Anticipation and anticipatory behavior

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Introduction to the special issue

Anticipation is a highly multidisciplinary theme, and a growing interest is emerging in the empirical, theoretical and computational literatures. There is now a converging body of evidence in psychology and neurobiology indicating the presence of several anticipatory mechanisms in the brain, and highlighting a crucial role of anticipation in a large array of cognitive functionalities such as vision, motor control, learning, motivational and emotional dynamics. Simulative and generative capabilities have been advocated for bridging the gap between situated action and high-level cognitive capabilities such as planning, imitation, theory of mind, and language use.

These advances in the understanding of the anticipatory nature of much human cognition does not only constitute a promising direction of investigation for experimental studies, but involve a rethinking of central theoretical notions such as representation and intentionality. Many studies provide strong support to the claim that representations are mainly action-oriented and deeply related to the motor apparatus, and that multiple representations of goals and expectations exist in the brain that mediate action selection, intention selection and deliberation: these facts have nowadays a tremendous impact on theories of cognition.

Anticipatory representations and mechanisms have now begun to be explored from a computational point of view, too, and recently there is much interest on how anticipations can be learned and exploited for selecting and controlling behavior in artificial systems.

The current special issue of Cognitive Processing focuses specifically on the convergence of empirical, theoretical and computational work about anticipation and anticipatory behavior. It follows a number of other initiatives of our research groups on the topic of anticipation, such as the ERCIM news special issue on ''Cognitive Systems'' (number 53, April 2003); the EU funded project MindRACES ''From Reactive to Anticipatory Cognitive Embodied Systems'', FP6-511931 (2004-2007); the ABi-ALS workshops on ''Anticipatory Behavior in Adaptive Learning Systems'' (2002, 2004 and 2006); the AAAI Fall Symposium: ''From Reactive to Anticipatory Cognitive Embodied Systems'' (2005).

We have invited contributions by key researchers in different disciplinary fields: philosophy, psychology, neurobiology and computer science. Our aim is to contribute to a general understanding of anticipation and anticipatory behavior in natural cognition, and to investigate how it can be modeled in artificial cognitive systems.

The contributions in the special issue highlight important aspects of anticipatory behavior in different aspects of cognition, from the point of view of different disciplines. Two papers are primarily psychological, one is primarily neurobiological, two papers are primarily theoretical and methodological, and one paper is the report of theoretical, psychological and computational work in the University of Würzburg. Besides, the contributions reveal complementary and highly correlated aspects of the phenomenon of

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anticipation. For this reason, we believe that another relevant contribution of the special issue is to present, or at least to suggest, a coherent perspective on anticipation and anticipatory behavior. We are not simply proposing that the brain exploits a plethora of anticipatory mechanisms representations, but that *anticipation is at the core of cognition*.

Of course, this claim needs to be further specified and investigated. We believe that one of the most important topics in cognitive science in the next few years will be to clarify and model the essentially future-oriented nature of cognition This will be done by understanding the brain mechanisms realizing anticipation in natural cognition, the way anticipations permit to realize simple and complex cognitive functions, and how to evolve the latter from the former. We think in fact that a new theoretical framework accommodating several empirical findings and theoretical models is emerging in which *the mind is conceived as a truly anticipatory device*, and our intention in this special issue is to contribute to this view. The contributions in this special issue illustrate vividly that the future-oriented perspective on cognition is sound, intriguing and potentially able to illuminate us about key aspects of cognition. We hope that our work here will provide inspiration for future empirical, theoretical, and computational work.

Anticipation and anticipatory behavior in the psychological literature

Which is the role of anticipation in the selection, preparation, and execution of action in living organisms, and in particular in humans? Which aspects of behavior are anticipatory? Psychological studies in the last decades have discovered anticipatory mechanisms involved in several cognitive functions such as vision, action control, planning, etc. In order to provide inspiration for further research, two papers, by Wilfried Kunde, Katrin Elsner and Andrea Kiesel, and by Simone Schuetz-Bosbach and Wolfgang Prinz, review the most interesting and challenging evidence and models about anticipation in natural cognition. Unitary principles behind these functions are proposed, too, with the aim of understanding the deepest relations between anticipation, action and representation.

Wilfried Kunde, Katrin Elsner and Andrea Kiesel offer a strong claim: ''acting without anticipating is impossible''. They highlight the role anticipations play in the preparation and initiation of voluntary behavior. Two functions are distinguished: first, it is argued that anticipations of the to-be-produced sensory effects (anticipatory effect codes) are crucial for addressing an appropriate action, which brings the desired effects about. Second, it is argued that the readiness to perform a certain voluntary act goes along with anticipations of stimulus conditions which signal that the corresponding action is to be (or can be successfully) executed. Numerous experimental results in support of both these views are reported and the authors clarify that by these results the common view according to which responding starts with the processing of the stimulus becomes obsolete: instead, responding starts with response-related anticipations and stimuli only become effective in relation to these anticipations.

Simone Schuetz-Bosbach and Wolfgang Prinz provide a profound outline of convincing evidence for the impact of anticipations of future events (a) on the perception of current (dynamic) events, (b) on the selection and initiation of voluntary actions, and (c) on the imagination of events (event simulation). The three lines of evidence are integrated by the theoretical notion that perceiving as well as acting refer likewise to external events and rely therefore on the same representations (common coding approach). Furthermore, it is argued that anticipations evolved from action-perceiving circles because anticipations allow for both, a stabilization of perception and goal-oriented in contrast to re-active behavior as well, thus improving the general ''fitness'' of organisms.

