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The role of prediction in mental processing: A process approach

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ABSTRACT

Although prediction plays a prominent role in mental processing, we have only limited understanding of how the brain generates and employs predictions. This paper develops a theoretical framework in three steps. First I propose a process model that describes how predictions are produced and are linked to behavior. Subsequently I describe a generative mechanism, consisting of the selective amplification of neural dynamics in the context of boundary conditions. I hypothesize that this mechanism is active as a process engine in every mental process, and that therefore each mental process proceeds in two stages: (i) the formation of process boundary conditions; (ii) the bringing about of the process function by the operation – within the boundary conditions – of a relatively 'blind' generative process. Thirdly, from this hypothesis I derive a strategy for describing processes formally. The result is a multilevel framework that may also be useful for studying mental processes in general.

1. Introduction

There is consensus about the importance of prediction in mental processing, but no broadly accepted theory is available that explains how the central nervous system (CNS) generates and employs predictions, and how this CNS function has evolved. In order to address these issues this paper develops a multilevel process model of the mental mechanisms that underlie behavior. This relates to a system-level approach, which means that the focus is on the functions of processes rather than on their neurophysiological mechanisms.

The process model is developed from a biological perspective in the sense that it applies to all animals with a CNS, and that mental functions are supposed to be related to facing the challenges that life imposes on the individual regarding survival and reproduction. In this perspective, using predictions is a specific strategy employed by the CNS for accomplishing its task of orchestrating actions that improve the chances of survival. Prominent in that strategy is the descriptive and predictive model of the environment on which the organism relies for its goal-directed behavior.

In 2003 Karl Friston made an important contribution to the so-called predictive brain approach of mental processing by describing the perception process as a cascade of inference loops. According to that description, in each loop the incoming sensory information is compared with predictions that have been generated in earlier loops, and detected differences are employed for adjusting the predictions. Friston also showed that this cascade can be described in terms of hierarchical predictive coding, which is a form of Bayesian probability calculus (Friston, 2003). This mathematical process description makes it possible to formulate quantitative hypotheses that can be tested experimentally (Clark, 2013; Hohwy, 2013).

Moreover Friston proposed that action could be described as an active inference that brings prediction of percepts and actual observation closer to each other, or in his own words: 'much innate orientating and tracking behavior is simply a reflection of the brain's inherent tendency to maintain a predictable sensory input' (Friston, 2003). This proposal has received some criticism (Bickhard, in press b; Clark, 2013), because it does not address some of the aspects of action that are highly relevant for survival and reproduction. For instance, according to the proposed description the playful behavior of a child could be explicated as the consequence of explaining away the child's sensory inputs. One of the important aspects that is ignored in this description is the presence of a positive decision bias in the child's mind that not only activates its playful behavior, but also promotes curiosity, exploration and learning *per se* (Singh, Lewis, Barto, & Sorg, 2010).

This paper develops a general framework for mental processing in the context of which different relevant aspects of action can be

Abbreviations: CNS, central nervous system; OFM, organic forward model of the environment; BANS, boundary condition-determined active noise shaping.

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addressed. The framework is centered on anticipation, which in turn is based on prediction. For developing this framework the forward model method is employed, a method that has been applied during the past decades for tackling a wide variety of problems in cognition, perception, robotics and computer vision (e.g. Grush, 2004; Rao & Ballard, 1997; Wolpert, Ghahramani, & Jordan, 1995; Wolpert & Kawato, 1998). These studies have led to what are known as enactivist formulations of perception – such as the theory on sensory-motor contingencies – that take an embodied approach and regard perception as probing the environment (e.g. O'Regan & Noë, 2001; Varela, Thompson, & Rosch, 1991).

The framework has important aspects in common with the interactivist approach developed by Donald Campbell and Mark Bickhard (Bickhard, 2009, in press a & b; Bickhard & Campbell, 2003). Both approaches are process-based instead of substance-oriented. In addition, both approaches provide an alternative for what is often characterized as the input-processor model of brain function. Finally, in both frameworks the focus on future possibilities, i.e., anticipation, is an essential element, and normativity is considered to be of vital importance; however, the model developed here is more specific about the processes by which normativity is achieved. More similarities will appear throughout the paper. Because of these similarities the proposed framework can be tagged in two ways: as a predictive brain approach with the special feature that it is specific regarding normativity, and as an interactivist model with emphasis on anticipation. The most noticeable difference between the two approaches is in the basic argumentation: the present paper mainly argues from biological plausibility with survival as the main goal, while in the interactivist model this argument plays a less prominent part.

