Jst Erato Asada Project

Cognitive Developmental Robotics Seeking for the Principle of Cognitive Development

Minoru Asada

JST ERATO Asada Synergistic Intelligence Project
Graduate School of Engineering, Osaka University

IEEE RAS Workshop on Robot Learning
@Nice, France, IROS 2008
September 22, 2008

Summary, first!

Jst Erato Asada Project

- Robot learning is NOT a branch of Machine Learning, but more...
- Human cognitive development is one of big mysteries of human being.
- Brain science seems too microscopic while developmental psychology is too macroscopic.
- Cognitive Developmental Robotics aims at not 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 that co-exist with us.

Outline of my talk

Jst Erato Asada Project

- What's Cognitive Developmental Robotics?
  - Design issues
  - Brain development
  - A recent view of social brain and the current structure of our project
  - Child Robot with Biomimetic-Body (CB^2): Artificial muscles with pneumatic cylindrical actuators and whole body tactile sensors.
- Two preliminary works
  - Fetus development simulation
  - Vowel imitation

Cognitive Developmental Robotics in Humanoid Science

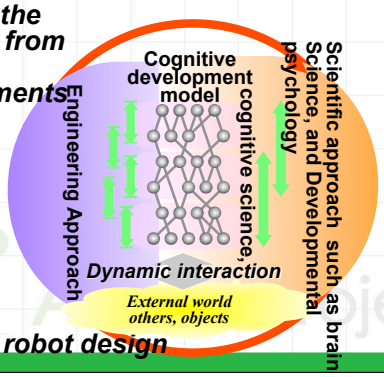
Jst Erato Asada Project

- A discipline "*Humanoid Science*" that aims at providing a new way of understanding ourselves and a new design theory of humanoids through mutual feedback between the design of human-like robots and human-related science.
- Emerging intelligence through the interaction with environment including humans.
- Synergistic effects with brain science, neuroscience, cognitive science, and developmental psychology.

Understanding ourselves through designing robots

Jst Erato Asada Project

Inform the results from robot experiments



Hints for robot design

What's Cognitive Developmental Robotics?

Jst Erato Asada Project

- From a viewpoint of artifact design:

1. What kinds of capabilities or structures should be embedded? → the design of self-developing structures inside the robot's brain
2. How to set up the environment so that the robots embedded therein can gradually adapt themselves to more complex tasks in more dynamic situations? → the environmental design
3. What's the temporal development structure?

- Discussion on the issues of underlying **neuromechanism** and **behavioral verification** are needed. *[Asada_Karl_Ishiguro_Kuniyosi01]*

Design Principle

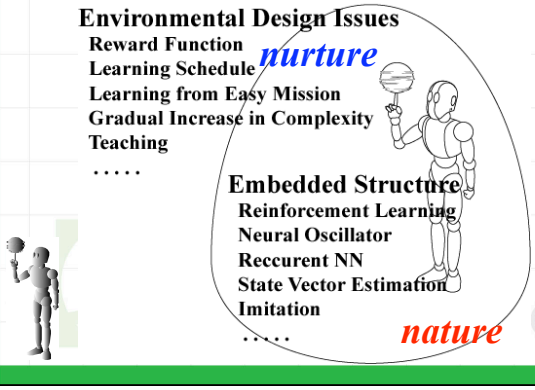
JST ERATO Asada Project

Environmental Design Issues
- Reward Function
- Learning Schedule
- Learning from Easy Mission
- Gradual Increase in Complexity
- Teaching
- .....

nurture

Embedded Structure
- Reinforcement Learning
- Neural Oscillator
- Reccurent NN
- State Vector Estimation
- Imitation
- .....

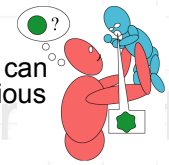
nature



Environmental design issues

JST ERATO Asada Project

- Parents, teachers, and other adults adapt themselves to the needs of children according to each child's level of maturity and the particular relationship they have developed with that child.
- Environmental issues include other agent behaviors.
- Other agents can be coaches, teachers, or demonstrators who can communicate with robots by various means.



Coincidence with the book?

