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David Vernon, Claes von Hofsten,
and Luciano Fadiga

A Roadmap for Cognitive Development in Humanoid Robots

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Rüdiger Dillmann, University of Karlsruhe, Faculty of Informatics, Institute of Anthropomatics, Humanoids and Intelligence Systems Laboratories, Kaiserstr. 12, 76131 Karlsruhe, Germany

Yoshihiko Nakamura, Tokyo University Fac. Engineering, Dept. Mechano-Informatics, 7-3-1 Hongo, Bukyo-ku Tokyo, 113-8656, Japan

Stefan Schaal, University of Southern California, Department Computer Science, Computational Learning & Motor Control Lab., Los Angeles, CA 90089-2905, USA

David Vernon, Department of Robotics, Brain and Cognitive Sciences, Italian Institute of Technology, Genoa, Italy

Authors

David Vernon
Department of Robotics, Brain and Cognitive Sciences
Italian Institute of Technology
Genoa
Italy
E-mail: david@vernon.eu

Claes von Hofsten
Psykologisk institutt
Universitetet i Oslo
Oslo
Norway
E-mail: claes.von_hofsten@psyk.uu.se

Luciano Fadiga
Section of Human Physiology
University of Ferrara
Italy
E-mail: fdl@unife.it

and

Department of Robotics, Brain and Cognitive Sciences
Italian Institute of Technology
Genoa

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Preface

The work described in this book is founded on the premise that (a) cognition is the process by which an autonomous self-governing agent acts effectively in the world in which it is embedded, that (b) the dual purpose of cognition is to increase the agent's repertoire of effective actions and its power to anticipate the need for and outcome of future actions, and that (c) development plays an essential role in the realization of these cognitive capabilities.

Cognitive agents act in their world, typically with incomplete, uncertain, and time-varying sensory data. The chief purpose of cognition is to enable the selection of actions that are appropriate to the circumstances. However, the latencies inherent in the neural processing of sense data are often too great to allow effective action. Consequently, a cognitive agent must anticipate future events so that it can prepare the actions it may need to take. Furthermore, the world in which the agent is embedded is unconstrained so that it is not possible to predict all the circumstances it will experience and, hence, it is not possible to encapsulate *a priori* all the knowledge required to deal successfully with them. A cognitive agent then must not only be able to anticipate but it must also be able to learn and adapt, progressively increasing its space of possible actions as well as the time horizon of its prospective capabilities. In other words, a cognitive agent must develop.

There are many implications of this stance. First, there must be some starting point for development — some phylogeny — both in terms of the initial capabilities and in terms of the mechanisms which support the developmental process. Second, there must be a developmental path — an ontogeny — which the agent follows in its attempts to develop an increased degree of prospection and a larger space of action. This involves several stages, from coordination of eye-gaze, head attitude, and hand placement when reaching, through to more complex exploratory use of action. This is typically achieved by dexterous manipulation of the environment to learn the affordances of objects in the context of one's own developing capabilities. Third, since cognitive agents rarely operate in isolation and since the world with which they interact typically includes other cognitive agents, there is the question of how a cognitive agent can share with other agents the knowledge it has learned. Since what an agent knows is based on its history of experiences in the world, the meaning of any shared knowledge depends on a common mode of experiencing the world. In turn, this implies that the shared knowledge is predicated upon the agents having a common morphology and, in the case of human-robot interaction, a common humanoid form.

The roadmap set out in this book targets specifically the development of cognitive capabilities in humanoid robots. It identifies the necessary and hopefully sufficient conditions that must exist to allow this development. It has been created by bringing together insights from four areas: enactive cognitive science, developmental psychology, neurophysiology, and cognitive modelling. Thus, the roadmap builds upon what is known about the development of natural cognitive systems and what is known about computational modelling of artificial cognitive agents. In doing so, it identifies the essential principles of a system that can develop cognitive capabilities and it shows how these principles have been applied to the state-of-the-art humanoid robot: the iCub.

The book is organized as follows. Chapter 1 presents a conceptual framework that forms the foundation of the book. It identifies the broad stance taken on cognitive systems — emergent embodied systems that develop cognitive skills as a result of their action in the world — and it draws out explicitly the consequences of adopting this stance. Chapter 2 begins by discussing the importance of action as the organizing principle in cognitive behaviour, a theme that will recur repeatedly throughout the book. It then addresses the phylogeny of human infants and, in particular, it considers the innate capabilities of pre-natal infants and how these develop before and just after birth. Chapter 3 then details how these capabilities develop in the first couple of years of life, focussing on the interdependence of perception and action. In doing so, it develops the second recurrent theme of the book: the central role of prospective capabilities in cognition. Chapter 4 explores the neurophysiology of perception and action, delving more deeply into the way that the interdependency of perception and action is manifested in the primate brain. While Chapters 2 – 4 provide the biological inspiration for the design of an entity that can develop cognitive capabilities, Chapter 5 surveys recent attempts at building artificial cognitive systems, focussing on cognitive architectures as the basis for development. Chapter 6 then presents a complete roadmap that uses the phylogeny and ontogeny of natural systems as well as insights gained from computational models and cognitive architectures to define the innate capabilities with which the humanoid robot must be equipped so that it is capable of ontogenetic development. The roadmap includes a series of scenarios that can be used to drive the robot's developmental progress. Chapter 7 provides an overview of the iCub humanoid robot and it describes the use of the the roadmap in the realization of the iCub's own cognitive architecture. Chapter 8 concludes by setting out an agenda for future research and addressing the most pressing issues that will advance our understanding of cognitive systems, artificial and natural.

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David Vernon
Claes von Hofsten
Luciano Fadiga

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