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1

Introduction

Where's the Action?

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Abstract

Cognitive science is witnessing a pragmatic turn away from the traditional representation-centered framework of cognition toward one that focuses on understanding cognition as being "enactive." The enactive view holds that cognition does not produce models of the world but rather subserves action, as it is grounded in sensorimotor skills. The conclusions of this Ernst Strüngmann Forum suggest that strong conceptual advances are possible when cognition is framed by an action-oriented paradigm. Experimental evidence from cognitive science, neuroscience, psychology, robotics, and philosophy of mind supports this position.

This chapter provides an overview of the discourse surrounding this collaborative effort. Core topics which guided this multidisciplinary perusal are identified and challenges that emerged are highlighted. Action-oriented views from a variety of disciplines have started to cross-fertilize, thus promoting an integration of concepts and creating fertile ground for a novel theory of cognition to emerge.

Overview

Over the last two decades, a "pragmatic turn" has started to emerge in cognitive science away from the traditional representation-centered framework toward a paradigm that focuses on understanding cognition as being "enactive"; that is, cognition as a form of practice (Varela et al. 1992; Clark 1998; Noë 2004). In contrast to classical cognitivist models, an enactive view holds that cognition should not be understood as serving to make models of the world, but rather as subserving action and grounded in sensorimotor skills. Accordingly, cognitive states and their associated neural activity patterns need to be studied with respect to their functional role in action generation. Moreover, this paradigm shift stipulates new views on the functional relevance and the presumed "representational" nature of neural processes.

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First evident in robotics, an action-oriented approach to cognition took longer to gain influence in cognitive psychology and neurobiology. Currently, action-oriented approaches are evolving in parallel in robotics, cognitive science, neuroscience, psychology and philosophy of mind. However, strong conceptual links across these domains have, for the most part, been lacking.

This Ernst Strüngmann Forum was convened to examine the key concepts of an emerging action-oriented view of cognition from multiple perspectives (e.g., robotics, cognitive science, neuroscience, psychology and philosophy of mind). The Forum provided the prerequisite intellectual setting in which to explore the preconditions and possible consequences of such a paradigm shift, and successfully brought together leading proponents from wide-ranging fields. Its interdisciplinary nature and open discussions enabled us to evaluate critically the different approaches and types of data. Importantly, it permitted us to search for novel and more integrated perspectives.

This book is the result of an extended dialogue between fifty colleagues and is made up of two types of contributions: articles that provide information on key aspects of action-oriented perspectives and collaborative reports of the discussion that ensued (see Pezzulo et al., Kilner et al., Seth et al., Dominey et al., this volume). As evidenced by the various chapters, action-oriented views from multiple fields have started to cross-fertilize, thus enabling conceptual integration and creating fertile ground for a novel theory of cognition to emerge. Action-oriented views are not only conceptually viable, they are supported by substantial experimental evidence. Numerous empirical findings overtly demonstrate the action-relatedness of cognitive processing or can be reinterpreted using this new framework.

In this introductory chapter, we present an overview of the "pragmatic turn" (i.e., how science has reached this point) and highlight challenges that emerged from the ensuing shift in paradigms. The core topics that guided our collaborative effort are identified to provide context, and main findings from the discussion groups are summarized.

The Pragmatic Turn

Since its formation as a discipline—intending to provide a naturalistic account of the mind and its processes—cognitive science has been dominated by a computational-representational view of cognition. The key assumptions that characterize this classical representation-centered paradigm include the following:

- Cognition is understood as computation over mental representations.
- The subject of cognition is a detached observer with a "bird's eye" view of the world.
- Intentionality is explained by the representational nature of mental states.

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- The architecture of cognitive systems is conceived as being highly modular.
- Processing in subsystems is assumed to be largely context invariant.
- Computations are thought to occur in a substrate-neutral manner (functionalism).
- Models of cognition take into account only the inner states of a cognitive system (individualism).

