An Overview of ”Developmental Robotics”

M. Mahdi Ghazaei Ardakani
mahdi.ghazaei@control.lth.se

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Abstract

The developmental robotics is a rather new field which is gaining more credence in recent years. We have tried to present a clear definition of this field by comparison with the related fields. The main challenges to find a computational model for the complex processes of development are discussed. We highlight some of the existing approaches and present results of three recent papers. Finally, we draw conclusion that unified theories and tools yet to be developed.

1 Introduction

The developmental robotics is a promising paradigm of research. The goal of this research is to create intelligent robots by allowing them to go through a developmental process, rather than being directly programmed by human engineers. By endowing an embodied robot with an appropriate initial control architecture and adaptive mechanisms, it learns through continual interactions with the world developing self-organized mental structures [1]. The following questions are concerned in this research. What should be innate in the robot? What adaptive mechanisms are needed? What motivates the robot to act? Would such a system need emotions?

According to [2], “Developmental robotics is an emergent area of research at the intersection of robotics and developmental sciences, in particular developmental psychology and developmental neuroscience. It constitutes an interdisciplinary and two-pronged approach to robotics, which on one side employs robots to instantiate and investigate models originating from developmental sciences, and on the other side seeks to design better robotic systems by applying insights gained from studies on ontogenetic development.”

There is a sub-area within developmental robotics, known as epigenetic robotics, that has the goal of creating robotic models of psychological development. The models are synthesized to be experimented on robotic platforms which results in the evaluation of cognitive theories and building more human-like robots. Developmental robotics and Epigenetic robotics share problems and challenges, and have a common vision. Epigenetic robotics focuses primarily on cognitive and social development. Developmental robotics encompasses a broader spectrum of issues, and investigates also morphological development, and the acquisition of motor skills [3].

The developmental robotics is related but differs from evolutionary robotics, inspired by the Darwinian principle of selective reproduction of the fittest, which seeks improved generations of artificial brains and morphologies. Developmental robotics also overlaps well with the study of humanoid robots, neurorobotics and perceptual robotics [4].

2 Motivation

Over the past several decades, scientists have taken one of three approaches to solve artificial intelligence (AI) problems: In the first, which is knowledge-based, an intelligent machine in a laboratory is directly programmed to perform a given task. In the second, learning-based approach, a computer is “spoon-fed” human-edited sensory data while the machine is controlled by a task-specific learning program. Finally, by a “genetic search,” robots have evolved through generations, mostly in a computer-simulated virtual world [5]. While none of these methods were capable of creating truly *task-independent* intelligence, developmental robotics advocates a methodology allowing robots to develop their own understanding of the tasks. In fact, this is the consequence of one of the basic tenets of developmental robotics [2]: “The designer should not try to engineer 'intelligence' into the artificial system (in general an extremely hard problem); instead, he or she should try to endow the system with an appropriate set of basic mechanisms for the system to develop, learn and behave in a way that appears intelligent to an external observer."

As a matter of fact, studies show [2] that the traditional approach based on the computer metaphor for human brain has ultimately failed to address the intimate linkage between brain, body and environment. This suggests that the study of behavioral and neural changes typical of ontogenetic development are important for the emergence of cognition. The evidences from cognitive science, psychology and robotic experiments [6] asserts that there is no need to accurately model the environment for a particular behavior, but rather the behavior might emerge as the result of the interaction of a simple system with a complex world.

According to [2], there are two driving forces for developmental robotics: 1- Engineers are seeking novel methodologies for construction of advanced robots which are more autonomous, adaptable and sociable robotic systems. In that sense, studies of cognitive development can be used as a valuable source of inspiration. 2- Robots can be employed as research tools for the investigation of embodied models of development. Neuroscientists, developmental psychologists, and also engineers, may gain considerable insight from trying to embed a particular model into robots. This approach is also known as synthetic neural modeling, or synthetic methodology.

The new field of developmental robotics has an ambitious goal to provide a unified framework for many cognitive capabilities – vision, audition, taction, language, planning, decision-making, and task execution. There are encouraging evidences that developmental principals are the same irrespective of modalities. Therefore, it is expectable that eventually developmental robots "live" with us and become smarter autonomously, under our human supervision [5]. The system based on mental development is required to be non-task specific, because the task is generally unknown at design time [3].

