What’s Cognitive Developmental Robotics?
A case study on fetal/neonatal development simulation
Introduction of myself: Minoru Asada

- Professor of Graduate School of Engineering, Osaka University, JAPAN (1995~).
  www.er.ams.eng.osaka-u.ac.jp


- The former president of RoboCup Federation (2002~2008) www.robocup.org

- The vice president of Japanese Society on Baby Science (2011~) www.childresearch.net/BABY
• A grand challenge: to build a team of 11 humanoids that can get a win against FIFA world-cup champion team
Outline of my talk

1. How do humans and humanoids develop?
2. What’s cognitive developmental robotics?
3. Summary and Future issues
Early Brain Development (1)

[Neuroscience: Dale Purves et al., 2008]
Early Brain Development (2)

[Neuroscience: Dale Purves et al., 2008]
Emergence of fetal movements and sense (Brain figures on the top are from Figure 22.5 in [Purves et al., 08], emergence of movements is from Figure 1 in [Vries et al., 84], and fetal senses are from [http://www.birthpsychology.com/lifebefore/fetalsense.html])
Infant development and learning targets

M / behaviors / learning targets

5 / hand regard / forward and inverse models of the hand

6 / finger the other’s face / integration of visuo-tactile sensation of the face

7 / drop objects and observe the result / causality and permanency of objects
Infant development and learning targets

M / behaviors / learning targets

8 / hit objects / dynamics model of objects
9 / drum or bring a cup to mouth / tool use
10 / imitate movements / imitation of unseen movements
11 / grasp and carry objects to others / action recognition and generation, cooperation
12 / pretend / mental simulation
Ridley presents a history of the long debate over genes versus the environment as the dominant influence on human behavior. He asserts that "versus" is wrong. His point of departure is the recent identification of the full sequence of the human genome. "The discovery of how genes actually influence human behaviour, and how human behaviour influences genes, is about to recast the debate entirely. No longer is it nature-versus-nurture, but nature-via-nurture."
Why such baby robots?

• Because, we’d like to make robots much more intelligent. But, what’s intelligence or how can humans be intelligent?

• In order to answer this question, it is not sufficient for only one discipline but interdisciplinary approaches seem promising.

• One approach is to include the process of building such robots that develop like humans.

→ the pathway to make robots more intelligent!
Why such baby robots, again?

We suppose ...

- Body shapes Brain: How does body development affect the development of the brain [Kuniyoshi 2008, Pfeifer and Bongard 2007]?

- Nature via Nurture: reduce “nature” side and maximize “nurture” side, in other words, make efforts to explain by learning and development as long as and as much as possible to acquire the blue print to design intelligence cognitive developmental robotics!
Outline of my talk

1. How do humans and humanoids develop?

2. What’s cognitive developmental robotics?

3. Summary and Future issues
What is cognitive developmental robotics?

- Cognitive developmental robotics aims at understanding human cognitive developmental process by synthetic or constructive approaches.
- Its core idea is "physical embodiment" and "social interaction" that enable information structuring through interactions with the environment including other agents.

Robots are:

• **reliable agents** as *controllable* *(reproducible)* **ones** for behavioral experiments,

• **computational models** to verify the hypotheses *(constructive approaches)*, and

• **social agents** in our future society.
JST ERATO Asada Synergistic Intelligence Project

Understanding Emergence of Human Intelligence

Design for Symbiotic Humanoids

Perso-SI

Physio-SI

Synergistic Intelligence

Socio-SI

SI-mechanism

www.jeap.jp

2005.09-2012.03
Our robots

- We (JST ERATO Asada Project) have developed several kinds of robot platforms with different mechanisms, supposing different ages and research purposes.
Platforms for Cognitive Developmental Approaches

15M walk alone
13M go up stairs
11M walk led by the hand
10M crawl
9M stand supported by furniture
8M stand with help
7M sit by itself
1M jaw up
0M fetal posture

Pneumatic Artificial Muscle

Rubber tube

Sleeve

[Osaka Univ. 2005]

[Hosoda and Narioka, 2007]
Anthropomorphic skin-covered hand

(Hosoda G. [Takamuku et al., 08])

[Neuroscience: Dale Purves et al., 2008]
Jumping robot

Bi-articular muscles coordinate a jumping motion!

[1. 腱骨筋
2. 大殿筋
3. 外側広筋
4. 膝窩筋
5. 大腿直筋
6. ハムストリング
7. 前頸骨筋
8. ヒラメ筋
9. 腓腹筋]

[Takayama et al., 2008]
Physical human-robot interaction

• We are focusing on physical human-robot interaction

• In human-human interaction, there are several kinds of physical interaction
  – Physical interaction between a mother and a baby
  – The baby can stand up despite she still cannot stand up by herself
Movies

- Expert
- Beginner (smooth)
- Beginner (nonsmooth)
- Beginner (failed)

[Ikemoto et al., 08, 09]
An expert can start an interaction from more synchronized state because he can predict robot’s motion.
An interaction successfully done needs continuous positive correlation, and the lag should be smaller.
Results (1)

Before learning

After learning

[Ikemoto et al., 08, 09]
Results (2)

Ikemoto et al., 08, 0
Robots in action
Vowel Acquisition by Maternal Imitation

- Vowel Imitation between Agents with Different Articulation Parameters by Parrot-like Teaching
  - Infants seem to acquire (imitate) phonemes:
    - without any explicit knowledge about the relationship between their sensorimotor system and phonemes, and
    - without a capability to reproduce the adult’s sound as they are.
- How can robots do that?