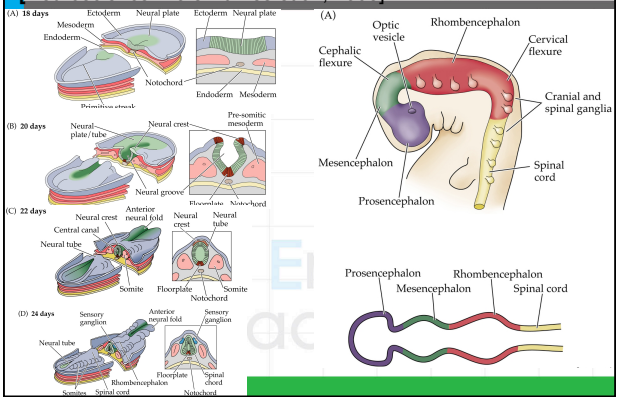
JST ERATO Asada Project

- **Nature Via Nurture: Genes, Experience and What Makes Us Human**
  Matt Ridley
- ***From Scientific American***
  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.

Early Brain Development (1)

[Neuroscience: Dale Purves et al., 2008]

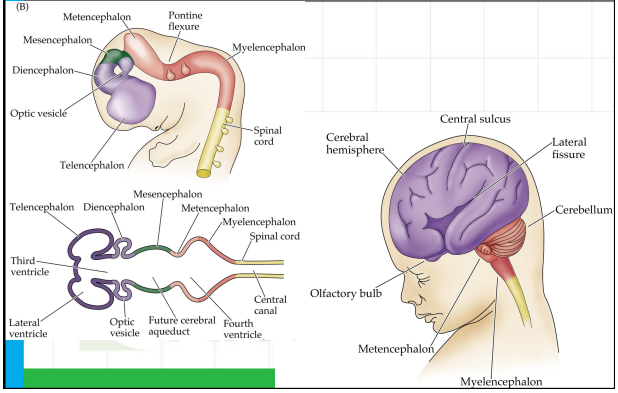
JST ERATO Asada Project



Early Brain Development (2)

[Neuroscience: Dale Purves et al., 2008]

JST ERATO Asada Project



What's going on in the womb (1)

JST ERATO Asada Project

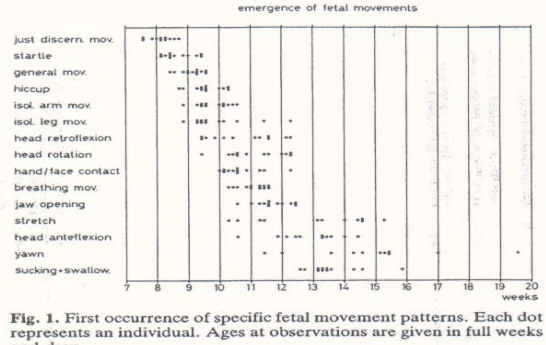
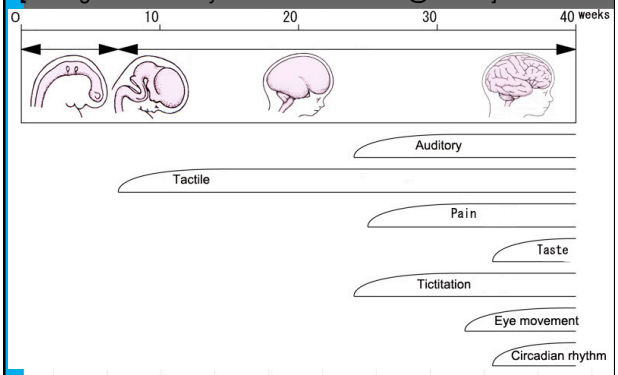


Fig. 1. First occurrence of specific fetal movement patterns. Each dot represents an individual. Ages at observations are given in full weeks and days.

