

Developmental Robotics

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INTRODUCTION

Human intelligence is acquired through a prolonged period of maturation and growth during which a single fertilized egg first turns into an embryo, then grows into a newborn baby, and eventually becomes an adult individual—which, typically before growing old and dying, reproduces. The developmental process is inherently robust and flexible, and biological organisms show an amazing ability during their development to devise adaptive strategies and solutions to cope with environmental changes and guarantee their survival. Because evolution has selected development as the process through which to realize some of the highest known forms of intelligence, it is plausible to assume that development is mechanistically crucial to emulate such intelligence in human-made artifacts.

BACKGROUND

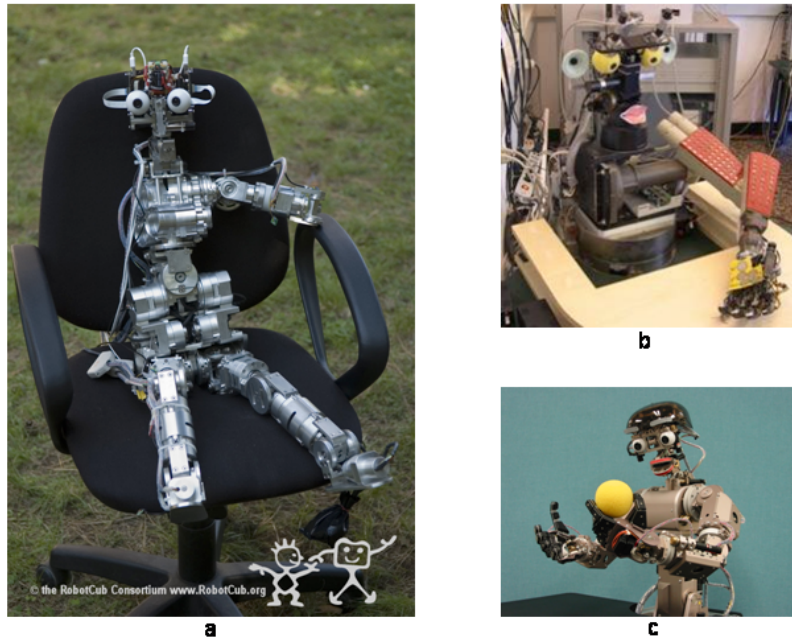
The idea that development might be a good avenue to understand and construct cognition is not new. Already Turing (1950) suggested that using some kind of developmental approach might be a good strategy. In the context of robotics, many of the original ideas can be traced back to embodied artificial intelligence (embodied AI), a movement started by Rodney Brooks at the beginning of the 1980s (Brooks et al., 1998), and the notion of enaction (Varela et al., 1991) according to which cognitive structures emerge from recurrent sensorimotor patterns that enable action to be perceptually guided. Researchers of embodied AI believe that intelligence can only come from the reciprocal interaction across multiple time scales between brain and body of an agent, and its environment. In a sense, throughout life, experience is learned and common sense is acquired, which then supports more complex reasoning. This general bootstrapping of

intelligence has been called “cognitive incrementalism” (Clark, 2001).

DEVELOPMENTAL ROBOTICS

Developmental robotics (also known as epigenetic or ontogenetic robotics) is a highly interdisciplinary subfield of robotics in which ideas from artificial intelligence, developmental psychology, neuroscience, and dynamical systems theory play a pivotal role in motivating the research (Asada *et al.*, 2001; Lungarella *et al.*, 2003; Weng *et al.*, 2001; Zlatev & Balkenius, 2001). Developmental robotics aims to model the development of increasingly complex cognitive processes in natural and artificial systems and to understand how such processes emerge through physical and social interaction. The idea is to realize artificial cognitive systems not by simply programming them to solve a specific task, but rather by initiating and maintaining a developmental process during which the systems interact with their physical environments (i.e. through their bodies or tools), as well as with their social environments (i.e. with people or other robots). Cognition, after all, is the result of a process of self-organization (spontaneous emergence of order) and co-development between a developing organism and its surrounding environment. Although some researchers use simulated environments and computational models (e.g. Mareschal et al., 2007), often robots are employed as testing platforms for theoretical models of the development of cognitive abilities – the rationale being that if a model is instantiated in a system interacting with the real world, a great deal can be learned about its strengths and potential flaws (Fig. 1). Unlike evolutionary robotics which operates on phylogenetic time scales and populations of many individuals, developmental robotics capitalizes on

Figure 1. Developmental robots. (a) iCub (<http://www.robotcub.org>) (b) Babybot (<http://www.liralab.it/babybot/robot.htm>) (c) Infanoid (<http://univ.nict.go.jp/people/xkozima/infanoid/robot-eng.html#infanoid>).



“short” (ontogenetic) time scales and single individuals (or small groups of individuals).

AREAS OF INTEREST

The spectrum of developmental robotics research can be roughly segmented into four primary areas of interest. Although instances may exist that fall into multiple categories, the suggested grouping should provide at least some order in the large spectrum of issues addressed by developmental roboticists.

Socially oriented interaction: This category includes research on robots that communicate or learn particular skills via social interaction with humans or other robots. Examples are imitation learning, communication and language acquisition, attention sharing, turn-taking behavior, and social regulation (Dautenhahn, 2007; Steels, 2006).

Non-social interaction: Studies on robots characterized by a direct and strong coupling between sensorimotor processes and the local environment (e.g. inanimate objects), but which do not interact

with other robots or humans. Examples are visually-guided grasping and manipulation, tool-use, perceptual categorization, and navigation (Fitzpatrick *et al.*, 2007; Nabeshima *et al.*, 2006).

Agent-centered sensorimotor control: In these studies, robots are used to investigate the exploration of bodily capabilities, the effect of morphological changes on motor skill acquisition, as well as self-supervised learning schemes not linked to any functional goal. Examples include self-exploration, categorization of motor patterns, motor babbling, and learning to walk or crawl (Demiris & Meltzoff, 2007; Lungarella, 2004).

Mechanisms and principles: This category embraces research on principles, mechanisms or processes thought to increase the adaptivity of a behaving system. Examples are: developmental and neural plasticity, mirror neurons, motivation, freezing and freeing of degrees of freedom, and synergies; characterization of complexity and emergence, study of the effects of adaptation and growth, and practical work on body construction or development (Arbib *et al.*, 2007; Oudeyer *et al.*, 2007; Lungarella & Sporns, 2006).

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