3 Challenges

Although the idea of relieving engineers from fitting robots to different tasks sounds appealing, it is not straightforward how an artificial system should be constructed through the application of a "developmental synthetic methodology". An adequate research methodology as well as a set of design principles supporting such a methodology are still open research issues. One possible reason is the complex notion of development itself, which is multifaceted, non-linear, complex and yet to be fully understood [2]. Currently, neuroscientists, psychologists and engineers are collaborating to discover computational principles of mental development [5]. In other words, the main challenge is to design a sufficient system which is able to autonomously bootstrap new skills.

In [3], the authors have attempted to classify different directions in developmental robotics. They have chosen rather restrictive criteria for the selection of the papers that firstly the study had to provide a clear evidence for robotic experiments (no simulation) and secondly the study had to show a clear intent to address hypotheses put forward in either developmental psychology or developmental neuroscience. However, they could identify quite a number of research papers satisfying the criteria. They proposed clustering of the selected papers according to their primary interest areas as follows:

1. Social interaction: includes acquiring social behaviors and different learning situation and techniques in social context. Low level imitation, shared or joined attention, social regulation, and development of language are among this category.

2. Sensorimotor control: deals with the coordination of action and perception e.g. visuo-motor.

3. Categorization: focuses on dynamic, interactive, and embodied view of how categories are formed.

4. Value system: as either an internal mediator of salient environmental stimuli and events, or as a mechanism to guide some sort of exploration process.

5. Developmental plasticity: explores the experience dependency of brain development and its adaptation to an environment and a body.

6. Motor skill acquisition and morphological changes: includes self exploration of the sensorimotor space and how limitations during different stages of morphological changes impact learning.

4 Ongoing Work

The new paradigm of developmental robotics stands in contrast to the mind-as-computer metaphor advocated by the traditional cognitive science. Accordingly, the body was seen as an output device that merely executes commands generated by a rule-based manipulation of symbols that are associated with an internal representation of the world [2]. In the new approach, brain, body, and environment are reciprocally coupled and the cognitive process arises from the interaction between a brain with certain capabilities through a body situated in the real world. In this section, we do not discuss about classical approaches. It suffices to mention that the classical AI does not attend to the embodiment issues and robotics has been mainly concerned with predefined tasks.

Early prototypes of developmental robots include Darwin V [7] and SAIL [8]. Darvin V demonstrated that translation invariance and pattern selectivity emerge due to the continuity of self-generated movement. The objective of SAIL-1 was to navigate through various settings and interact with humans using vision, speech and its arm. In addition, several theories emerged around the same time. In [9], the concept of bootstrapping of skills from previously acquired skills, i.e. the layering of new skills on top of existing ones, was explored. The main focus was learning to saccade and to reach toward a visually identified target. The authors in [10] proposed a developmentally inspired approach "cognitive developmental robotics" (CDR) theory for the design and construction of humanoid systems. One of the key aspects of CDR is to have the robot acquire its own understanding of its physics, through interaction with the environment. In a different approach, "autonomous mental development" [5], a machine has to develop its own understanding of the task. According to this model, robots should be designed to go through a long period of autonomous mental development, from "infancy to adulthood."

A study in 2006 on the trends of epigenetic robotics [11] revealed that almost half of the papers and posters dealt with research on attention which included a wide range from models of visual saccades and active vision system to experiments of human robot interaction. The second major topic was imitation, both purely robotic experiments and experiments involving human subjects. In terms of models, a third of the contributions used models based on neural networks and the same amount of papers explicitly discussed the issue of building internal representations.

5 Recent Examples

5.1 Some Basic Principles of Developmental Robotics

The author in this paper [12], formulates five basic principles of developmental robotics as recurring themes in the literature. These principles are verification principle, embodiment, subjectivity, grounding, and incremental development. He illustrates these principles and explain how four of these principles follow logically from the verification principle. The author believes that these principles could guide further research in this area.

5.2 Coupling of mental concepts to a reactive layer: incremental approach in system design

This paper [13] explain a structure for bootstrapping of new skills through incremental approach. A reactive layer has been coupled with a layer of multi-modal expectation generation which allows transition to goal-directed behavior. The expectations which are not met by sensory input activate mismatch resolution. The proposed framework suggests a scalable task/scenario independent solution to the development problem. The evaluation of auditory labels is done on the humanoid robot ASIMO.