[Yoshikawa et al., 03]
Human Vocalization [Deacon 98]

- Vocalization $\rightarrow$ the interaction of the oral and respiratory tracts $\rightarrow$ special association with midbrain systems.

- To organize vocalization $\rightarrow$ coordinated activation of the cluster of motor neurons that control the muscle of breathing, the tension of the larynx, and the movement of the oral and facial muscles. $\rightarrow$ the motor neurons controlling all of these are located in the upper brain stem.
Human Vocalization [Deacon 98]

- Two evolutionary shifts producing increasing cortical control over motor output from brain stem articulatory and vocal systems. These shifts were produced by an increase in the proportions of the cerebral cortex in comparison to these brain stem structures.
A constructivist approach

• The purpose ➔ To build a robot that acquires the vowels of a human caregiver
• Design issues:
  – What kind of mechanism should be embedded?
  – What should be the behavior of the caregiver?

[Yoshikawa et al., 03]
Observations in human infants

- Infant’s speech-like cooing tends to make its mother utter [Masataka and Bloom’94].
- **Maternal imitation of infant's cooing** (i.e., parrot-like vocalization) increases vocalization rates of a three-month-infant [Pelaez-Noqueras ’96].

Conjectures
- It reinforces infants’ speech-like cooing.
- It helps to find the correspondence between cooing and phonemes.

[Yoshikawa et al., 03]
The robot

Output sound

Sound source

Silicon tube

Articulation vector

PC

Motors deforming

Microphone

Formant extractor

Formant vector

[Yoshikawa et al., 03]
What’s Formant Space?

- Resonant frequency changes depending on the shape of vocal tract.
- Vocal feature for vowel discrimination.
- Non-human primates and birds utilize as perceptual cues [Fitch 2000]

Formant distribution of Japanese average female [Yoshikawa et al., 03]
A model of interaction

The caregiver

Randomly cooing

The robot

Parrot-like teaching

Random articulator

Articulation layer

Auditory layer

Learning module

[Yoshikawa et al., 03]
Learning mechanism

- Clustering the articulation parameters and the formant vectors by the SOM algorithm.
- Connections are updated based on Hebbian learning.

[Yoshikawa et al., 03]
Acquired vowels

• The acquired vowels can be interpreted as Japanese vowels.

/Yoshikawa et al., 03/
Childlike voice?

[Yoshikawa et al., 03]
Visual imitation, too!

[Miura et al., 2006]
Mutual attachment in caregiver-child relationship (3)

AFFETTO:
A child robot with realistic facial expressions that develops based on affective attachment with a caregiver

Hisashi Ishihara
Yuichiro Yoshikawa
Minoru Asada
Osaka Univ., Japan/JST ERATO Asada Project
Japan Society for the Promotion of Science

www.youtube.com/watch?v=VXgKNFQE-4I
www.youtube.com/watch?v=Quai3SpKD08
From physical interaction to cognitive one

Dynamic Motion
- standing with support, early
- whole body motion & assist
- crawling
- holding during neonate & infant
- rolling over
- intersubjectivity

Functional development
- voluntary motions
- reflection
- sensory motor mapping
- higher cognition

Fetus Simulation

Self/other discrimination

From emergence of social behavior through interactions with caregiver to development of communication
Is a paradigm shift possible? (1)

To summarize the CDR approach,
1) integrate the knowledge, evidences, and findings (utilize the existing paradigms and synthesize them), not to deny the existing disciplines but to involve them. Therefore, CDR researchers should have the minimum amount of knowledge in these disciplines.

2) build a model or a hypothesis that have no contradiction with the existing disciplines or resolve the contradiction or controversial issues, a key point for the CDR researchers to hit on an idea that reflects the integrated knowledge in 1) and,

3) Find a new factor that provides a solution to mystery through the verification process of the model or the hypothesis by simulations or real experiments.

[Asada 2011]
Is a paradigm shift possible? (2)

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.

[Asada 2011]
I believe conscious mind arises when a self process is added onto a basic mind process.

.. the two notions of correspond to two stages of evolutionary development of the self, the self-as-knower having had its origin in the self-as-object.

Given that the work associated with either attitude continues to produce useful ideas, there is no need, as yet, to decide which approach will turn out to be more satisfactory. But, we need to acknowledge that the resulting account are different.

Summary

- Cognitive developmental robotics is a promising approach to new science of human cognition based on design theory.
- Physical embodiment and social interaction are keys for robots (infants) to develop their cognitive functions.
- Robots cannot be completely same as human! Advantage or disadvantage? \( \rightarrow \) potential to shed a new insight [Asada 2011]
References (1)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Authors and Title</th>
</tr>
</thead>
</table>
### References (3)


References (4)

