# Can Cognitive Developmental Robotics Shift the Paradigm?

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*Abstract*— **This paper discusses how cognitive developmental robotics (hereafter, CDR) can make a paradigm shift in science and technology. A synthetic approach is revisited as a candidate for the paradigm shift, and CDR is reviewed from this viewpoint. Trans-disciplinary approach seems a necessary condition and how to represent and design "subjectivity" seems an essential issue.**

## I. INTRODUCTION

It is no wonder that new scientific findings are dependent on the most advanced technologies. A typical example is brain imaging technologies such as fMRI, PET, EEG, and so on that have been developed to expand the observations of brain activities from local and static ones to more global and dynamic ones, and therefore have been revealing new mysteries. Artifacts have been supposed to be supporting tools for nature analysis, but is there any possibility that it could be a means for new science invention?

If robots, as one kind of artifact, could be such a thing, it means that robotics can make a paradigm shift in both science and technology. Understanding natural phenomena by constructive or synthetic approaches has been done, but does not seem to cause a paradigm shift, yet. Are the consequences of artifact production able to be not simply useful tools in our daily life but also a means to impact existing scientific disciplines? One possibility could be a constructive approach taht is a methodology which creates reality by constructing situations. It attempts to verify the hypothesis or to find necessary conditions to realize biological behavior through (1) synthesizing the system based on the knowledge of biology or hypothesis, (2) experimenting with the system in real situations, and (3) comparing the consequences of the system with real phenomena, and/or exploring new findings [1]. Hashimoto et al. continue their statement like this:

"Since we often treat the biological, cognitive, linguistic and social issues in constructive studies, the models are usually agent-based and consist of cognitive individuals. The individuals are equipped with internal structure, internal dynamics and mechanisms to change their internal states and internal structures. The individuals change their internal structures according to interactions with the circumstances and other individuals. The individuals develop their own ways to behave in their world, which is a basis of subjectivity and autonomy. The researchers study the whole system consisting of such individuals objectively. Using evolutionary constructive approach, we may be able to embed systems having subjectivity and autonomy or systems having the ability to develop subjectivity and autonomy in a system that is an object of scientific investigation. Conventional scientific methodology is not good at dealing with subjectivity, since scientific research becomes possible by finding an objective entity in which subjective feature is stripped off. But treating subjectivity scientifically is unavoidable, if we are going to deepen our insight about complex systems. We should develop further the evolutionary constructive approach in order to make such embedding possible."

In this article, we review the meaning and value of CDR [2], and its studies so far. We discuss the methodology and the consequences of these studies and any possibility of causing a paradigm shift, in paticular.

## II. THE MEANING OF CONSTRUCTIVE APPROACHES

The value of the constructive approach is to generate a completely new understanding through the cycles of hypothesis and verification, targeting the issues that are very hard or almost impossible to solve under the existing scientific paradigms. A typical one is evolutionary computation that virtually creates the past we cannot observe, and shows the evolutionary process (ex., [1]). If we reduce the time scale, the onto-genetic process, that is, the individual development process can be the next target for the constructive approaches. Development of neuromechanisms in the brain or cognitive functions in infants are at considerably different levels. The former has its own history as developmental biology and the researchers approach to the mystery under this discipline. The latter deals with cognitive development in developmental psychology, cognitive science, and so on. Depending on the age, given (already acquired) functions and faculties to be acquired through interactions with environment including other agents should be clearly discriminated.

The subjectivity by Hashimoto et al. [1] would be meaningful if we focus on human individuals. That is, the process of self-establishment by infants provide various kinds of mysteries in developmental psychology, cognitive science, and sociology, including the issue of communication. Therefore, approaches to the mysteries that are difficult to solve under a single existing discipline might be able to be found by the constructive ones. Especially, for the infant's cognitive development, developmental psychology that greatly depends on the observation from outside (macroscopic), or neuroscience that tends to be microscopic and brain imaging is more difficult to apply to infants than adults. Thus, a single paradigm seems difficult to approach, and not easy to verify

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the hypothesized models. Then, it's turn for the constructive approaches to play an active role.

