A Computational Analysis of Joint Decision Making Processes

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Abstract. In this paper a computational analysis is made of the circumstances under which joint decisions are or are not reached. Joint decision making as considered does not only concern a choice for a decision option, but also a good feeling about it, and mutually acknowledged empathic understanding. As a basis a computational social agent model for joint decision making is used. The model was inspired by principles from neurological theories on mirror neurons, internal simulation, and emotion-related valuing. The computational analysis does not only determine the different possible outcomes of joint decision making processes, but also the possible types of processes leading to these outcomes, and how these may relate to specific cognitive and social neurological characteristics of the persons.

1 Introduction

Joint decision making is sometimes characterised to occur when different persons make a choice for a common decision option. However, joint decision making involves more than just making such a common choice. Is it really a joint decision when a common choice is made, but one of the persons does not feel good about it? And can it really be called a joint decision when one of the persons feels good with the chosen option by itself, but does not experience any empathic understanding from the other person? For the genuine joint decision making processes addressed in this paper the answer on such questions is 'no'. For example, when a person does not feel good about a chosen option, probably any future occasion will be used to come to a different choice; decisions without a solid emotional grounding may not last long. As another example, feeling good about a chosen option, but not experiencing empathic understanding from another person may also cast doubt on the chosen option. Also in this case it may be questioned whether the decision has a solid grounding. To take into account such realistic social phenomena, a joint decision as addressed here is considered to be characterised by three elements:

- A choice for a common decision option
- A good feeling about the chosen option
- Mutually acknowledged empathic understanding

Not all joint decision making processes may end up satisfying all three criteria. Maybe a common choice is made but one (or both) of the persons does not feel good about it. Or a common choice is made and both the persons feel good about it, but due to lack of verbal and/or nonverbal communication no mutual empathic understanding is acknowledged. Moreover, one type of outcome can be reached in different ways. Was one of the persons ahead in the process and affecting the other(s)? For a given person, did the choice for the option come first and the good feeling later, or was it the other way around? How does failing on one of the three criteria relate to characteristics the persons involved? Viewed from this perspective, joint decision making processes offer a complex landscape with a wide variety of possibilities to be explored.

Developments in social neuroscience indicate some of the mechanisms underlying the different elements in joint decision making processes (e.g., [7, 13, 18]). In [40] a computational social agent model was introduced incorporating such mechanisms. In the current paper this model will be used as a point of departure to analyse computationally the different types of joint decision making processes that may occur, and how they may relate to characteristics of the persons involved.

In the paper, first in Section 2 some core concepts used are briefly reviewed. Next, in Section 3 the adopted social agent model is presented. Section 4 presents a classification of the different types of outcomes of joint decision making processes. In Section 5 the same is done for the different types of processes leading to such outcomes. Finally, Section 6 is a discussion.

2 Mirroring, Internal Simulation and Emotion-Related Valuing

Two concepts used here as a basis for joint decision making are mirror neurons and internal simulation; in combination they provide an individual's mental function of mirroring mental processes of another individual (see also [39]). Mirror neurons are not only firing when a subject is preparing an action, but also when somebody else is performing or preparing this action and the subject just observes that. They have first been found in monkeys (cf. [15, 34]), and after that it has been assumed that similar types of neurons also occur in humans, with empirical support, for example, in [25] based on fMRI, and [14, 30] based on single cell experiments with epilepsy patients (see also [23, 24, 27]). The effect of activation of mirror neurons is context-dependent. A specific type of neurons has been suggested to be able to indicate such a context. They are assumed to indicate self-other distinction and exert control by allowing or suppressing action execution; e.g., [6, 19, 24], and [23], pp. 196-203.

Activation states of mirror neurons play an important role in *mirroring* mental processes of other persons by *internal simulation*. In [26] the following causal chain for generation of felt emotions is suggested (see also [12], pp. 114-116):

sensory representation → preparation for bodily changes → expressed bodily changes →
emotion felt = based on sensory representation of (sensed) bodily changes

As a further step *as-if body loops* were introduced bypassing actually expressed bodily changes (cf. [8], pp. 155-158; see also [10], pp. 79-80; [11, 12]):

sensory representation → preparation for bodily changes = emotional response →
emotion felt = based on sensory representation of (simulated) bodily changes

An as-if body loop describes an *internal simulation* of the bodily processes, without actually affecting the body, comparable to simulation in order to perform, for example, prediction, mindreading or imagination; e.g., [2], [16], [17], [20], [28]. The feelings generated in this way play an important role in valuing predicted or imagined effects of actions, in relation to amygdala activations; see, e.g., [29], [31]. The emotional response and feeling mutually affect each other in a bidirectional manner: an as-if body loop usually has a cyclic form (see, for example, [11], pp. 91-92; [12], pp. 119-122):

emotion felt = based on sensory representation of (simulated) bodily changes →
preparation for bodily changes = emotional response

As mirror neurons make that some specific sensory input (an observed action of another person) directly links to related preparation states, they combine well with as-if body loops; see also [39], or [12], pp. 102-104. In this way states of other persons lead to activation of some of a person's corresponding own states that at the same time play a role in the person's own feelings and decisions for actions. This provides an effective mechanism for how observed actions and feelings and own actions and feelings are tuned to each other. Thus a mechanism is obtained which explains how in a social context persons fundamentally affect each other's individual decisions and states, including feelings. Moreover, it is also the basis for empathic understanding of other persons' preferences and feelings. Both the tuning and convergence of action tendencies and the mutual empathic understanding play a crucial role in joint decision making processes. Mutually acknowledged empathic understanding as used here is based on the following criteria (see also [36]): (1) showing the same state as the other agent (nonverbal part of the empathic response), and (2) acknowledging that the other agent has this state (verbal part of the empathic response).

