5th International Conference on Cognitive Systems 2012 Cognitive Developmental Robotics as Embodied Cognitive Systems

Minoru Asada

Graduate School of Engineering, Osaka University JST ERATO Asada Synergistic Intelligence Project Former president (2002-2008) of RoboCup Federation



5th International Conference on Cognitive Systems



February 22 - 23, 2012, TU Vienna, Austria



Introduction of myself: Minoru Asada

- Professor of Graduate
 School of Engineering,
 Osaka University, JAPAN.
 www.er.ams.eng.osaka-u.ac.jp
- Research director of JST ERATO (Exploratory Research for Advanced Technology) Asada Project www.jeap.jp
- The former president of RoboCup Federation www.robocup.org





Thank you for your kind words!



 Still very hard to recover physically and economically!



 We appreciate everything you have done so far!



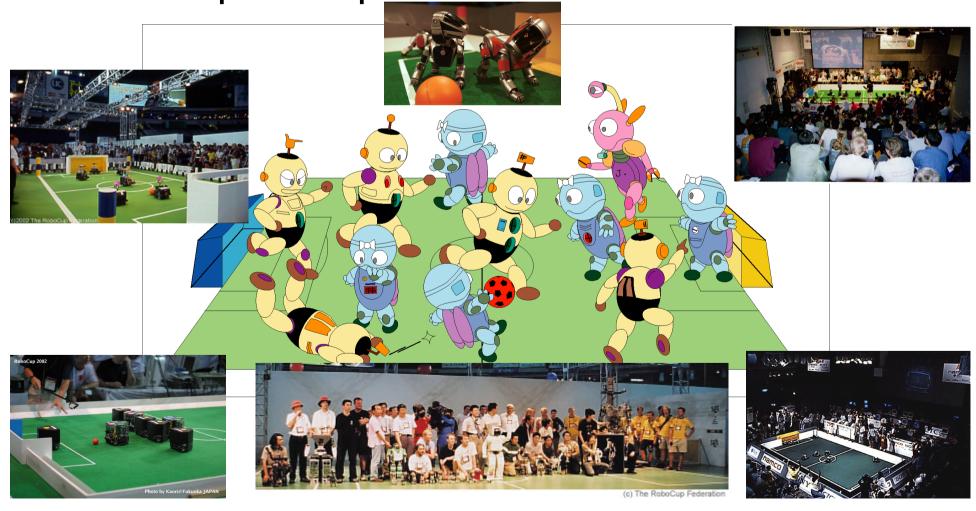
 Japanese robotics researchers built a community to help any kinds of activities. [roboticstaskforce.wordpress.com]

Major Projects on Robotics in Osaka

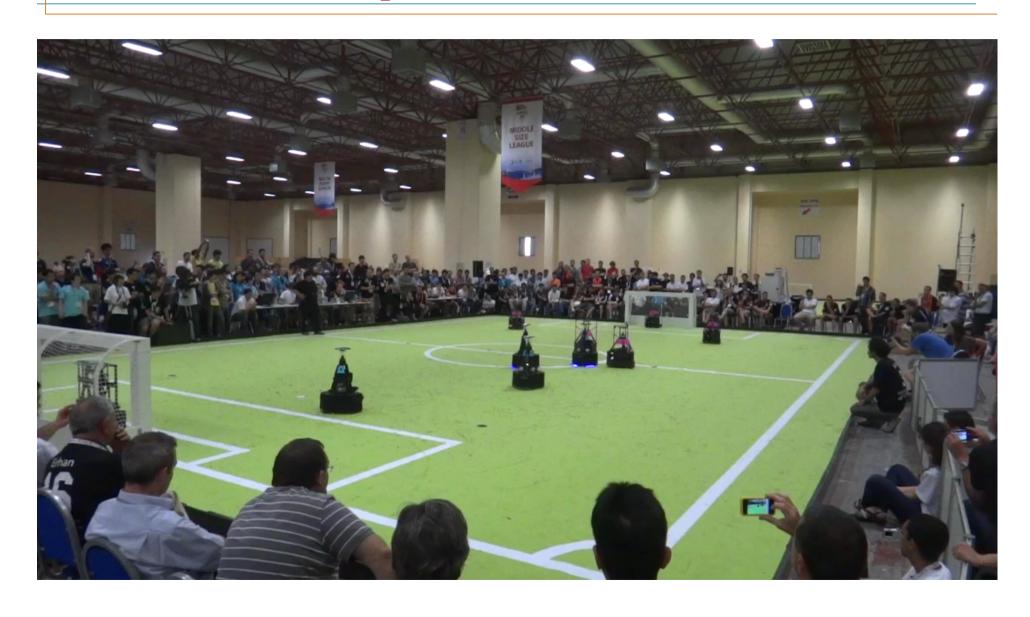
- JST ERATO Asada Synergistic Project (2005.09-2011.03, 2011.04-2012.03 (one year extension) 16,000K + 500K (Euro))
 - Profs. Ásada (research director), Hosoda, and Ishiguro (group leaders)
- JST CREST Ishiguro Studies on cellphone-type teleoperated androids transmitting human presence (2010.10-2016.03) 5,000K?
- JSPS Global COE Program: Cognitive Neuroscience Robotics (2009.04-2014.03) Profs. Ishiguro (leader), Asada (sub-leader), Arai, Miyazaki, Hosoda 6,000K
- JSPS grant-in-aid scientific research: Fundamental Structure (S):
 - Prof. Asada (2010.04-2015.03) 1,600K
 - Prof. Hosoda (2011.04-2016.03) 1,300K
- MEXT: Establishment of a new area of Hyper Bio Assembler for 3D Cellular Systems Prof. Tatsuo Arai (2011.10-2016.03) about 25,000K?

RoboCup

 A grand challenge: to build a team of 11 humanoids that can get a win against FIFA world-cup champion team



RoboCup 2011 Istanbul



RoboCup 2012

18 - 24 June 2012

Mexico City



Home Schedule Competitions Demonstration Symposium Participants Visitors Sponsors Location Organization Photo Gallery FAQ

About RoboCup



Welcome to RoboCup 2012

The RoboCup Federation and the Mexican Robotics Federation are pleased to invite you to RoboCup 2012 to be held in Mexico City from Monday 18th through Sunday 24th June 2012.

RoboCup objective:

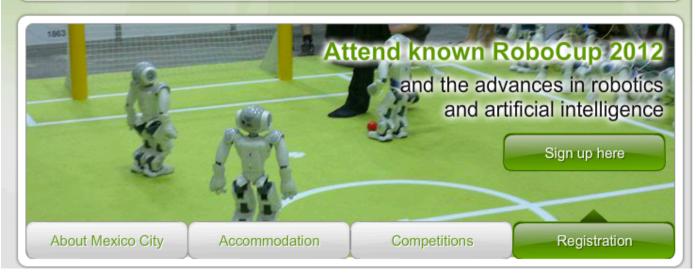
It is our intentions to use RoboCup as a vehicle to promote robotics and AI research, by offering publicly appealing, but formidable challenge. One of the effective ways to promote engineering research, apart from specific application developments, is to set a significant long term goal. When the accomplishment of such a goal has significant social impact, it is called the grand challenge project. Building a robot to play soccer game itself do not generate significant social and economic impact, but the accomplishment will certainly considered as a major achievement of the field. We call this kind of project as a landmark project. RoboCup is a landmark project as well as a standard problem.

The Dream

We proposed that the ultimate goal of the RoboCup Initiative to be stated as follows:

By mid-21st century, a team of fully autonomous humanoid robot soccer players shall win the soccer game, comply with the official rule of the FIFA, against the winner of the most recent World Cup.

We propose that this goal to be the one of the grand challenges shared by robotics and Al community for next 50 years.





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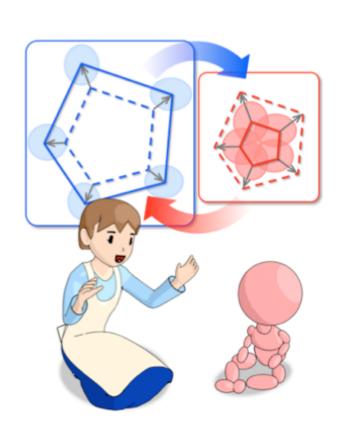






Outline of my talk

- 1. How do humans and humanoids develop?
- 2. What's cognitive developmental robotics?
- 3. How do the concept of self and mirror neuron system develop?
- 4. How do infants vocalize vowels?
- 5. Future issues



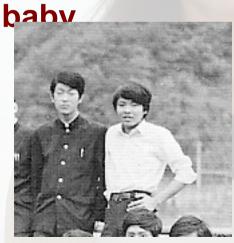
What's human development?



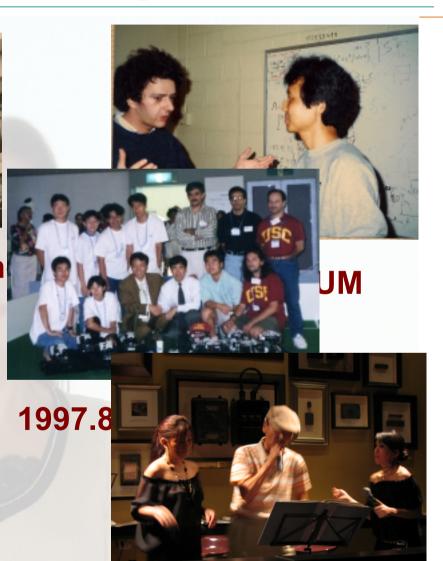


Elementary sch





Junior high school High school



2009.6.5@Shanghai

Early Brain Development (1)

Cervical

flexure

Spinal cord

Spinal cord

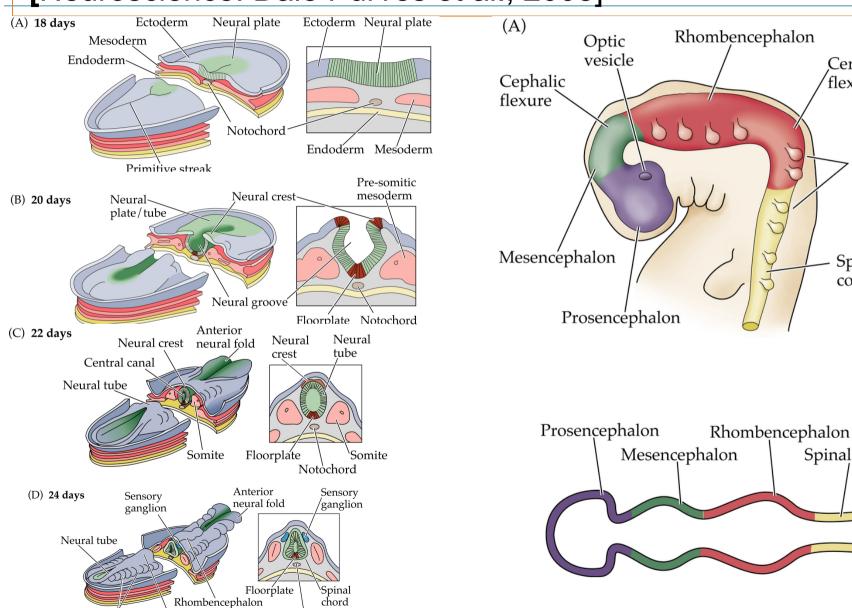
Cranial and

spinal ganglia

[Neuroscience: Dale Purves et al., 2008]

