ISSA Summer School 2015@Kobe

Artificial Empathy:

Affective and Cognitive Developmental Robotics

Minoru Asada
7th division head of IAI
Adaptive Machine Systems
Osaka University

August 10th, 2015@Center for Planetary Science

Constructive Developmental Science
Based on Understanding the Process
from Neuro-Dynamics to Social Interaction

2012 - 2016
JSPS Grant-in-Aid
for Specially Promoted Research

Introduction of myself

- Prof. of Osaka Univ., Grad. Sch. Of Eng. (1995~) ***www.er.ams.eng.osaka-u.ac.jp***
- Research director of JST ERATO (**E**xploratory **R**esearch for **A**dvanced **T**ech**no**logy) Asada Project (2005-11) ***www.jst.go.jp/erato/asada/***
- The former president of RoboCup Federation (2002-8) ***www.robocup.org***
- PI for JSPS Grand-in-Aid for Specially Promoted Research (2012-17) ***www.er.ams.eng.osaka-u.ac.jp/asadalab/tokusui/index_en.html***
- Board member of Japanese Society of Baby Science ***www.childresearch.net/BABY/index.html***



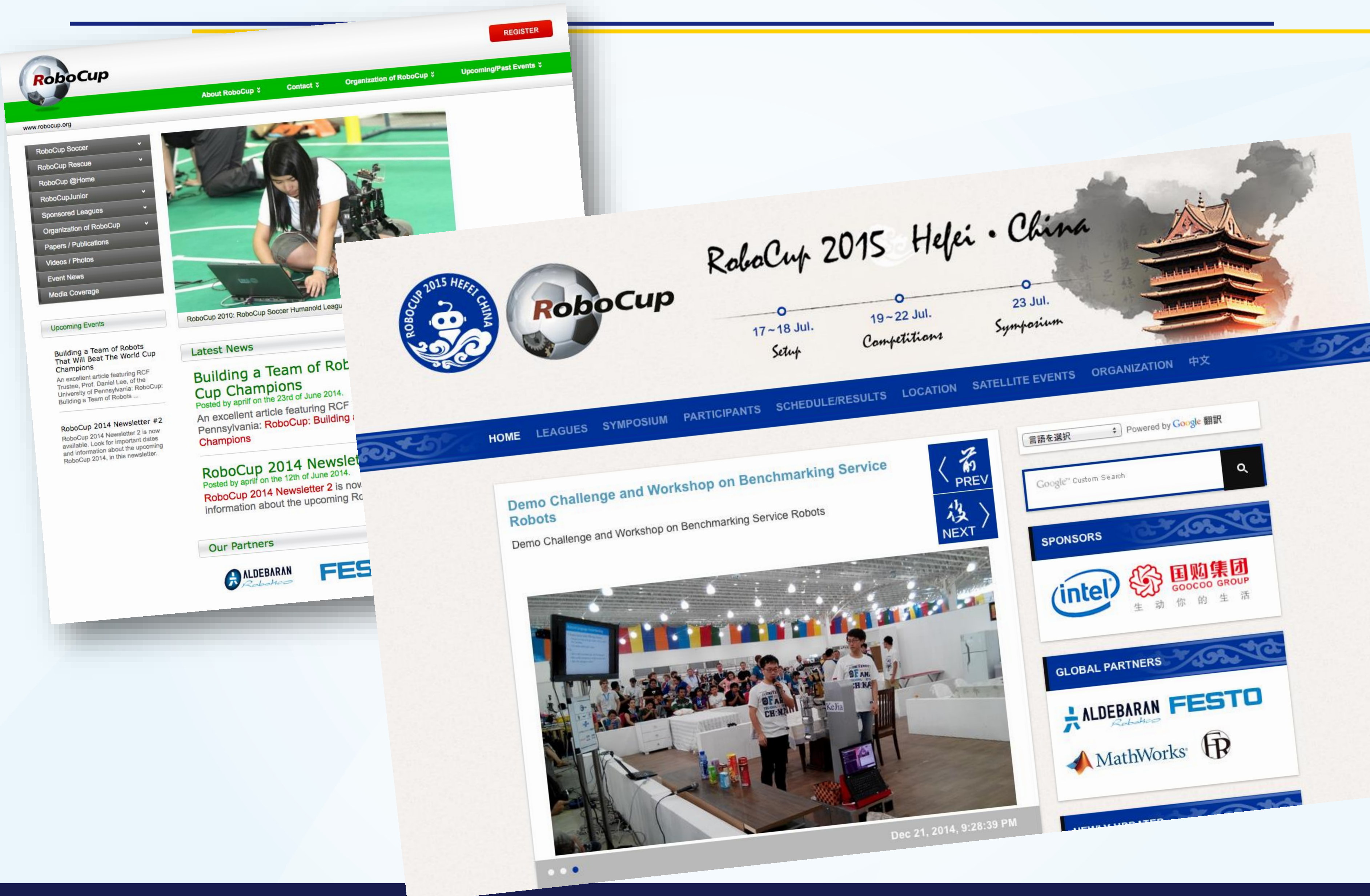
Acknowledgement

- JST ERATO Asada Project (2005-2011).
- Grants-in-Aid for Scientific Research (Research Project Number: 24000012: 2012-2017).

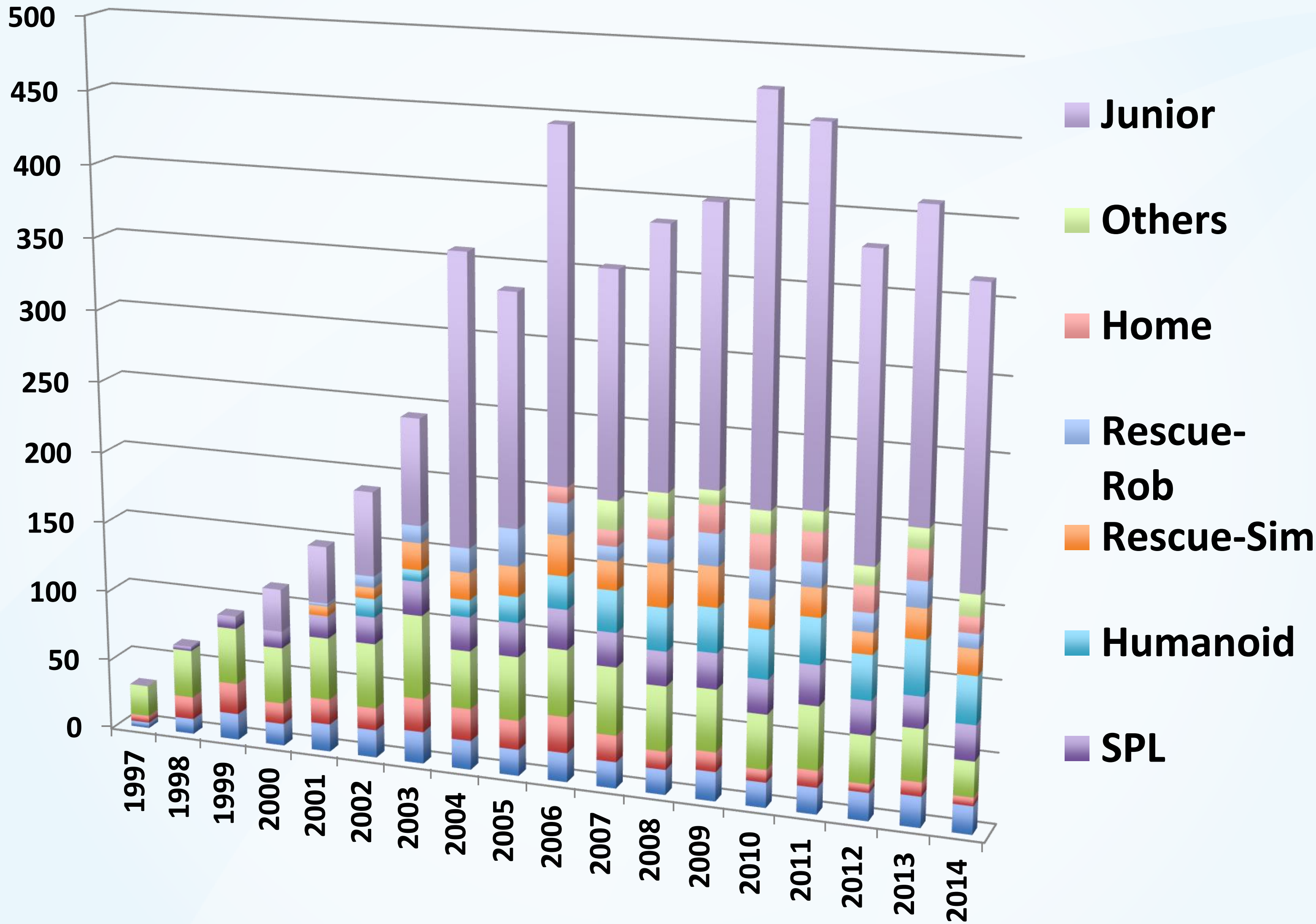
✧ Members of the above projects

✧ Members of my lab.

RoboCup (www.robocup.org)



Number of teams in RoboCups



JoiTech got the best humanoid award!

- In RoboCup 2013, "***JoiTech***", a RoboCup joint team with Osaka University and Osaka Institute of Technology got a win!

http://www.flickr.com/photos/robocup2013/9177211488/in/photostream/

RoboCup2013 Digest!

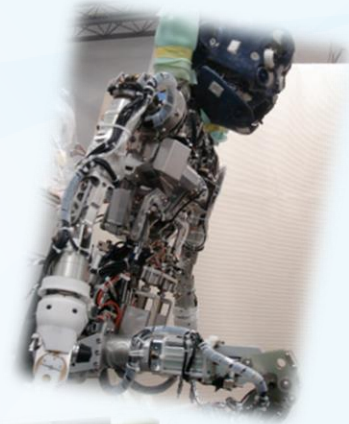
https://www.youtube.com/watch?feature=player_embedded&v=zcDsYD6GJos

From the web ISSA summer school

We are using the notion of awareness in a broad sense: we include consciousness in general as well as self-awareness, and responsiveness of autonomous agents in complex systems to each other and to their environment. We thus include neuroscience; cognitive science; artificial intelligence; artificial life and ***robotics***; logic and philosophy, in particular phenomenology. We also include high performance computing and other techniques and methodologies, useful in the areas mentioned above.

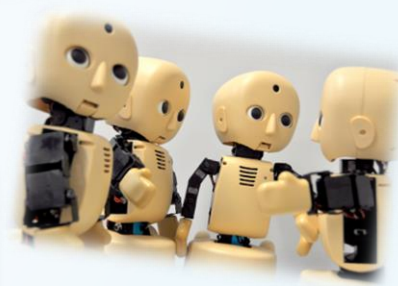
What does robotics mean in my talk?

1. **Design theory**: constructive approaches to the cognitive issues by utilizing virtual and real robots.



2. **Developmental aspects**: not given a priori but obtaining through learning and development as much as possible!

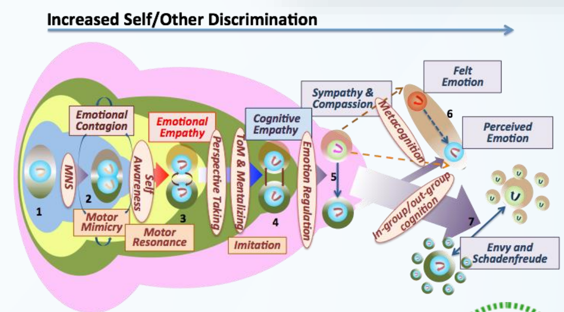
3. **Robots as tools** for studying humans' behaviors and minds

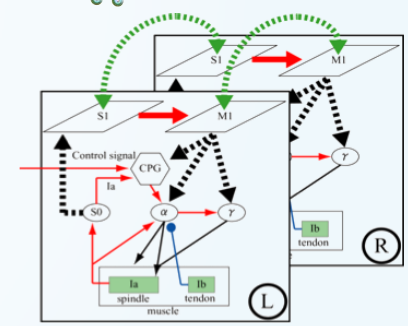


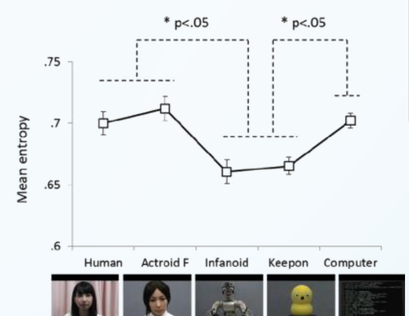
- **Cognitive vs. Affective** issue towards artificial empathy

Outline of my talk

1. **Cognitive Developmental Robotics**
   - What's development?
   - Developmental Robotics,
     Cognitive Developmental Robotics
2. **Towards Artificial Empathy**
   - Self/other cognition
   - A developmental model
   - Cognitive vs. Affective
3. **Brain-Body Interaction**
4. **Mind Holder and Mind Reader**
5. **Future issues**







What's human's development ?