In the area of decision making the role of emotions has been discussed for example, in [1, 8]. If you make a decision with a bad feeling it may be questioned how robust the decision is. The focus in decision making is on how to perform valuing of decision options. Feelings generated in relation to an observed situation and prepared action option play an important role in valuing predicted or imagined effects of such an action in the situation. Such valuations have been related to amygdala activations (see, e.g., [1, 8, 29, 31]). Although traditionally an important function attributed to the amygdala concerns the context of fear, in recent years much evidence on the amygdala in humans has been collected showing a function beyond this fear context. Stimuli trigger emotional responses for which (by internal simulation) a prediction is made of consequences. Feeling these emotions represents a way of experiencing the value of such a prediction: to which extent it is positive or negative. This valuation in turn affects the activation of the decision option.

3 The Adopted Social Agent Model

The issues and perspectives briefly reviewed in Section 2 have been used as a basis for the neurologically inspired social agent model presented in [40]; in summary:

- Decision making is based on *emotion-related valuing* of the *predicted effects* of each action option
- Both the tendency to go for an action and the associated emotion are transferred between agents via *mirroring processes* using *internal simulation*
- The mirroring processes induce a process of mutually *tuning* the considered actions and their emotion-related valuations, and the development of mutual *empathic understanding*
- The outcome of a joint decision process in principle involves three elements: a *common action* option, a *shared positive feeling* and *valuation* for the effect of this action option, and mutually *acknowledged empathic understanding* for both the action and feeling
- The mutually acknowledged empathic understanding is based on the following criteria:
  (a) Showing the same state as the other agent (nonverbal part of the empathic response)
  (b) Acknowledging that the other agent has this state (verbal part of the empathic response)

For an overview, see Fig. 1. Here the circles denotes states and the arrows temporal-causal connections between states. In the model s denotes a *stimulus*, a an *option* for an *action* to be decided about, and e a world state which is an *effect* of the action. The effect state e is *valued* by associating a *feeling* state b to it, which is considered to be positive for the agent (e.g., in accordance with a goal). The state properties used in the model are summarised in Table 1.

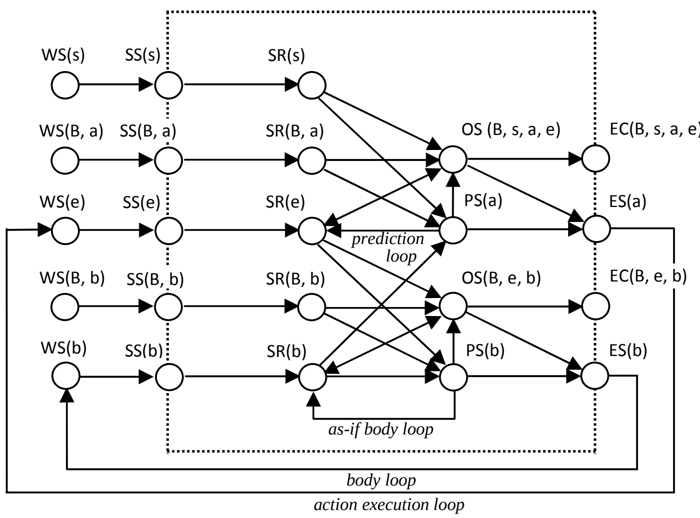


Fig. 1. Overview of the social agent model

The social agent model uses ownership states for actions a and their effects e, both for self and other agents, specified by OS(B, s, a, e) with B another agent or self, respectively (see Fig. 1). Similarly, ownership states are used for emotions indicated by body state b, both for self and other agents, specified by OS(B, e, b) with B another agent or self.

Table 1. State properties used

notation	description
WS(W)	world state W: for an action a of agent B, a feeling b of agent B, a stimulus s, effect e, or an emotion indicated by body state b
SS(W)	sensor state for W
SR(W)	sensory representation of W
PS(X)	preparation state for X: action a or expressing emotion by body state b
ES(X)	execution state for X: action a or expressing emotion by body state b
OS(B, s, a, e)	ownership state for B of action a with effect e and stimulus s
OS(B, e, b)	ownership state for B of emotion indicated by body state b and effect e
EC(B, s, a, e)	communication to B of ownership for B of action a with effect e and stimulus s
EC(B, e, b)	communication to B of ownership for B of emotion indicated by b and effect e

As an example, the four arrows to OS(B, s, a, e) in Fig. 1 show that an ownership state OS(B, s, a, e) is affected by the preparation state PS(a) for the action a, the sensory representation SR(b) of the emotion-related value b for the predicted effect e, the sensory representation SR(s) of the stimulus s, and the sensory representation SR(B) of the agent B. Note that s, a, e, b, and B are parameters for stimuli, actions, effects, body states, and agents. In a given agent model multiple instances of each of them can occur.

Prediction of effects of prepared actions is modelled using the connection from the preparation PS(a) of the action a to the sensory representation SR(e) of the effect e. Suppression of the sensory representation of a predicted effect (according to, e.g., [3], [4], [28]) is modelled by the (inhibiting) connection from the ownership state OS(B, s, a, e) to sensory representation SR(e). The control exerted by the ownership state for action a is modelled by the connection from OS(B, s, a, e) to ES(a). Communicating ownership for an action (a way of expressing recognition of the other person's states, as a verbal part of showing empathic understanding) is modelled by the connection from the ownership state OS(B, s, a, e) to the communication effector state EC(B, s, a, e). Similarly, communicating of ownership for an emotion for effect e indicated by b is modelled by the connection from the ownership state OS(B, e, b) to the communication effector state EC(B, e, b). Connections between states j and i (the arrows in Fig. 1) have strengths or weights, indicated by $\omega_{j,i}$. A weight usually has a value between -1 and 1 and may depend on the specific instance for agent B, stimulus s, action a and/or effect state b involved. Note that in general weights are assumed non-negative, except for inhibiting connections, which model suppression of the sensory representation of effect e, or of the sensory representation of body state b. In [40] the dynamics following the connections between the states in Fig. 1 are described in more detail. This is done for each state by a dynamic property specifying how the activation value for this state is updated based on the activation values of the states connected to it (the incoming arrows in Fig. 1). For a state i depending on multiple other states, to update its activation level, input values for incoming activation levels are to be combined to some aggregated input value $agginput_i$. This update itself then takes place according to a differential equation