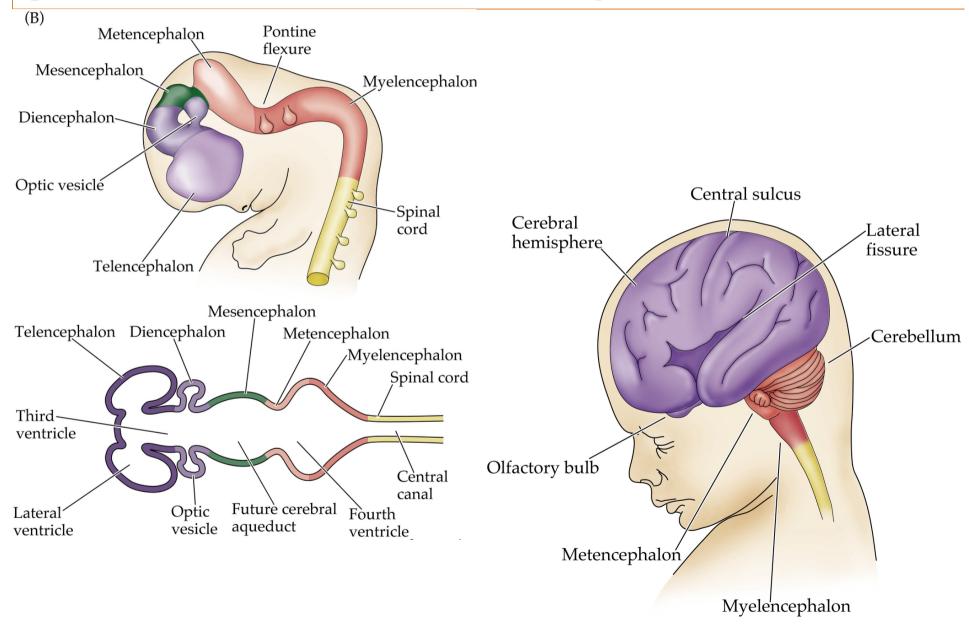
Notochord

Somites Spinal cord

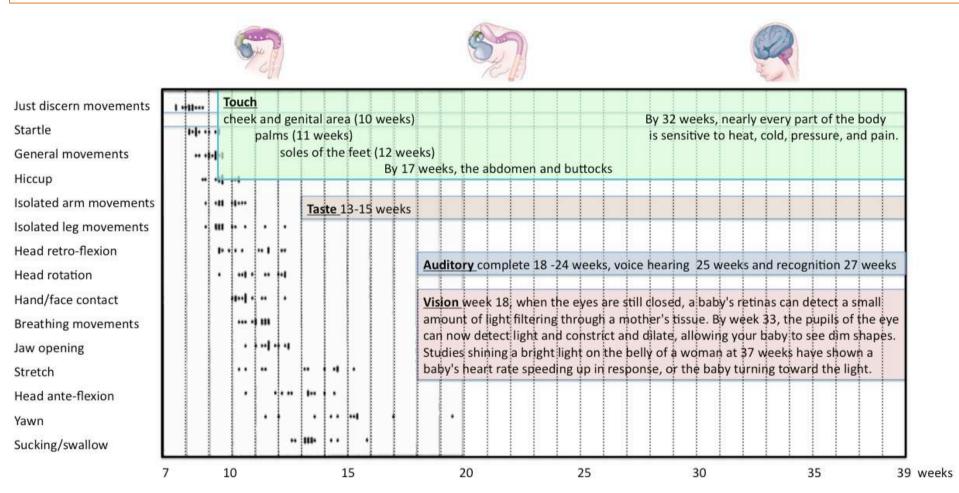


Early Brain Development (2)

[Neuroscience: Dale Purves et al., 2008]



What's going on in the womb (1)



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]

What's going on in the womb (2)

[through the courtesy of Dr. Yukuo Konishi@Doshisha Univ.]

36 weeks



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



11 / grasp and carry objects to others / action recognition and generation, cooperation

12 / pretend / mental simulation



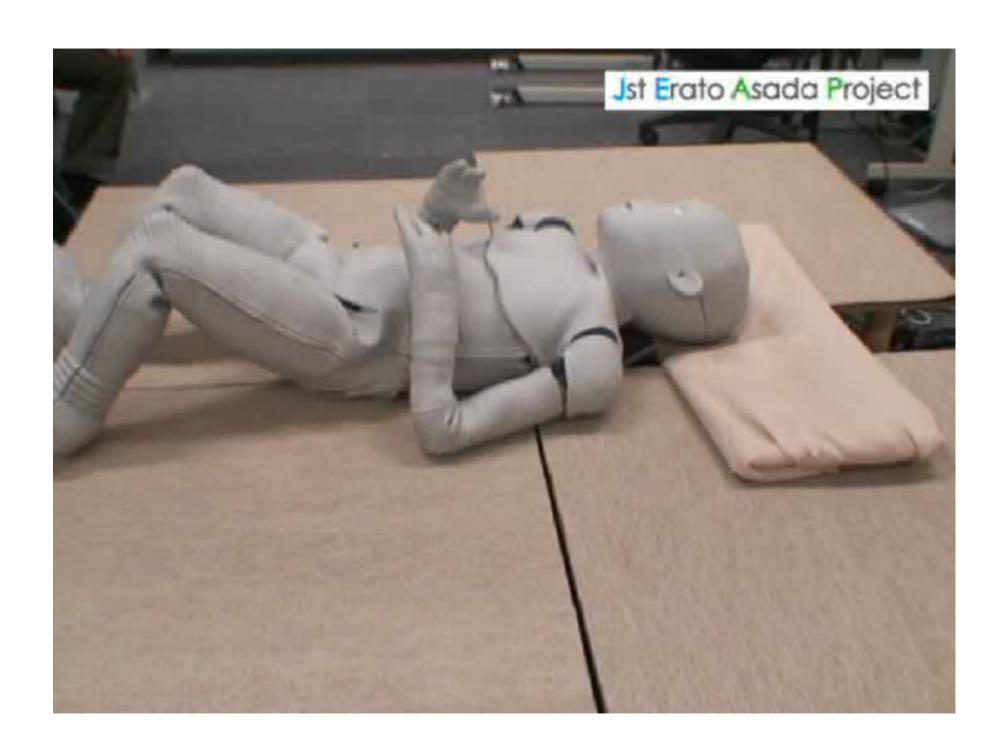
Nature vs Nurture?

Nature Via Nurture: Genes, Experience and What Makes Us Human Matt Ridley



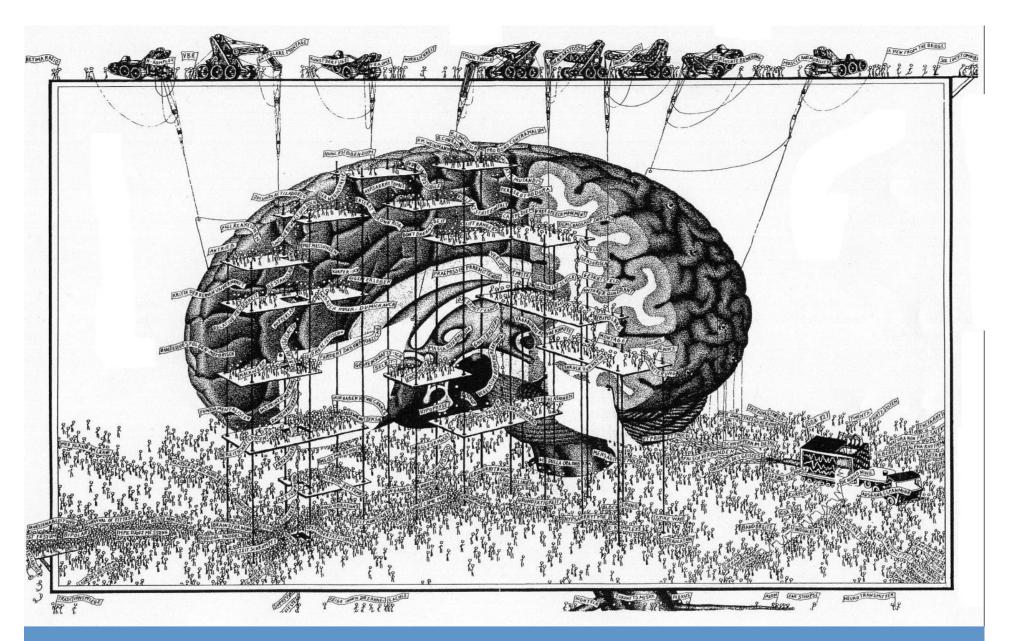
Ridley presents a history of the long debate over genes versus the environment as the dominant influence on human behavior. He asserts that "versus" is wrong. His point of departure is the recent identification of the full sequence of the human genome. "The discovery of how genes actually influence human behaviour, and how human behaviour influences genes, is about to recast the debate entirely. No longer is it nature-versusnurture, but nature-via-nurture.

[From Scientific American]



Why such baby robots?

- Because, we'd like to understand how humans can be intelligent by building such robots that develop like humans.
- Why not other approaches such as brain science or psychology?
- Because, it seems difficult for only one discipline but interdisciplinary approach seems promising:
 - Brain science → tends to microscopic (see next slide)
 - Psychology → macroscopic (based on observation)



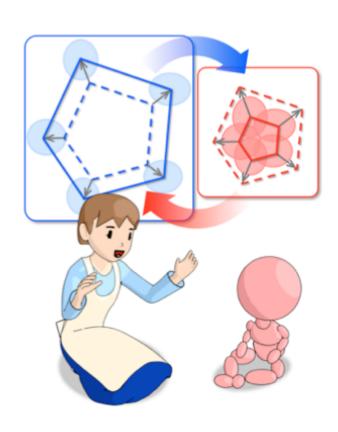
"A huge crowd of brain researchers work like ants on a gigantic brain: This is the view of the graphic designer Uwe Brandi from Göttingen, about how scientists trye to unravel details of the thinking organ. But how do the details fit together in a realistic way?"
© Uwe Brandi, drawing and text from: GEO-Wissen Nr. 1, page 31, 1987.

Basic idea: Humanoid Science



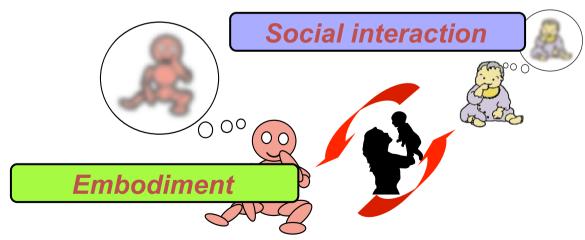
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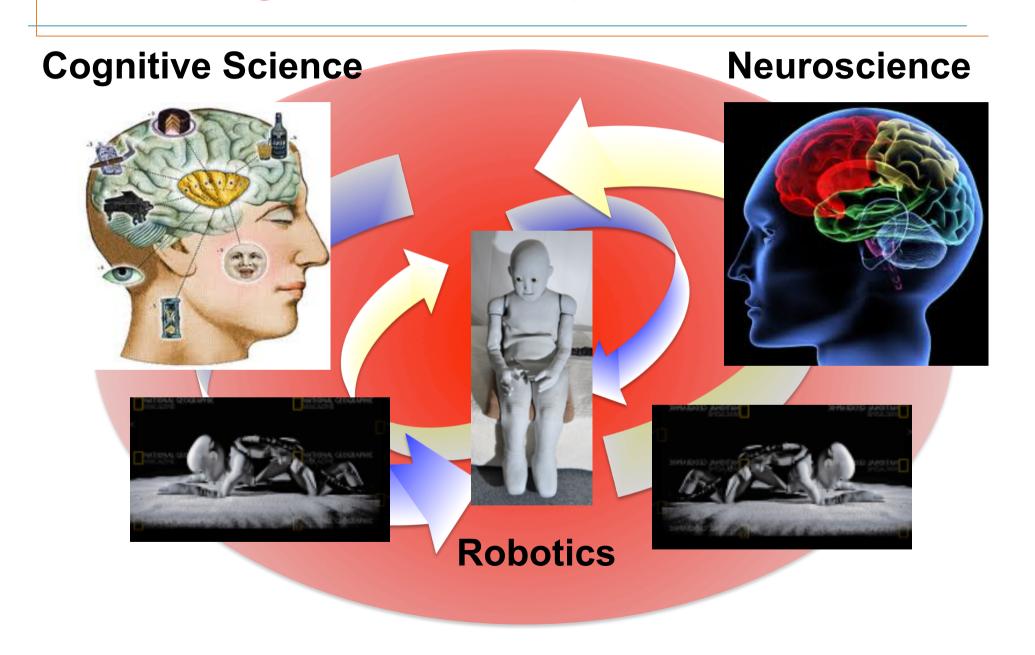
What is cognitive developmental robotics?