These assumptions, which go back to the work of Fodor (1981), Newell and Simon (1972), and other protagonists of the representational theory of mind, seem to be present in most theoretical accounts of cognition, albeit with varying degrees of emphasis. Although the paradigm was highly fruitful in stimulating important research in the early decades of cognitive science, massive criticism arose, and with it claims that the classical view may be highly biased, if not misleading, in nature (Winograd and Flores 1986; Brooks 1991b; Varela et al. 1992; Dreyfus 1992; Clark 1995, 1998; O'Regan and Noë 2001; Noë 2004; Engel 2010; Engel et al. 2013).

Out of this criticism emerged the beginnings to an action-oriented paradigm (Varela et al. 1992; Clark 1998; O'Regan and Noë 2001; Noë 2004; O'Regan 2011). Initially, the paradigm shifted and was most explicitly developed in the field of robotics (Winograd and Flores 1986; Brooks 1991b; Dreyfus 1992; Pfeifer and Bongard 2006). More recently, it gained influence in cognitive psychology (Hommel et al. 2001; O'Regan and Noë 2001; Schütz-Bosbach and Prinz 2007) and neuroscience (Jeannerod 2001; Beauchamp and Martin 2007; Friston 2010; Friston, Daunizeau, et al. 2010; Pulvermüller and Fadiga 2010; Engel 2010; Engel et al. 2013).

The basic idea behind an action-oriented paradigm holds that cognition should not be understood as a capacity for deriving world models, which in turn would provide a database to support thinking, planning, and problem solving. Instead, cognitive processes are closely intertwined with action. Cognition is thus best understood as "enactive"; that is, as a form of practice itself. This enactive view (advocated by Varela et al. 1992; Clark 1998; Noë 2009; Engel 2010; O'Regan 2011; Engel et al. 2013) can be summarized as follows:

- Cognition is understood as the capacity to generate structure by action.
- The cognitive agent is immersed in its task domain.
- System states acquire meaning through their functional role in the context of action.
- The functioning of cognitive systems is thought to be inseparable from embodiment.
- A holistic view on the architecture of cognitive systems prevails, emphasizing the dynamic nature and context-sensitivity of processing.
- Models of cognition take into account the "extended" nature of cognitive systems.

The concept of action, as used here, is neither coextensive with that of behavior nor with that of movement (Mead 1938; Engel et al. 2013). Expression of action is used in a wider sense, including acts not involving any overt movements (e.g., thinking, calculating, imagining, or deciding). The description of acts or actions typically makes references to goals, whereas behavior can be described without making any reference to mental states.

An action-oriented paradigm is supported by a number of prominent and highly discussed conceptual approaches. The notion that cognition can only be understood by considering its inherent action-relatedness is a key postulate of the "enactive" approach developed by Varela, Thompson, and Rosch (1992). In their view, cognition should not be considered as producing veridical representations of the environment but rather as the capacity of generating structure by action (Varela et al. 1992). A related, strongly action-oriented view of cognition has also been advocated by Clark (1995, 1998).

Of particular relevance in this context is the sensorimotor contingency theory put forward by O'Regan and Noë (2001). This approach builds on earlier approaches to explain the fundamental role of action for perception and awareness as in, for example, Gibson's affordances (Gibson 1979). It also relates to older neurobiological concepts, such as the "reafference principle" of von Holst and Mittelstaedt (1950), who discovered that an efference copy is needed for the unambiguous interpretation of sensory signals (Wolpert and Flanagan 2001; Friston 2010; Wolpert et al. 2011). According to O'Regan and Noë (2001), an agent's sensorimotor contingencies (SMCs) are constitutive for cognitive processes. In this framework, SMCs are defined as law-like relations between movements and associated changes in sensory inputs that are produced by the agent's actions. Once acquired, an agent can use these SMCs to predict consequences of its own actions.

Recent work in cognitive robotics suggests that the learning of such predictions may mediate the acquisition of object concepts (Krüger et al. 2007; Bergström et al. 2011; Maye and Engel 2012), thus grounding knowledge of objects in repertoires of actions that can be performed on them. This theoretical perspective is also closely related to the active inference approach to action and perception (Friston and Stephan 2007; Friston 2010; Friston, Daunizeau, et al. 2010) as well as to models of predictive coding (Rao and Ballard 1999).