$$\boldsymbol{dy_i/dt} = \gamma_i\ [agginput_i - y_i\ ]$$

where γ_i is the update speed for state i, $agginput_i$ is the aggregated input for i, and y_i is the activation level of state i. The aggregation is created from the individual inputs $\omega_{j,i}\,y_j$ for all states j connected toward state i, where $\omega_{j,i}$ is the strength of the connection from j to i (a number between -1 and 1). For this aggregation a combination function $f(V_1, \ldots, V_k)$ is needed, applied to the different incoming values $V_j = \omega_{j,i}\,y_j$. Using this, the above differential equation can be expressed as:

$$\boldsymbol{dy_i/dt} = \gamma_i\ [f(\omega_{1,i}\,y_1, \ldots, \omega_{k,i}\,y_k) - y_i\ ]$$

Here only for states j connected to state i the value of $\omega_{j,i}$ can be nonzero, for not connected states they are trivially set 0; for simplicity of notation, often the arguments for not connected states are left out of the function f. The combination function f is a function for which different choices can be made, for example, the identity function $f(W) = W$ or a combination function based on a continuous logistic threshold function of the form

$$th(\sigma, \tau, X) = \left(\frac{1}{1+e^{-\sigma(X-\tau)}} - \frac{1}{1+e^{\sigma\tau}}\right)(1+e^{-\sigma\tau}) \quad \text{or} \quad th(\sigma, \tau, X) = \frac{1}{1+e^{-\sigma(X-\tau)}}$$

with σ a steepness and τ a threshold value, when $X \geq 0$, and 0 when $X < 0$. Note that for higher values of $\sigma\tau$ (e.g., $\sigma > 20/\tau$) the right hand side threshold function can be used as an approximation. In the example simulations, for single connections, f is taken the identity function $f(W) = W$, and for the other states f is a combination function based on the logistic threshold function: $f(X_1, X_2) = th(\sigma, \tau, X_1+X_2)$, and similarly for other numbers of arguments; other types of combination functions might be used as well.

Note that in the model s, a, e, b, and B are parameters for stimuli, actions, effects, body states, and agents, respectively; multiple instances for each of them can be used.

The agent model has been computationally formalised in differential equation format and using the hybrid modeling language LEADSTO (cf. [5]); see [40] for further details of the social agent model.

4 Different Types of Outcomes

The variety of possibilities for joint decision processes is explored in two steps. First, in this section the different possible outcomes are analysed (abstracting from the temporal dimension), and their dependence on the different possible contributions by the different agents. Abstracting from the temporal dimension means that the exact timing is left out of consideration in the current section, as, for example, is also done in a numerical equilibrium analysis. These temporal aspects will be addressed as a second step in the next section. It is very hard to explore in a systematic manner all different possibilities for a model with numerical values. Therefore both in this and in the next section the introduced approach abstracts from the quantitative aspects of (activation levels of) states; instead abstracted binary qualitative states are adopted, for which states either occur or do not occur; they can be related to numerical values by assuming some threshold value, for example, 0.5. To obtain a limited number of (qualitative) states some one-to-one dependencies of states are assumed. More specifically, it is assumed that within a given agent *A* faithful expression and communication takes place with respect to any other agent *B*, which is formulated as follows:

- *A* has an intention for option *O* if and only if *A* expresses this intention
- *A* has a positive feeling for option *O* if and only if *A* expresses this feeling
- *A* acknowledges understanding that another agent *B* has the intention for option *O* if and only if *A* has an ownership state for *B* for this intention
- *A* acknowledges understanding that another agent *B* has a positive feeling for option *O* if and only if *A* has an ownership state for *B* for this feeling

Given these assumptions the number of relevant states can be limited. A contribution of one of the agents *A* with respect to another agent *B* is then assumed to be represented as any subset of the set of the following four states that can be generated (at some point in time) by agent *A* or not:

- *A* has an intention for option *O*
- *A* has a positive feeling for option *O*
- *A* acknowledges understanding that *B* has an intention for option *O*
- *A* acknowledges understanding that *B* has a positive feeling for option *O*

Given these four states that each can occur or not occur for a given agent, theoretically 16 possibilities can be distinguished, as shown in Table 2. Note that it is assumed that both for feeling and for intention acknowledgements always occur, for feeling or no feeling, and for intention or no intention. For example, labels in Tables 2 and 3 such as 'no intention acknowledgement' are interpreted as acknowledgement for no intention.