## III. COGNITIVE DEVELOPMENTAL ROBOTICS AS A CONSTRUCTIVE APPROACH

A representative constructive approach is CDR [2]. Similar approaches can be found in [3] or [4], but CDR puts more emphasis on the human/humanoid cognitive development. A slightly different approach is taken by ATR team [5] who aims to program humanoid behavior through the observation and understanding of human behavior and by doing so, give a clearer idea of the nature of human behavior. Though partially sharing the purpose of human understanding, they do not exactly deal with developmental aspect.

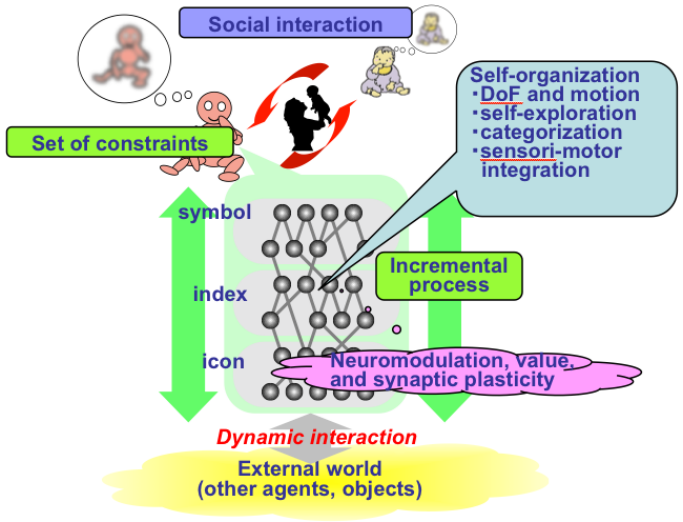


Fig. 1. Various aspects of the development from viewpoints of external observation, internal structure, its infrastructure, and social structure. Here, we briefly review the issue considering the underlying mechanisms in different forms

Fig. 1 summarizes the various aspects of the development according to the survey by Lungarella et al. [6] from viewpoints of external observation, internal structure, its infrastructure, and social structure, especially focusing on the underlying mechanisms in different forms.

Roughly speaking, the developmental process consists of two phases: the individual development at an early stage and the social development through interaction between individuals at a later stage. The former relates to mainly neuroscience (internal mechanism), and the latter to cognitive science and developmental psychology (behavior observation). Intrinsically, both should be seamless, but there is a big difference between them at the representation level for the research target to be understood. CDR aims not at simply filling the gap between them but more challengingly at building a new paradigm that provides new understanding of ourselves and at at the same time new design theory of humanoids symbiotic with us. So far, CDR has been mainly focusing on the computational model of cognitive development, but in order to more deeply understand how humans develop, robots can be used as new means as reliable reproduction tools in certain situations such as psychological experiments. The following is a summary:

A: construction of computational model of cognitive development
   1) hypothesis generation: proposal of a computational model or hypothesis based on knowledge from existing disciplines
   2) computer simulation: simulation of the process difficult to implement with real robots such as physical body growth
   3) hypothesis verification with real agents (humans, animals, and robots), then go to 1)

B: offer new means or data to better understand human developmental process → mutual feedback with A
   1) measurement of brain activity by imaging methods
   2) verification using human subjects or animal ones
   3) providing the robot as a reliable reproduction tool in (psychological) experiments

According to the above two approaches, there are many studies inspired by the observations in developmental psychology and by the evidences or findings in neuroscience. The survey by Asada et al. [2] introduces these studies based on the constructive model of development they hypothesize.

