0.5					
X_6	$ss_{s,A}$	1					5	0.5					
X_7	$ss_{s,B}$	1					5	0.5					
X_8	$ss_{B,ac,A}$	1					5	0.5					
X_9	$ss_{A,ac,B}$	1					5	0.5					
X_{10}	$ss_{B,bo,A}$	1					5	0.5					
X_{11}	$ss_{A,bo,B}$	1					5	0.5					
X_{12}	$ss_{A,bo,A}$	1					5	0.5					
X_{13}	$ss_{B,bo,B}$	1					5	0.5					
X_{14}	$srs_{s,A}$	1					5	0.5					
X_{15}	$srs_{s,B}$	1					5	0.5					
X_{16}	$srs_{e,A}$	1					5	0.2					
X_{17}	$srs_{e,B}$	1					5	0.2					
X_{18}	$srs_{B,ac,A}$	1					5	0.5					
X_{19}	$srs_{A,ac,B}$	1					5	0.5					
X_{20}	$srs_{B,bo,A}$	1					5	0.5					
X_{21}	$srs_{A,bo,B}$	1					5	0.5					
X_{22}	$srs_{A,bo,A}$	1					5	0.6					
X_{23}	$srs_{B,bo,B}$	1					5	0.6					
X_{24}	$ps_{ac,A}$	1					5	1					
X_{25}	$ps_{ac,B}$	1					5	1					
X_{26}	$ps_{bo,A}$	1					5	0.9					
X_{27}	$ps_{bo,B}$	1					5	0.9					
X_{28}	$os_{B,s,ac,e,A}$	1					8	0.7					
X_{29}	$os_{A,s,ac,e,B}$	1					8	0.7					
X_{30}	$os_{B,e,bo,A}$	1					8	0.7					
X_{31}	$os_{A,e,bo,B}$	1					8	0.7					
X_{32}	$os_{A,s,ac,e,A}$	1					8	2.5					
X_{33}	$os_{B,s,ac,e,B}$	1					8	2.5					
X_{34}	$os_{A,e,bo,A}$	1					8	2.5					
X_{35}	$os_{B,e,bo,B}$	1					8	2.5					
X_{36}	$ec_{B,s,ac,e,A}$	1					20	0.6					
X_{37}	$ec_{A,s,ac,e,B}$	1					20	0.6					
X_{38}	$ec_{B,e,bo,A}$	1					20	0.6					
X_{39}	$ec_{A,e,bo,B}$	1					20	0.6					
X_{40}	$es_{ac,A}$	1					5	1.8					
X_{41}	$es_{ac,B}$	1					5	1.8					
X_{42}	$es_{bo,A}$	1					5	1.8					
X_{43}	$es_{bo,B}$	1					5	1.8					
X_{44}	$met_{coo,A}$	1					5	0.5					
X_{45}	$met_{coo,B}$	1					5	0.5					
X_{46}	$met_{com,A}$	1					5	0.5					
X_{47}	$met_{com,B}$	1					5	0.5					
X_{48}	$\mathbf{W}_{srs_{s,A},met_{coo,A}}$		1						0.99				
X_{49}	$\mathbf{W}_{srs_{s,B},met_{coo,B}}$		1						0.95				
X_{50}	$\mathbf{W}_{srs_{s,A},met_{com,A}}$		1						0.95				
X_{51}	$\mathbf{W}_{srs_{s,B},met_{com,B}}$		1						0.99				
X_{52}	$\mathbf{W}_{met_{coo,A},os_{A,s,ac,e,A}}$			1						-1	1		
X_{53}	$\mathbf{W}_{met_{coo,B},os_{B,s,ac,e,B}}$			1						-1	1		
X_{54}	$\mathbf{W}_{met_{com,A},os_{A,s,ac,e,A}}$			1						1	-1		
X_{55}	$\mathbf{W}_{met_{com,B},os_{B,s,ac,e,B}}$			1						1	-1		
X_{56}	$\mathbf{W}_{met_{coo,B},os_{A,e,bo,A}}$			1						-1	1		
X_{57}	$\mathbf{W}_{met_{coo,B},os_{B,e,bo,B}}$			1						-1	1		
X_{58}	$\mathbf{W}_{met_{com,B},os_{A,e,bo,A}}$			1						1	-1		
X_{59}	$\mathbf{W}_{met_{com,B},os_{B,e,bo,B}}$			1						1	-1		
X_{60}	$\mathbf{Hw}_{A,met}$	1					5	0.3					
X_{61}	$\mathbf{Hw}_{B,met}$	1					5	0.3					

Fig. 10.8 Aggregation role matrices **mcfw** (for combination function weights) and **mcw** (for combination function parameters)

Finally, for *timing* characteristics, in role matrix **ms** a list of speed factors for all states are given; see Fig. 10.9. Moreover, in Fig. 10.9 also a list of initial values is given. Note that also here self-model states are indicated, in particular in rows 48 to 59. Here it is specified how the adaptation process is controlled.