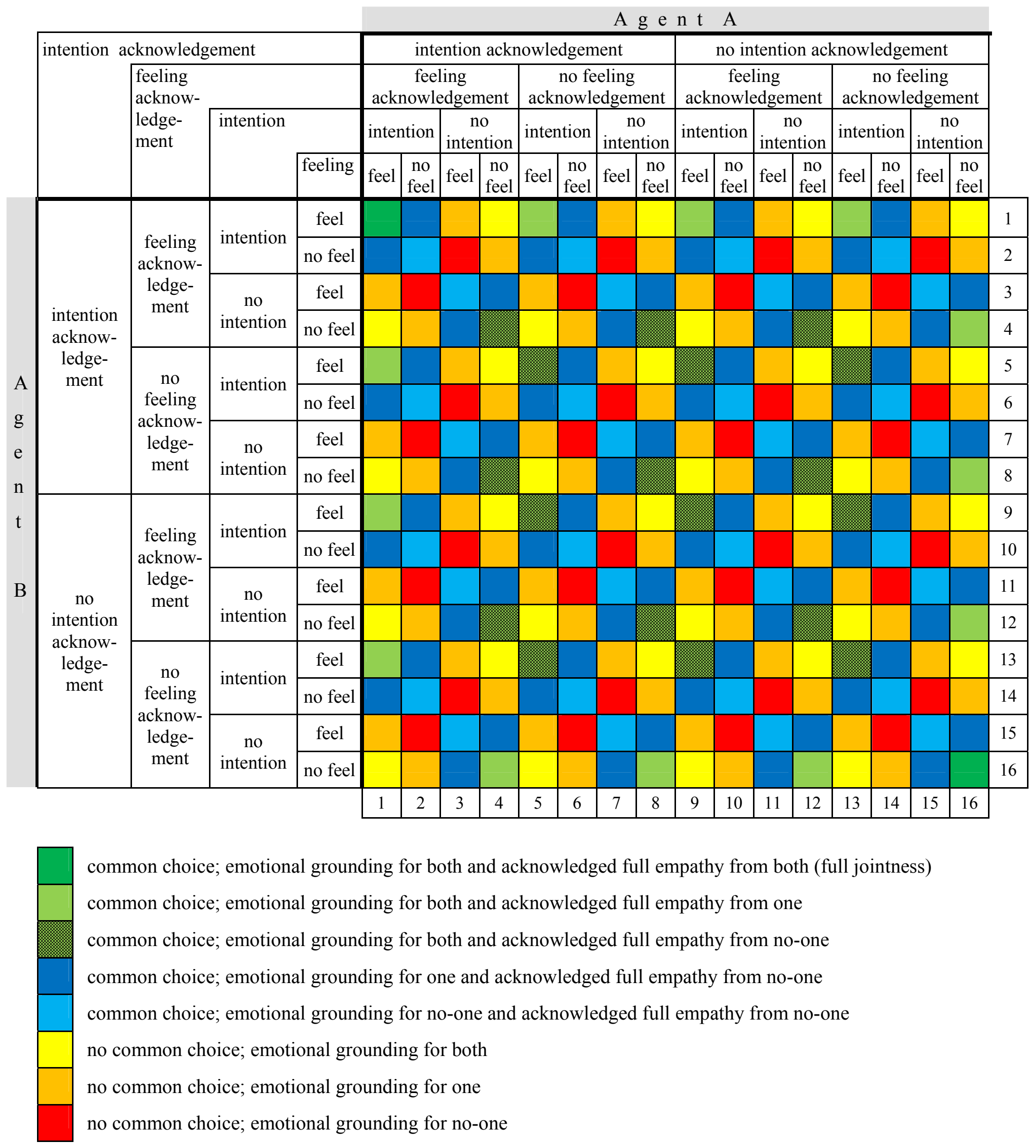
Table 2. The 16 different possible outcomes for one agent

A acknowledges understanding of *B*'s intention for *O*	intention acknowledgement								no intention acknowledgement							
A acknowledges understanding of *B*'s positive feeling for *O*	feeling acknowledgement				no feeling acknowledgement				feeling acknowledgement				no feeling acknowledgement			
A has an intention for *O*	intention		no intention		intention		no intention		intention		no intention		intention		no intention	
A has a positive feeling for *O*	feel	no feel	feel	no feel	feel	no feel	feel	no feel	feel	no feel	feel	no feel	feel	no feel	feel	no feel
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

For example, the possibility indicated by 9 describes a case in which agent *A* has a positive feeling and intention for option *O*, and has acknowledged understanding that *B* has a positive feeling for *O* as well, but acknowledged understanding that *B* has an no intention for *O*. As another example, possibility 4 describes a case in which agent *A* has a no positive feeling and no intention for option *O*, but has acknowledged understanding that *B* has a positive feeling for *O*, and has acknowledged understanding that *B* has an intention for *O*. The possibility described by 1 is the most positive one: feeling, intention and acknowledgements all occur. The possibility described by 16 is the opposite of 1: an emotionally grounded choice for no intention to go for option *O*.

Such possible outcomes for one agent *A* have to be interpreted in the context of other agents *B*, which themselves also show one of these 16 possibilities. To be able to present a feasible systematic overview, the approach is illustrated for the case of two agents. In this case all theoretically possible pairings can be visualised in a two-dimensional form as shown in Fig. 2 for two agents *A* (vertical axis) and *B* (horizontal axis). This pairing leads to 16x16 = 256 possibilities, all shown in the matrix in Fig. 2. States in this matrix can be indicated by their coordinates (x, y), where x is the column number referring to agent A and y the row number referring to agent B.

Fig. 2. The 256 different combined possible outcomes for two agents A and B



In this set of all combined states some subsets can be distinguished, indicated in Fig. 2 4 by different colours. First of all there is the subset of full joint decisions: decisions with full emotional grounding and full mutual acknowledged empathy. There are only two of such states (indicated in dark green); they are the full joint decision to go for the option, found in (1, 1), and the opposite joint decision to not go for the option, depicted in (16, 16). The other 254 possible outcomes are not fully joint decisions. However, there is a subset of 12 possibilities concerning at least a common choice with full emotional grounding for each of the agents, and acknowledged empathy by one of the agents (indicated in light green); these can be considered as almost fully joint decisions. Instances can be found at (1, 5), (1, 9), (1, 13), (4, 16), (5, 1), (8, 16), (13, 1) and (16, 4), (16, 8), (16, 12). The set of all possibilities with common choice with full emotional grounding and acknowledged empathy by none of the agents has 20 different states (indicated in light green with shading). This type of decisions can still be solid due to the individual emotional grounding at both sides, but there is no exchange of empathic understanding between the agents. The other states with a common choice have no full emotional grounding (indicated in light and dark blue), and for this reason can be considered as less solid. On the other end of the spectrum, there are also many possibilities of outcomes without a common choice (indicated in yellow, orange and red, depending on the emotional grounding).