- 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.



[1] M. Asada et al., "Cognitive developmental robotics: a survey," IEEE Transactions on Autonomous Mental Development, 1(1):12–34, 2009.

What's cognitive developmental robotics?



What's cognitive developmental robotics?

Robots are:

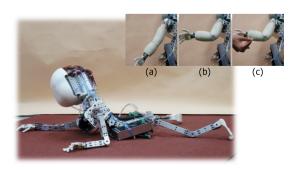
 reliable agents as controllable (reproducible) ones for psychological and social experiments,



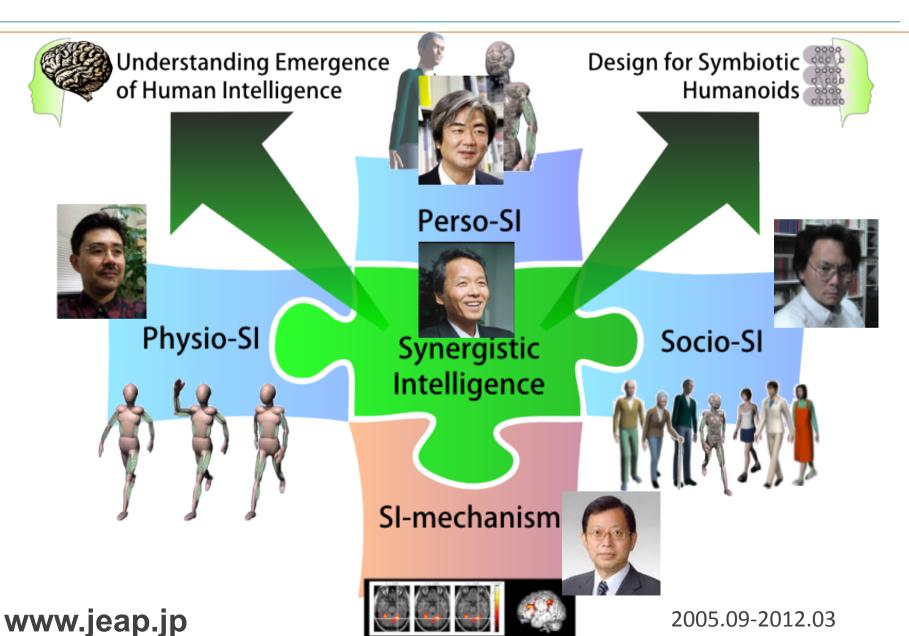


- computational models to verify the hypotheses (constructive approaches), and
- social agents in our future society.





JST ERATO Asada Synergistic Intelligence P



Our robots

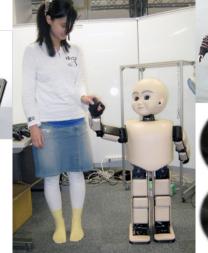
- We (JST ERATO Asada Project) have developed several kinds of robot platforms with different mechanisms, supposing different ages and research purposes.
- CB2: pneumatic actuators with whole body tactile, and other sensors. → Neony, Knidy, and Synchy, Pneuborn-7, 13: PMA, Noby: compliant body with sophisticated mech.

















Platforms for Cognitive Developmental Approaches

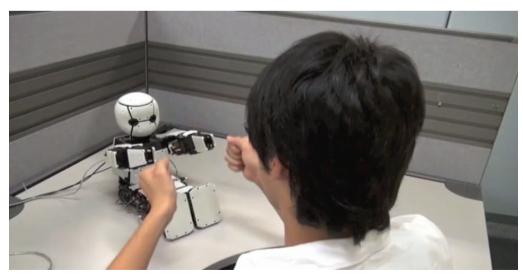


Robots in action

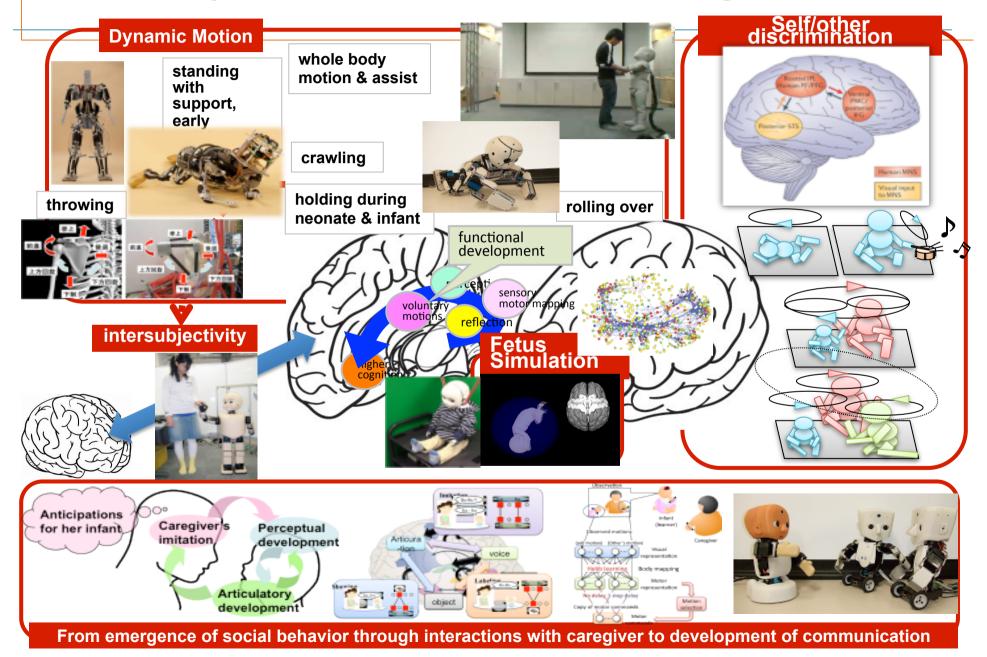








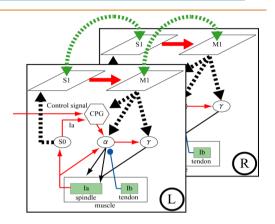
From physical interaction to cognitive one



Some examples of physical embodiment

- Fetus and Neonate simulation (extension from the last CogSys10 talk by Yasuo Kuniyoshi [Mori & Kuniyoshi 10])
- 2. Repetitive grasping with anthropomorphic skin-covered hand enables robust haptic recognition (Hosoda G. [Takamuku et al., 08])
- 3. Visual attention by saliency leads cross-modal body representation [Hikita et al., 07]

Physical embodiment changes the way to think about!

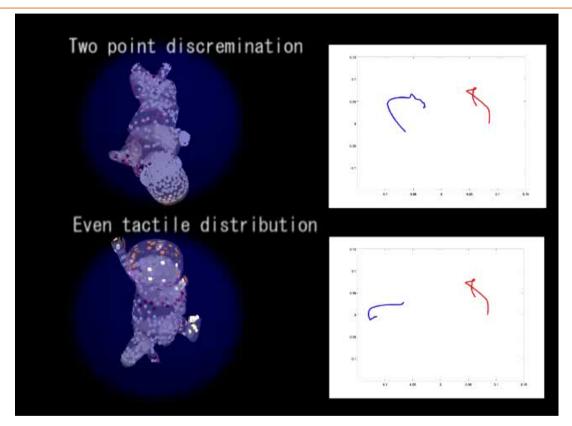




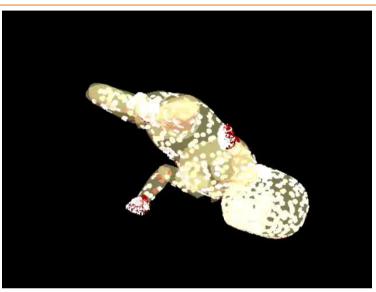


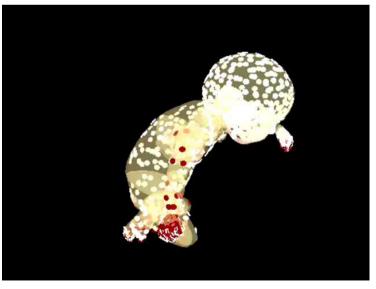
Fetus and Neonate simulation

[Mori & Kuniyoshi 10]



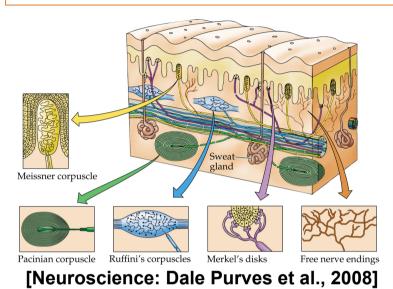
More realistic bodies have been simulated such as ones with soft skin.

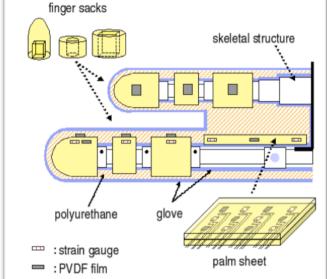




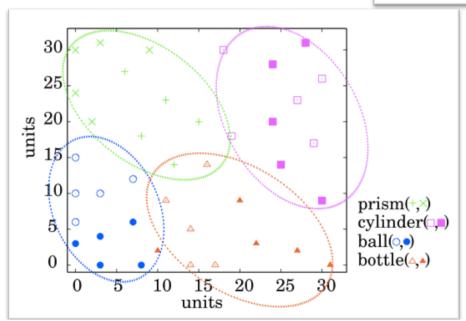
Anthropomorphic skin-covered hand

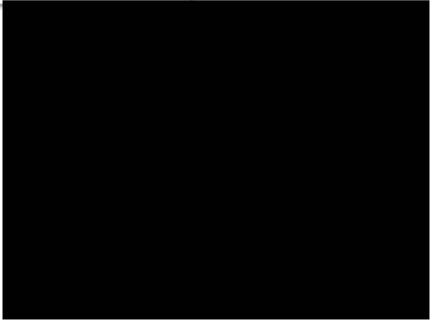
(Hosoda G. [Takamuku et al., 08])







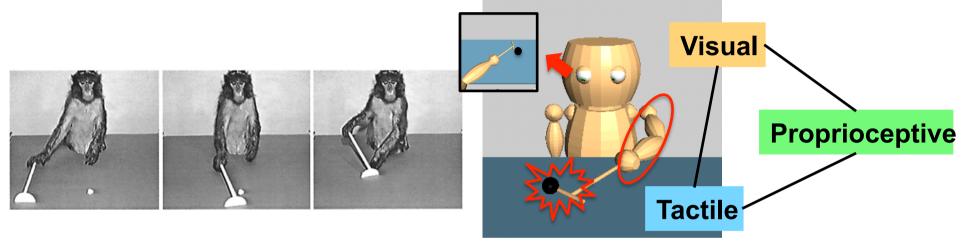




Dynamic body representation (1)

[Hikita et al., 07]

 Bimodal neuron: body image extension by tool use. [Iriki_et_al,96,01]

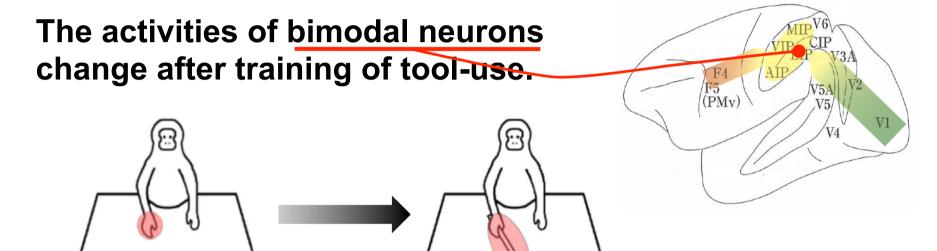


- Body scheme → unconscious, dynamic process of body control.
- Body image → conscious representation of self body.
- Interaction between external environment (vision) and body scheme.