Elementary school

UM

When I was a baby…

1997.8

Junior high school

High school

2009.6.5@Shanghai

What's going on in the womb?

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

26 weeks

36 weeks

Infant development and learning targets (1)

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 (2)

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

Nature vs. Nurture ?

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

Matt Ridley

No longer is it nature-versus-nurture, but nature-via-nurture.

[From Scientific American]

- A balance between nature (embedded) and nurture (learning and development) sides is an issue in designing humanoids.

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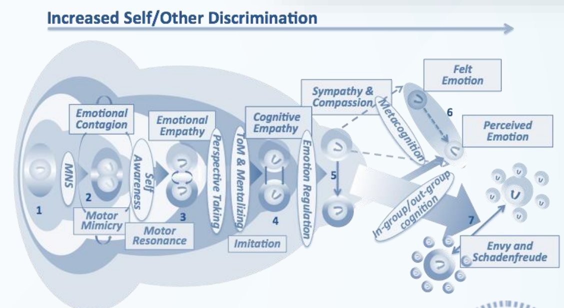
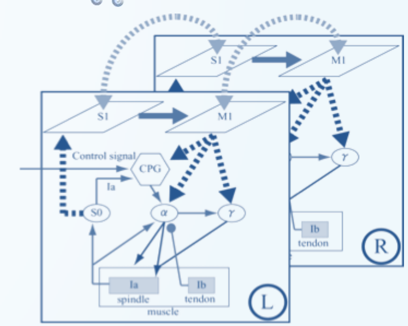
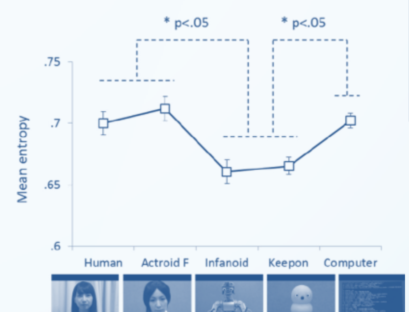
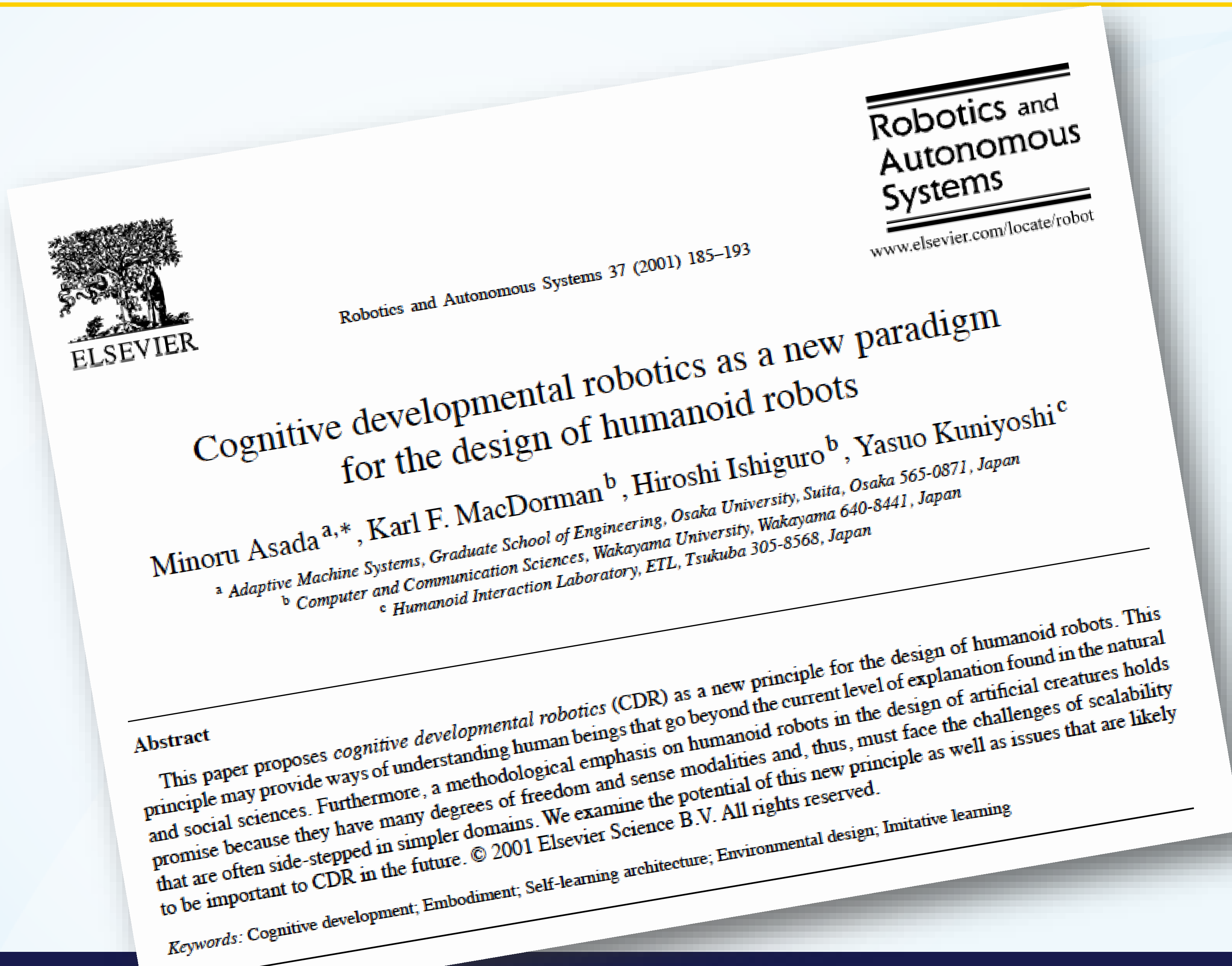






Cognitive Developmental Robotics (1)

[Asada et al., 2001]



Robotics and Autonomous Systems 37 (2001) 185–193

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Robotics and Autonomous Systems

www.elsevier.com/locate/robot

Cognitive developmental robotics as a new paradigm for the design of humanoid robots

Minoru Asada [a,*], Karl F. MacDorman [b], Hiroshi Ishiguro [b], Yasuo Kuniyoshi [c]

[a] *Adaptive Machine Systems, Graduate School of Engineering, Osaka University, Suita, Osaka 565-0871, Japan*
[b] *Computer and Communication Sciences, Wakayama University, Wakayama 640-8441, Japan*
[c] *Humanoid Interaction Laboratory, ETL, Tsukuba 305-8568, Japan*

Abstract

This paper proposes *cognitive developmental robotics* (CDR) as a new principle for the design of humanoid robots. This principle may provide ways of understanding human beings that go beyond the current level of explanation found in the natural and social sciences. Furthermore, a methodological emphasis on humanoid robots in the design of artificial creatures holds promise because they have many degrees of freedom and sense modalities and, thus, must face the challenges of scalability that are often side-stepped in simpler domains. We examine the potential of this new principle as well as issues that are likely to be important to CDR in the future.

Keywords: Cognitive development; Embodiment; Self-learning architecture; Environmental design; Imitative learning

Developmental Robotics (1)

[Lungarella et al., 2003]




Connection Science, Vol. 15, No. 4, December 2003, 151–190

Taylor & Francis
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Developmental robotics: a survey

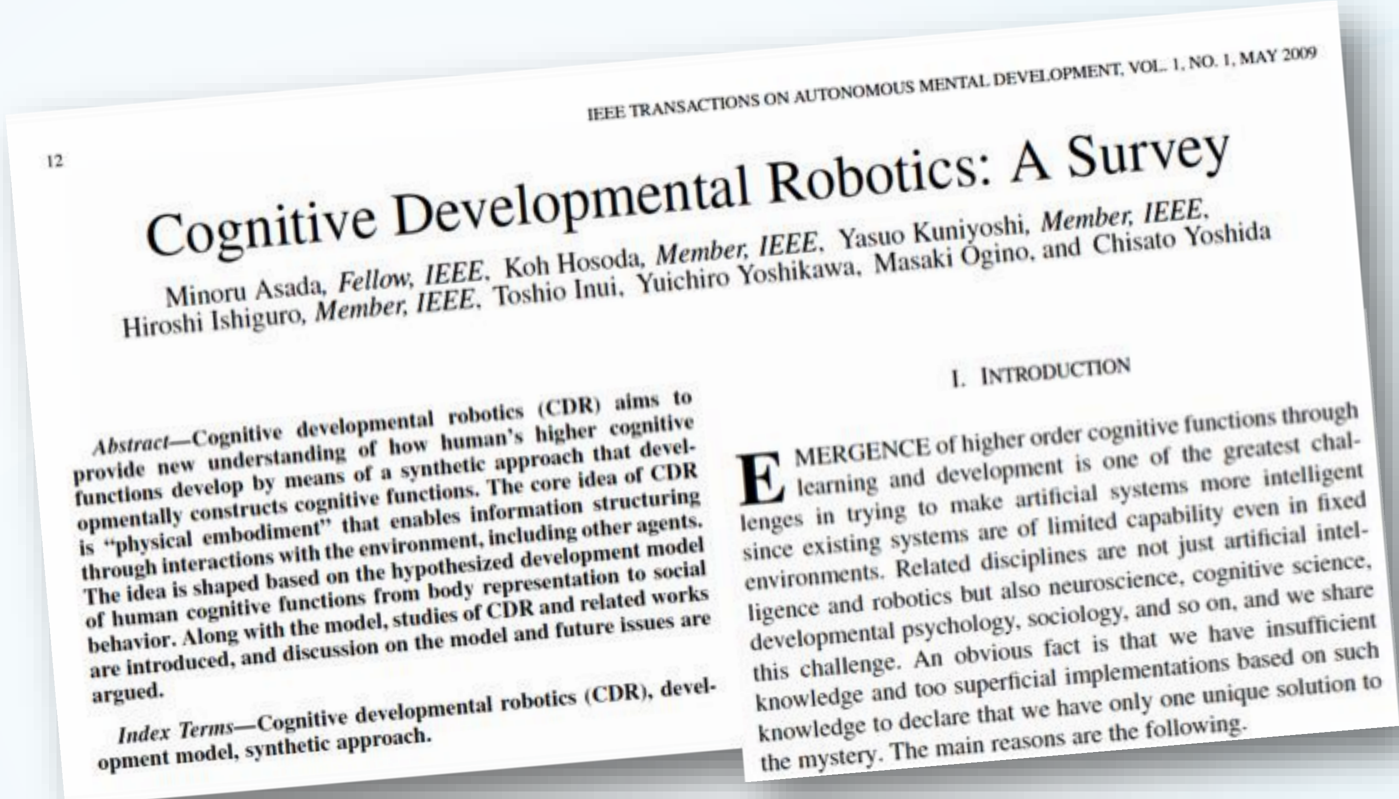
Max Lungarella*, Giorgio Metta[†], Rolf Pfeifer[‡] and Giulio Sandini[†]
**Neuroscience Research Institute, Tsukuba AIST Central 2, Japan*
[†]*LIRA-Lab, DIST, University of Genova, Italy*
[‡]*Artificial Intelligence Laboratory, University of Zurich, Switzerland*
email: max.lungarella@aist.go.jp, pasa@dist.unige.it

Abstract. Developmental robotics is an emerging field located at the intersection of robotics, cognitive science and developmental sciences. This paper elucidates the main reasons and key motivations behind the convergence of fields with seemingly disparate interests, and shows why developmental robotics might prove to be beneficial for all fields involved. The methodology advocated is synthetic and two-pronged: on the one hand, it employs robots to instantiate models originating from developmental sciences; on the other hand, it aims to develop better robotic systems by exploiting insights gained from studies on ontogenetic development. This paper gives a survey of the relevant research issues and points to some future research directions.