2. A process model of how predictions are generated and used

This section focuses on anticipation, which is the process of orchestrating action in advance. It discusses the function of anticipation, its evolution, the role of prediction in it, and how prediction is produced.

2.1. The function and evolution of anticipation

For an animal, anticipation has the major advantage that it allows very precise timing of actions such as the interception of a fast moving prey or the escape from an attacker. As Fig. 1 explains, a crucial factor for precise timing is the compensation of the action delay caused by time-consuming neural processes such as the processing of sensory signals by the CNS and the transmission of signals from the sensor to the CNS, and from the CNS to the muscles.

Anticipation also has other benefits: it provides the opportunity to avoid risks, to recognize opportunities on time, and to notice mistakes so that the animal can adapt its behavioral strategies accordingly. The latter makes the creature antifragile, which means that exposure to disturbances improves its capabilities (Taleb, 2012). Also at basic processing level anticipation has advantages: incomplete perceptual information may be filled in from prediction, which enhances the effectiveness of the perception process under harsh conditions, and it allows filtering out irrelevant sensory data, as will be discussed below. For more benefits see e.g. Wolpert et al., 1995. Because reduction of action delay has a direct and significant impact on survival, this benefit is likely to have been the main driving power for the development – during brain evolution – of anticipation as a key function of the CNS.

Organisms that cannot anticipate are entirely dependent on the

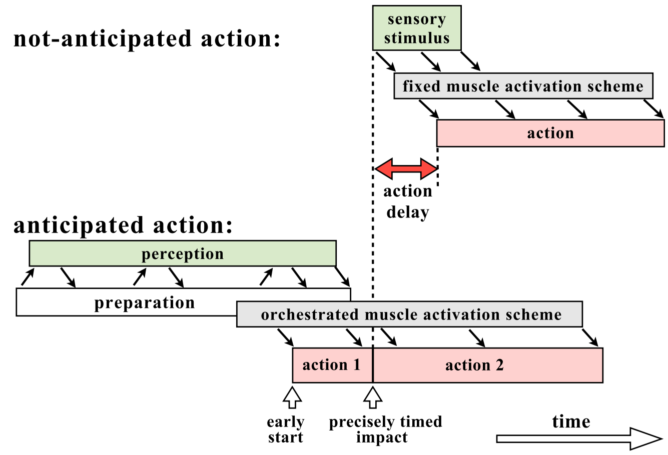

Fig. 1. Flow diagram showing how anticipation improves the accuracy of action timing. Top: Without anticipation. A sensory stimulus triggers a fixed response scheme in accordance with which the action is executed. The time needed for signal transport and signal processing causes action delay. Bottom: The action is prepared in advance, which includes perceptual activity; the early start of the action compensates for signal delay, so precise timing of the crucial part of the action can be achieved. An example is the bird of prey that intercepts a small bird in flight: 'action 1' is the swoop towards the prey, which is so precisely aimed and timed that impact actually occurs; during 'action 2', the bird secures the prey.

forces exerted on them from the surroundings; an example is seaweed that is passively moved around by the tide. In stark contrast, an anticipating animal can plan and shape its own course of action because it is able to manipulate time and space in its mind; in this way it can escape from imprisonment in here-and-now causality.

2.2. Anticipation builds on simulation processes

Anticipation can only improve the chances of survival if adequate action choices can be made before the action is executed. This implies that the CNS must be able to develop a notion about how an intended action can be expected to unfold, and in particular about what the action consequences will be. I follow Germund Hesslow's proposal that action predictions are produced by means of action simulation processes (Hesslow, 2012). An action simulation process consists of a swift and sketchy mental exploration of the course of the intended action with a degree of detail that is just good enough for making an adequate action choice. In terms of probability calculus: the simulation process reduces the uncertainty regarding future mental states to an acceptable level.

Within the simulation process an embodied valuation process – which will be described in Section 2.5.1 – is active that produces an indication of the extent to which the expected action outcome contributes to the welfare of the animal; this makes the simulation normative.

Simulated actions take place – imaginatively – in an environment that may be different from the present surroundings. The estimation of this remote environment requires a second simulation activity: the simulation of that environment. A relevant consideration in that context is that as an animal moves through its environment, many aspects of the surroundings change only gradually, so it would be a waste of effort to produce a new simulation of the environment for every action simulation. It is more efficient – and therefore more likely – for the CNS to employ the following strategy: (i) it produces – by means of simulation – one comprehensive and realistic model of all the relevant aspects of the present environment; (ii) it continually updates this model by means of ongoing observation of the surroundings; (iii) for every