Dynamic body representation (2)

[Hikita et al., 07]

Tool-use by the Japanese macaque [Iriki et al. 1996]



The receptive field was extended to the tool.

Before tool-use

? How such representation is acquired?

After tool-use

Proposed model

[Hikita et al., 07] The model consists of 3 modules. Integration module 3Integration module Associates the arm posture map Hebbian learning with the attention map by Hebbian Learning using a tactile sensation as a trigger Arm posture Map **Attention Map Attention** module Arm posture module **2**Attention module **Detects the visual attention point** based on Saliency Map ★Saliency Map Self Organizing Map ①Arm posture module Represents the current arm posture by Self-Organizing Map

Joint angles

Visual image

Tactile sensor

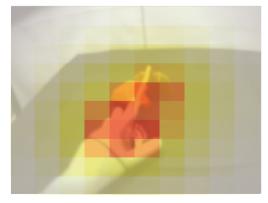
Dynamic body representation (3)

Results: Experiment with a real robot

The connection weights



With hand



With a tool



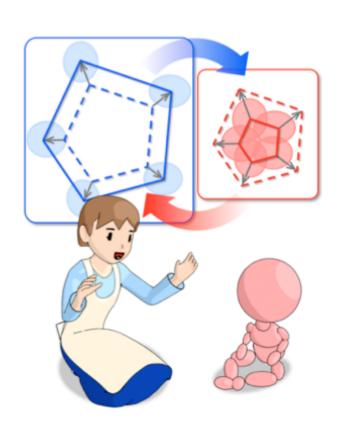


CB² (Minato et al. 2007)



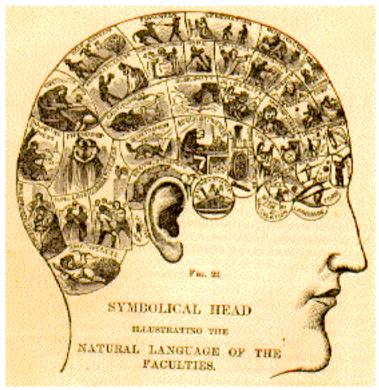
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Social development: the concept of self and mirror neuron system

- Symbolic goals of CDR are language and mind
- The development process of the concepts of self and others → from nonverbal communication to verbal one [Arbib, 2006]
- Memory and the concept of time.
- Research platform to promote CDR studies.



MNS Connects Physical Embodiment and Social Entrainment (1)

- Mirror neuron system may have an important role in the process of social behavior emergence.
- Observation and action execution

 others' behavior understanding.
- Monkey → Goal oriented (actions of transitive verbs)
- Human → plus actions of intransitive verbs





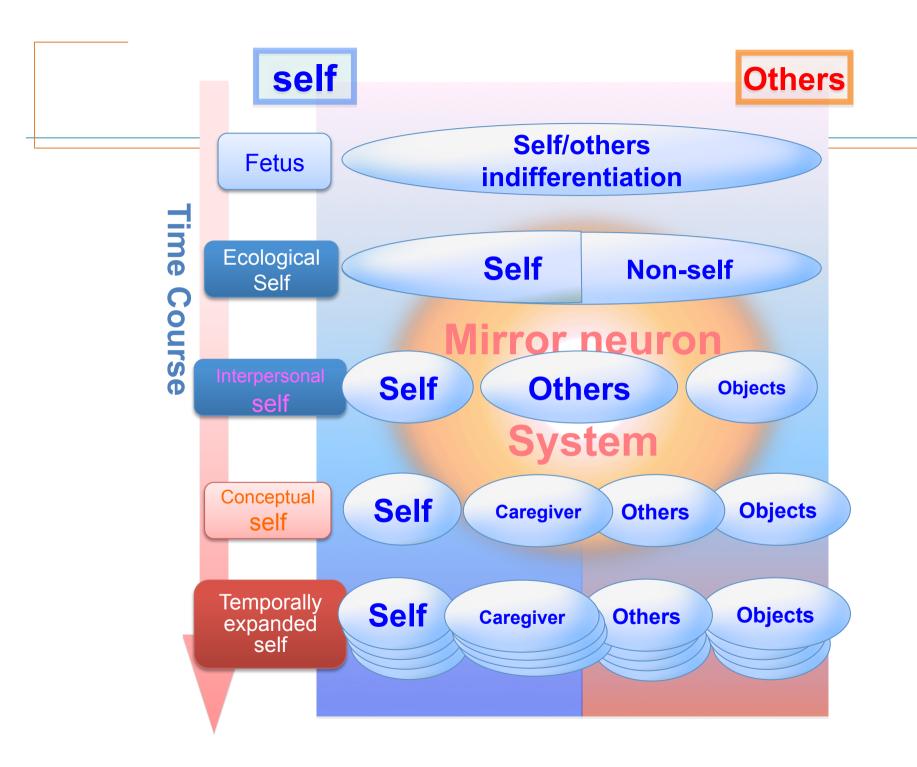
- 1. Sharing self and other's body representation
- 2. The difference between efference copy and sensory feedback → self motor perception or other's body.

MNS Connects Physical Embodiment and Social Entrainment (2)

- Mirror neuron system may have an important role in the process of social behavior emergence.
- 1) Self/others indifferenciation

[Neisser, 1993]

- 2)Self/Non-self discrimination → ecological self
- 3)Self-other-object relation → *interpersonal self*
- 4)Self-caregiver (others)-object relationship → conceptual self
- 5)Concept of time -> temporally extended self
- Mechanism for the seamless emergence of the above representation from 1) to 4) or 5). It is not necessary to have explicit representation.



MNS Connects Physical Embodiment and Social Entrainment (3)

- Be careful for too much expectation of the roles of MNS [Hickok, 2009]
- A more general and fundamental structure might be needed. → synchronization of oscillations [Yamaguchi, 2008, Taga's group, 2007, 2008, 2009]
- 1. Synchronization with environment through rhythmic motions such as beating, hitting, knocking and/or reaching behavior
- 2. Synchronization from caregivers: motherese [Kuhl, 1997] or motionese [Nagai & Rohlfing, 2009]
- 3. Desynchoronization with others

MNS Connects Physical Embodiment and Social Entrainment (4)

(1) ecological self (2) interpersonal self (3) social self

sprouting of self

self/other identification (MNS infrastructure)

Self/other separation

Synchronization with environment



Synchronization from caregiver



desynchronization from others



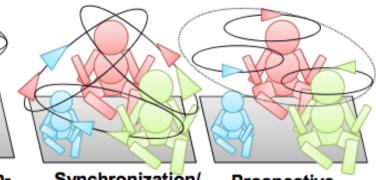
Physical body in synchronization → self/other identification Desynchronization → self/other separation

I. Synchronizing body environment Reaching

II. Synchronization initiated by caregiver



III. Synchronizing and desynchronizing bodies

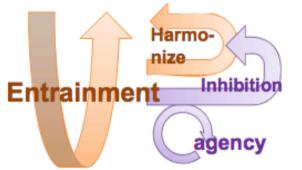


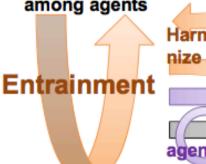
Synchronization Rhythmic with

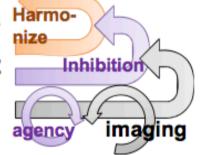
Synchronization Response, Turnmovement from caregiver imitation taking

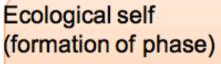
Synchronization/ **Prospective** desynchronization Synchronization among agents

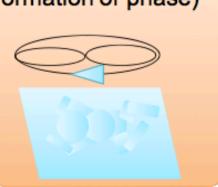


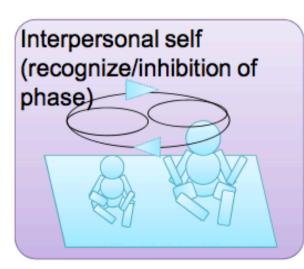


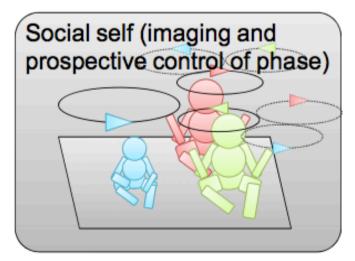












Early Development of Mirror Neuron **System** [Nagai et al., 2011, Kawai et al., 2011]