Note that the overview in Table 2 and Fig. 2 show the theoretically possible combinations; it is not claimed that all of these possibilities have the same extent of plausibility, or proper functioning. As an example, as discussed earlier possibility 4 describes a case in which agent *A* has a no positive feeling and no intention for option *O*, but has acknowledged understanding that *B* has a positive feeling for *O*, and has acknowledged understanding that *B* has an intention for *O*. However, acknowledging understanding of an intention or a feeling without having (and showing) the same intention or feeling can be considered to be not grounded, and at least is not considered as fulfilling the criteria for showing empathic understanding. More in general, note that, for cases with opposite intentions, full empathy (which also involves expressing the intention of the other) is not feasible: for the set of outcomes without a common choice the expressed intentions are opposite. When in addition the opposite intentions each have emotional grounding (indicated in yellow), apparently not only the intentions are opposite, but also the feelings about them. In Section 5 it will be addressed in more detail how different theoretically possible options can (or cannot) develop over time.

5 Different Types of Processes

This section addresses the temporal aspects for joint decision processes, in a qualitative fashion. These temporal aspects relate to the main causal relationships in the social agent model as depicted in Fig. 1. In accordance with the social agent model, a single agent can be activated either by a world stimulus or by social interaction with other agents. More specifically, activation takes place either by observing a world stimulus obs(s), or by observing the expression from an other agent for feeling by generating obs(f) and/or for intention by generating obs(i). Internally, an agent can develop an intention after:

- observing a world stimulus, or
- observing the intention expression from another agent, or
- as a result of developing feeling.

Likewise, an agent can develop feeling after:

- observing the intention expression from another agent, or
- as a result of developing intention.

Following the development of feeling, an agent will express its feeling by generating expr(f), and acknowledge an observed feeling expression from another agent by generating ack(f). Similarly, following the development of an intention, an agent will express its intention by generating expr(i), and acknowledge an observed intention expression from another agent by generating ack(i). These main causal relationships from the social agent model lead to in total 18 possible types of processes, as shown in a tree representation in Fig. 2. Here each path represents a specific type of single agent process. For example, the path indicated by 8 describes a case in which the agent is activated by a world stimulus and subsequently develops intention. After this, the agent expresses intention and also develops feeling. The developed feeling is also expressed. After another agent expresses feeling and intention, these expressions are acknowledged. As another example, the path indicated by 12 describes a case in which the agent's process is socially activated by a feeling expression from another agent. As a consequence the agent develops and expresses feeling. In this case the agent also mirrors an observed intention expression from another agent and subsequently develops intention. This results in expressing and acknowledging intention. The single agent process type described by path 18 is a special case in which the agent's process is not activated at all. As a consequence, neither feeling nor intention is developed and therefore no expressions and acknowledgements are generated.