## IV. IS A PARADIGM SHIFT POSSIBLE?

Many studies introduced in [2] show different aspects of CDR, but are not sufficient to cause a paradigm shift, yet. One point by Hashimoto et al. [1] is "Conventional scientific methodology is not good at dealing with subjectivity, since scientific research becomes possible by finding an objective entity in which subjective feature is stripped off. But treating subjectivity scientifically is unavoidable, if we are going to deepen our insight about complex systems." Analysis based approach from a God's viewpoint faces with twofold difficulties when it focus on humans as living things. One is how to understand living things. Biology has been differentiated into many subdisciplines, and recent progress of the most advanced technologies accelerates more and more microscopic views with various kinds of levels and representations such as those in cell biology or molecular biology. The other is how to understand human beings as social agents, that involves psychology, cognitive science, and sociology. Here is a necessary condition to cause a paradigm shift since it seems hard or insufficient under a single scientific paradigm, therefore interdisciplinary approach seems essential.

What is a sufficient condition? Is it impossible by integrating the existing scientific disciplines? Is CDR completely independent from them? Of course not! By involving them, CDR should raise its meaning by prospecting the limits of the existing scientific disciplines. In this context, the issue to be attacked is "interaction" between neurons or brain regions or individual persons. Even though the level and the representation are different, communication, a kind of interaction between subjective agents may involve the language development in the level of the individual persons,

and therefore seems difficult to formalize the interaction. At the levels of neurons or brain regions, Kuniyoshi and Sangawa [7] show the fetus development in the womb that no one has revealed before.

To summarise the CDR approach,

1) integrate the knowledge, evidences, and findings (utilize the existing paradigms and synthesize them),
2) build a model or a hypothesis that have no contradiction with the existing disciplines or resolve the contradiction or controversial issues, and
3) find a new fact or provide a solution to mystery through the verification process of the model or the hypothesis by simulations or real experiments.

The above item 1) implies not to deny the existing disciplines but to involve them. Therefore, CDR researchers should have the minimum amount of knowledge in these disciplines to discuss the issues with researchers in these areas such as developmental psychology and brain science. The item 2) is a key point for the CDR researchers to hit on an idea that reflects the integrated knowledge in 1) maximumly utilizing a sense of design principle. If CDR can emerge new things that could not be predicted or imagined in a single discipline, the role of CDR may change from serving to bridge the gap between different existing disciplines to being the principal one of the paradigm shift. The item 3) asks us if the consequence of 2) can give an impact in the related areas in 1). One of the most serious issues is whether the performance of CDR can be regarded as not being superior to that of the existing discipline under the sense of the value of the existing paradigm. To overcome this, CDR should create the new value of the new paradigm. This is the final condition of the paradigm shift. What is it?

Regarding the relationship between an infant and its caregiver as a developing process of interaction between individual agents, key issues are neonate imitation (ex., [8] and [9] as a synthetic approach. Hereafter, the same style), joint attention ([10], [11], and [12] ), vocal imitation ([13], and [14], [15]), peekaboo ([16], and [17]), pointing ([18]), delayed imitation (game of make-believe), linkage between lexicon and action, and so on. The common issues are body representation, rhythm and timing, multimodal input/output (vision, auditory, touch, somatosensory, motion, vocalization etc.), self-other separation, sociality acquisition, and so on. If CDR can provide the constructive and unified form of the representation that can explain and simultaneously design the cognitive development of these issues, instead of representing them separately, this may lead to the creation of a new value of the paradigm shift. To enable this, the studies of developmental disorders in addition to the studies of normal children may help the unified model construction of cognitive development. This may correspond to "The researchers study the whole system consisting of such individuals objectively. Using evolutionary constructive approach, we may be able to embed systems having subjectivity and autonomy or systems having the ability to develop subjectivity and autonomy in a system that is an object of scientific investigation." by Hashimoto et al. [1].

## V. A CONCLUDING REMARK

This article does not have any conclusion but just initiated the future discussion on how CDR or related niches can make a paradigm shift in science and technology. I hope many young (mentally?) researchers discuss the issue in relation to their achievements.


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