Keywords: development, embodied cognitive science, robotics, synthetic methodology

Cognitive Developmental Robotics (2)

[Asada et al., 2009]



12 IEEE TRANSACTIONS ON AUTONOMOUS MENTAL DEVELOPMENT, VOL. 1, NO. 1, MAY 2009

Cognitive Developmental Robotics: A Survey

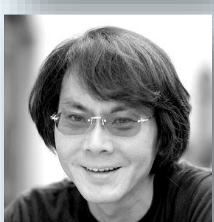
Minoru Asada, *Fellow, IEEE*, Koh Hosoda, *Member, IEEE*, Yasuo Kuniyoshi, *Member, IEEE*, Hiroshi Ishiguro, *Member, IEEE*, Toshio Inui, Yuichiro Yoshikawa, Masaki Ogino, and Chisato Yoshida

***Abstract*—Cognitive developmental robotics (CDR) aims to provide new understanding of how human's higher cognitive functions develop by means of a synthetic approach that developmentally constructs cognitive functions. The core idea of CDR is "physical embodiment" that enables information structuring through interactions with the environment, including other agents. The idea is shaped based on the hypothesized development model of human cognitive functions from body representation to social behavior. Along with the model, studies of CDR and related works are introduced, and discussion on the model and future issues are argued.**

***Index Terms*—Cognitive developmental robotics (CDR), development model, synthetic approach.**

I. Introduction

EMERGENCE of higher order cognitive functions through learning and development is one of the greatest challenges in trying to make artificial systems more intelligent since existing systems are of limited capability even in fixed environments. Related disciplines are not just artificial intelligence and robotics but also neuroscience, cognitive science, developmental psychology, sociology, and so on, and we share this challenge. An obvious fact is that we have insufficient knowledge and too superficial implementations based on such knowledge to declare that we have only one unique solution to the mystery. The main reasons are the following.

Developmental Robotics (2)

[Cangelosi A. & Schlesinger M., 2014]

COGNITION, BRAIN, & BEHAVIOR → COMPUTER SCIENCE AND INTELLIGENT SYSTEMS → DEVELOPMENTAL ROBOTICS

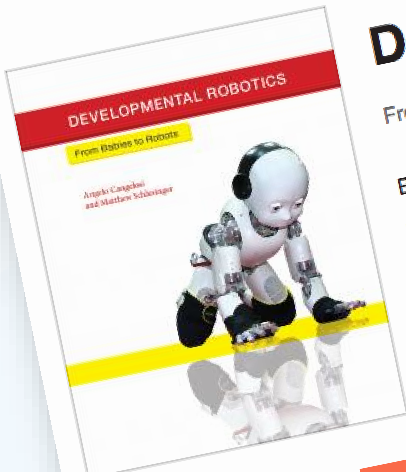
From Intelligent Robotics and Autonomous Agents series

Developmental Robotics

From Babies to Robots

By Angelo Cangelosi and Matthew Schlesinger

Foreword by Linda B. Smith



Buying Options

Hardcover | $60.00 Short | £41.95 | ISBN: 9780262028011 | 408 pp. | 7 x 9 in | 99 b&w illus.| January 2015

Google Preview

Overview

Developmental robotics is a collaborative and interdisciplinary approach to robotics that is directly inspired by the developmental principles and mechanisms observed in children's cognitive development. It builds on the idea that the robot, using a set of intrinsic developmental principles regulating the real-time interaction of its body, brain, and environment, can autonomously acquire an increasingly complex set of sensorimotor and mental capabilities. This volume, drawing on insights from psychology, computer science, linguistics, neuroscience, and robotics, offers the first comprehensive overview of a rapidly growing field.

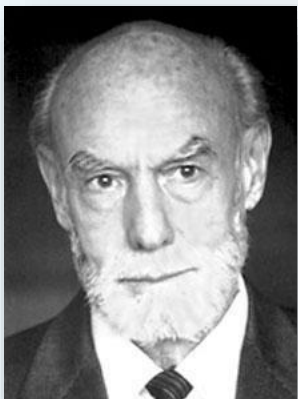
After providing some essential background information on robotics and developmental psychology, the book looks in detail at how developmental robotics models and experiments have attempted to realize a range of behavioral and cognitive capabilities. The examples in these chapters were chosen because of their direct correspondence with specific issues in child psychology research; each chapter begins with a concise and accessible overview of relevant empirical and theoretical findings in developmental psychology. The chapters cover intrinsic motivation and curiosity; motor development, examining both manipulation and locomotion; perceptual development, including face recognition and perception of space; social learning, emphasizing such phenomena as joint attention and cooperation; language, from phonetic babbling to syntactic processing; and abstract knowledge, including models of number learning and reasoning strategies. Boxed text offers technical and methodological details for both psychology and ...experiments.

What’s cognitive developmental robotics?

- Cognitive developmental robotics aims at understanding human cognitive developmental processes 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.

Physical Embodiment

- To understand the mind, begin with patterns of motor activities and derive the underlying mental structures from them. [Sperry, 1952]



NEUROLOGY AND THE MIND-BRAIN PROBLEM

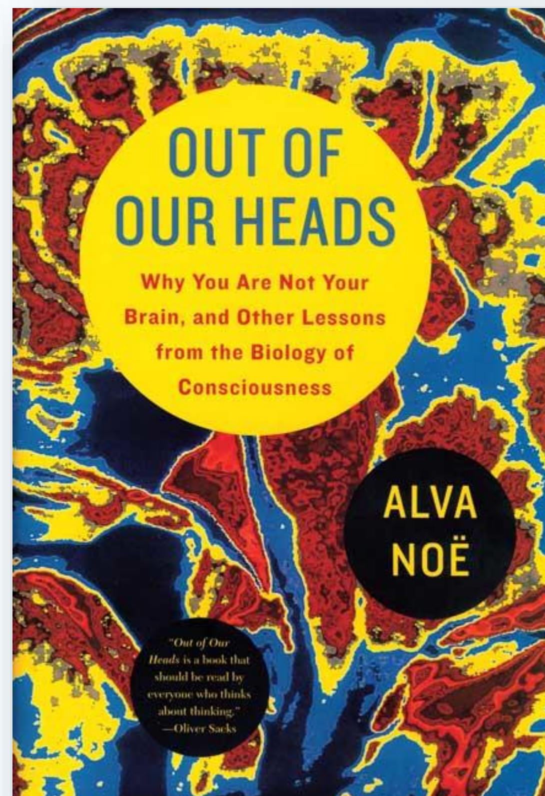
By R. W. SPERRY

Hull Anatomical Laboratory, University of Chicago

THE discrepancy between physiological processes in the brain and the correlated psychic experiences to which they give rise in consciousness has ever posed a baffling puzzle to students of psychology, neurology, and the related sciences. Despite steady advancement in our knowledge of the brain, the intrinsic nature of mind and its relation to cerebral excitation remains as much an enigma today as it was a hundred years ago.

Social Interaction

- The mind cannot be understood except in terms of the interaction of a whole organism with the external environment, especially the social environment. [Noe, 2009]



Approaches of CDR

A: construction of computational model of cognitive development

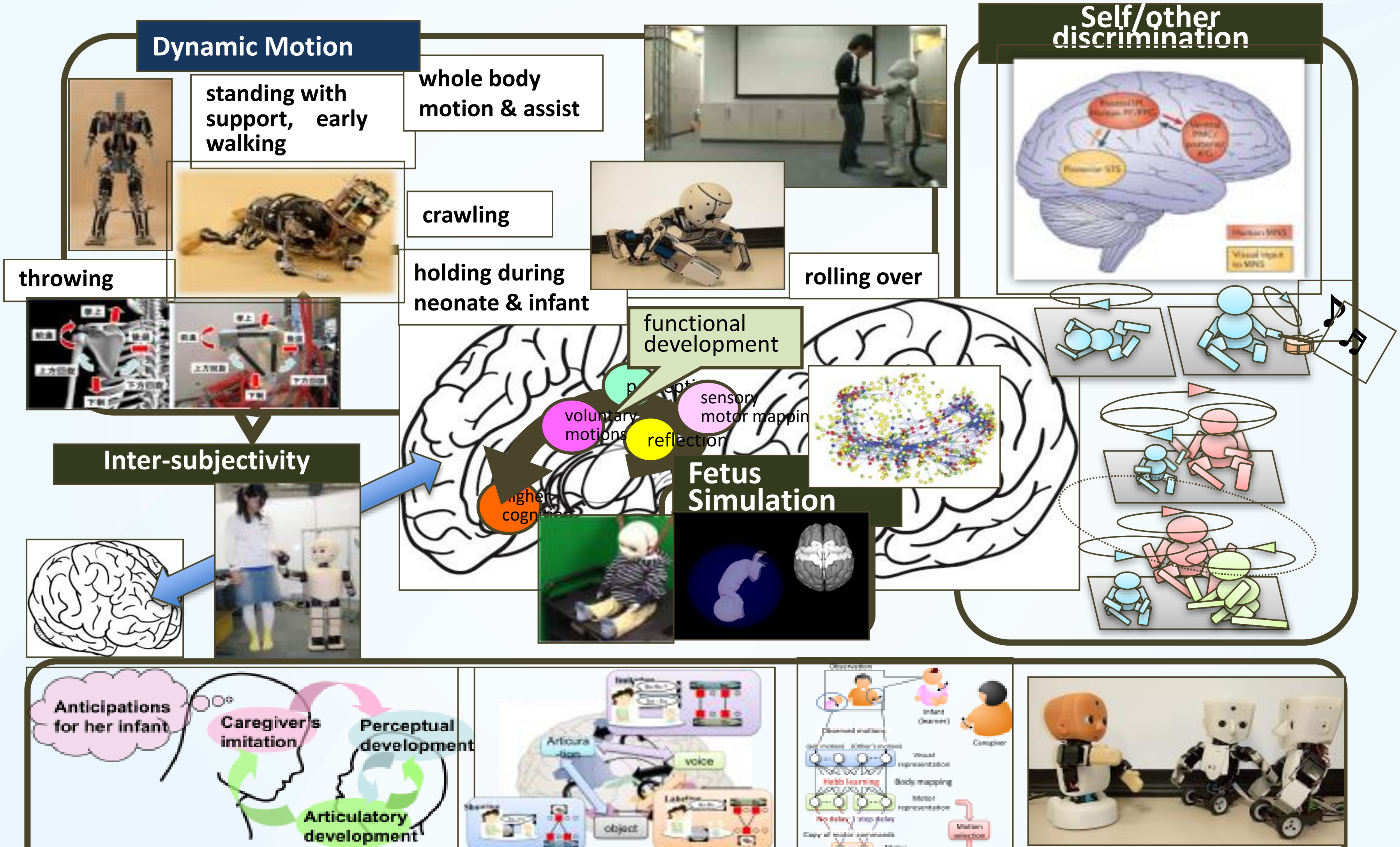
1) hypothesis generation
2) computer simulation
3) ***hypothesis verification with real agents, then go to 1)***

B: offer new means or data to know 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***