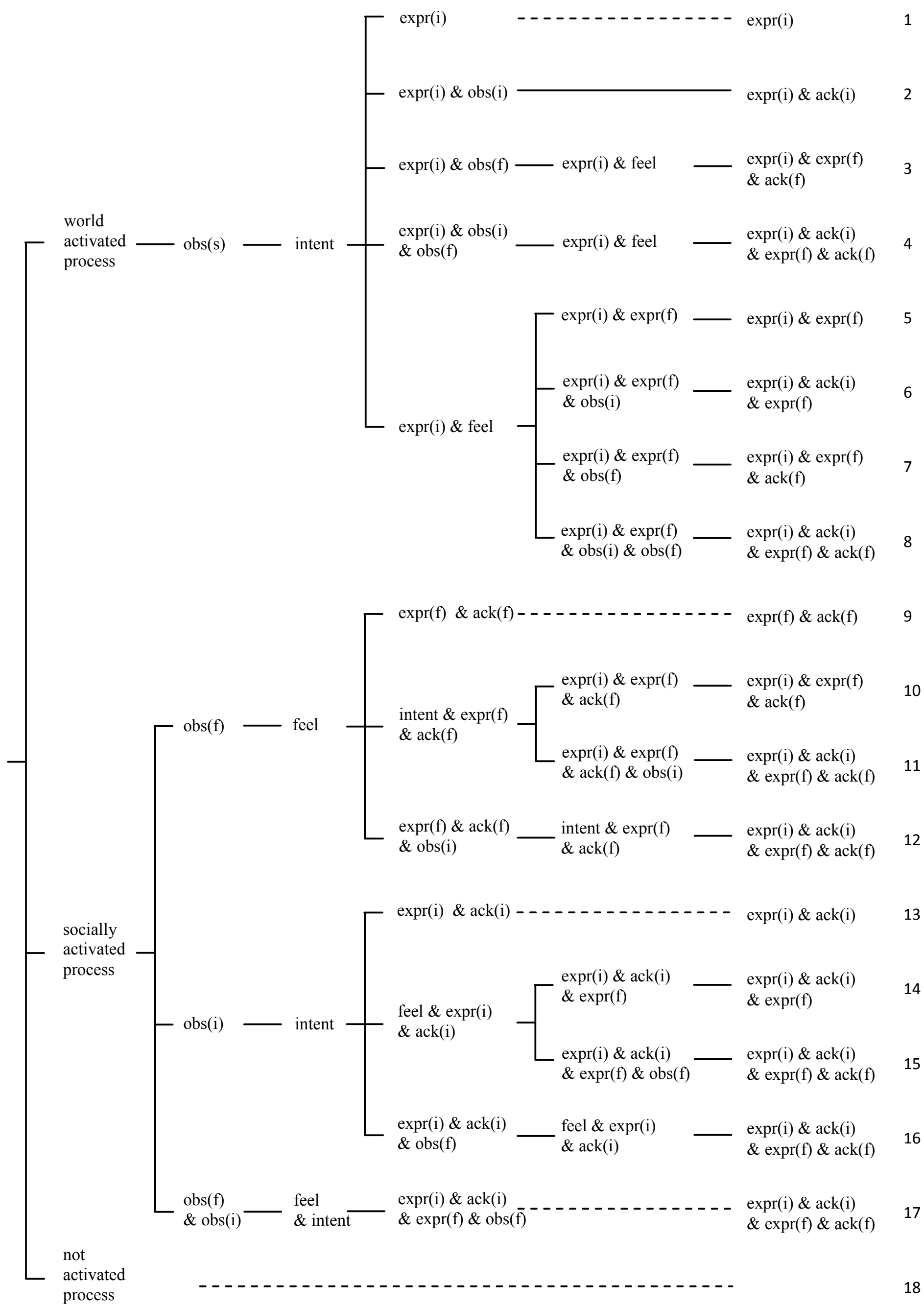


Fig. 3. The 18 different possible types of processes for one agent

The analysis of the process types for two interacting agents is based on combining two single agent process types and representing them as cells in an interaction matrix (Fig. 3) and an initiation matrix (Fig.4).

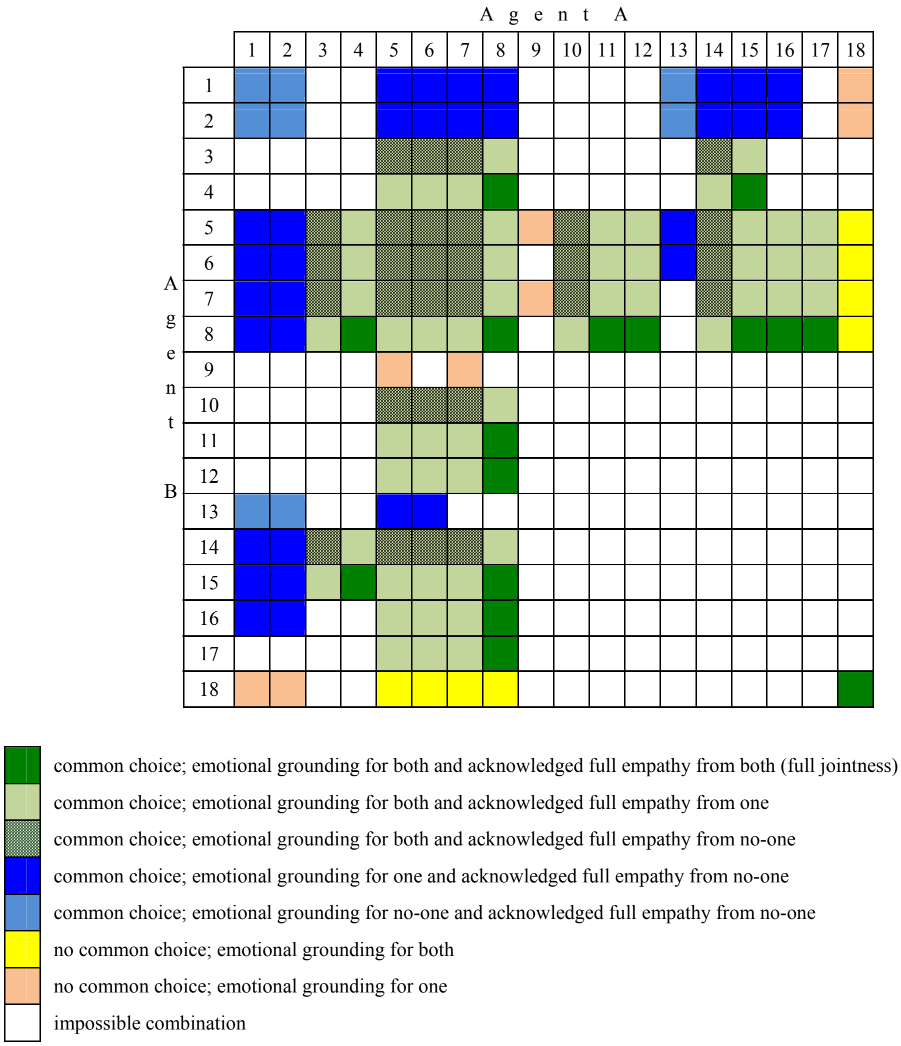


Fig. 4. The different possible combinations of types of processes for two agents

Each matrix dimension represents the 18 single agent process types corresponding to the different paths in the tree depicted in Fig. 2. Each matrix cell represents whether the two single agent process types can occur in combination, and if so, what is the outcome for this specific combination of single agent process types. The outcome of an interaction process between two agents can be classified according to the several outcome-types, as also discussed in Section 4. These outcome-types range from reaching a common choice with emotional grounding and acknowledged full empathy for both interacting agents, to not reaching a common choice and without emotional grounding for any of the interacting agents. In the matrix the relevant outcome-types are distinguished by different colors.

The interaction matrix has a number of regions with impossible combinations (indicated by cells left blank), where the two types of single agent processes cannot co-occur. This is the case when one agent does not develop the intention or feeling that the other agent needs for activating its process; for example, agent A needs obs(f), but agent B does not generate expr(f), as is the case for (10, 1) and (10, 2). Another reason for impossibility of a combination is when such a combination would entail a circular mutual dependency. Cells of special interest show a full joint decision with emotional grounding and mutually acknowledged empathic understanding. Examples are cell (18,18) and cell (8,4).

