Neural Networks 62 (2015) 112–117

Contents lists available at ScienceDirect

Neural Networks

journal homepage: www.elsevier.com/locate/neunet

2015 Special Issue

Communication, concepts and grounding

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ARTICLE INFO

Article history:
Available online 16 July 2014

Keywords:
Assemblies
Communication
Concepts
Grounding
Situated cognition

ABSTRACT

This article discusses the relation between communication and conceptual grounding. In the brain, neurons, circuits and brain areas are involved in the representation of a concept, grounding it in perception and action. In terms of grounding we can distinguish between communication within the brain and communication between humans or between humans and machines. In the first form of communication, a concept is activated by sensory input. Due to grounding, the information provided by this communication is not just determined by the sensory input but also by the outgoing connection structure of the conceptual representation, which is based on previous experiences and actions. The second form of communication, that between humans or between humans and machines, is influenced by the first form. In particular, a more successful interpersonal communication might require forms of situated cognition and interaction in which the entire representations of grounded concepts are involved.

1. Introduction

Communication occurs at different levels of organization. Examples are neurons that can communicate by emitting and receiving spikes, humans that can communicate by exchanging language, and, nowadays, humans and machines that can communicate using language or visual displays and actions. A link between these forms of communication can be found in the brain. Communication between neurons determines to a large extent how the brain operates. In turn, brain operation determines to a large extent how communication between humans or communication between humans and machines proceeds.

More specifically, a pivotal role in linking these forms of communication could be played by the way the brain forms representations of concepts. On the one hand, concepts play an important role in the communication between humans or humans and machines. On the other hand, concepts arise in brain structures and circuits, so communication between neurons would play an important role in developing and activating concepts, also when they are used in interpersonal communication.

The view of how concepts are formed and used has changed considerably over the last decades. In the first decades of cognitive science it was, quite generally, assumed that concepts are represented as amodal data structures, not unlike digital representations as found in the brain (e.g., Fodor & Pylyshyn, 1988; Newell, 1990). Clearly, these data structures could be communicated between humans (or humans and machines) through language.

But the communication of concepts by means of amodal data structures raised the question of what the basis would be for their meaning. Pylyshyn (1984) argued that 'transducers' would transform information from the senses into symbolic data structures, but it remained unclear how this could proceed. Harnad (1991) argued that symbols as used in cognition (and with it, in communication) would have to be grounded in, for example, perception and action, to give them meaning. This idea has been extended further to the notion that all our concepts, including those that can be expressed in language, are ultimately grounded in a variety of (neural) processes related to perception, motion, action and emotion (e.g., see Pezzulo et al., 2013, for a recent review).

Grounding of concepts as discussed in this article refers to the notion that concepts are represented by neural network structures that arise in development. These structures contain both the circuits that are activated in learned perception, e.g., by a stimulus that initiates the activation of a concept, and the neuronal circuits that initiate learned responses related to the concept. Examples of such representations are the neural assemblies discussed by Hebb (1949), as illustrated later on.

This article aims to investigate what the grounding of concepts would implicate for communication. In this respect, we can distinguish between two forms of communication. The first would be the communication between neurons, circuits and brain areas that are involved in the representation of a concept. The second would be (e.g., interpersonal) communication in which these concepts play

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http://dx.doi.org/10.1016/j.neunet.2014.07.003
0893-6080/

a role. An illustration of both forms of communication can be given with the example of phantom sensations.

2. Grounded representations in phantom sensations

Ramachandran (Ramachandran and Blakeslee 1998) investigated a patient whose left lower arm was amputated, but who still reported sensations as if they arose from this arm and the left hand. Ramachandran discovered that he could induce these sensations by stroking the left side of the face (and the upper left arm) of this patient. It turned out that a complete map of the left hand was present on his face and upper arm, with detailed representations of the fingers of the left hand. Stroking these areas on the face or upper arm would induce the sensation as if the corresponding parts in the left hand were touched.

Ramachandran provided a plausible basis for the explanation of the phenomenon, in terms of the representation of the body in the sensory cortex. The human body is represented as a map on the surface of the sensory cortex. This map roughly has the same shape as the body itself, although certain parts are enlarged, such as the hands and the face. Furthermore, the hand and face areas are adjacent on this map (perhaps due to the fetal posture, in which the hands are close to the face). Ramachandran argued that, after amputation of the left hand, neuronal fibers from the face area in the sensory cortex would begin to activate the hand area of the sensory cortex as well (e.g., by lateral connections between the two areas in the sensory map), because of its position adjacent to the face area. Similar effects have been demonstrated experimentally in the monkey cortex (e.g., Pons, Preston, & Garraghty, 1991). In this way, a stimulation of the face would also result in a sensation that the hand was touched as well.