[Vries et al. 84]

What's going on in the womb (2)

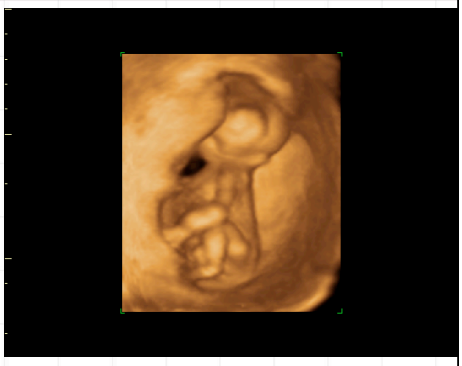
[Through the courtesy of Dr. Yukuo Konishi@TWMU]



What's going on in the womb (3)

[Through the courtesy of Dr. Yukuo Konishi@TWMU]

14 weeks

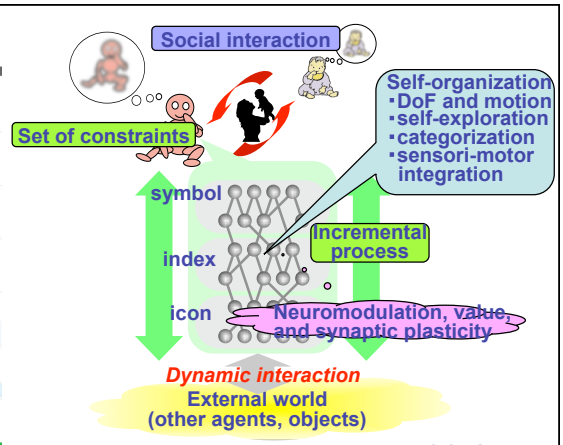


What's going on in the womb (8)

[Through the courtesy of Dr. Yukuo Konishi@TWMU]

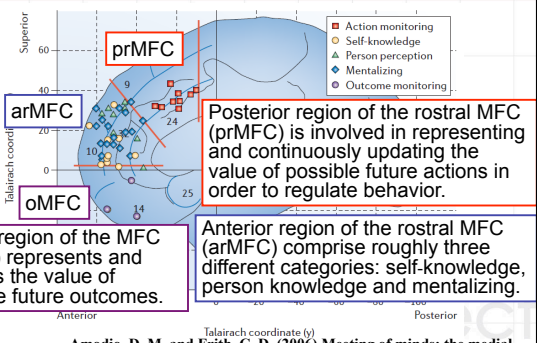
36 weeks

Facets of development



Based on [Lungarella_Metta_Pfeifer_Sandini03]

A recent view of social brain



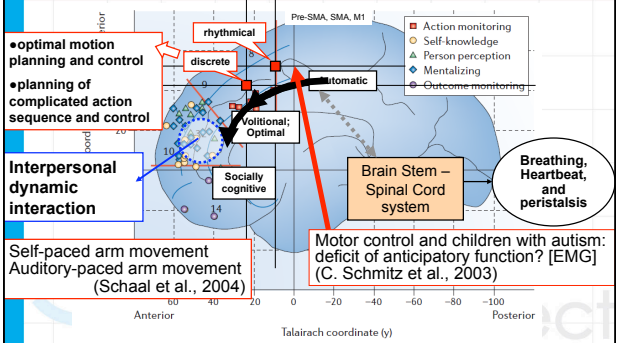
Posterior region of the rostral MFC (prMFC) is involved in representing and continuously updating the value of possible future actions in order to regulate behavior.

Orbital region of the MFC (oMFC) represents and updates the value of possible future outcomes.

Anterior region of the rostral MFC (arMFC) comprise roughly three different categories: self-knowledge, person knowledge and mentalizing.

Amodio, D. M. and Frith, C. D. (2006) Meeting of minds: the medial frontal cortex and social cognition. *Nat. Rev. Neurosci.*, 7, 268-277.

Towards modeling cognitive development



Self-paced arm movement
Auditory-paced arm movement
(Schaal et al., 2004)

Motor control and children with autism: deficit of anticipatory function? [EMG] (C. Schmitz et al., 2003)