5.3 Generalization and Transfer in Robot Control

The aim of this research [14] is that a robot should learn common-sense behaviors in a practical amount of time and adapts its skill to new situations. This is achieved by the introduction of a methodology for generalization and transfer. The use of factorable control-based approach provides a discrete abstraction of underlying continuous state/action space and thus allows for the application of learning algorithm such as Q-learning. Both simulation and implementation on a bi-manual robot confirms their generalization technique produces better results compared to flat representation. It is also shown how learning in stages provides a means of transferring polices from one context to another.

6 Conclusion and Future work

The observation of living creatures going through a form of development process in the nature strongly affirms that development is an indispensable part of gaining flexibility and adaptivity. The developmental robotics is trying to understand the mechanisms of this ubiquitous phenomena to endow robots with a similar capability.

Currently, majority of papers are related to social interaction and sensorimotor control. The important areas within this field, as the subject of continuous research, are autonomy (in its strong sense), value system, mechanisms of physical and neural entrainment [2, 3]. Additionally, two important aspects of living systems which have not to date been sufficiently addressed are morphology and materials [2].

We conclude that developmental robotics is still in its infancy. In order to achieve maturity, we need to find answers to fundamental questions and formulate critical theories. The success of this field hinges on the joint effort of many scientists including computer scientists, neuroscientists, psychologists, philosophers, and engineers.

References

[1] http://www.cs.swarthmore.edu/meeden/cs81/s06/cs81.html.

[2] M. Lungarella and G. Metta, "Beyond gazing, pointing, and reaching: A survey of developmental robotics," in *Proc. Third Int. Workshop Epigenet. Robot.*, pp. 81–99, 2003.

[3] M. Lungarella, G. Metta, R. Pfeifer, and G. Sandini, "Developmental robotics: a survey," *Connection Science*, vol. 15, no. 4, pp. 151–190, 2003.

[4] B. Siciliano and O. Khatib, eds., *Handbook of Robotics*, ch. 62 and 63. Berlin: Springer-Verlag, 2008.

[5] J. Weng, J. McClelland, A. Pentland, O. Sporns, I. Stockman, M. Sur, and E. Thelen, "Autonomous mental development by robots and animals," *Science*, vol. 291, no. 5504, pp. 599–600, 2001.

[6] R. Brook, "Intelligence without representation. Artificial Intelligence," vol. 47, pp. 139–160, 1991.

[7] N. Almassy, G. M. Edelman, and O. Sporns, "Behavioral constraints in the development of neuronal properties: A cortical model embedded in a real-world device," *Cerebral Cortex*, vol. 8, no. 346, 1998.

[8] J. Weng, *Visual Communication and Image Processing*, ch. Learning in Computer Vision and Beyond: Development. New York: Marcel Dekker, 1998.

[9] M. Marjanovic, B. Scassellati, , and M. Williamson, "Self-taught visually-guided pointing for a humanoid robot," in *Proc. of the 4th Int. Conf. on Simulation of Adaptive Behavior*, pp. 35–44, 1996.

[10] M. Asada, K. MacDorman, H. Ishiguro, and Y. Kuniyoshi, "Cognitive developmental robotics as a new paradigm for the design of humanoid robots," *Robotics and Autonomous Systems*, vol. 37, pp. 185–193, 2001.

[11] F. Kaplan and P. Oudeyer, "Trends in epigenetic robotics: Atlas 2006," in *Proc. of Sixth Int. Workshop on Epigenetic Robotics*, 2006.

[12] A. Stoytchev, "Some basic principles of developmental robotics," *Autonomous Mental Development, IEEE Tran. on*, vol. 1, pp. 122–130, aug. 2009.

[13] I. Mikhailova, M. Heracles, B. Bolder, H. Janssen, H. Brandl, J. Schmudderich, and C. Goerick, "Coupling of mental concepts to a reactive layer: incremental approach in system design," in *Proc. of the Int. Conf. on Epigenetic Robotics*, pp. 77–84, 2008.

[14] S. Hart, S. Sen, and R. Grupen, "Generalization and transfer in robot control," in *Proc. of the Int. Conf. on Epigenetic Robotics*, pp. 37–44, 2008.