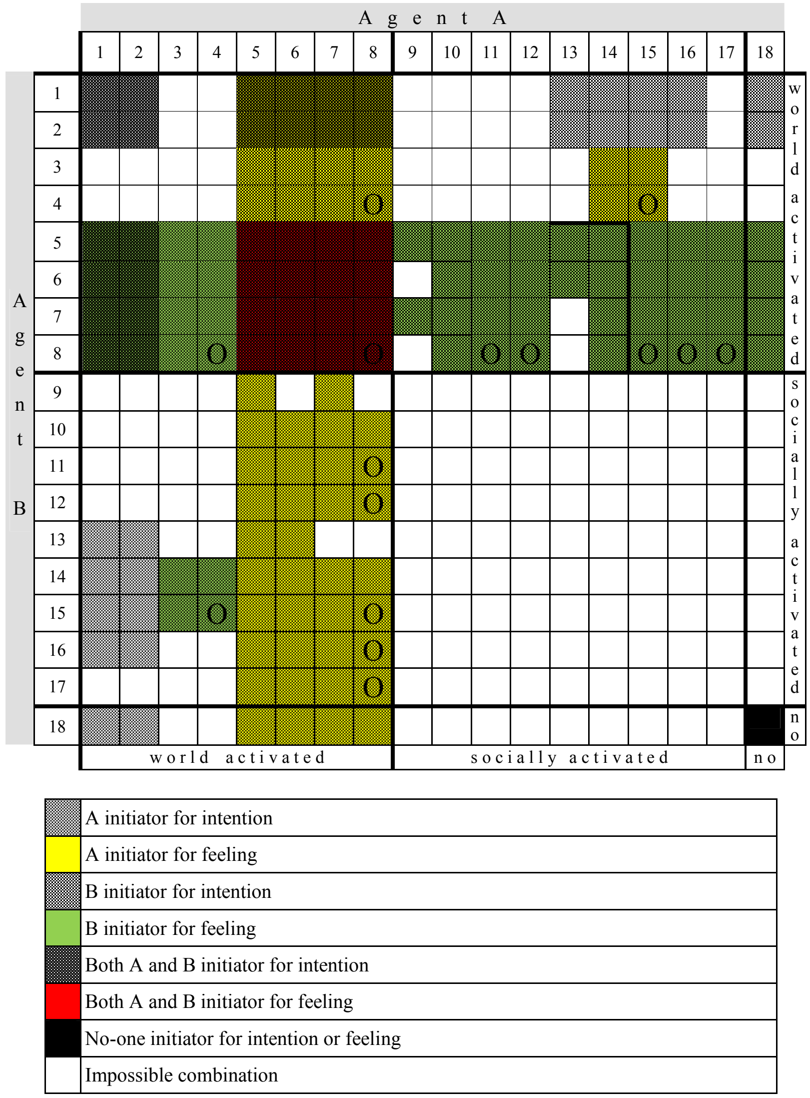


Fig. 5. The 324 different possibilities for initiation for two agents A and B; processes leading to full joint decisions to go for the option are marked by O

The columns 5 to 8 show processes in which agent A initiates both the intention and the feeling feeling. Some of the types of processes in column 8 lead to a full joined decision to go for the option (marked by an O) for example the one depicted at (8, 17). This represents a process achieving a full joint decision where one person fully develops the decision to go for the option first and then persuades or contages the other person to go for the option too. The same applies to (17, 8) in which the initiative is from the other agent. In the processes depicted in (8, 4), (8, 11), (8, 12), (8, 15) and (8, 16) (and (4, 8), (11, 8), (12, 8), (15, 8) and (16, 8)) more overlap takes place between the development in one person and the contagion of the other person. In the red shaded area the type of processes are depicted where both agents initiate both the intention and the feeling. For (8, 8) these processes lead to a full joined decision to go for the option.

As another example, representing a more complex interaction, the cells (3, 14), (3,15), (4, 14) and (4, 15) depict processes where agent A initiates and expresses the intention which is observed by agent B, who in turn develops the intention as well, and based on that initiates and expresses the feeling which in turn is observed by agent A. For (4, 15) these processes lead to a full joint decision. A similar but opposite process can be found in (15, 4). This shows more types of processes leading to a full joint decision.

6 Simulation Examples

Various simulation experiments have been performed to generate example of the different types of processes that have been identified. In this section some of them are discussed. As a first example, Fig. 6 shows two agents A and B that reach full jointness illustrating cell (8,15) in the process-type matrices. In this scenario agent A is world-activated and first develops intention and subsequently develops feeling, both represented by their respective preparation states. Agent B is socially activated and follows agent A in first developing intention and then feeling. Both agents express intention and feeling and acknowledge the expressions from the other agent.

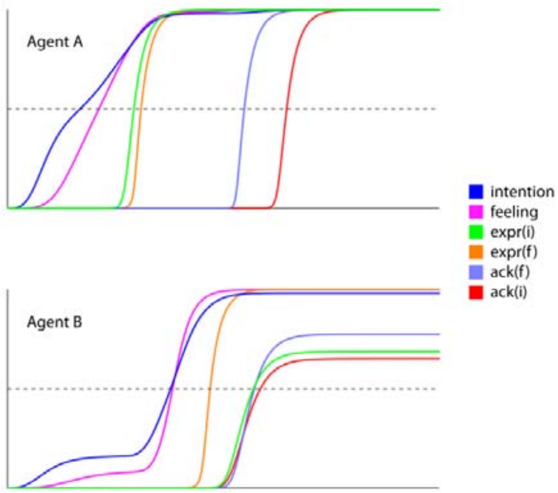


Fig. 6 Example simulation showing a full joint decision, illustrating cell (8, 15)

As another example, Fig. 7 shows an agent A with reduced observation capabilities. In this situation agent B still follows process-type 15, but agent A cannot fully observe the expressions from agent B and therefore does not generate acknowledgements ack(i) and ack(f). Agent A follows process-type 5, the scenario illustrating matrix cell (5,15).