Synergistic Intelligence Project

Understanding Emergence of Human intelligence

Design for symbiotic humanoids

Perso-SI
Yasuo Kuniyoshi's group

Physio-SI
Koh Hosoda's group
Artificial Muscles

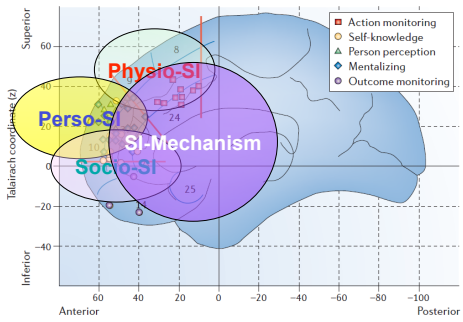
Synergistic Intelligence

Socio-SI
Hiroshi Ishiguro's group

SI-mechanism
Toshio Inui's group

SI-group structure

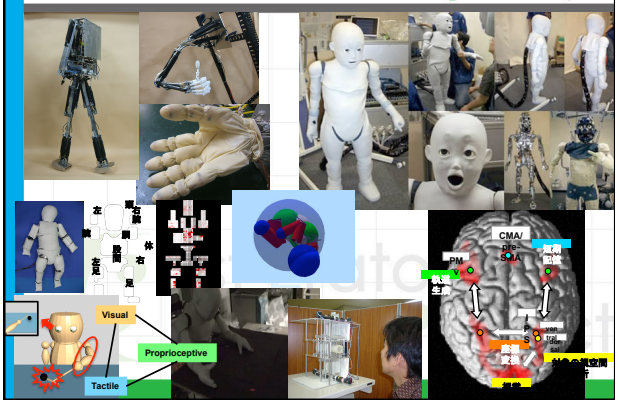
Jst Erato Asada Project



Amodio, D. M. and Frith, C. D. (2006) Meeting of minds: the medial frontal cortex and social cognition. *Nat. Rev. Neurosci.*, 7, 268-277.

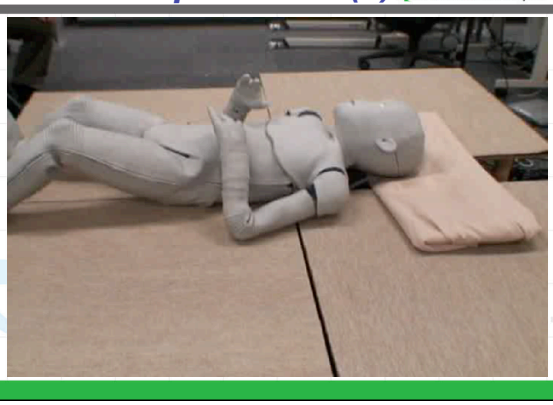
Studies in SI

Jst Erato Asada Project



Video Clips of CB² (1)

Jst Erato Asada Project



Video Clips of CB² (3)

Jst Erato Asada Project

Outline of my talk

Jst Erato Asada Project

- What's Cognitive Developmental Robotics?
  - Design issues
  - Brain development
  - A recent view of social brain and the current structure of our project
  - Child Robot with Biomimetic-Body (CB²): Artificial muscles with pneumatic cylindrical actuators and whole body tactile sensors.
- Two preliminary works
  - Fetus development simulation → ***individual development (interaction among CPG-muscle-environment)***
  - Vowel imitation → ***social development (interaction between agents)***

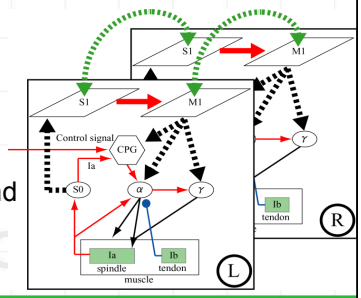
Towards the principle of cognitive development

- Rethinking "embodiment" or more correctly "Shintaisei (身体性)" explained as event that the body specifies the interaction between active agent and environment, and its contents. That is also the infrastructure to form the cognition and behaviors by providing the structure to the interaction.
- So, what is the minimal block to start, and what is the key issues?
- I do not have exact answers, but show some trials that, we expect, the fundamental block of cognitive development.
- First is fetus brain-body development as starting point (very bottom-up approach).
- Second is vowel imitation as a typical aspect of interaction model between active agents.

Fetus Brain Development (1)

[Sangawa & Kuniyoshi 06]

- A model of neuro-musculo-skeletal system is constructed capturing essential features of biological systems.
- It consists of a skeleton, muscles, spindles, tendon organs, spinal circuits, medullar circuits (CPGs), and a basic cortical model.