Once role matrices have been specified, they do not only provide a good basis for communication between modelers, but they can also be used as input for the software environment to run simulations based on them.

		ms speed factors	**iv** initial values
X_1	ws_s	2	0
X_2	$ws_{A,ac}$	0.5	0
X_3	$ws_{B,ac}$	0.5	0
X_4	$ws_{A,bo}$	0.5	0
X_5	$ws_{B,bo}$	0.5	0
X_6	$ss_{s,A}$	0.5	0
X_7	$ss_{s,B}$	0.5	0
X_8	$ss_{B,ac,A}$	0.5	0
X_9	$ss_{A,ac,B}$	0.5	0
X_{10}	$ss_{B,bo,A}$	0.5	0
X_{11}	$ss_{A,bo,B}$	0.5	0
X_{12}	$ss_{A,bo,A}$	0.5	0
X_{13}	$ss_{B,bo,B}$	0.5	0
X_{14}	$srs_{s,A}$	0.5	0
X_{15}	$srs_{s,B}$	0.5	0
X_{16}	$srs_{e,A}$	0.5	0
X_{17}	$srs_{e,B}$	0.5	0
X_{18}	$srs_{B,ac,A}$	0.5	0
X_{19}	$srs_{A,ac,B}$	0.5	0
X_{20}	$srs_{B,bo,A}$	0.5	0
X_{21}	$srs_{A,bo,B}$	0.5	0
X_{22}	$srs_{A,bo,A}$	0.5	0
X_{23}	$srs_{B,bo,B}$	0.5	0
X_{24}	$ps_{ac,A}$	0.5	0
X_{25}	$ps_{ac,B}$	0.5	0
X_{26}	$ps_{bo,A}$	0.5	0
X_{27}	$ps_{bo,B}$	0.5	0
X_{28}	$os_{B,s,ac,e,A}$	0.5	0
X_{29}	$os_{A,s,ac,e,B}$	0.5	0
X_{30}	$os_{B,e,bo,A}$	0.5	0
X_{31}	$os_{A,e,bo,B}$	0.5	0
X_{32}	$os_{A,s,ac,e,A}$	0.5	0
X_{33}	$os_{B,s,ac,e,B}$	0.5	0
X_{34}	$os_{A,e,bo,A}$	0.5	0
X_{35}	$os_{B,e,bo,B}$	0.5	0
X_{36}	$ec_{B,s,ac,e,A}$	0.1	0
X_{37}	$ec_{A,s,ac,e,B}$	0.1	0
X_{38}	$ec_{B,e,bo,A}$	0.1	0
X_{39}	$ec_{A,e,bo,B}$	0.1	0
X_{40}	$es_{ac,A}$	0.1	0
X_{41}	$es_{ac,B}$	0.1	0
X_{42}	$es_{bo,A}$	0.1	0
X_{43}	$es_{bo,B}$	0.1	0
X_{44}	$met_{coo,A}$	0.5	0
X_{45}	$met_{coo,B}$	0.5	0
X_{46}	$met_{com,A}$	0.5	0
X_{47}	$met_{com,B}$	0.5	0
X_{48}	$\mathbf{W}_{srs_{s,A},met_{coo,A}}$	X_{60}	0.1
X_{49}	$\mathbf{W}_{srs_{s,B},met_{coo,B}}$	X_{61}	0.1
X_{50}	$\mathbf{W}_{srs_{s,A},met_{com,A}}$	X_{60}	0.1
X_{51}	$\mathbf{W}_{srs_{s,B},met_{com,B}}$	X_{61}	0.1
X_{52}	$\mathbf{W}_{met_{coo,A},os_{A,s,ac,e,A}}$	X_{60}	0
X_{53}	$\mathbf{W}_{met_{coo,B},os_{B,s,ac,e,B}}$	X_{61}	0
X_{54}	$\mathbf{W}_{met_{com,A},os_{A,s,ac,e,A}}$	X_{60}	0
X_{55}	$\mathbf{W}_{met_{com,B},os_{B,s,ac,e,B}}$	X_{61}	0
X_{56}	$\mathbf{W}_{met_{coo,B},os_{A,e,bo,A}}$	X_{60}	0
X_{57}	$\mathbf{W}_{met_{coo,B},os_{B,e,bo,B}}$	X_{61}	0
X_{58}	$\mathbf{W}_{met_{com,B},os_{A,e,bo,A}}$	X_{60}	0
X_{59}	$\mathbf{W}_{met_{com,B},os_{B,e,bo,B}}$	X_{61}	0
X_{60}	$\mathbf{Hw}_{A,met}$	0.1	0
X_{61}	$\mathbf{Hw}_{B,met}$	0.1	0

Fig. 10.9 Timing role matrix **ms** (for speed factors) and initial values **iv**

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