MNS [Rizzolatti & Craighero, '04] activates both when

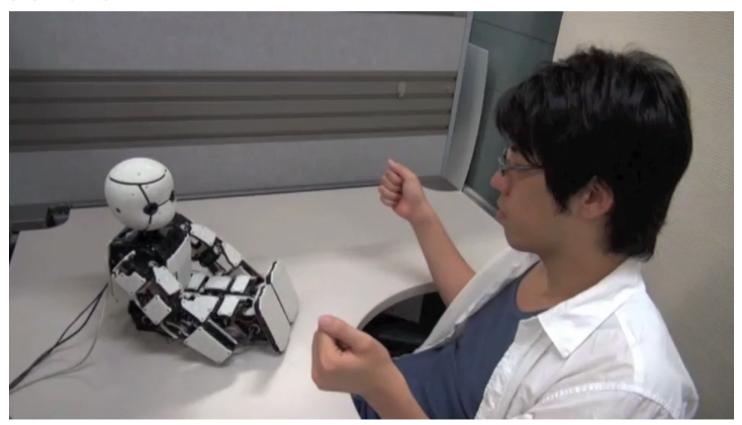
- executing an action

by others

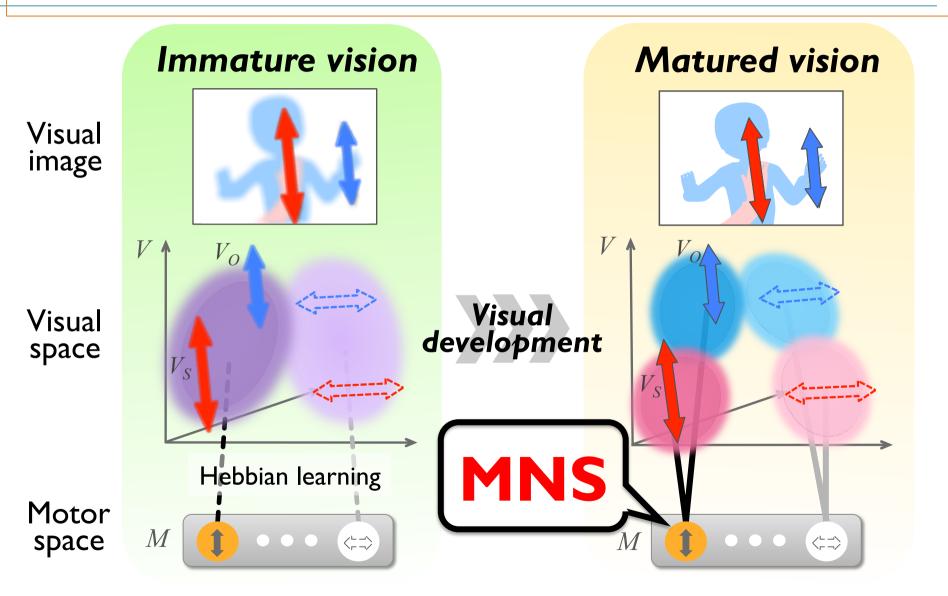


executing an action
 observing the same action

Self-other correspondence

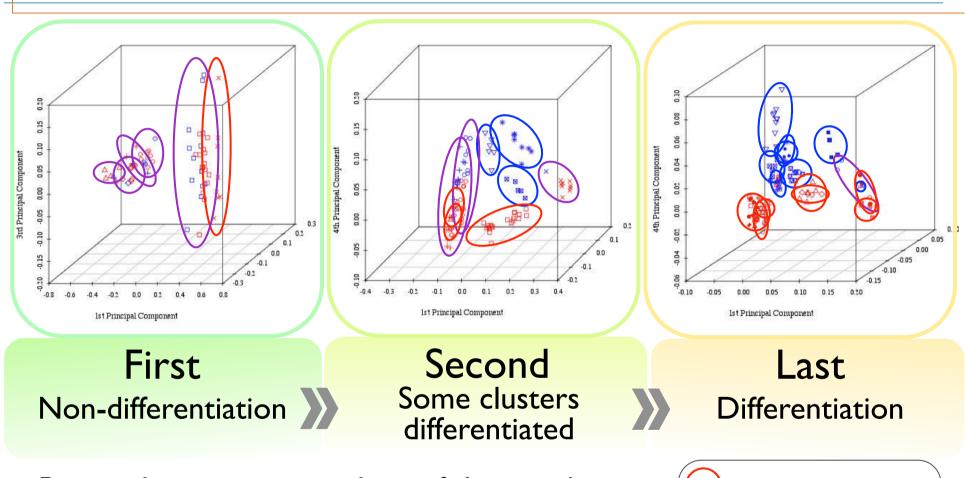


Model for emergence of the early MNS



[Nagai et al., 2011, Kawai et al., 2011]

Result (1) Self-other differentiation



Principal component analysis of the visual space in the each stage of development

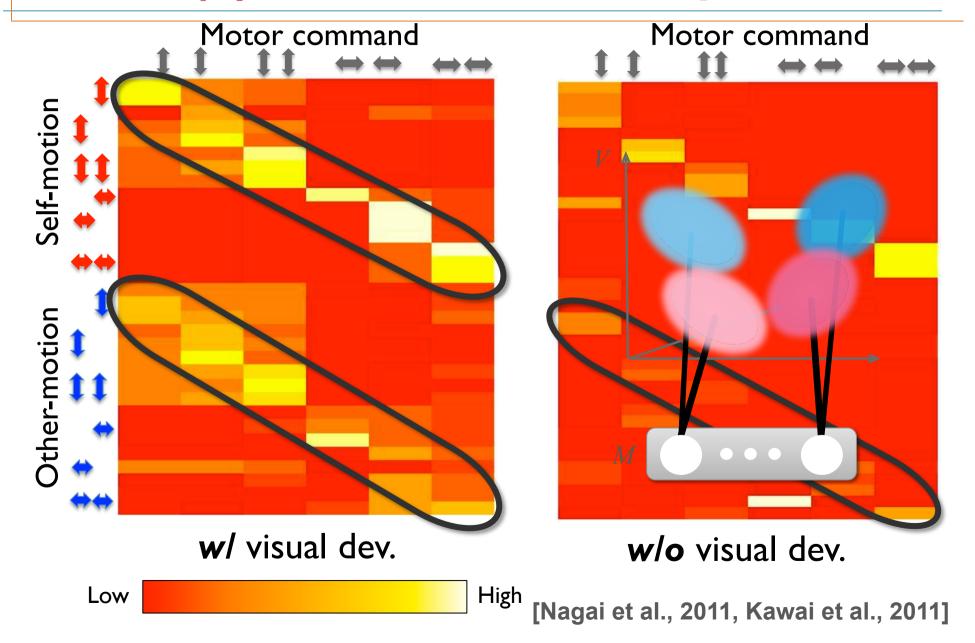
Sual space

Other

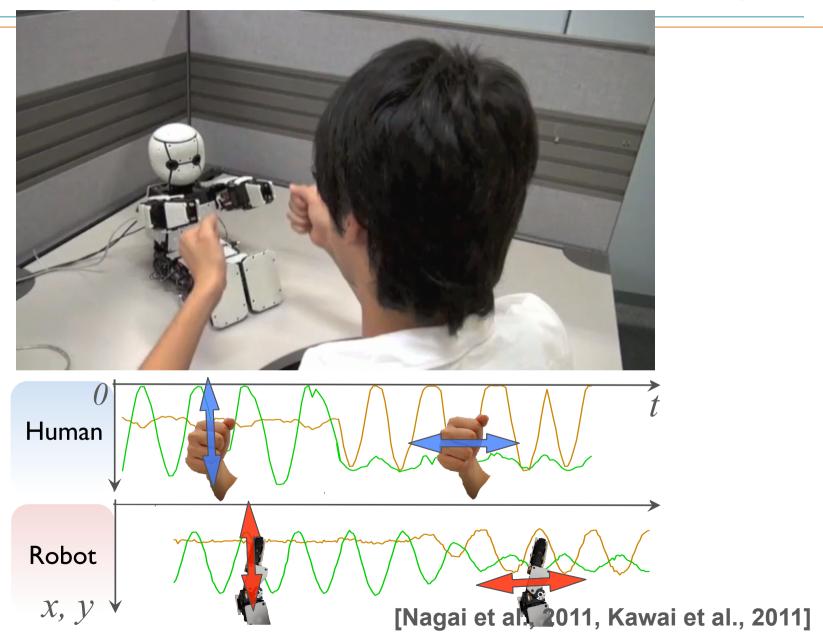
Non-differentiated

[Nagai et al., 2011, Kawai et al., 2011]

Result (2) Self-other correspondence

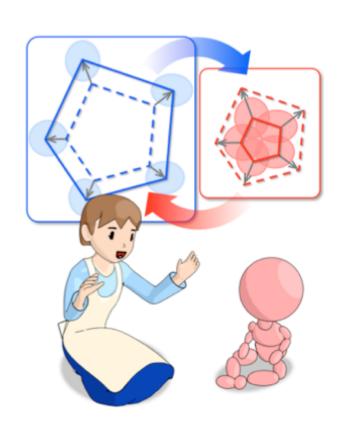


Result (3) Imitation after learning



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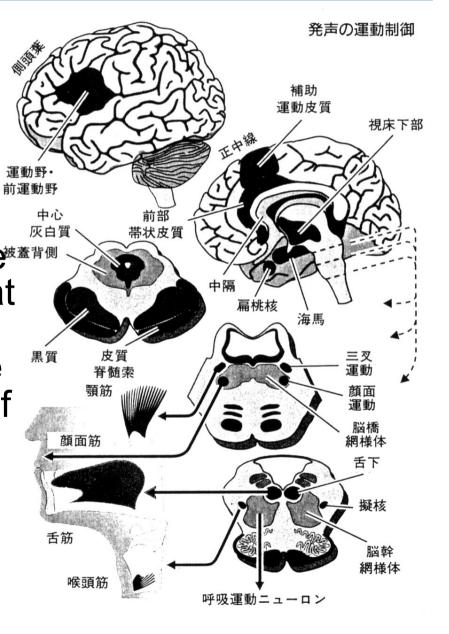
Vowel Acquisition by Maternal Imitation

- 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?

Human Vocalization [Deacon 98]

 Vocalization → the interaction of the oral and respiratory tracts → special association with midbrain systems.

 To organize vocalization → coordinated activation of the 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. → the motor neurons controlling all of these are located in the upper brain stem.

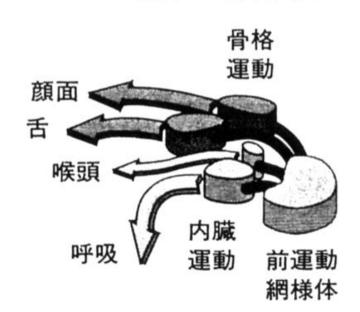


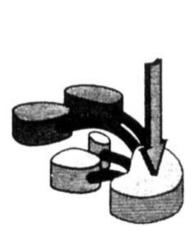
Human Vocalization [Deacon 98]

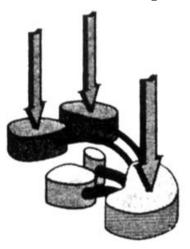
 Two evolutionary shifts producing increasing cortical control over motor output from brain stem articulatory and vocal systems. These shifts were produced by an increase in the proportions of the cerebral cortex in comparison to these brain stem structures.

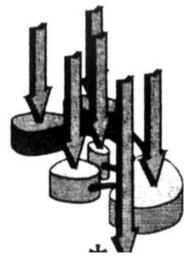
脳幹運動神経核

Cortex-brain stem projection









Non-primate

Primate

Human

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?

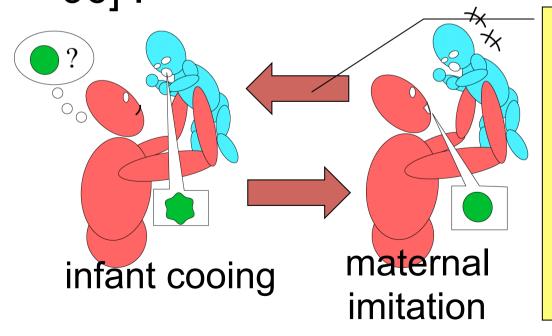
Robot's mechanism?



Caregiver's behavior?

Observations in human infants

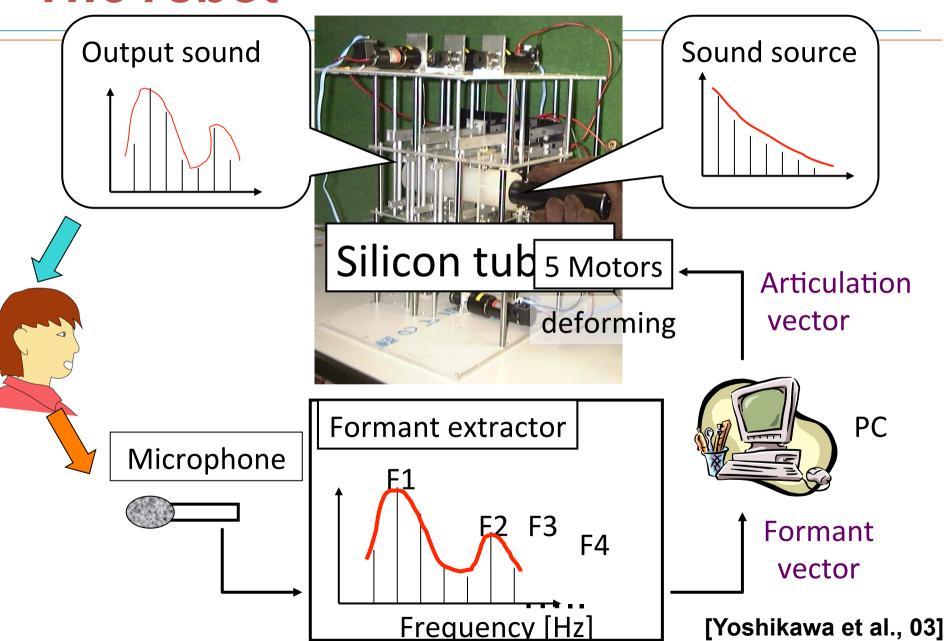
- Infant's speech-like cooing tends to make its mother utter [Masataka and Bloom'94].
- Maternal imitation of infant's cooing (i.e., parrot-like vocalization) increases vocalization rates of a three-month-infant [Pelaez-Noqueras '96].