Anticipation and anticipatory behavior in the neurobiological literature

Which is the neural substrate supporting goal-oriented and anticipatory capabilities? Several brain structures have been related in the neurobiological literature with anticipation and simulation, such as the cerebellum, the basal ganglia and the hippocampus. However, research in this field is still largely in the early stages. Research on the mirror neuron system is perhaps the most flourishing one nowadays. In these years, several research groups have deeply investigated mirror neurons, providing impressive evidence that representations and actions are not two separate domains, and highlighting the involvement of the motor apparatus in activities that were traditionally considered unrelated to situated action. Such findings fit nicely in a conceptual framework that puts anticipation and goal-orientedness at the center of natural cognition, and the mirror system is among the good candidates for implementing at the neural level several anticipatory and simulative capabilities. Of course, much remains to be known and studied. The fact that representations related to the basic repertoire of actions have a situated and embodied nature is rarely disputed. It remains to be understood how much of the ''motor'' dimension remains in more abstract and complex representations, and in our more complex cognitive operations. Is there (still) a place for amodality and abstractness in natural cognition? If actions and action

representations are organized hierarchically, in which way are the ''higher layers'' related to situated action?

The paper by Jonas T. Kaplan and Marco Iacoboni provides a significant advancement in the understanding of these topics. The authors present neuroimaging evidence that the left ventral premotor cortex may provide an action representation that abstracts across both agency (self and other) and sensory modality (hearing and seeing). This study is particularly significant for understanding the relations between representations and modality. In particular, the evidence reported by the authors contributes to clarify how the multisensory integration of action-related information is realized in the brain, and how representations undergo a process of progressive abstraction: an important precursor of language functions.

Theoretical and methodological aspects of anticipation

Although, the main emphasis of the empirical studies in this special issue is on human behavior, all the authors offer theoretical perspectives that have relevance for understanding simpler living organisms, too. One tenet of this special issue is that not only anticipatory mechanisms are widespread in natural cognition, but also that anticipation has to be considered as one of the main ''architectural'' and unitary principles of cognition. Living organisms do evolve and adapt to their present environment, to the here-and-now. But they also develop the capability to coordinate with the future, and to produce specific, desired future states, their goals. Since several cognitive capabilities are developed as a part of the transition from present-directed to future-directed capabilities, a better understanding of anticipation can shed light on the nature of cognition in general. The two theoretical and methodological papers, by Lawrence Barsalou, Cynthia Breazeal and Linda B. Smith and by Giovanni Pezzulo and Cristiano Castelfranchi, address this topic from two different but converging perspectives.

Lawrence Barsalou, Cynthia Breazeal and Linda B. Smith present a challenging view of how cognition emerges from the coordination of subsystems, mostly non-cognitive, with an emphasis on their embodied and situated origin. They suggest a methodology for research: focusing on coordination of processes, not just on individual processes in isolation. In this sense, anticipation is paradigmatic. The authors then propose the emergence of anticipation and anticipatory phenomena as a case study for their methodology: anticipation is deeply involved in a range of phenomena, such as perception, action, goal management and learning, that can hardly be investigated and understood in isolation.

Giovanni Pezzulo and Cristiano Castelfranchi propose that anticipation is the crucial mechanism which permits evolving of complex cognitive functionalities from simpler ones. The authors describe the *symbol detachment problem*: how can natural (and artificial) systems which are engaged in situated interaction with their environment, evolve representations? How can representations maintain their aboutness and groundedness while becoming increasingly abstract? They propose that anticipatory mechanisms, initially developed for the online control of action, are then exapted for bootstrapping increasingly complex cognitive functions. Complex cognitive agents are in fact largely autonomous from the stimuli they receive from the environment, since they can conceive the future and even the non-existent. Moreover, they can work mentally on their representations before (or instead of) acting in their environment. All these capabilities have to be understood in a naturalistic framework. The authors then present a developmental pathway describing the evolution of increasingly complex event representations and goal representations, and illustrate a roadmap for a similar development in artificial cognitive systems.

Research on anticipatory behavioral control at the University of Würzburg

The Cognitive Psychology Unit of the University of Würzburg, ties up to the tradition of German philosophers and scientists that explored phenomena of anticipation in relation to behavioral control (e.g. Johann Friedrich Herbart), perception (e.g. Erich von Holst, Horst Mittelstaedt), and the human will (Narziss Ach). In the last few years, a comprehensive conceptual framework (the ABC theory: Anticipatory Behavioral Control) has been elaborated about which a laboratory report is presented by Joachim Hoffmann, Michael Berner, Martin V. Butz, Oliver Herbort, Andrea Kiesel, Wilfried Kunde, and Alexandra Lenhard. The ABC framework focuses on the learning dependent formation of anticipatory structures of behavioral control. According to the ABC framework, behavioral control relies primarily on action–effect relations which secondarily becomes contextualized so that finally anticipations of to-be-produced effects address those actions which have been experienced as producing the desired effect in the present context. The theoretical considerations are supplemented by experimental evidence in support of the formation and efficiency of contextualized action–effect relations in behavioral control. The report closes with discussing the importance of feedback for a continuous updating of the behaviorally related anticipations and with simulations of the assumed learning mechanisms.

Conclusions

We believe that the phenomenon of anticipation is crucial in natural cognition. Only by understanding the future-directed nature of behavior and cognition in living systems we will really understand why brains and minds are evolved and work in that way. There is nowadays a growing interest on this topic in cognitive science, but the field is still very fractionated and in search of good instruments for thinking anticipation in a comprehensive perspective. The current special issue of Cognitive Processing on ''anticipation and anticipatory behavior'' intends to fill this gap. It includes theoretical, experimental and computational contributions by key researchers, and it offers a multidisciplinary perspective on anticipation and anticipatory behavior in natural and artificial cognition. ''The purpose of brains is to produce future'', as the poet Paul Valery said; and we hope that our work will be inspiring and motivating for the interdisciplinary community of Cognitive Processing.