An action-oriented paradigm has the potential to change our view of the brain and its function profoundly. If mapped to the neuroscientific level of description, the conceptual premises of the pragmatic stance may lead to a redefinition of some of the basic explananda. Then, neuroscience would not need to explain how brains act as world-mirroring devices (Marr 1982; Churchland et al. 1994) but rather as "vehicles of world-making" (Varela et al. 1992): vehicles which support, based on individual learning history, the construction of the experienced world and the guidance of action. Data from developmental and cognitive neuroscience seem to advocate such a departure from more classical views on cognition and brain function.

Challenges and Controversies

The shift toward inherently action-oriented views of the brain and cognition has brought with it a number of challenges. In our brief discussion of these issues which follows, we highlight chapters in this volume where critical discussion is offered.

Questioning Representations

Understanding the functional role and semantics of neural states constitutes a key challenge. The insight that cognition may be fundamentally grounded in action seems to enforce a radical change in how we conceive of the functional significance of neural activity patterns. Some argue that brain states prescribe possible actions, rather than describe states of the outside world (Clark 1998). Thus, brain states might better be understood as "directives" that guide action, rather than as "representations." Such "directives" could be conceptualized as dispositions for action embodied in dynamic activity patterns (Engel et al. 2013).

Gallagher (this volume) argues that a holistic, enactive conception of cognition focuses on the rich dynamics of brain-body-environment systems; thus, it may have higher explanatory power than classical views which rely on "representation-in-the-head" models. Menary (this volume) examines this issue further, reflecting on the classical work of American pragmatism. He proposes an action-oriented view which suggests that cognitive systems do not encode representations that are then processed computationally, but rather explore and sample the environment in the service of action.

Contradicting the enactive view, Barsalou (this volume) argues that action-oriented accounts have difficulties in providing a comprehensive view of mediating processes, which are characteristic of human cognition (including conceptualization, affect or self-regulation) and may require a notion of representation. Friston (this volume) proposes the concept of probabilistic representations within the framework of predictive coding. On his account, even if reformulated in probabilistic terms, internal states in a cognitive system must still stand in for or represent external states (see also Kilner et al., this volume).

Cognitive Role of Motor Brain Structures

To what degree can the function of motor regions be understood as directly supporting cognition, as opposed to a view which assigns merely "output" functions to these circuits? For instance, attention and decision making may rely much more on motor regions than previously assumed (Rizzolatti et al. 2002; Engel et al. 2013). Imaging studies show that object concepts in semantic memory do not solely rely on sensory features but depend critically on motor properties associated with the object's use (Martin 2007; Beauchamp and Martin 2007). An intriguing finding is that motor and premotor systems, basal

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ganglia, and cerebellum are also active during mental simulation of events as occurs, for instance, during mental rotation of objects (Jeannerod 2001). If subjects are trained to perform functional tasks on certain objects, premotor regions become active during visual perception of these objects (Weisberg et al. 2007).

Strong support for the cognitive role of motor circuits has been provided by research on the mirror neuron system (Rizzolatti et al. 2002; Rizzolatti and Craighero 2004), which suggests that the processing of social events (e.g., observing and coordinating with the actions of other subjects) involves action-generating neural systems. Importantly, evidence shows that the mirror neuron system also includes primary motor cortex (Hatsopoulos and Suminski 2011). The observation of visual and somatosensory responses in primary motor cortex suggests that this area may also be involved in predicting future sensory consequences of actions. Similar conclusions have emerged from studies which demonstrate an involvement of motor and premotor cortex in speech perception and language comprehension (Pulvermüller and Fadiga 2010; Pulvermüller, this volume).

From the viewpoint of an integrated sensorimotor approach, does it make sense to use the classical categories of "motor" and "sensory" cortex? These cortical regions could instead be viewed as proprioceptive and exteroceptive sensorimotor areas that encode SMCs. For example, visual cortex might be considered to be the recipient of top-down predictions about the consequences of oculomotor acts.