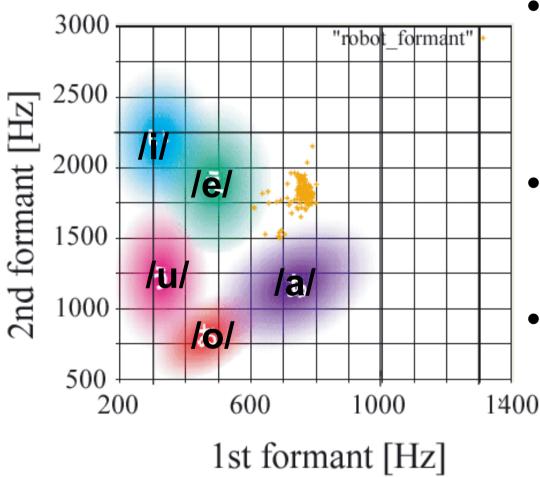
Conjectures

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

The robot



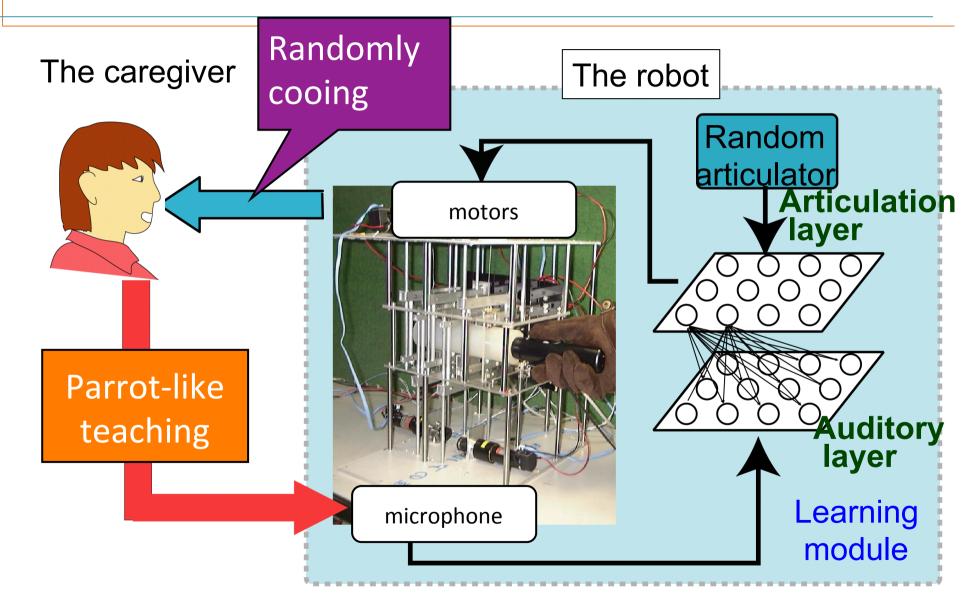
What's Formant Space?



- 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

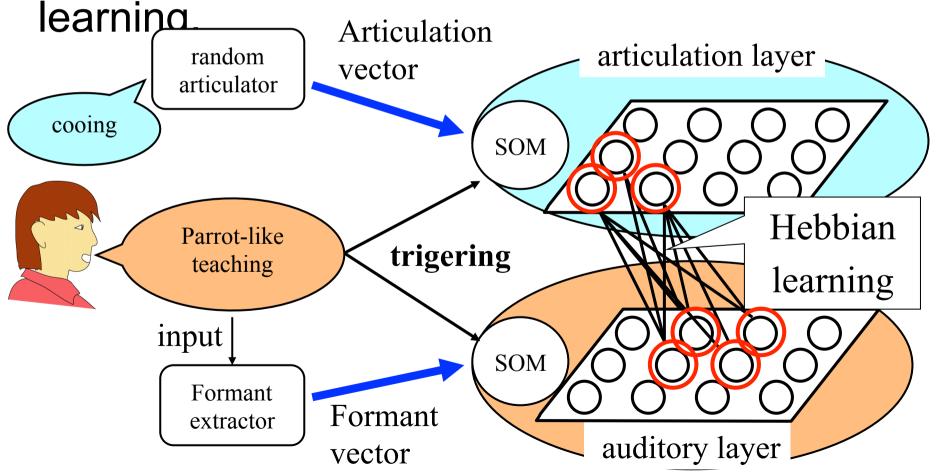


Learning mechanism

[Yoshikawa et al., 03]

 Clustering the articulation parameters and the formant vectors by the SOM algorithm.

Connections are updated based on Hebbian

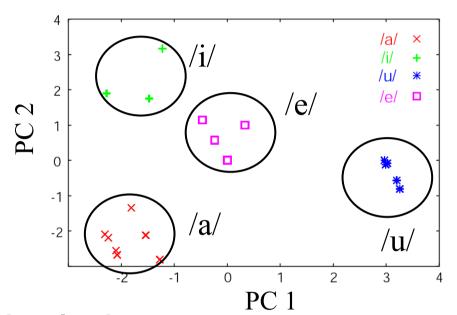


Experiment



One Japanese caregiver

Result: how does it acquire vowels? [Yoshikawa et al., 03]



The articulation vectors corresponding to the variation of the caregiver's vowels

- The vowel /o/ is not acquired due to the difference in shape of vocal tracts.
- There is "arbitrariness" in correspondence.

Introducing subjective criteria

[Yoshikawa et al., 03]

- A "<u>subjective</u>" criterion: more facile articulation is better.
 - less torque ($^{C}_{trq}$)
 - less deformation change ($^{C}_{idc}$)

Articulation layer

 w_{ij}

Auditory layer

Basic Hebbian rule

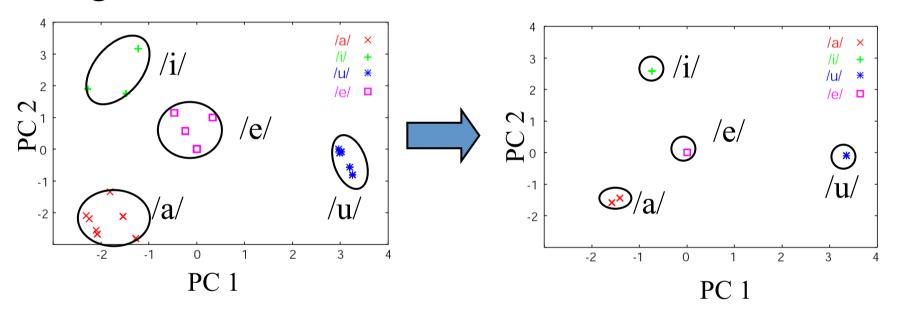
$$\Delta w_{ij} \propto a_i^f a_j^m$$



$$\Delta w_{ij} \propto \eta(c_{trq}, c_{idc}) a_i^f a_j^m$$

Result: effect of subjective criteria [Yoshikawa et al., 03]

Comparing the distribution of the articulation vectors corresponding to the variation of the caregiver's vowels



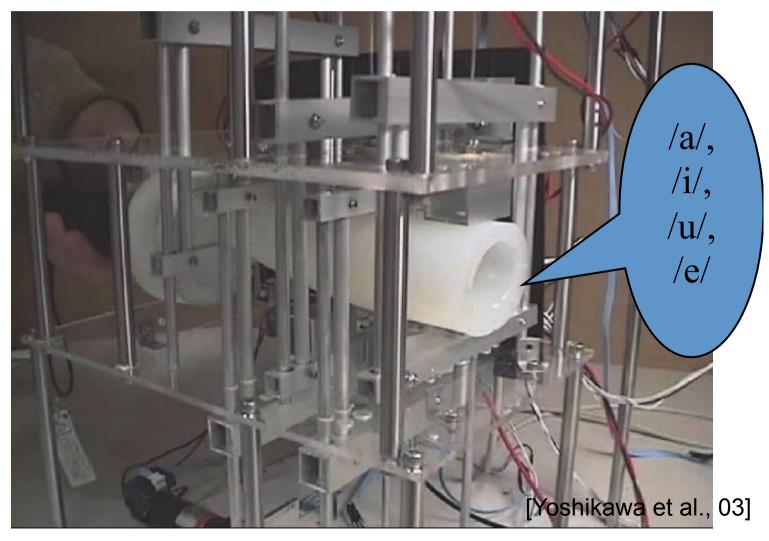
Basic Hebbian rule

Subjective criteria

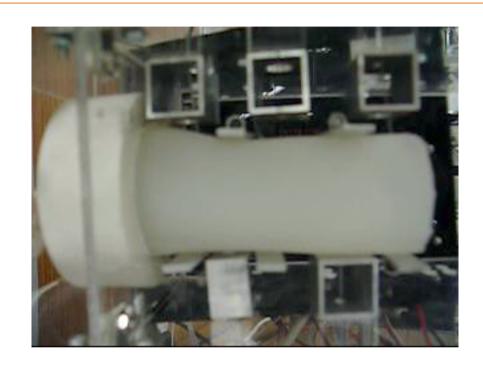
Subjective criteria can reduce arbitrariness.

Acquired vowels

 The acquired vowels can be interpreted as Japanese vowels.



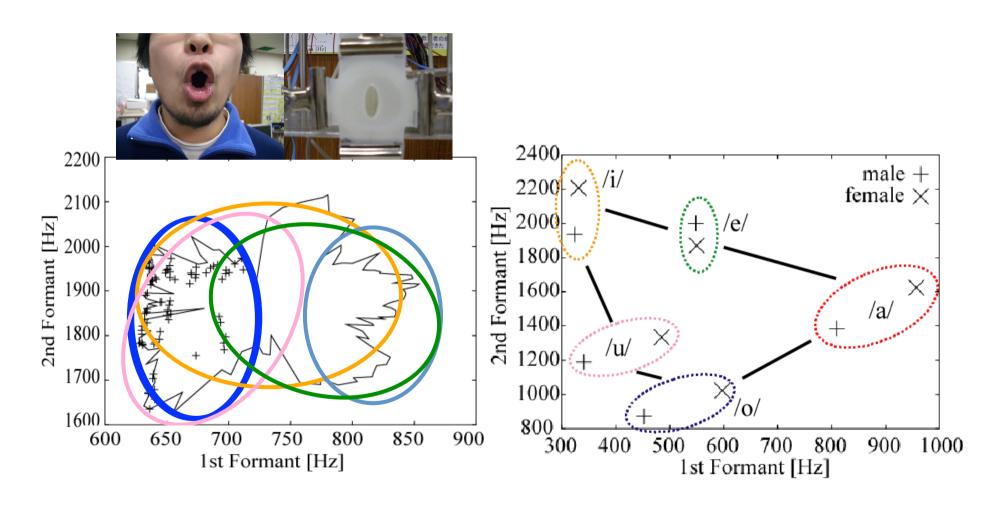
Childlike voice?