Fetus Brain Development (2)

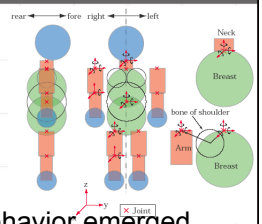
[Sangawa & Kuniyoshi 06]

- Through a series of experiments with a minimally simple body model, it is shown that the model has the capability of generating partially ordered behavior, a mixture of chaotic exploration and ordered entrained patterns.
- Models of self-organizing cortical areas for primary somatosensory and motor areas are introduced.
- They participate in the explorative learning by simultaneously learning and controlling the movement patterns.

Fetus Brain Development (3)

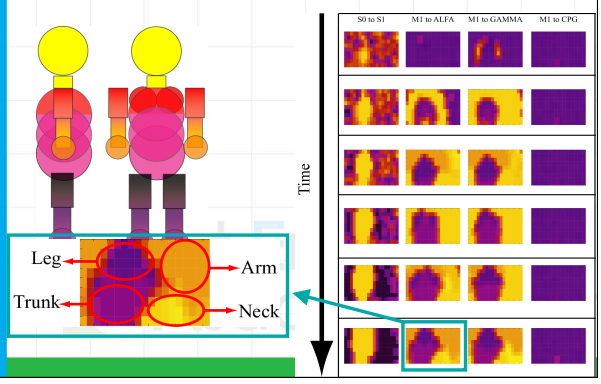
[Sangawa & Kuniyoshi 06]

- A scaled up version of the model, a human infant model, is constructed and put through preliminary experiments.
- 19 segments and 198 muscles
- Some meaningful motor behavior emerged including rolling over and crawling-like motion. The results show the possibility that a rich variety of meaningful behavior can be discovered and acquired by the neural-body dynamics without pre-defined coordinated control circuits.



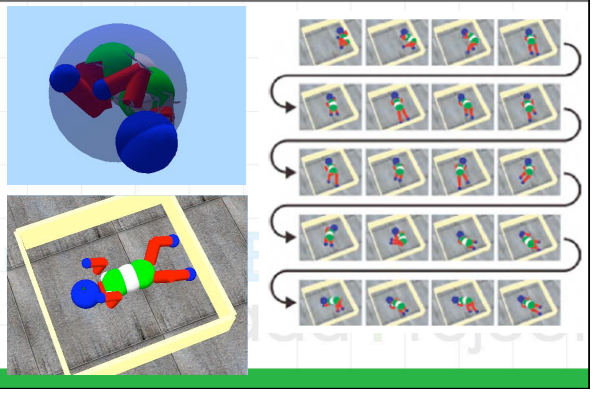
Fetus Brain Development (4)

[Sangawa & Kuniyoshi 06]



Fetus Brain Development (5)

[Sangawa & Kuniyoshi 06]



A Preliminary Study on 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, 2003]

A constructivist approach

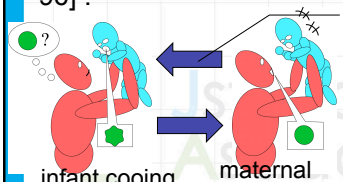
- The purpose →To build a robot that acquires the vowels of a human caregiver
- Design issues:
  - What kind of mechanism should be embedded?
  - What should be the behavior of the caregiver?

Robot's mechanism?

Caregiver's behavior?

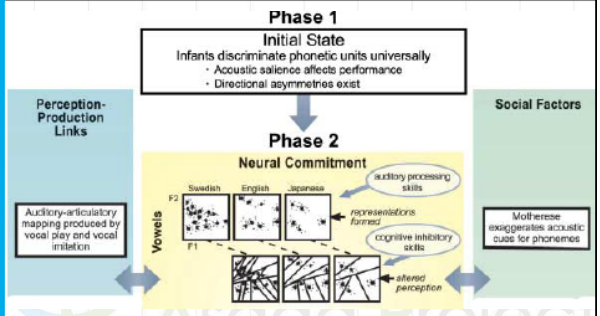
Observations in human infants

- 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] .