Role of Sensorimotor Contingencies

The concept of SMCs refers to the learning and deployment of the patterns of correlation between movements and associated changes in sensory inputs that are produced by an agent's actions. Clearly, SMCs play an important role in basic sensorimotor integration, because they are necessary for an organism to distinguish self-generated sensory changes from those not related to the organism's own action (von Holst and Mittelstaedt 1950; Crapse and Sommer 2008). The importance of this principle has been well established in the context of eye movements as well as grasping or reaching movements (Crapse and Sommer 2008). A critical question is to what extent more complex cognitive functions can be achieved by learning SMCs (Maye and Engel 2012, 2013).

Similar principles of predicting sensory inputs may also play a key role in more complex cognitive processes, such as language comprehension (Pickering and Garrod 2007) or predictions about sequences of abstract stimuli (Schubotz 2007). Furthermore, prediction of sensory outcomes of actions is critical for the sense of agency; that is, the conscious experience of oneself as the initiator and executor of one's own actions (David et al. 2008). Malfunction of action-outcome contingencies have been implicated in the pathogenesis of psychiatric disorders such as schizophrenia (Frith et al. 2000b; Ford et al. 2008).

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The challenging question is whether SMC knowledge is sufficient to implement complex cognitive functions, or whether higher cognitive processes based on other principles are required. Recent work in cognitive robotics suggests that SMC learning may mediate acquisition of object concepts (Bergström et al. 2011; Maye and Engel 2012; Bohg and Kragic, this volume), grounding knowledge of objects in repertoires of actions that can be performed on them (Beauchamp and Martin 2007). Maye and Engel (this volume) suggest that the concept of SMCs can be extended to accommodate more complex types of action-related contingencies. They propose that this might include object-related contingencies; that is, sets of SMCs that describe the multisensory impression an object leaves upon actions of the agent. Furthermore, intention-related contingencies might comprise the long-term correlation structure between complex action sequences and the resulting outcomes or rewards which the agent learns to predict over extended timescales. After learning, these intention-related SMCs could be used to predict whether an action will be rewarding or not, and rank alternatives. At the same time, such contingencies could provide the basis for action plans that involve several steps to reach an overall goal. Another consequence is that anticipation and anticipatory behavior as well as the sense of agency might be grounded in SMCs.

Jost (this volume) discusses the issue of SMCs with respect to principles that can serve to optimize the sensorimotor interaction of a system with its environment. One of the relevant principles is empowerment: the amount of information that an agent can inject into the environment through use of its effectors and recapture through its sensory organs (Klyubin et al. 2005). Jost emphasizes the limitations of the SMCs approach and suggests that structural priors will be required for learning in SMCs-based systems, since acquiring correlation structures is difficult for high-dimensional data sets.

Role in Development

One of the key aims of this Forum was to evaluate action-oriented concepts of cognition against a developmental background and to discuss to what extent evidence from developmental studies is able to support an action-oriented framework for cognition (see Pezzulo et al., this volume). In developmental robotics, this issue is pertinent to address issues, for example, related to how robots can achieve mastery of high-dimensional action spaces.

From a developmental perspective, Pezzulo (this volume) emphasizes that action and cognition can hardly be viewed as separate domains. Instead, pragmatic skills (e.g., the mastery of SMCs) are integral components required to develop higher cognitive capabilities. Although this basic developmental relevance is undisputed, this premise can be integrated into several accounts which differ in how they conceptualize the exact developmental role of action. Under an interactionist view, influential in the field of robotics, cognitive development is an incremental process of self-organization in which the results

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of a given agent-environment interaction can give rise to increasingly more complex skills and cognitive capabilities. According to a "cognitive mediation" account, sensorimotor processes involved in action control are seen as mediating, but not as being constitutive for, higher cognitive abilities. Still another account predicts that action-related mechanisms are important for the acquisition of cognitive capacities, but not for their deployment once they have been learned. Pezzulo concludes that further experimental evidence is needed to evaluate these three accounts.