[Yoshikawa et al., 03]

Lip shape imitation



[Miura et al., 2006]

Visual imitation, too!



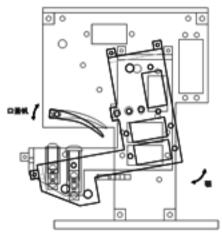
[Miura et al., 2006]

Why not using a speaker?

 Physical embodiment enables to introduce subjective criterion such as less torque and less deformation (easy to vocalize).

 We introduce respiration to realize turn taking with caregiver towards natural interaction → now we are designing more realistic infant vocal robot with artificial lung.







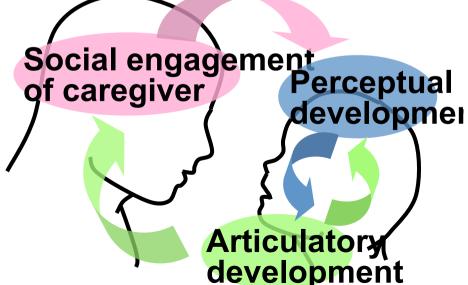
Infant's Vowel Development

[Ishihara et al., 08.09]

- Sharing process of perceptual & behavioral primitives between a caregiver and her infant across their different bodies
 - Physical quantities of their producible vowels are different [Vorperian & Kent.'07]

Infants' audition [Polka & Werker.'94] & articulation [Kuhl & Meltzoff.'96] adapt to mother-tongue (become native)

 Dynamic process including intrapersonal interaction
 & social interaction
 [Kuhl et al.'08]

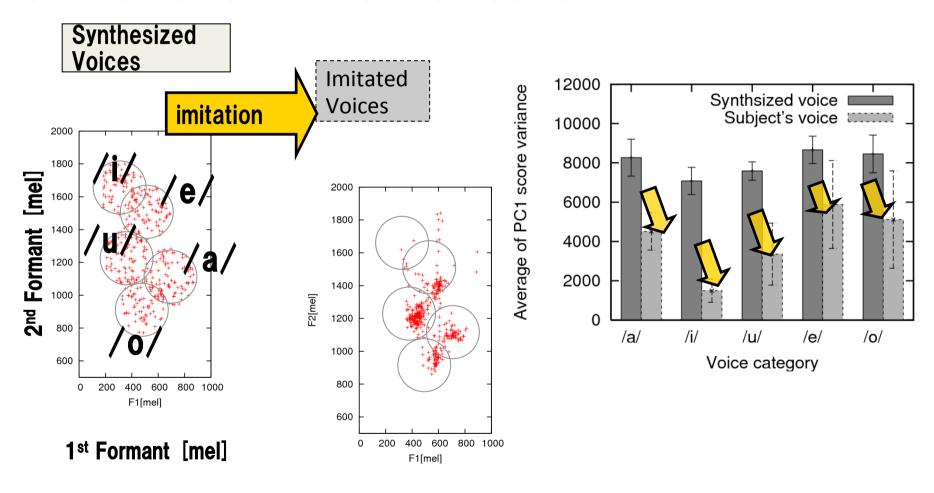


Caregiver's Sensorimotor Magnets Lead Infant's Vowel Acquisition through Auto Mirroring [Ishihara et al., 08.09]

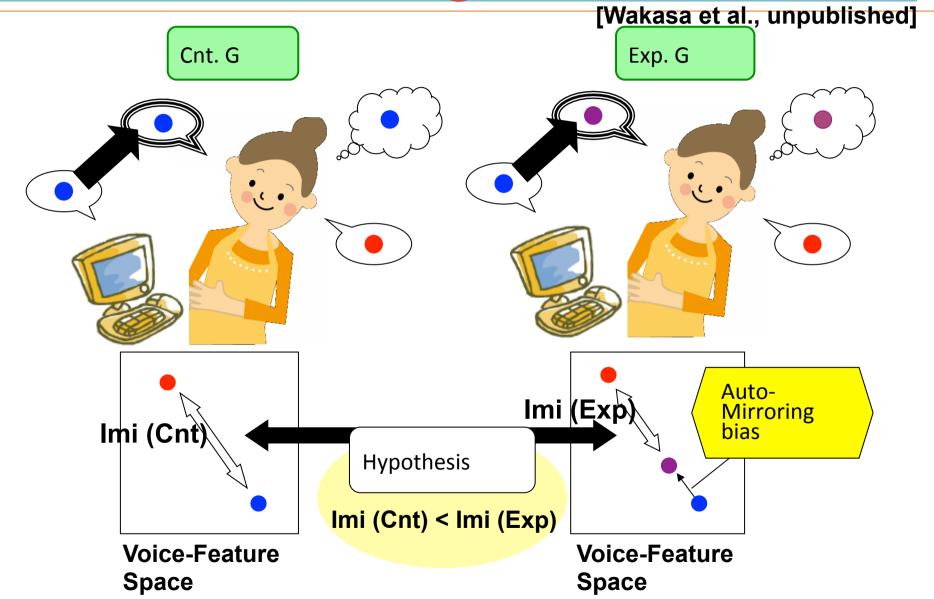
- A method that aids unconscious guidance in mutual imitation for infant development based on a biasing element with two different kinds of modules.
- 1. The normal magnet effect in perceiving heard vocal sounds as the listener's own vowels (perceptual magnet) and also includes another magnet effect 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

How humans imitate the sound?

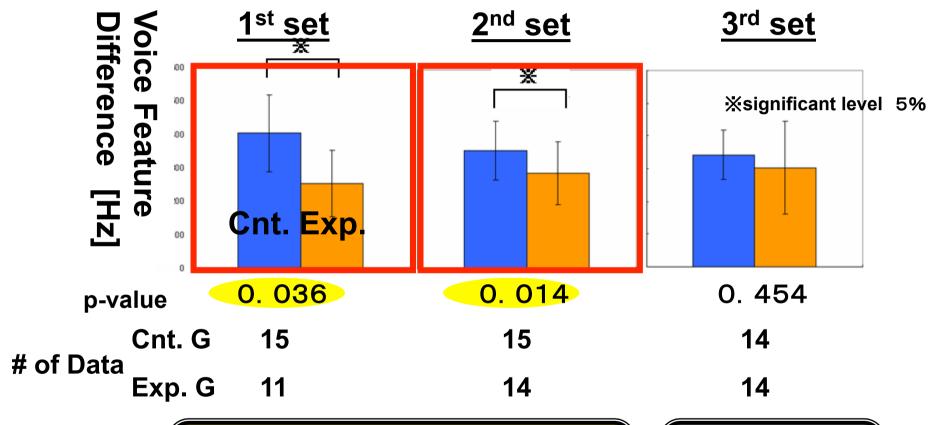


Psychological experiment for auto-mirroring bias



Psychological experiment for auto-mirroring bias

[Wakasa et al., unpublished]



Significant difference

Auto-mirroring bias exists!

No significant difference

Concentration level down

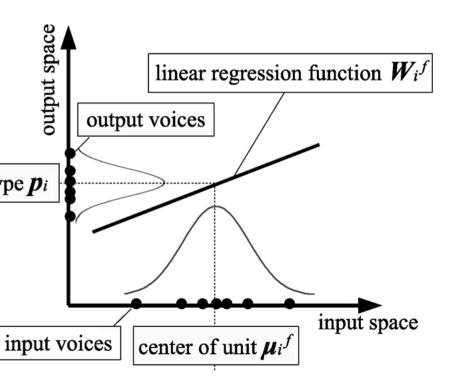
Automirroring and magnet biases

[Ishihara et al., 08, 09]

• Automirroring Bias Module: Other's voice s(t) is biased to automirroring anticipation $s^g(t-1)$ and converted to $s^b(t)$ that is given by:

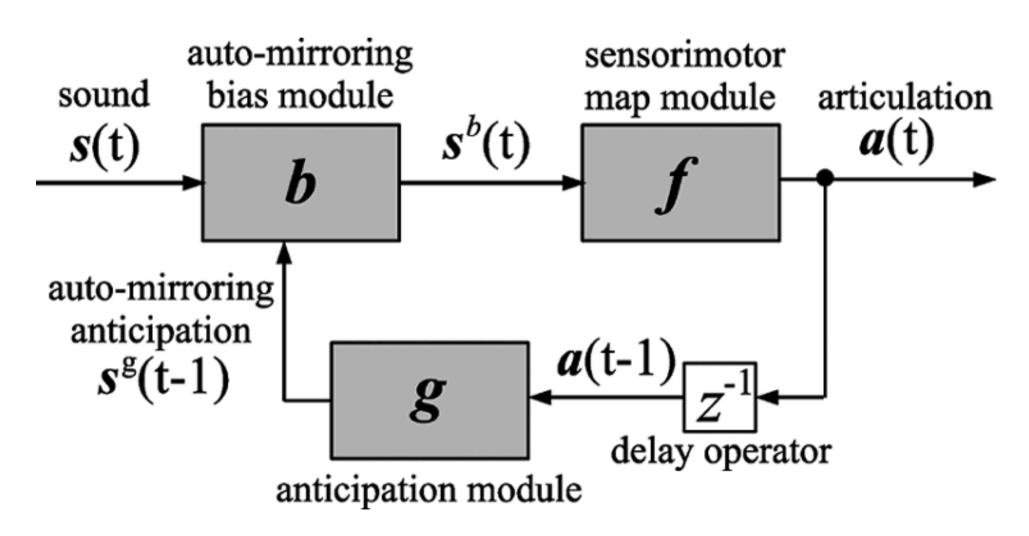
$$s^{b}(t) = s(t) + \alpha (s^{g}(t-1) - s^{b}(t)) (0.0 \le \alpha \le 1.0)$$

• Sensorimotor Map Module: We use the normalized Gaussian network (NGnet) to map the other's vowel prototype pi utterable vowel region onto the listener's own.