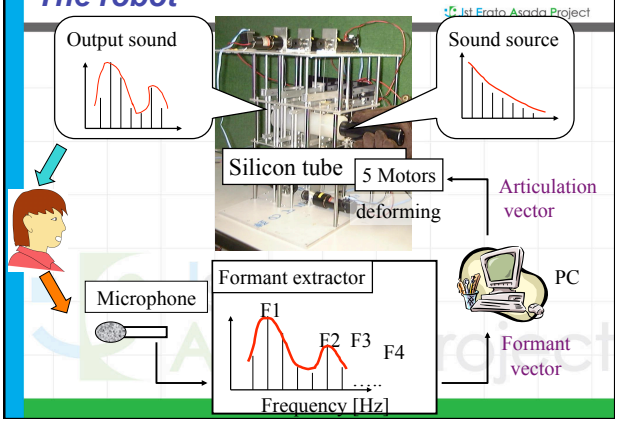
Conjectures
- It reinforces infants' speech-like cooing.
- It helps to find the correspondence between cooing and phonemes.

From Infant study

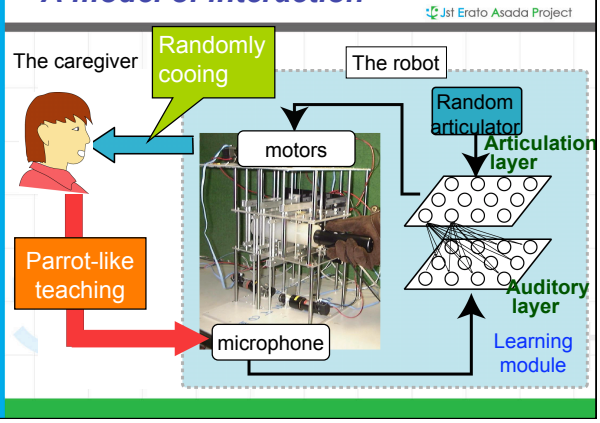


Is speech learning 'gated' by the social brain? (Patricia K. Kuhl, 2007)

The robot



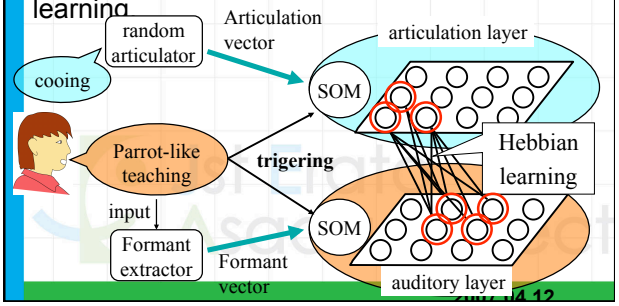
A model of interaction



Learning mechanism

Jst Erato Asada Project

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



Experiment

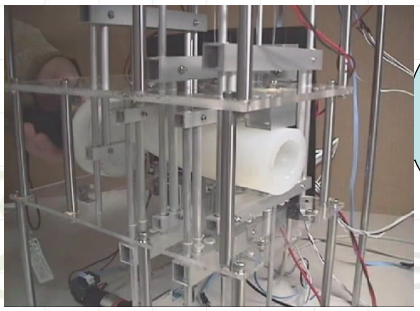
Jst Erato Asada Project

One Japanese caregiver

Acquired vowels

Jst Erato Asada Project

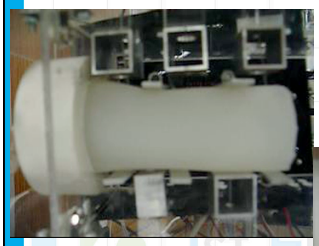
- The acquired vowels can be interpreted as Japanese vowels.

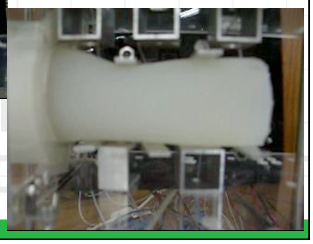


/a/, /i/, /u/, /e/

Childlike voice?

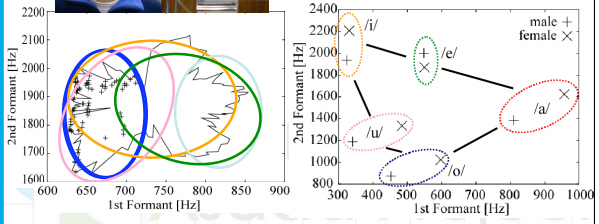
Jst Erato Asada Project





Lip shape imitation

Jst Erato Asada Project



[Miura et al, 2006]

Visual imitation , too!