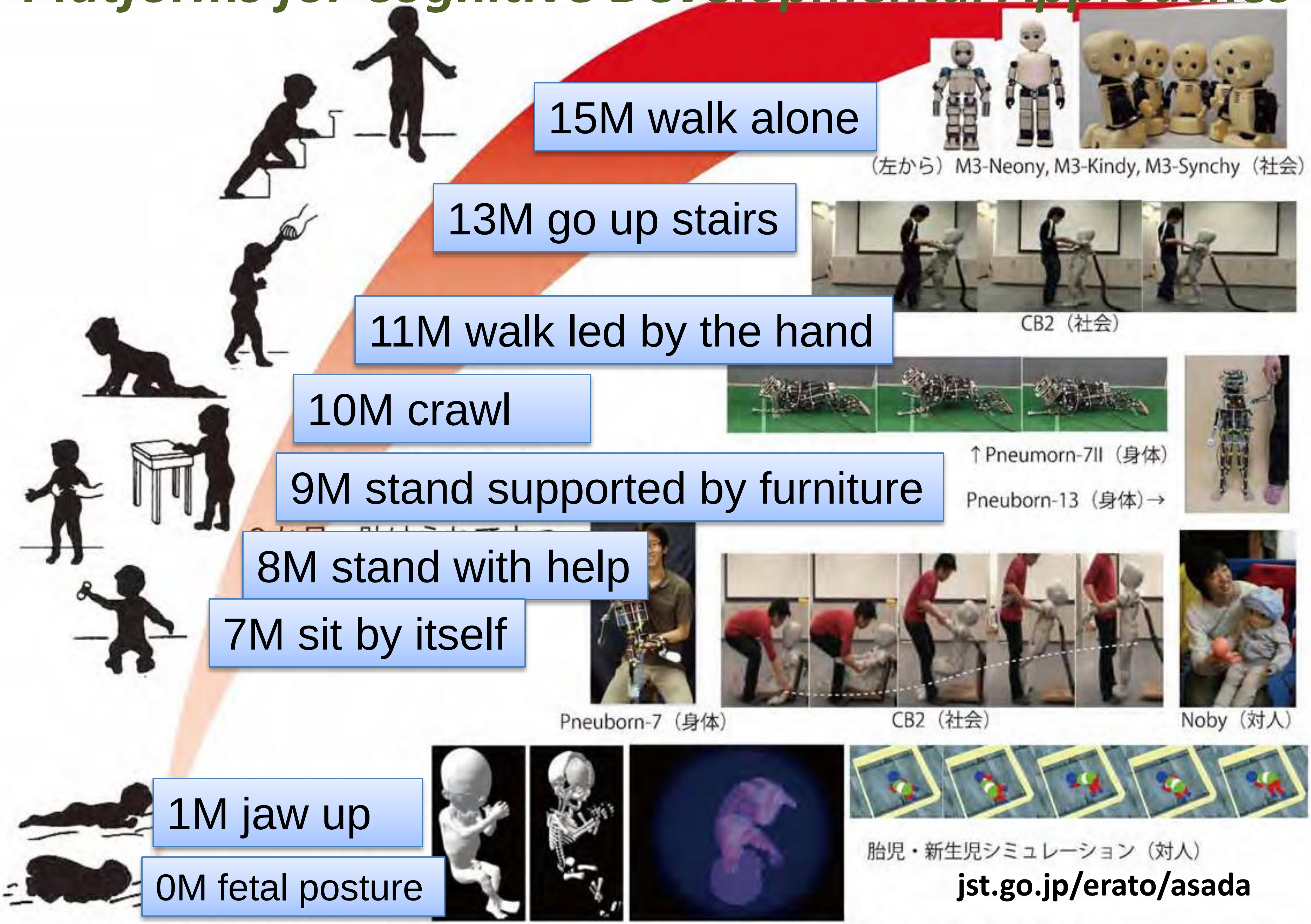
From physical interaction to social one

jst.go.jp/erato/asada



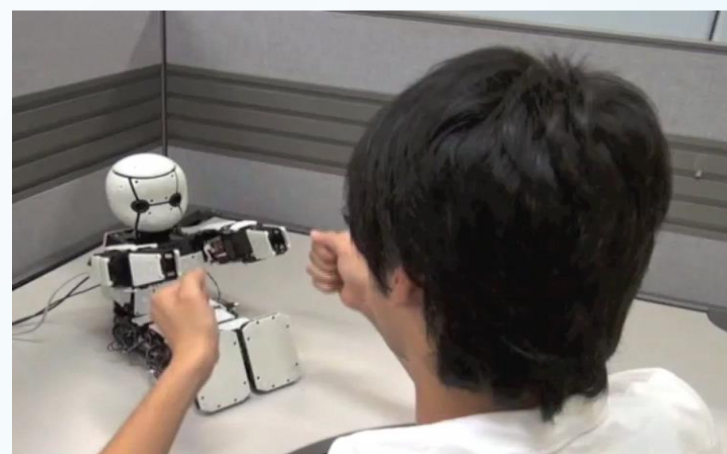
From emergence of social behavior through interactions with caregiver to development of communication

Platforms for Cognitive Developmental Approaches



Shirley, M. M. (1961) The first two years. Institude Child Welf. Monogr., 7, Univ. of Minnesota Press. ; 川島 (編著) 図で読む心理学：発達、福村出版

Robot platforms



Outline of my talk

1. Cognitive Developmental Robotics
   – What's development?
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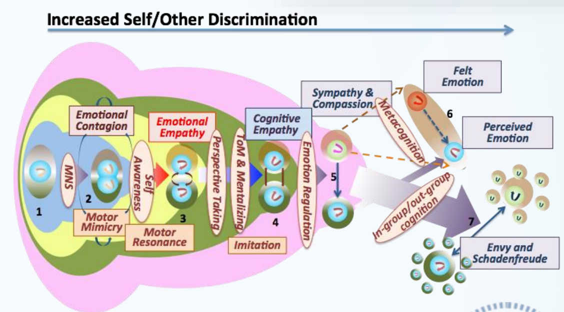
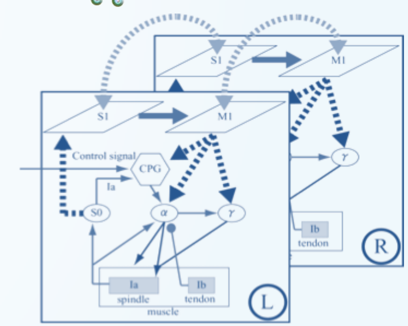
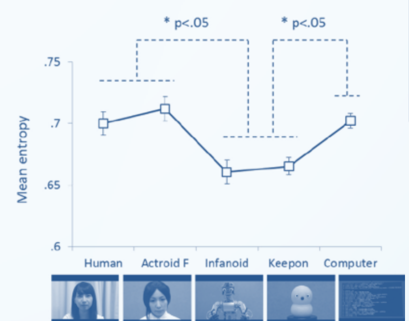
2. **Towards Artificial Empathy**
   – **Self/other cognition**
   – **A developmental model**
   – **Cognitive vs. Affective**



3. Brain-Body Interaction
4. Mind Holder and Mind Reader
5. Future issues

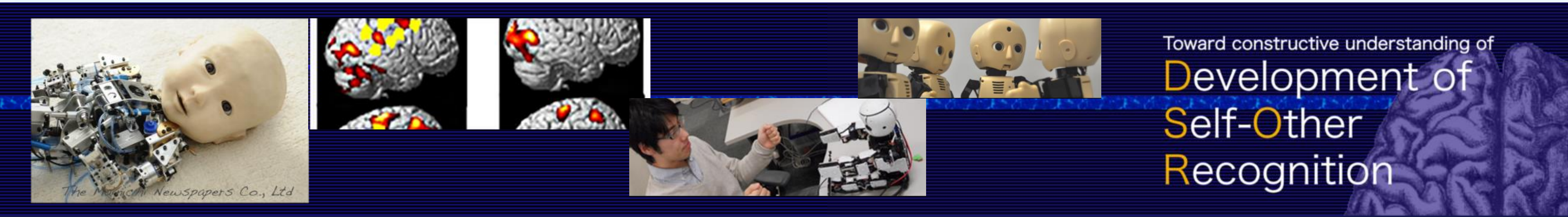




Our current project

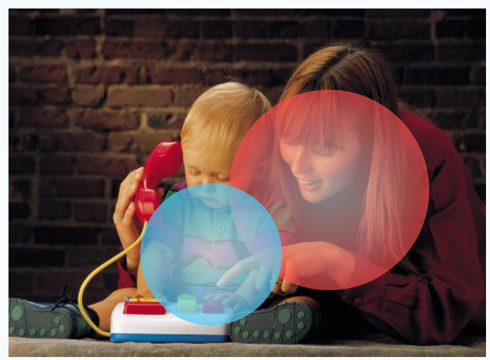
Towards Constructive Developmental Science: Understanding and designing the process from neural dynamics to social interaction

