Communicative signaling and self-other distinction: Next steps for an embodied hierarchical model of dynamic social behavior and cognition

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1 Introduction

In order to engage in a continuous social interaction, participants must be able to dynamically understand, predict, and influence the mental states and actions, so as to enable a process of efficient and interactive grounding of shared meaning. We follow the argument that the mentalizing network and the mirror-neuron system in our social brain together provide the basis for these abilities [1, 2]. However, how these systems exactly operate and how they work together is still unclear. Building on previous work on the interplay of mentalizing and mirroring in embodied communication, here we lay out next steps towards an embodied hierarchical model of dynamic social behavior and cognition. The proposed next steps target the early and reliable self-other distinction and integration in the sensorimotor system, which in turn informs mentalizing, so that it can distinguish between own and other's beliefs in complex situations of simultaneous action perception and production. Also, we propose that social cognitive systems informed in such a way have the information to allow for strategic signaling behavior by selecting actions necessary to make their action goals easier to disambiguate, and thus to communicate efficiently and successfully.

2 Current model

In a first step towards this goal, we developed a model of two distinct networks of the human social brain - mentalizing and mirroring - which allows them to interact during embodied communication. The model connects a mentalizing system based on simple heuristics for attributing and inferring different orders of belief about own and other's mental states, with a hierarchical predictive processing model of online action perception and production based on the common coding of underlying action representations [3]. To investigate the role of mentalizing and mirroring interacting in inter-agent coordination and to test the model, we conducted simulation experiments in which two virtual agents were each equipped with this model. Different mentalizing capacity configurations were tested, as well as different noise conditions, thus influencing the robustness of the communication. The agents engage in non-verbal communication behavior to which the embodied action representations in the mirroring system can resonate because of their close coupling of perception and production, while taking uncertainty from noise into account. Resonating action representations inform the mentalizing system, which in turn can guide successful interaction. Results from our simulations on this first model demonstrate how mentalizing can afford higher robustness of communication by enabling interactive grounding processes.

3 Next steps

Although our model was able to act upon and infer beliefs about own and other's mental states, it could only produce or perceive an action at a time. Of course, this is a special case of interaction that can occur, but in our dynamic world our social brain has to cope with simultaneous interaction with multiple partners, as well as simultaneous production and perception of actions. As a starting point for an account of simultaneous action and perception, the first step is to enable early self-other distinction within the sensorimotor system. Being able to run predictive sensorimotor processes for both self and other selectively provides the basis for the next step: enabling the mentalizing and mirroring system to plan social actions towards achieving our communicative goal. This allows for communicative signaling, in which a motor act (signal) is being strategically adjusted in order to maximize the expected probability of successful reception.

As research into schizophrenia has shown, reliable and early self-other integration and distinction is important not only for the correct attribution of a sense of agency, but also in turn for the correct attribution of intentions and emotions in social interactions [4]. Two major mechanistic models of self-other integration and distinction have been identified. One model, which makes use of people's ability to precisely predict the sensory consequences of their own actions, allows to decrease the intensity of incoming signals by "sensory attenuation", which enables people to distinguish between self-caused actions and their outcomes and those actions and outcomes caused by others. Research even suggests that sensory attenuation correlates with activation in the mirror neuron system [4], and that such attenuation increases during interaction with other people [5]. The second mechanism, which is also influenced by the prediction of action-outcomes, allows for the integration of sensory signals from multiple modalities during a "temporal binding window" [6], which selects perceived actions and their outcomes for integration as long as they occur within a narrow temporal window. Because we have more experience in predicting our own body that window is more narrow for own action-outcomes, than for other people's actions. Being able to make such a distinction allows people to monitor, infer and distinguish between causal relations for own and other's behavior.

How can these mechanisms work in unison to allow us to make such distinctions, even in situations where we simultaneously observe another person perform an action while producing one ourselves?

It is now widely agreed upon, that actions share a common representation for production and perception. Of course, such a common representation is ecological for the brain, since having to sustain multiple representations for one action were quite costly, but also such a common coding can lead to problems like interferences. Such interferences were observed when in a simultaneuous action perception and production scenario where the perceived action would be incongruous to the produced one, led to measurable interferences, as a slight mix of the observed action with the produced one [7]. The previously mentioned sensory attenuation can shed light on this effect, since it attenuates predicted action-outcomes only to the degree that we trust the prediction of an action. From a predictive processing perspective, the simultaneous incongruent perception and production of actions would probably lead to strong prediction error signals [8], but a mechanism of sensory attenuation for self-caused predicted action-outcomes can minimize the influence of such a prediction error. However, the observable interferences still indicate that activations due to production or perception can influence each other. Thus, by means of attenuation the sensorimotor system is able to produce and get feedback for own actions while simultaneously perceive actions of others.

This ability to distinguish between own and other's behavior can inform processes that infer beliefs about other people, i.e. a communicative intention that I want an interlocutor to understand, and her behavior that gives me a clue about her understanding of this. This inferred mental state of others, together with my own mental state and a communicative goal, are information that can be used to make following actions and their underlying communicative intent maximally distinguishable from other possibly plausible interpretations, or to compensate for noise. This can be done by communicative signaling as an attempt to strategically alter one's own action kinematics to better achieve the communicative goal [9]. The concept of communicative (or strategic) signaling entails the question on how such alterations are constructed. We will model signaling on an exemplar based approach, where from a set of available actions a selection is made to produce the most distinguishable.

These mentioned mechanisms for self-other distinction, and the resulting ability to make communicative signaling alterations to own behavior are the next steps to be implemented in our embodied hierarchical model of social behavior.

To then be able to achieve self-other distinction in our embodied motor system and make use of the collected information, we plan to test and account for four scenarios that involve embodied agents interacting in a simulated environment, and that require successively increasing abilities for self-other distinction and signaling: In scenario 1, the system will just produce and perceive its own action, to test whether attenuation and temporal binding are working properly. Scenario 2 will test the system's ability to basically face itself in a virtual mirror, so that its own action-outcome and an identical, reflected action-outcome will need to be distinguished. In scenario 3, the system will face a second system, producing a similar, but not equal action, to test its ability to distinguishing between action-outcomes of self and other, as well as to trigger communicative signaling. As in scenario 4, a similar setup will be used, but the second system will produce a completely different action, to test the system's ability to distinguish both actions and trigger communicative signaling as well.

4 Outlook

We are confident that the next steps we have laid out here will propel research towards an embodied hierarchical model of social behavior. We expect this model to provide novel and detailed accounts for several predicted phenomena: First, well known actions are less prone to interference from simultaneously perceived actions. This is due to the increased attenuation for action-outcomes of well known actions and the resulting decreased influence of prediction errors. Second, an exemplar based approach to signaling will allow for a wide variety of possible strategic signaling, which is only limited to the number of actions learned and experienced by the system.

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