Hamilton, Southgate, and Hill (this volume) discuss evidence from developmental studies in humans relevant to this issue. Studies of links between motor and cognitive systems in young children suggest that motor skills are relatively weakly linked to executive function (e.g., prediction and planning). More robust links seem to exist, however, to the development of social skills, with changes in motor skills predicting later performance in communication and social interaction.

Predictive Coding and Active Inference

A key mechanism for cognitive processing seems to be the optimization of predictions and the minimization of prediction errors (Rao and Ballard 1999). It has been suggested that new views unifying perception, cognition, and motor control may emerge from this basic principle (Friston 2010; Friston, Daunizeau, et al. 2010). Implications of this principle for the understanding of the relation between action and cognition were another key topic of the Forum (see Kilner et al., this volume). Friston (this volume) reviews the notion of active inference, in which the brain tries to infer the causes of its sensory input while sampling that input to minimize uncertainty about its inferences. This view implies that action and perception cannot be separated because both are needed to suppress prediction errors by optimizing the states and parameters in the brain's model of its exchanges with the world (Friston and Stephan 2007; Friston 2010; Friston, Daunizeau, et al. 2010).

Hohwy (this volume) explores the implications of the prediction error minimization principle for aspects of embodiment, such as the sense of body ownership and the sense of agency. He suggests that within this framework, experience of body ownership can be conceptualized as a case of perceptual inference, and that the sense of agency is not only related to error minimization in predictive forward models but also to the ability to reason counterfactually about possible actions. Menary (this volume) relates the principle of active inference to concepts of exploratory inference in classical pragmatism. He shows that the pragmatist "abductive" approach developed by Peirce (1931) already encompasses important elements of the predictive coding frameworks that emerged much later. However, he also emphasizes that "predictive processing is a subpersonal account of neural processes that fits within a larger account of the brain-body-niche nexus" (Menary, p. 228, this volume).

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Action-Relatedness of Phenomenal States

In more classical accounts, conscious awareness is largely detached from action and the activation of motor circuits. An important question thus involves whether implications of the pragmatic turn also relate to current models of consciousness. The sensorimotor account (O'Regan and Noë 2001; O'Regan 2011) claims to provide a radically novel approach to consciousness and phenomenal states. Accordingly, conscious awareness is the process of exploiting the mastery of SMCs for planning, prediction, reasoning, and generating behavior (e.g., speech). For instance, being visually aware of a scene means to gear relevant sets of SMCs to "see" the scene. Thus, the sensorimotor account predicts that action plays a constitutive role in the emergence of phenomenal states (O'Regan and Noë 2001; O'Regan 2011). This view was strongly debated at the Forum (see Seth et al., this volume), with one of the points of controversy stipulating that there could be no conscious phenomenology without (potential) voluntary action.

Considering the relation between action and consciousness from the reverse perspective, Frith and Metzinger (this volume) emphasize the role of consciousness in optimizing human behaviors. In their account, conscious experience is particularly relevant for optimizing flexible social interactions as well as for the emergence of cultural phenomena, including cultural narratives.

Verschure (this volume) advocates an action-related view which also holds that consciousness is defined through repertoires of SMCs of embodied and situated agents. Verschure, however, suggests that a number of conceptual ingredients be added to the basic sensorimotor framework, including virtualization of action-effect predictions in a dedicated memory system, the assumption of intentionality priors that interpret novel states as being caused by other agents, and the notion of consciousness as an integrated sequential process. In his view, consciousness is seen as a form of memory that unifies and interprets the states of the agent to facilitate the optimization of its parallel real-time control loops that are driving action.

Joint Action and Social Cognition

Social aspects of cognitive processing have, by many accounts, been conceptualized as mainly involving "theory of mind"-type representations in the individual brain. A key question is whether this largely disembodied approach fully captures the nature of social interactions. Alternatively, a perspective aimed at grounding social cognition in joint action (including, e.g., synchronized movements) might have great potential. Ambitious questions are whether enactive approaches to social cognition might also extend to interactions between humans and robots, and what mechanisms might establish social cognition in artificial agents. These issues are addressed by Dominey et al. (this volume).