- "(de)Synchronization"
- Neural dynamics
- MNS
- Self/other discrimination



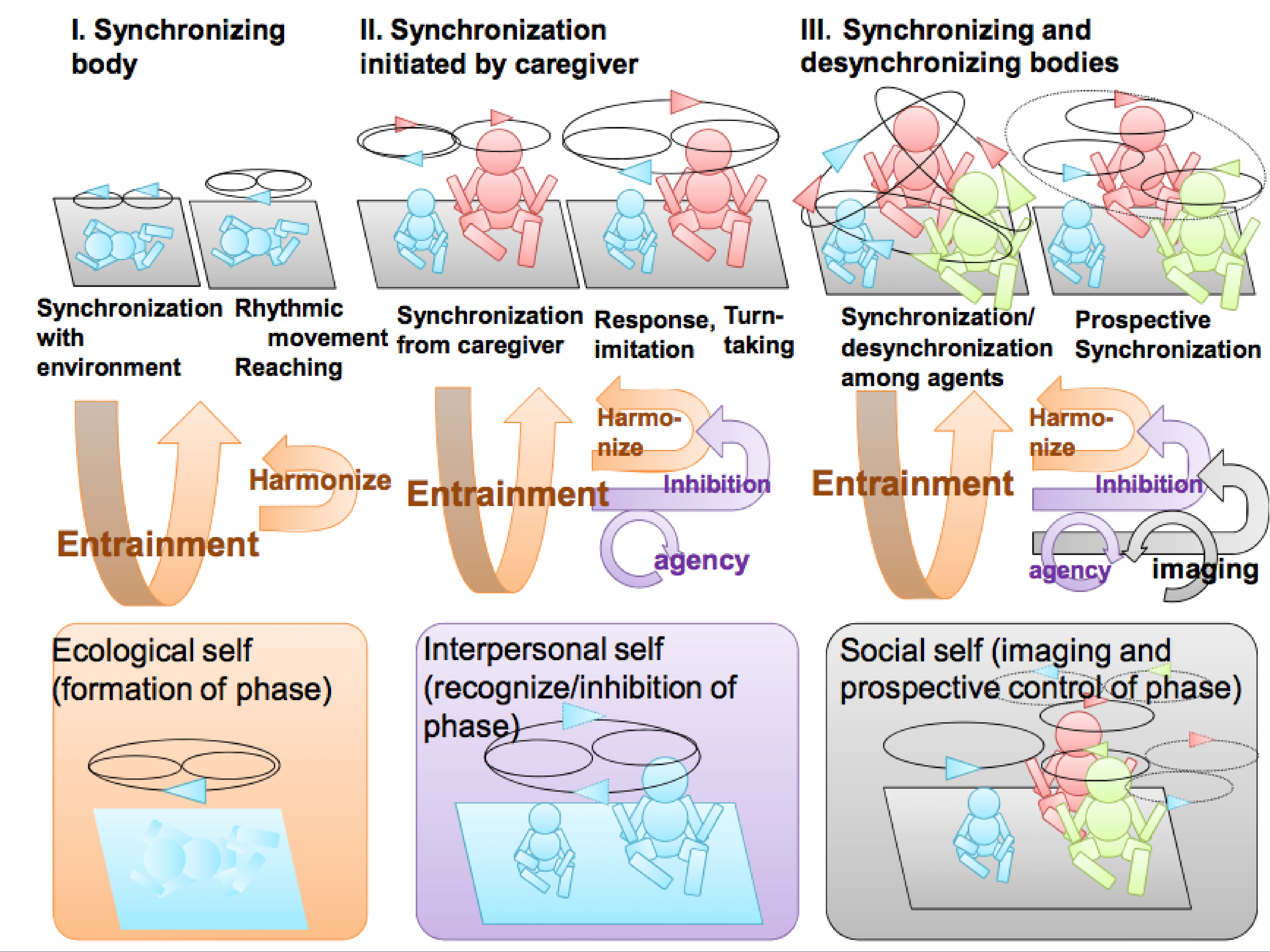
Development of self/other cognition

(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



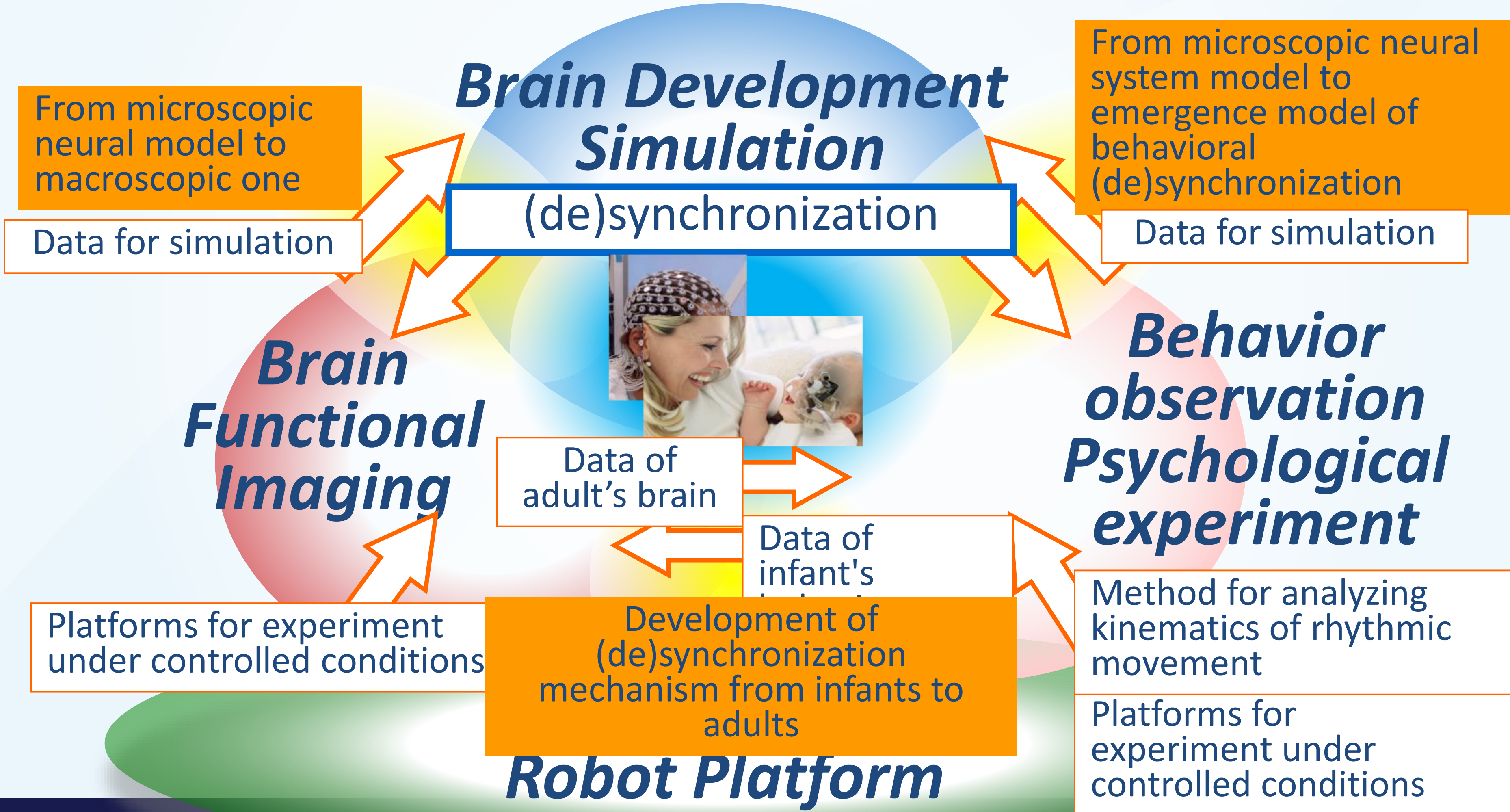
Physical body in synchronization → self/other identification

Desynchronization → self/other separation


I. Synchronizing body
II. Synchronization initiated by caregiver
III. Synchronizing and desynchronizing bodies
Synchronization with environment
Rhythmic movement
Reaching
Synchronization from caregiver
Response, imitation
Turn-taking
Synchronization/ desynchronization among agents
Prospective Synchronization
Harmonize
Entrainment
Harmo-nize
Inhibition
agency
Entrainment
Entrainment
Harmo-nize
Inhibition
agency
imaging
Ecological self (formation of phase)
Interpersonal self (recognize/inhibition of phase)
Social self (imaging and prospective control of phase)

An Overview of our current project

Understanding and designing the self/other cognition process through the observation and computational modeling



The Evolution of Empathy

Increased Self/Other Distinction

Imitation

True imitation emulation

Coordination, Shared goals

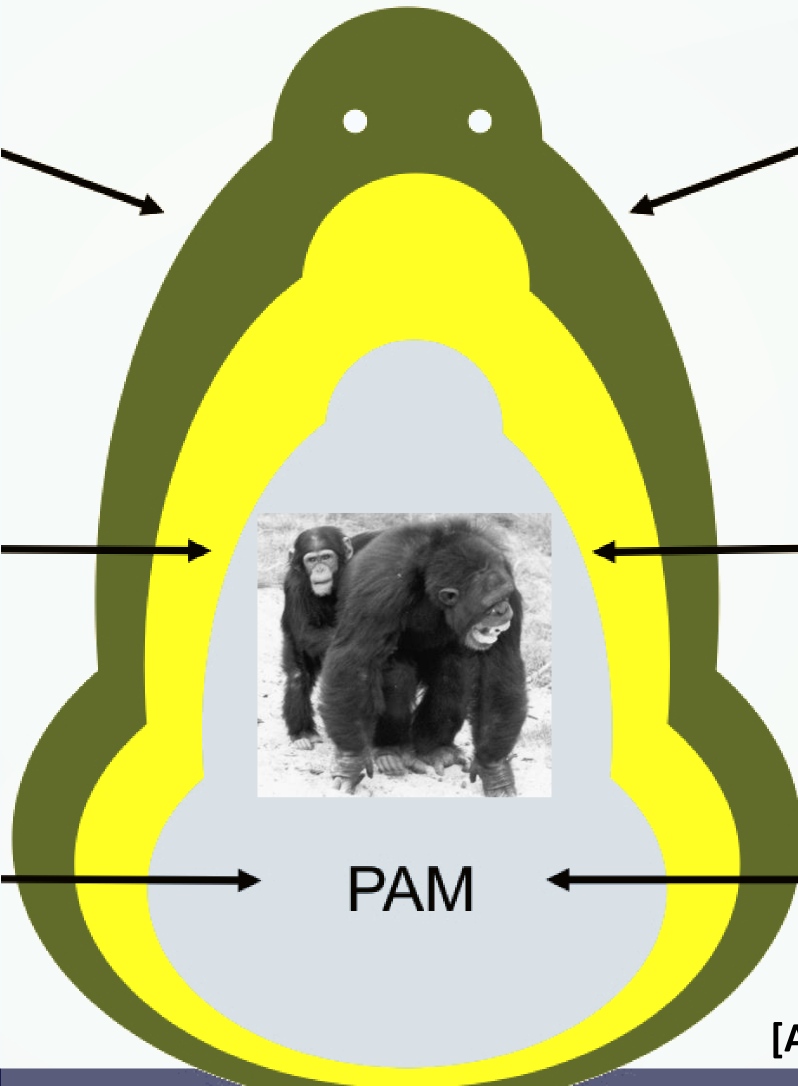
Motor mimicry

Empathy

Perspective-taking, targeted helping

Sympathetic concern, consolation

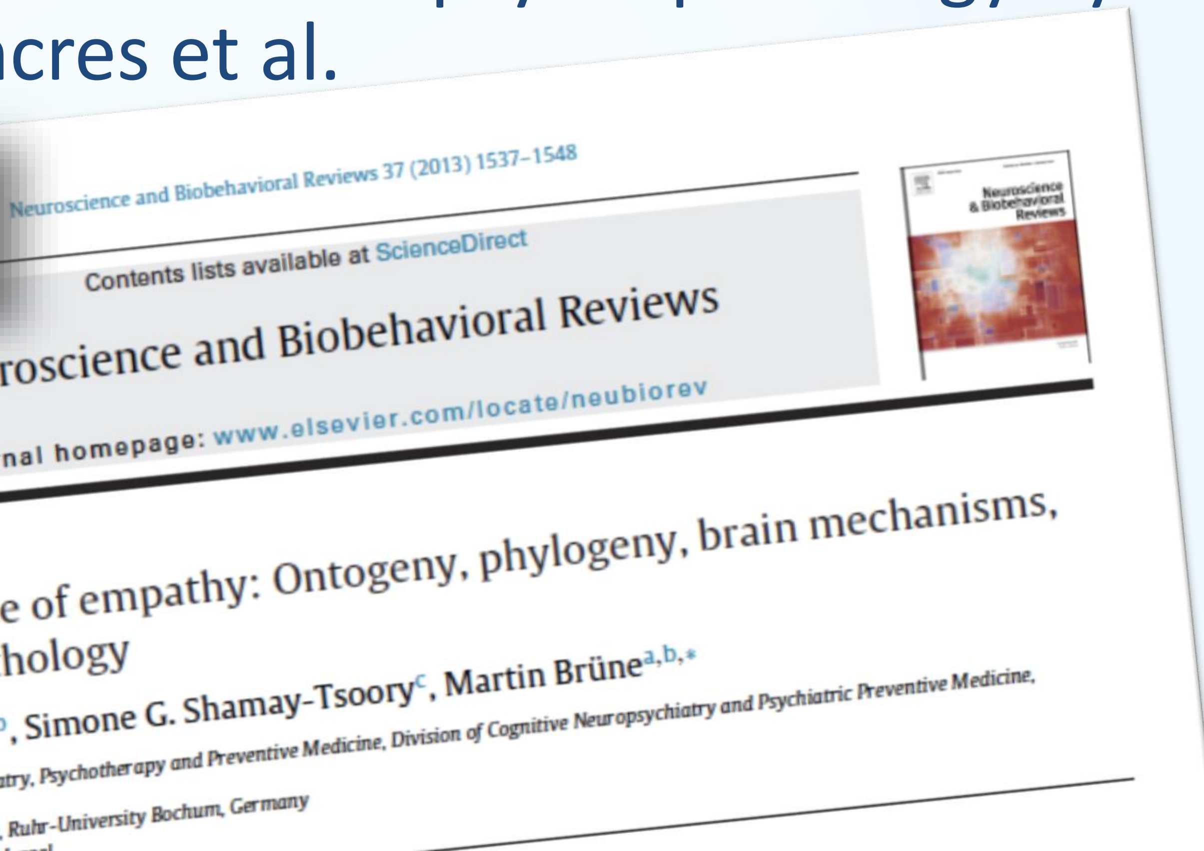
Emotional contagion



[Adopted from de Waal, 2008]

Evolution and development of empathy

- We follow the definition of the empathy in a review of neuroscience of empathy from viewpoints of ontogeny, phylogeny, brain mechanisms, context and psychopathology by Gonzalez-Liencres et al.