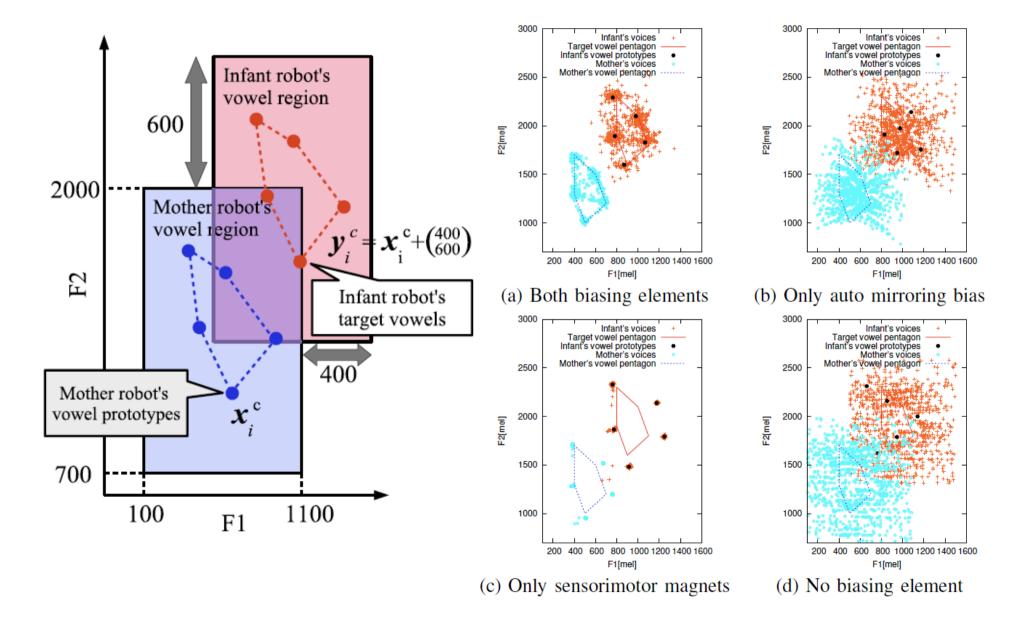
Proposed imitation mechanism with biases

[Ishihara et al., 08, 09]



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

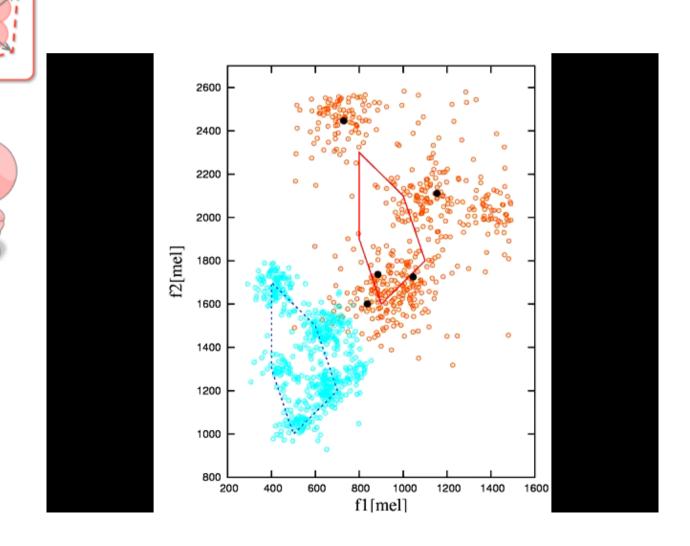
[Ishihara et al., 08, 09]

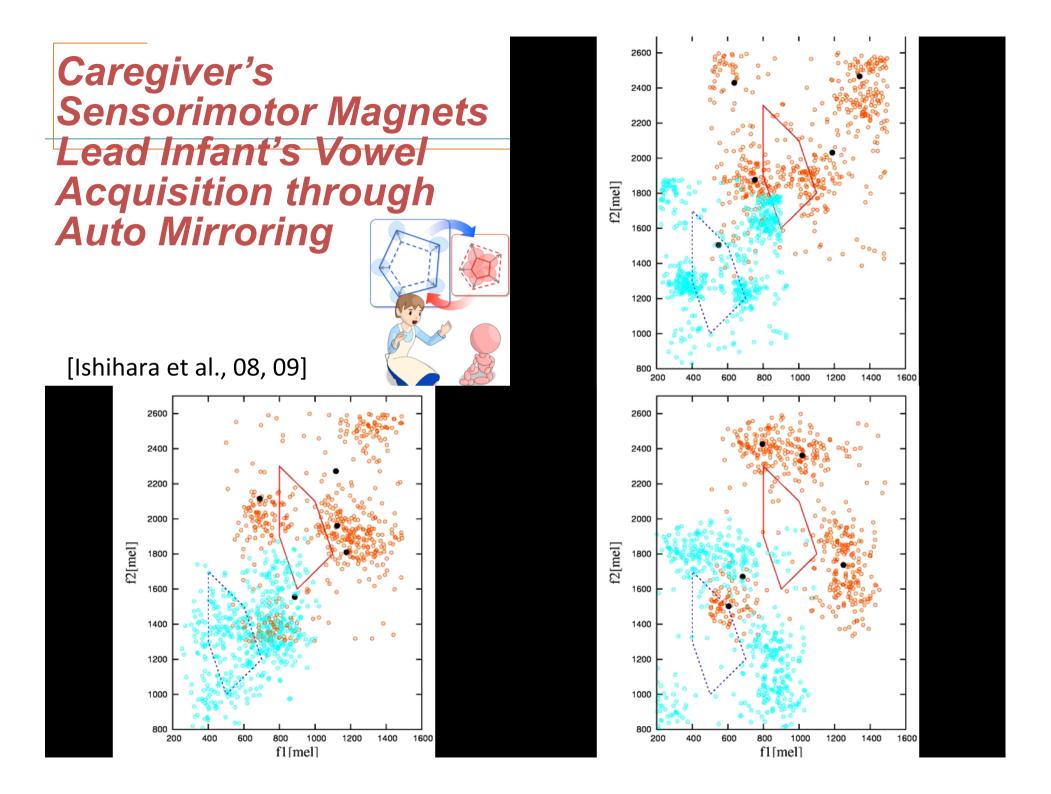


Caregiver's Sensorimotor Magnets Lead Infant's Vowel Acquisition through Auto Mirroring

[Ishihara et al., 08, 09]

With both biases



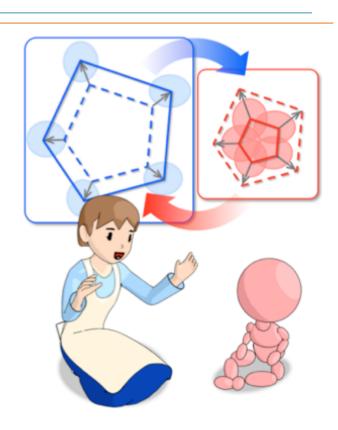


Outline of my talk

- 1. How do humans and humanoids develop?
- 2. What's cognitive developmental robotics?
- 3. How do the concept of self and mirror neuron system develop?
- 4. How do infants vocalize vowels?

5. Future issues

- 1. Theoretical foundation
- 2. Connection/interaction in infants and robots
- 3. More realistic infant robot

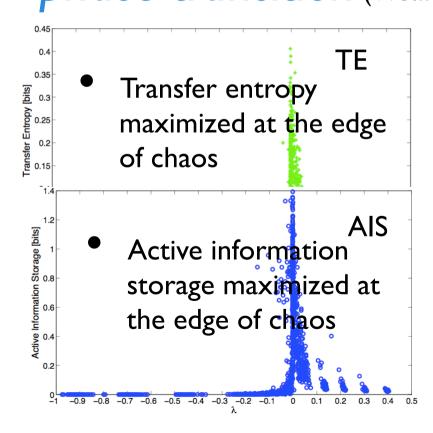


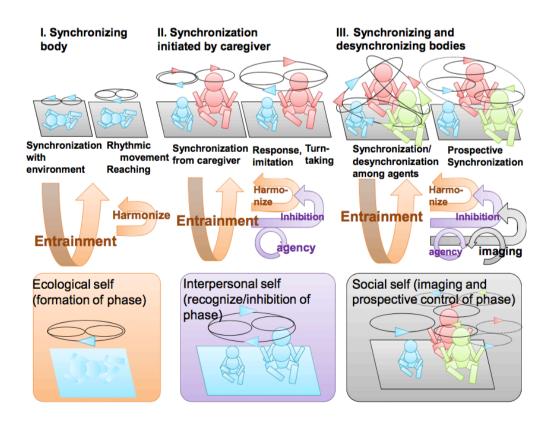
Edge of chaos and reservoir computing

Conjecture

[Boedecker et al., 2011]

Computational capabilities of a dynamical system are maximized at the order-chaos bhase transition (Wolfram, 1984), (Langton, 1990), or (Kauffman, 1993)





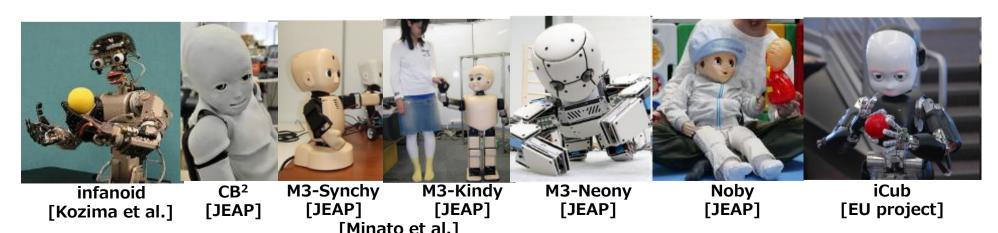
How are different systems connected and how do they interact?

- "Distance errors" and "Scale errors" are examples showing disintegration of perception-action systems at 12 months and at 18 months.
- Such errors in infants' development reveal how different systems are connected and how they interact, and give the hints for their constructive models. We propose a general model to explain the developmental process considering these errors.

Please visit the poster by Beata J. Grzyb et al.!

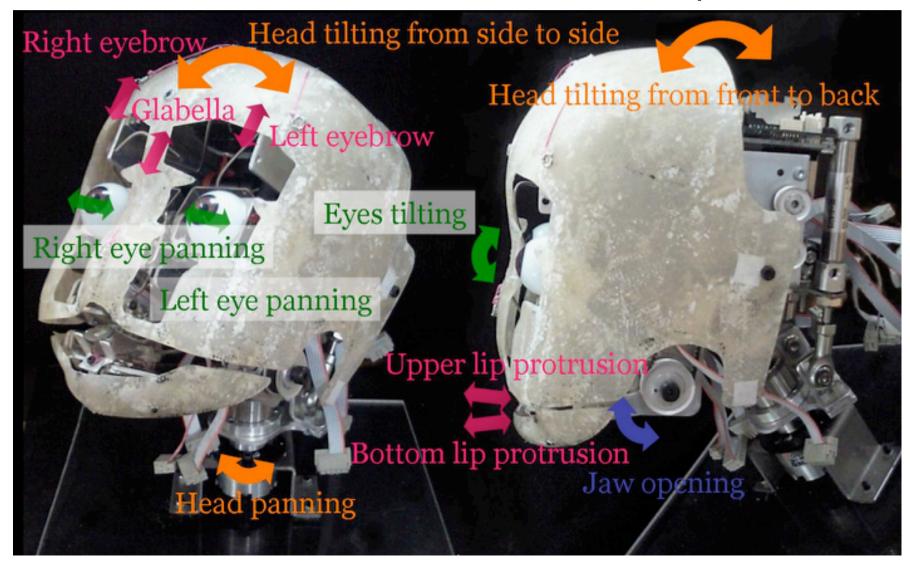
Mutual attachment in caregiver-child relationship (1) [Ishihara et al., 2011]

- A number of theoretical models → to understand developmental of caregiver-child attachment
- Several child robots → no realistic
- What kinds of treatment robots could receive from the "caregivers" appears to depend on what kinds of impression the robots give to their caregivers.
- Therefore, more realistic robots more close to a real children are needed. Affetto, that has realistic appearance of 1- to 2-year-old child



Mutual attachment in caregiver-child relationship (2) [Ishihara et al., 2011]

Affetto: a child robot with realistic facial expressions



Mutual attachment in caregiver-child relationship (3) [Ishihara et al., 2011]

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

AFFETTO:

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

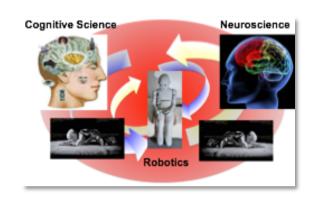
Hisashi Ishihara Yuichiro Yoshikawa Minoru Asada

Osaka Univ., Japan/JST ERATO Asada Project /Japan Society for the Promotion of Science

www.youtube.com/watch?v=Quai3SpKD08

Summary

- Cognitive developmental robotics is a promising approach to new science of human cognition with design theory.
- Physical embodiment and social interaction are keys for robots (infants) to develop their cognitive functions.
- Designing robots and their environments as close as humans' produces new research issues to be attacked.







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 - Assoc. Prof. Yukie Nagai
 - Yuji Kawai (M1)
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