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In the classical framework, which has also been termed the "spectator theory" of social cognition (Schilbach et al. 2013), the primary mode of social interaction is that of a detached observer who theorizes and produces inferences about other participants. The pragmatic turn has inspired an alternative view which holds that even complex modes of social interaction, which may be grounded in basic sensorimotor patterns, enable the dynamic coupling of agents (Di Paolo and De Jaegher 2012). A key hypothesis deriving from this view is that learning and mastery of action-effect contingencies may be critical to predict the consequences of actions from others and, thus, to enable effective coupling of agents in social contexts.

This agrees well with a model of social cognition, which predicts that shared intentionality can arise from joint action (Sebanz et al. 2006). Along similar lines, Prinz (this volume) emphasizes the role of action for alignment in social contexts (e.g., in social imitation or mirroring). According to his view, this raises the need for common coding mechanisms for action perception and action production.

Pragmatic Cognitive Science

It remains to be seen whether the conceptual shifts implied by the pragmatic turn can actually lead to the development of novel experimental paradigms and strategies. A radical action-orientedness would violate many practical constraints and theoretical premises of cognitive science as they have functioned in the past. For instance, if the representational stance is largely abandoned, a new view on the functional roles of neural states will need to be developed: rather than encoding information about pregiven objects or events in the world, neural states support the capacity of structuring situations through action. An interesting consequence of this view is that the "meaning" of neural states would eventually be determined by their functional role in the guidance of action, not by a mapping to a stimulus domain as assumed in many representationist accounts. Thus, the action-oriented view advocated here has the potential to open up a novel perspective on the grounding of neural semantics (Engel 2010; Engel et al. 2013).

The pragmatic turn may eventually bring about consequences in actual research praxis. Will the inherent conceptual shifts lead to the development of different experimental settings and paradigms, or new styles of experimentation? Clearly, research in a framework for pragmatic neuroscience requires us to avoid studying passive subjects and to use, instead, paradigms with active exploration. If neural states are individuated through their functional role in action generation, then the primary focus of experimentation should be on studying the relation of neural activity patterns to action contexts, rather than on investigating their dependence on external stimuli—a view which has dominated classical neurophysiology for decades.

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Prescott and Verschure (this volume) discuss the implications of the pragmatic turn for the agenda of cognitive science with respect to a number of relevant application domains, including biomimetic approaches in robotics, enactive approaches to the development of sensory substitution devices or commercial gaming equipment, and immersive virtual reality and telepresence technologies. As they argue, these domains highlight action-oriented approaches as cases of "mode-2 science": the traditional distinction between basic and applied research will become increasingly blurred, and research will occur within transdisciplinary groupings and a stronger mix of research cultures and involve an increased diversity of actors from a broad set of stakeholders. They also emphasize that research into action-oriented cognition has real-world consequences and entails social risk. Thus such research should be performed openly and in dialogue with the wider public.

Dimensions of Discourse

To examine the key concepts of an emerging action-oriented view of cognition and the consequences of such a paradigm shift, working groups met to address:

1. The role of action in the development and acquisition of cognitive capabilities (Pezzulo et al., this volume)
2. Action-oriented models of cognitive processing (Kilner et al., this volume)
3. The relevance of action-oriented approaches to understanding consciousness and phenomenal experience (Seth et al., this volume)
4. The potential implications of a shift toward action-oriented views in cognitive science (Dominey et al., this volume)

Each group defined their own approach to their specific theme and were asked to consider, in addition, a number of overarching questions: Which methodological and theoretical principles does the pragmatic turn suggest? What are testable hypotheses that derive from those principles and which critical experiments could serve to validate these? Which empirical data presently support action-oriented models of cognitive processing? What are the limitations of action-oriented explanatory strategies? Below, we briefly summarize the main aspects of the groups' discussions.