Neuroscience and Biobehavioral Reviews 37 (2013) 1537–1548

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Review

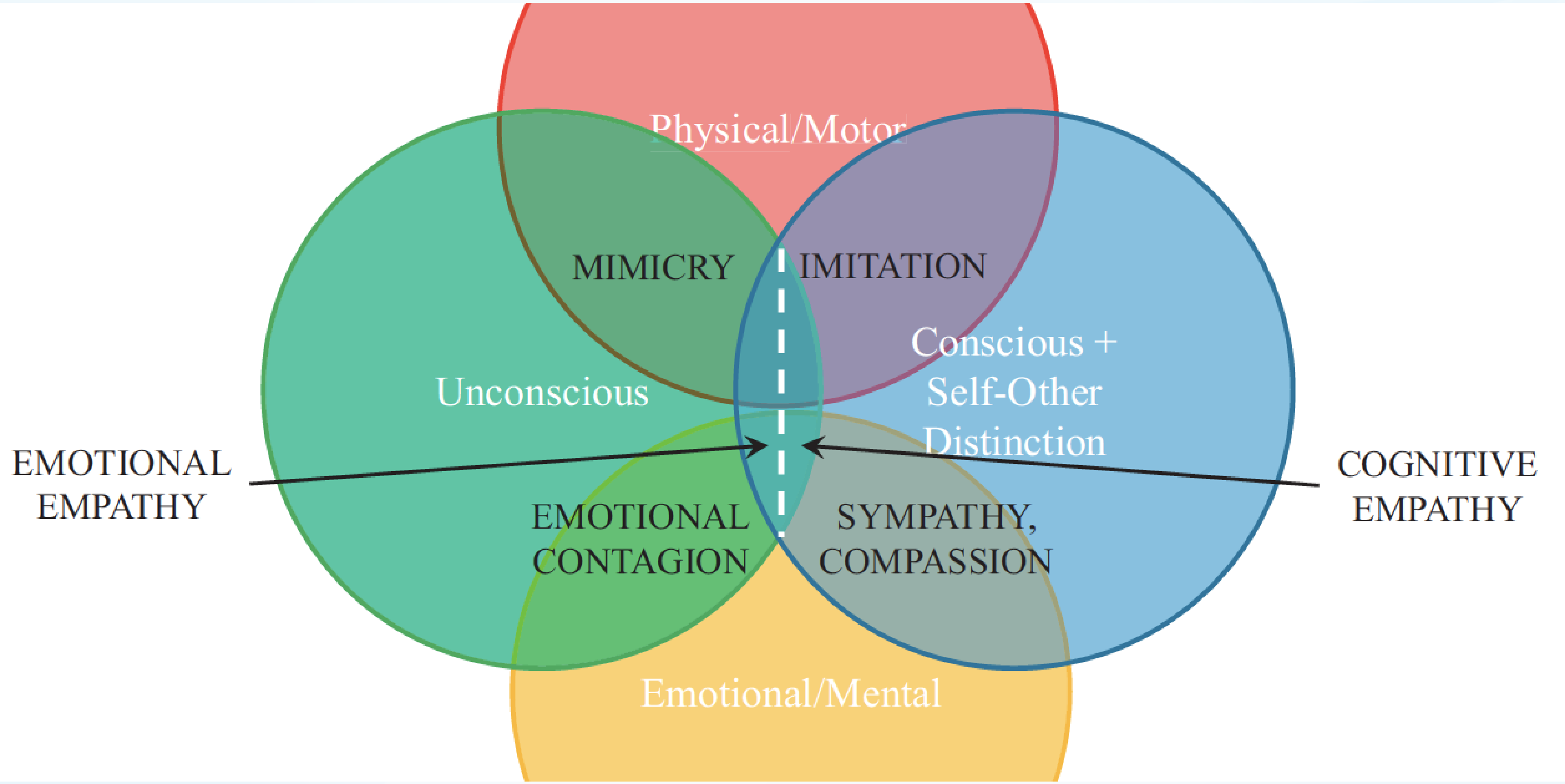
Towards a neuroscience of empathy: Ontogeny, phylogeny, brain mechanisms, context and psychopathology

Cristina Gonzalez-Liencres[a,b], Simone G. Shamay-Tsoory[c], Martin Brüne[a,b,*]

[a] LWL University Hospital, Department of Psychiatry, Psychotherapy and Preventive Medicine, Division of Cognitive Neuropsychiatry and Psychiatric Preventive Medicine, Ruhr-University Bochum, Germany

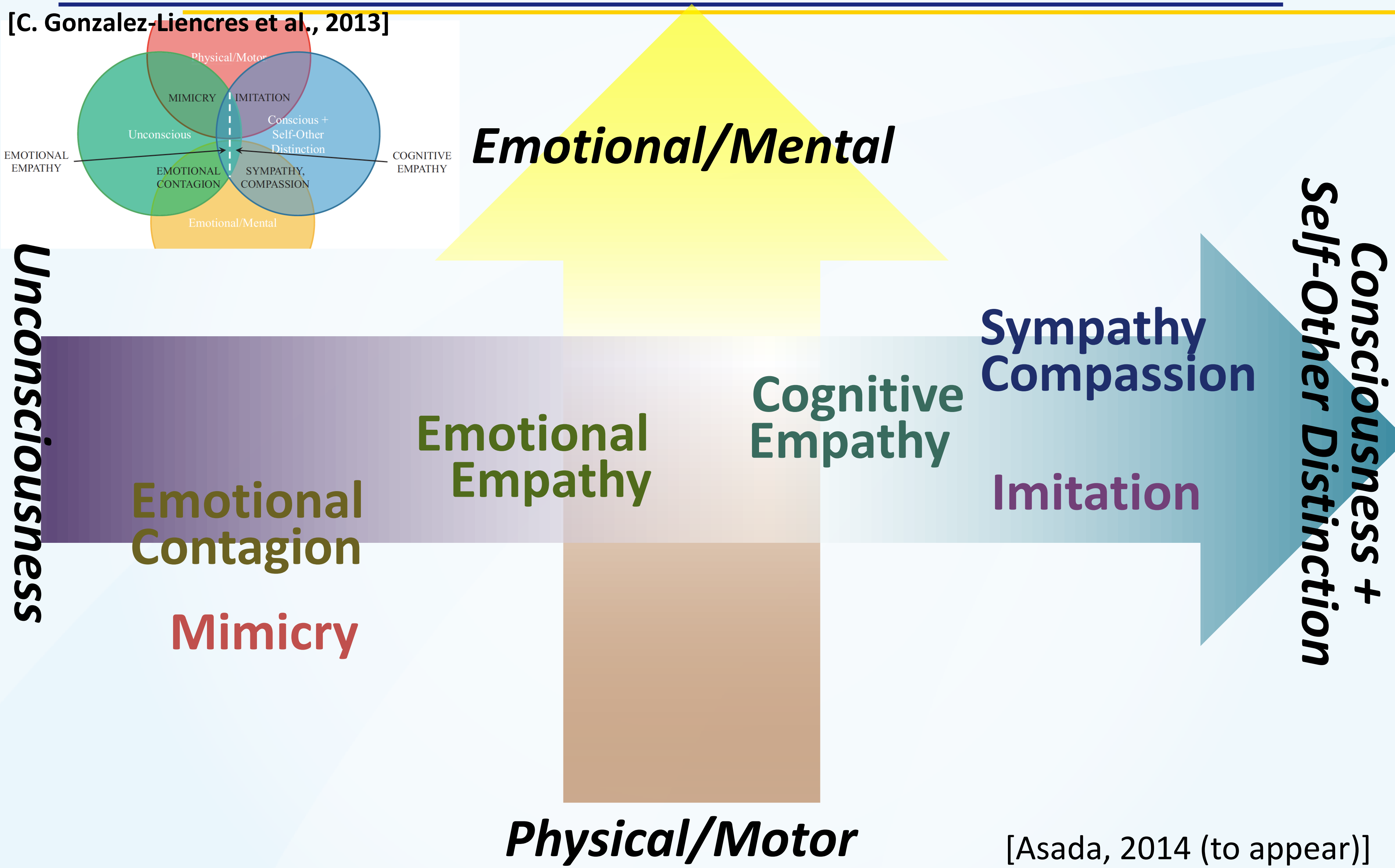
... School of Neuroscience, Ruhr-University Bochum, Germany

Schematic depiction of the terminology



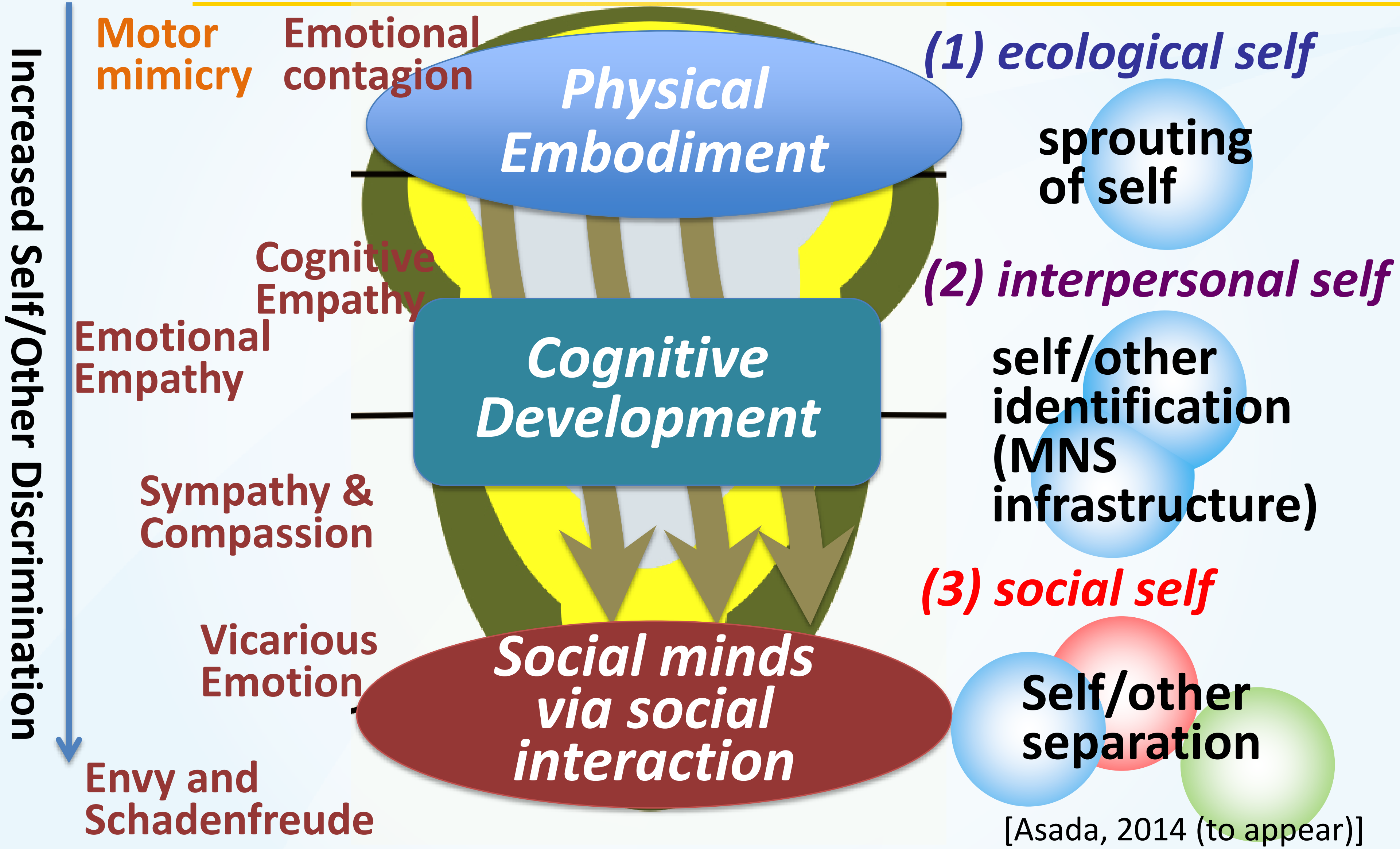
[C. Gonzalez-Liencres et al. / Neuroscience and Biobehavioral Reviews 37 (2013) 1537–1548]

Developmental (Evolutionary?) Pathway of Empathy



[Asada, 2014 (to appear)]