Jst Erato Asada Project

Caregiver's Sensorimotor Magnets Lead Infant's Vowel Acquisition through Auto Mirroring

Jst Erato Asada Project

[Ishihara et al, 2003]

- A method that aids unconscious guidance in mutual imitation for infant development based on a biasing element with two different kinds of modules.

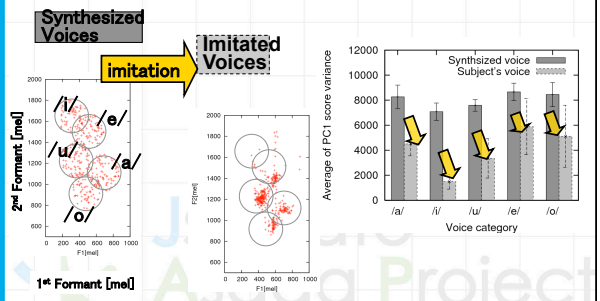
1. The normal magnet effect in perceiving heard vocal sounds as the listener's own vowels (perceptual magnet) and also includes another magnet effect for imitating vocal sounds that resemble the imitator's vowels (articulatory magnet).
2. What we call "auto mirroring bias," by which the heard vowel is much closer to the expected vowel because the other's utterance is an imitation of the listener's own utterance.

Caregiver's Sensorimotor Magnets Lead Infant's Vowel Acquisition through Auto Mirroring

Jst Erato Asada Project

[Ishihara et al, 2003]

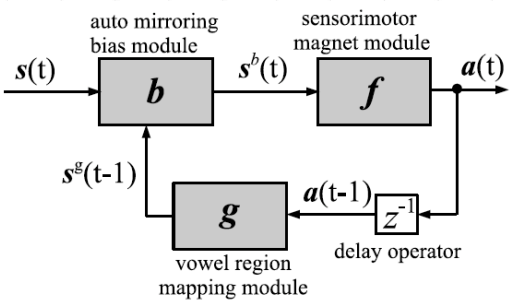
How humans imitate the sound?



Caregiver's Sensorimotor Magnets Lead Infant's Vowel Acquisition through Auto Mirroring

Jst Erato Asada Project

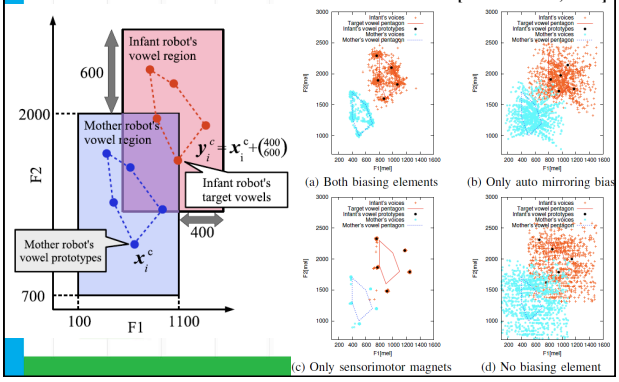
[Ishihara et al, 2003]



Caregiver's Sensorimotor Magnets Lead Infant's Vowel Acquisition through Auto Mirroring

Jst Erato Asada Project

[Ishihara et al, 2003]



Summary

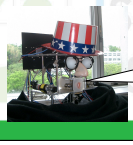
Jst Erato Asada Project

- Robot learning is NOT a branch of Machine Learning, but more...
- Human cognitive development is one of big mysteries of human being.
- Brain science seems too microscopic while developmental psychology is too macroscopic.
- Cognitive Developmental Robotics aims at not 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 that co-exist with us.

Acknowledgement

Jst Erato Asada Project

- **Group Leaders and Research Contributors :**
  - Prof. Koh Hosoda (Osaka Univ.)
  - Prof. Yasuo Kuniyoshi (Univ. of Tokyo)
  - Prof. Hiroshi Ishiguro (Osaka Univ.)
  - Prof. Toshio Inui (Kyoto Univ.)
  - Dr. Yuichiro Yoshikawa (JST ERATO, vowel imitation)
  - Dr. Chisato Yoshida (JST ERATO, modeling)
  - Katsushi Miura (JST ERATO, and Osaka Univ., vowel imitation)



Thank you for your attention!

Merci Beaucoup!