The possibility of (new) lateral connections between areas in the sensory map, and the phantom sensations that could result from it, provides important information about the nature of grounded representations and the communication between brain parts. A stimulation of the left hand or the left side of the face can be used to initiate a specific action, targeted at the position of the left hand or the left side of the face. For example, if you feel an itch on your left arm or left side of your face, you can use your right hand to scratch yourself. Fig. 1(a) depicts this situation. A stimulation of the left hand (felt as an itch) activates the neurons in the hand area of the sensory cortex. In turn, these neurons activate the motor neurons that direct the right hand to the position of the left hand, to scratch it. In the same way, the stimulation of the left side of the face (felt as an itch) activates the neurons in the face area of the sensory cortex. These neurons then activate motor neurons that guide the right arm to the left side of the face.

In Fig. 1, S1 and S2 stand for neural circuits in the sensory cortex (sensory map of the body) that are activated by a stimulation of the left arm or the left face respectively. They connect to neural circuits in the motor cortex (M1 and M2) that can initiate an action to the left hand or face. Thus, S1 and S2 (and M1 and M2) are a part of the neural circuits that integrate stimulation and response. For example, feeling an itch could refer to a bug crawling on the skin. Bugs are potentially dangerous (e.g., spreading diseases) so it would be useful to initiate an action, e.g., by the right arm, to remove the bug. This requires a representation of the location of the bug on the body and the ability to move the right arm to that location. Being able to perform these actions requires a prolonged learning period (e.g., consider the time young children spend to learn to direct their arm to specific locations). Viewed in this way, one could argue that the representation of the location of the bug on the skin is at least in part encoded in the learned network structures that can direct the arm to that location.

Fig. 1(b) depicts what happens in the case of a missing left hand. The input fibers from the left hand to the sensory neurons coding for the left hand are missing. But (new) lateral connections between S2 and S1 could now have developed (or be activated). So, when the left side of the face is stimulated, it activates not only the sensory neurons coding for the face (S2), but also the sensory neurons coding for the left hand (S1). As before, the connection between S2 and M2 represents the circuit that guides the right arm to scratch the left side of the face. So, when the left side of the face is stimulated, the right hand can be used to scratch it.

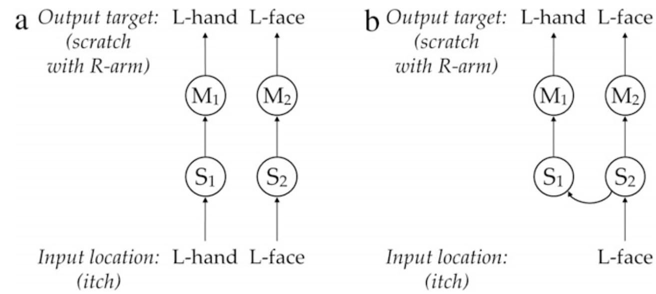

Fig. 1. An account of phantom sensations (based on Ramachandran and Blakeslee, 1998). In (a), a stimulation of the left hand (face) is registered by neurons in the (somato)-sensory cortex. In turn, these neurons can activate neurons in the motor cortex that direct the right arm to scratch the left hand (face). In (b), the left hand is missing, but a stimulation of the left face can (also) induce a sensation (and action) related to the left hand. L = left, R = right, S = sensory, M = motor.

However, also as before, the connection between S1 and M1 represents the circuit that guides the right arm to scratch the left hand, and this circuit is still functioning, even though the left hand is no longer present. But now the circuit between S1 and M1 can be activated by stimulating the left side of the face, so that the right hand can be directed to the location of the left hand, to scratch it. In this way, the location of the left hand is still 'present' as the output location for a specific action.

Notice that this also changes the representation encoded by S2 (or better, of which S2 is part). That is, the outgoing connections of S1 are (or become) a part of the outgoing connections of S2. This results in the sensation of feeling the L-hand when in fact the left face is stimulated. So, the representation of which S2 is a part has changed in this way.

Presumably, a similar account can be given of why sensations are still felt in the left hand. All neural circuits that emerge from S1 are still present, so when S1 is activated by touching the left side of the face, these circuits become activated as well. And the sensations in the left hand will be associated with the activation of these circuits.

The account of phantom sensation illustrated in Fig. 1 reveals an important characteristic of grounded representations and communication. One might assume that S1 represents the left hand (e.g., sensations felt in the left hand), because it is activated by the left hand, as in (a). But when S1 is activated as in (b), the left hand is still felt, and the right arm can still be directed to scratch it. As argued above, this would be due, at least in part, to the fact that the circuits that emerge from S1 are still available and are activated whenever S1 is activated. But then S1 does not just represent the left hand because it is activated by it, but (also) because S1 itself activates circuits that have become associated, through learning, with the sensations felt in the left hand and as a target for an action. So, its outgoing connections determine, at least in part, what S1 represents.

3. Communication in neural circuits

The example of phantom sensations emphasizes the fact that a representation is grounded due to its entire connection structure. If S1 in Fig. 1 would represent a concept (e.g., left hand) then the connections emerging from it seem to be even more important in