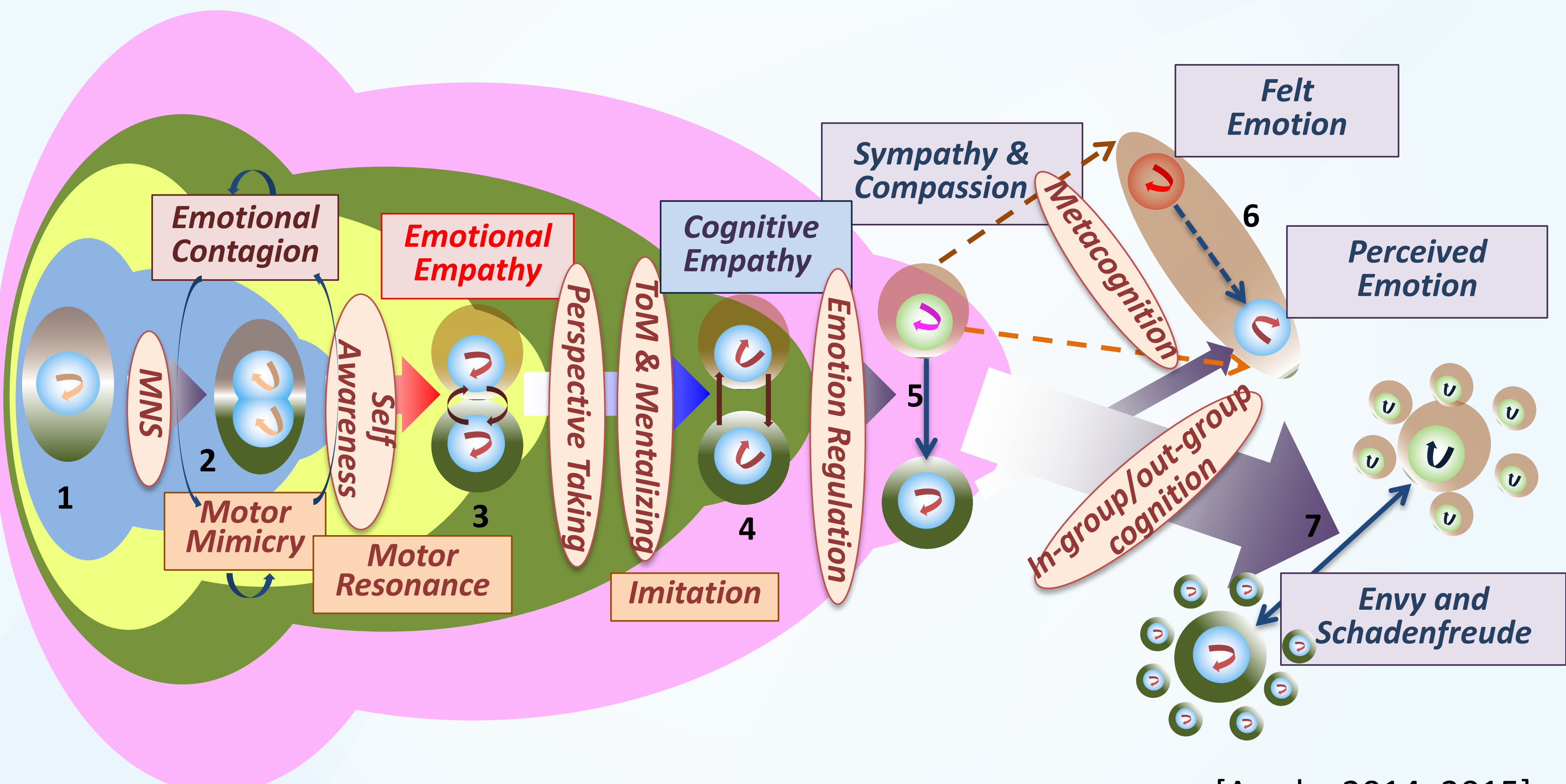
Development of empathy and self/others discrimination



[Asada, 2014 (to appear)]

Russian Model for Empathy Development

Increased Self/Other Discrimination



[Asada, 2014 ,2015]

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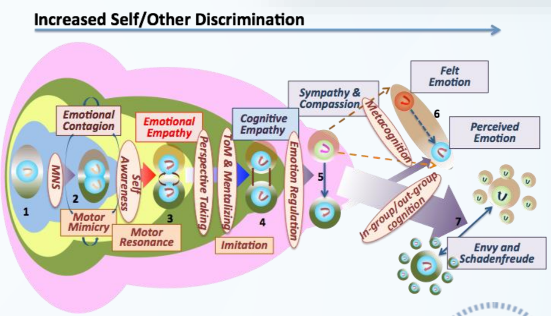
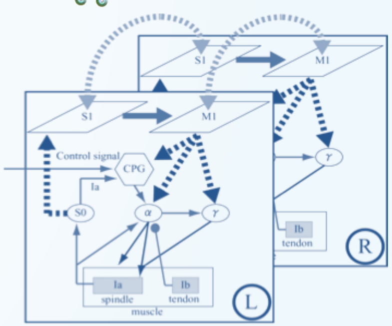
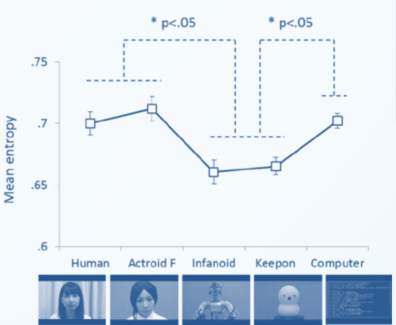
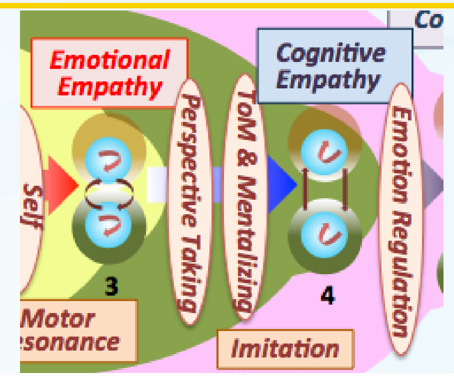






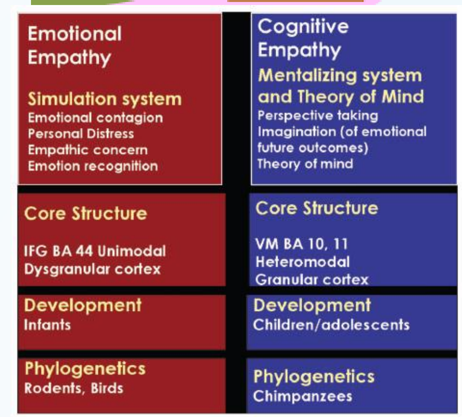
Cognitive vs. Affective in Empathy

1. Evolutionarily (and developmentally, too) , emotional empathy is included by cognitive empathy!



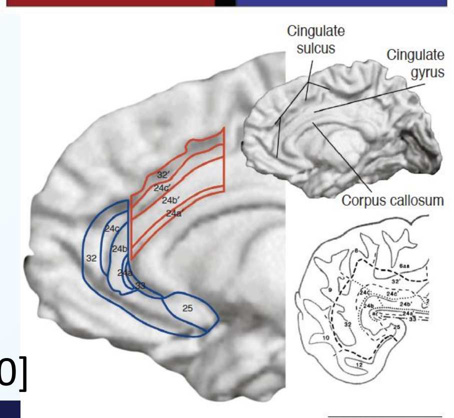
Based on [Preston & de Waal, 2002]

2. Two systems for empathy: differences in function, brain region, and period of development → independent structure!



[Shamay-Tsoory et al., 2009]

3. Cognitive and emotional influences in anterior cingulate cortex: two different systems!



[Bush et al., 2000]

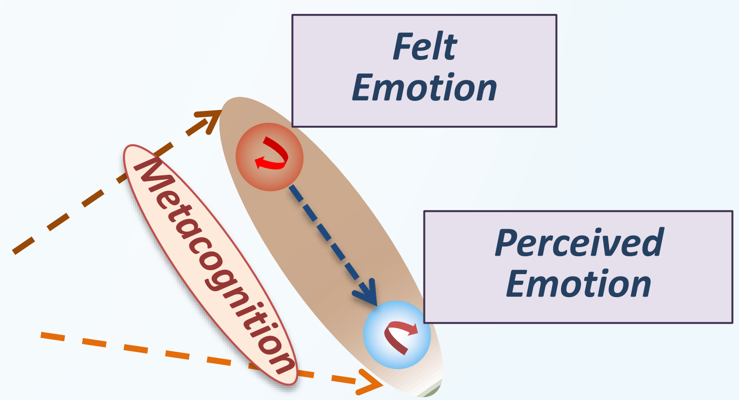
Cognitive vs. Affective ?

- Sad music induces pleasant emotion!
  - Perceived emotion: cognitive?
  - Felt emotion: affective?

[Kawakami et al., 2013a, 2013b, 2014]

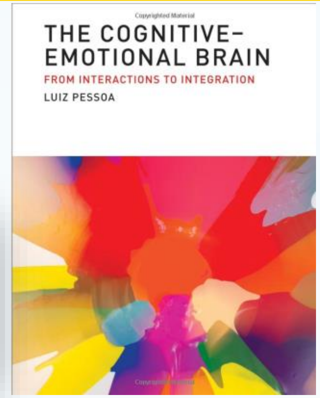
→The relationship is not a simple inclusion nor a complete separate one. But, more complicated!

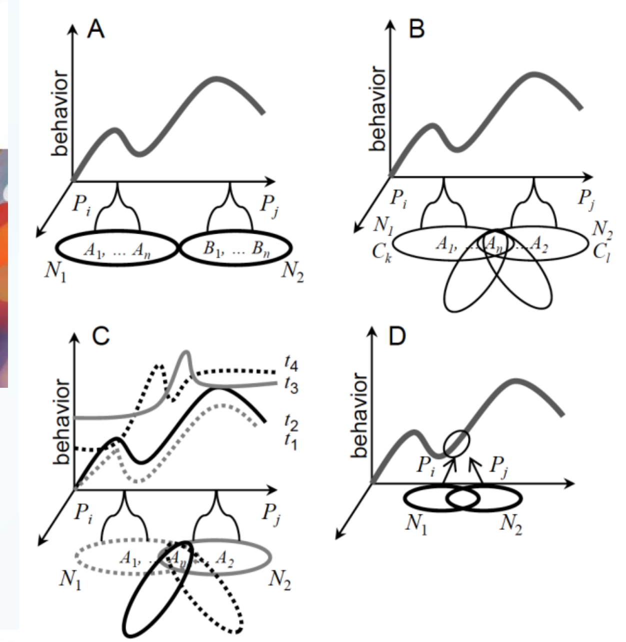
→The perceived emotion itself is a target of the felt emotion, and the situation itself is organized by a cognitive process (metacognition).



Cognitive vs. Affective ?

- Developmental changes: Inclusion → separation → metacognition?!

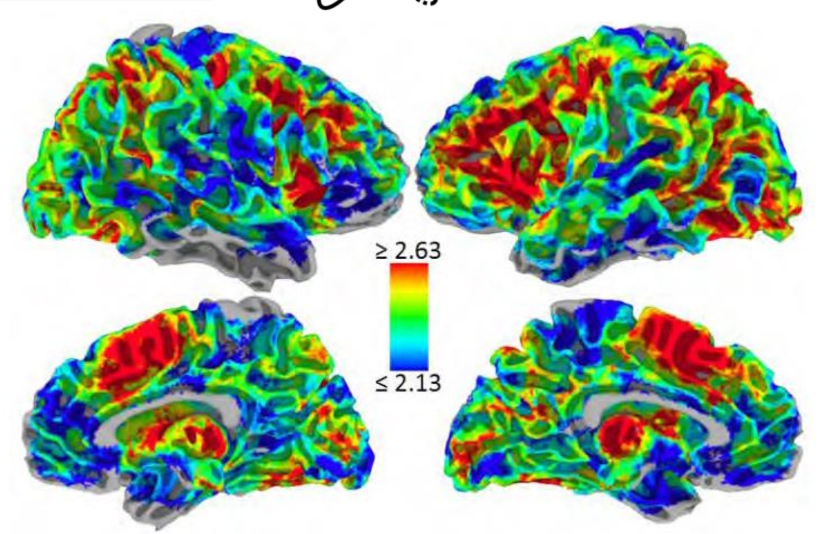




- The cognitive-emotional brain → from the dichotomy to dynamic network structure (D)

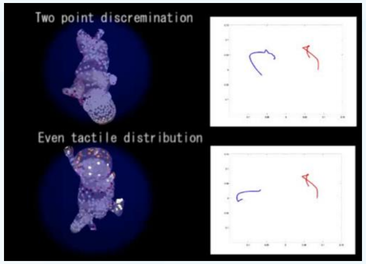
[Pessoa, 2013]