Development, Acquisition, and Adaptation of Action-Oriented Processing

Despite decades of research, cognitive science lacks a comprehensive framework to study and explain cognitive development. The paradigm of action-based cognition implies that cognitive development itself is an active process, not a passive, automatic, and self-paced maturational process. In this context, it is important to note that "active" refers not only to sensorimotor activity

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but also to autonomous exploration, as present in active perception or active learning.

In their discussions, Pezzulo et al. (this volume) asked: What mechanisms are involved in acquiring action-derived cognitive processing? What synergies exist between cognition and action in development? To what extent do these synergies provide a scaffold for adaptive behavior and cognition in the mature agent? Can action be exploited to acquire higher cognitive capabilities, like mastery of abstract concepts? What are the brain mechanisms that support the learning of SMCs?

Pezzulo et al. explore how an emphasis on action affects our understanding of cognitive development and concluded that an action-based approach offers a much-needed integrative theory for cognitive development. Their report reviews multiple factors and mechanisms that influence development (e.g., sensorimotor skills; genetic, social, and cultural factors; and associated brain mechanisms), focusing on how these can be incorporated into a comprehensive action-based framework. They take the position that a research agenda for action-based cognitive development must consider how all factors are integrated, how they interact over time, and what action-oriented aspects of development explain higher cognitive abilities.

In addition, Pezzulo et al. present key challenges to such a research agenda (e.g., problems inherent in explaining higher-level cognitive abilities or in the construction of novel experimental methodologies). Emergent from their discussions is a picture of a novel field that is beginning to take form—an action-based approach to cognitive development. Still in its infancy, this field holds great promise to improve scientific understanding of cognitive development and is likely to have further, important implications for education and technology.

Action-Oriented Models of Cognitive and Functional Processing

Kilner et al. (this volume) consider action-oriented processing from a model-oriented point of view. Key questions addressed by this group included: Which cognitive functions can be grounded in sensorimotor processes? How can this be modeled and formalized exploiting, for example, predictive coding, active inference, or information theory? What is the role of action in understanding social interactions? Which neuroscientific evidence or constraints specifically speak to an action-oriented account of cognition? Does an action-oriented approach furnish novel hypotheses on neural mechanisms of cognitive processes?

In their report, Kilner et al. discuss possible relationships between action and cognition, in abstract or conceptual terms, and scrutinize models of their interrelationships as well as their role in mediating cognitively enriched behaviors. Examples of conceptual models inspired by an action-oriented paradigm are briefly surveyed, with a particular focus on ideomotor theory. Subsequently, Kilner et al. introduce formal versions of these theories, drawing

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on formulations in systems biology, information theory, and dynamical systems theory. An attempt is made to integrate these perspectives under the enactivist version of the Bayesian brain, namely active inference. Implications of this formalism and more generally of action-oriented views of cognition are addressed.

Kilner et al. consider issues that need to be addressed before action-oriented models can be tested. These relate, in particular, to experimental approaches to study the activation of simultaneously active neural circuits in the brain when responding to naturalistic stimuli. Necessary advances include the design of software to make and annotate naturalistic stimuli, the use of virtual reality to allow more naturalistic interaction while maintaining experimental control, the use of mobile measures of neural signals, as well as novel analytic tools and data-constrained modeling based on this data.

Action-Oriented Understanding of Consciousness and the Structure of Experience

Given the emphasis on the role of action in shaping (or constituting) perception, cognition, and consciousness, Seth et al. (this volume) examine how an action-oriented approach might alter our understanding of consciousness and the structure of experience, combining viewpoints from philosophers, neuroscientists, psychologists, and clinicians. This is an exciting area of enquiry, since most of the resurgent activity in consciousness science has focused on the neural, cognitive, and behavioral correlates of perception, independently of action. Throughout their wide-ranging discussion, Seth et al. scrutinize how actions shape consciousness and what determines consciousness of actions. They consider the specific context of self-experience, from its bodily aspects to its social expression.