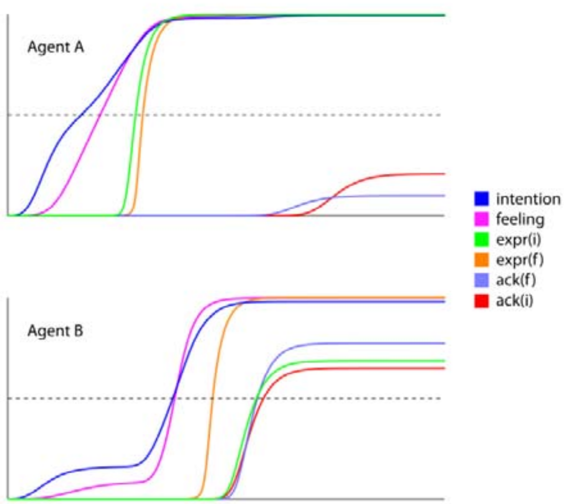


Fig. 7 Example simulation showing no acknowledgements, illustrating cell (5, 15)

In the example depicted in Fig. 8, agent B shows reduced mirroring capabilities for intention. Because of the reduced intention mirroring, feeling mirroring takes over and agent B first develops feeling, followed by developing intention. Agent B does neither expresses intention nor acknowledges the intention-expression from agent A. Because agent B does not express intention, agent A does not acknowledge intention. This scenario illustrates matrix cell (7,10).

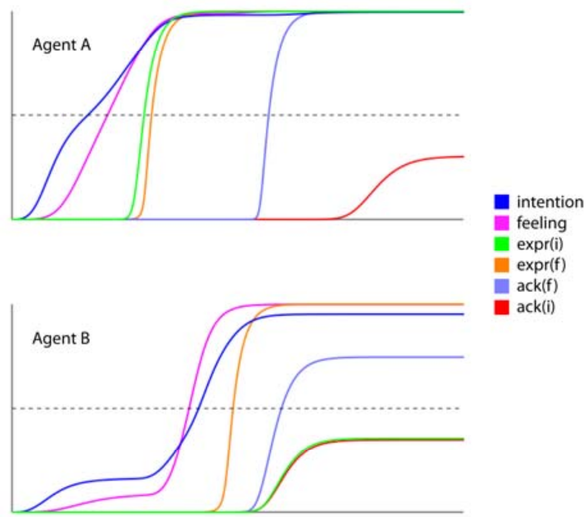


Fig. 8 Example simulation showing reduced mirrorin, illustrating cell (7, 10)

Table 1 provides an overview of the connections and their weights as used in the example simulation experiments discussed here. The world stimulus for agent A is 1.0 and for B 0.6 in all scenarios. The context is 1.0 for both agents in all scenarios. All other settings are in accordance with the original social agent model.

Table 3 Overview of setting for the example simulations

Connection		Weight values					
From	To	Scenario 1		Scenario 2		Scenario 3	
		Agent A	Agent B	Agent A	Agent B	Agent A	Agent B
SR(B,a)	PS(a)	1.00	0.60	1.00	0.60	1.00	0.35
SR(B,b)	PS(b)	1.00	0.50	1.00	0.50	1.00	0.50
SR(B,a)	OS(B,s,a,e)	1.00	0.90	1.00	0.90	1.00	0.90
SR(s)	OS(B,s,a,e)	1.00	0.90	1.00	0.90	1.00	0.90
SR(s)	OS(A,s,a,e)	1.00	0.90	1.00	0.90	1.00	0.90
SR(B,b)	OS(B,e,b)	1.00	0.90	1.00	0.90	1.00	0.90
SR(e)	OS(B,e,b)	1.00	0.90	1.00	0.90	1.00	0.90
SR(e)	OS(A,e,b)	1.00	0.90	1.00	0.90	1.00	0.90
SR(b)	PS(a)	1.00	0.80	1.00	0.80	1.00	0.80
SR(b)	OS(B,e,b)	1.00	0.70	1.00	0.70	1.00	0.70
SR(b)	OS(A,e,b)	1.00	0.70	1.00	0.70	1.00	0.70
OS(B,s,a,e)	EC(B,s,a,e)	1.00	0.90	1.00	0.90	1.00	0.90
OS(B,e,b)	EC(B,e,b)	1.00	0.80	1.00	0.80	1.00	0.80
OS(A,s,a,e)	ES(a)	1.00	0.90	1.00	0.90	1.00	0.90
PS(a)	ES(a)	1.00	0.90	1.00	0.90	1.00	0.90
OS(A,e,b)	ES(b)	1.00	0.90	1.00	0.90	1.00	0.90
PS(b)	ES(b)	1.00	0.90	1.00	0.90	1.00	0.90
SS(B,a)	SR(B,a)	1.00	1.00	0.50	1.00	1.00	1.00
SS(B,b)	SR(B,b)	1.00	1.00	0.32	1.00	1.00	1.00

7 Discussion

This paper presented a computational analysis of different types of processes to reach a common decision. A genuine joint decision does not only concern a choice for a common decision option, but also a good feeling about it, and mutually acknowledged empathic understanding. As a basis for the computational analysis a numerical computational social agent model for joint decision making is used, adopted from [40]. This model was inspired by principles from neurological theories on mirror neurons, internal simulation, and emotion-related valuing. For the analysis, this model was abstracted to a qualitative form.

The analysis provided on the one hand a systematic overview of the different possible outcomes of fully successful and less successful joint decision making processes, abstracting from the temporal dimension of the processes involved. On the other hand it provided a systematic overview of the possible types of processes leading to these outcomes.

The different types of outcomes and processes may relate to specific cognitive and social neurological characteristics of the persons. For example, persons with a not well-functioning mirror system may experience difficulties both in reaching a common choice and affective and empathic states in a decision process; e.g., [23, 32, 35]. On the other hand, persons who have a not well-functioning system for emotion-related valuing turn out to experience often problems in decision making in general; e.g., [1, 8, 9, 10, 11, 31]. The computational analysis contributed in this paper may provide a basis to further explore such relationships in the context of joint decision making.

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