Their report focuses on specific theoretical frameworks that emphasize the role of action in cognition. Four candidate frameworks are discussed which put specific emphasis on action: (a) the Bayesian brain, equipped with mechanisms of active inference (see also Friston, this volume); (b) sensorimotor contingency theory (O'Regan and Noë 2001; O'Regan 2011), (c) distributed adaptive control (see also Verschure, this volume), and (d) enactive autonomy and autopoiesis. All four frameworks converge on the notion that action shapes and structures conscious experiences in ways that extend beyond the trivial case of selecting sensory samples. Action emphasizes the openness of consciousness to extrapersonal influences. More controversial is the suggestion that emerges, in particular from SMC theory and enactive autonomy approaches; namely, that actions (possibly social actions) are constitutive of conscious experiences.

Seth et al. identify a number of potential challenges for action-oriented theories of consciousness that stem, for example, from work in patients with disorders of motor control. If action is important in shaping (or even constitutive in) conscious contents, then motor control disorders (e.g., amyotrophic lateral sclerosis, locked-in syndrome) should dramatically affect consciousness. Establishing changes in consciousness in such patients may not, however, be straightforward, and a number of relevant strategies are discussed.

Implications of Action-Oriented Paradigm Shifts in Cognitive Science

In their discussions, Dominey et al. (this volume) reviewed the status and implications of the action-oriented paradigm shift, posing questions such as: What are epistemological implications of the pragmatic turn (e.g., for our view of reality and our ways of acquiring knowledge)? What are the societal implications of action-oriented approaches (e.g., for educational programs, structuring of social processes)? What are the implications of a pragmatic turn for research programs and experimental strategies in cognitive science? What are implications for the modeling of cognitive processes and the implementation of artificial sentient systems? What are the potential implications for a better understanding of cognitive dysfunctions and the pathogenesis of neuropsychiatric disorders?

An action-oriented perspective changes the concept of an individual from a passive observer to an actively engaged agent who interacts in a closed loop with the world. Crucially, this interaction involves engaging with others and, within a landscape of cognition and action, cognition exists to serve action. Surveying this landscape, Dominey et al. address the current and potential influence that an action-oriented perspective could have on the study of cognition (including perception, social cognition, social interaction, sensorimotor entrainment, and language acquisition) as well as on neuroscience.

In addition, Dominey et al. discuss the impacts on science. They find that an action-oriented perspective has already changed the way perception, social cognition and interaction, as well as their underlying neurophysiological mechanisms, are viewed, and they note its potential to alter approaches to engineering. Further impacts include the application of enactive control principles to couple action and perception in robotics and the construction of more holistic systems design in engineering. Practical applications range from using an action-oriented approach in education to the design of therapeutic approaches in developmental and psychopathological disorders to the future development of neural prostheses. Dominey et al. conclude with a discussion of the possible societal implications that could result from the pragmatic turn.

Conclusion

The pragmatic turn has permitted a novel action-oriented framework for cognition to emerge—one that is receiving increased support from researchers trying to cope with problems not adequately solved by orthodox cognitive science. At this point in time, the pragmatic turn entails more of an agenda for the future

From "The Pragmatic Turn: Toward Action-Oriented Views in Cognitive Science,"
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rather than a paradigm already in place. According at least to its more radical proponents, the ultimate goal is eventually to transform the whole theory of cognition into a theory of action. Notably, this is not a behaviorist move, since the dynamics of the cognitive system lie at the very heart of the enterprise, and clear reference is made to internal states of the cognitive system. Conceptually, this view is seamlessly compatible with embodiment and "extended mind" approaches.

Concurrent with the conceptual implications of the pragmatic turn stands an increasing body of experimental evidence in support of an action-oriented framework of cognition. Will these conceptual shifts eventually lead to a different style of experimentation, to different settings and to new "laboratory habits"? An increasing number of researchers are already implementing approaches inspired by concepts of pragmatic cognitive science: from the use of natural stimuli to complex sensorimotor paradigms, massively parallel recording techniques, and less restrained subjects. Above all, the pragmatic turn inherently implies that the return of the active cognizer to the lab is a matter of practice, rather than of theory.

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