➢ ***Attempt to build such a structure through constructive approaches!***

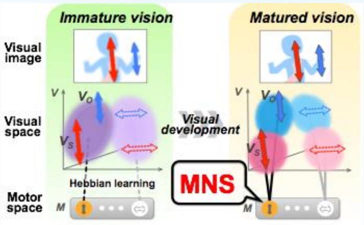


Approaches at individual stages

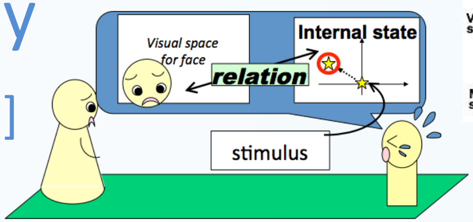
1. **Fetal and neonatal simulations** [Kuniyoshi & Sangawa 2006, Mori & Kuniyoshi 2010, Mori et al., 2013]



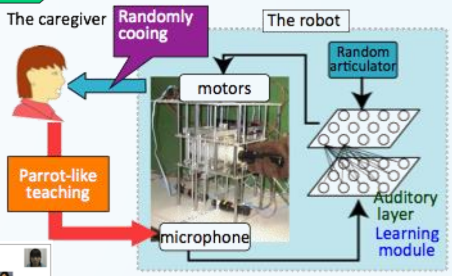
2. Early development of MNS [Nagai et al., 2011]



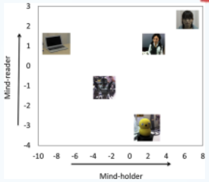
3. Intuitive Parenting for empathy development [Watanabe et al., 2007]



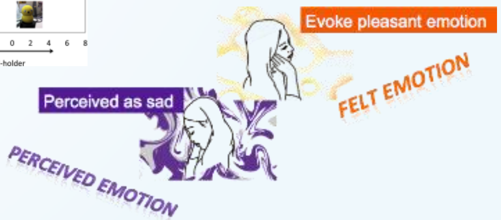
4. Vowel Acquisition by Maternal Imitation [Yoshikawa et al., 2003, Ishihara et al., 2009, Miura et al., 2013]



5. **Social brain analysis** [Takahashi et al., 2014]



6. Sad music induces pleasant emotion [Kawakami et al., 2013a, 2013b, 2014]



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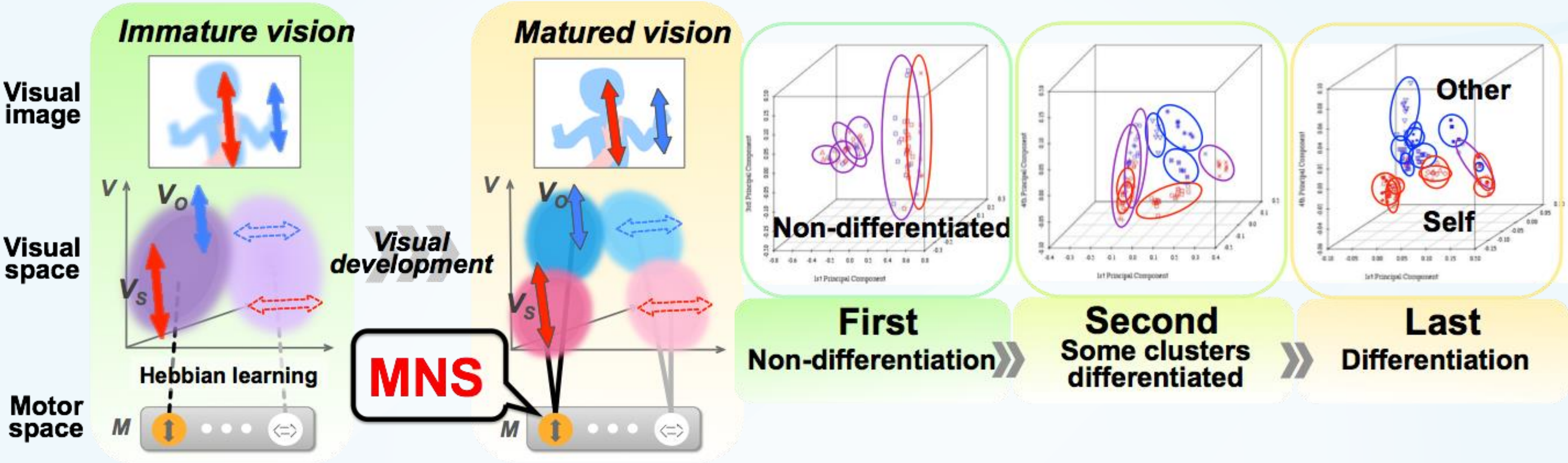

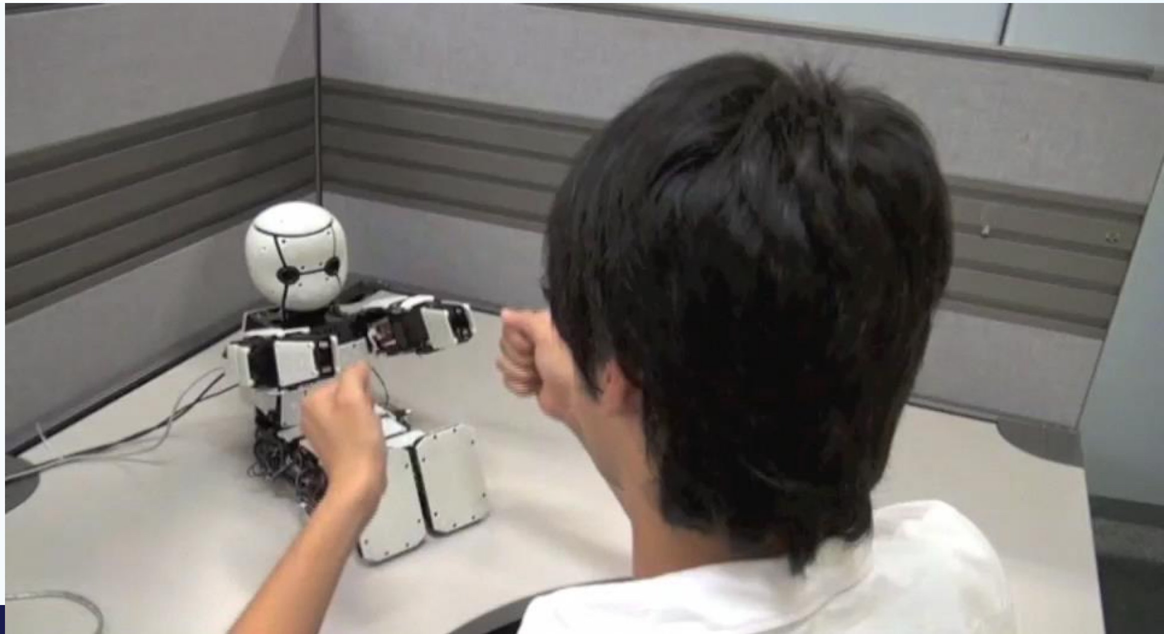

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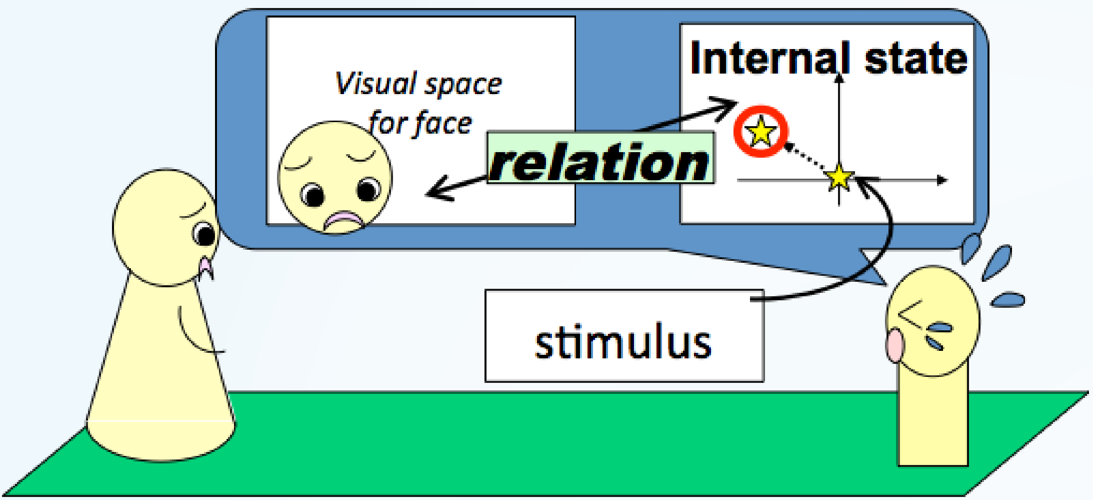

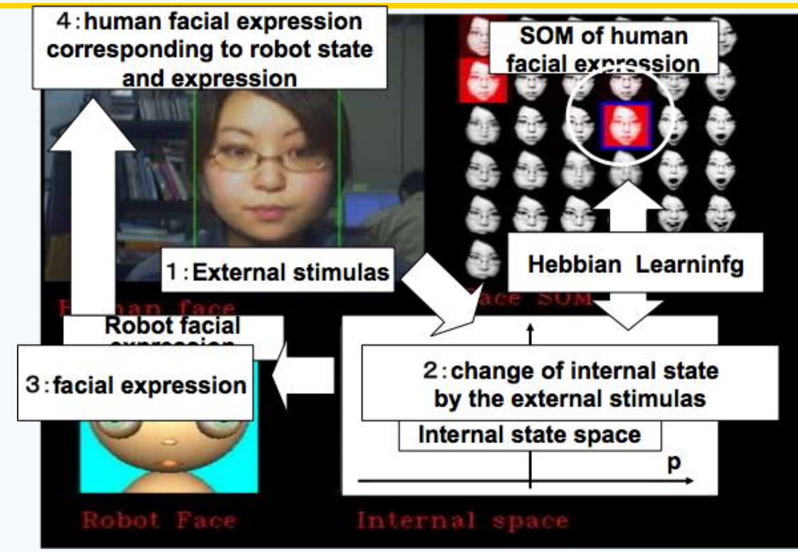

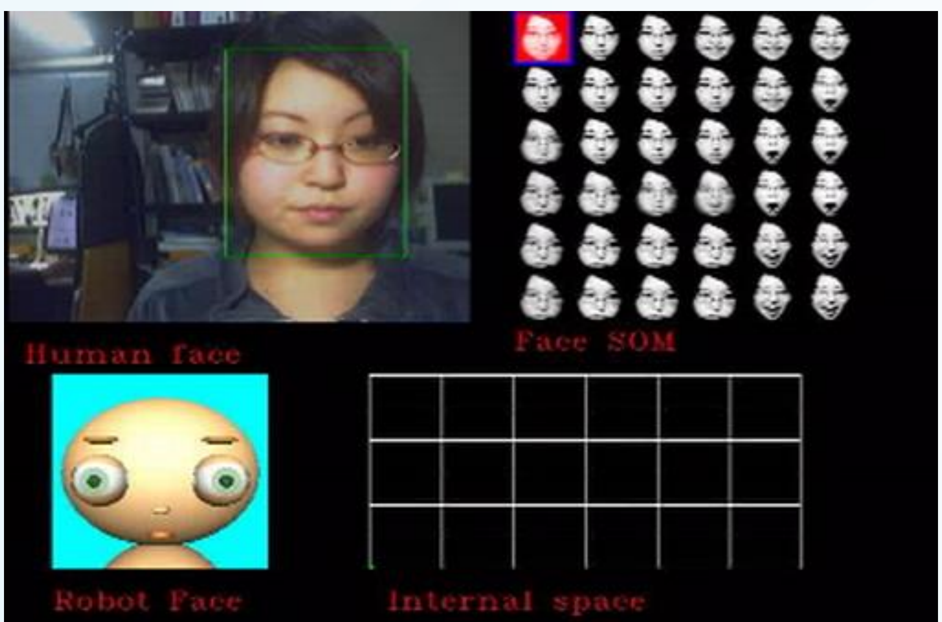

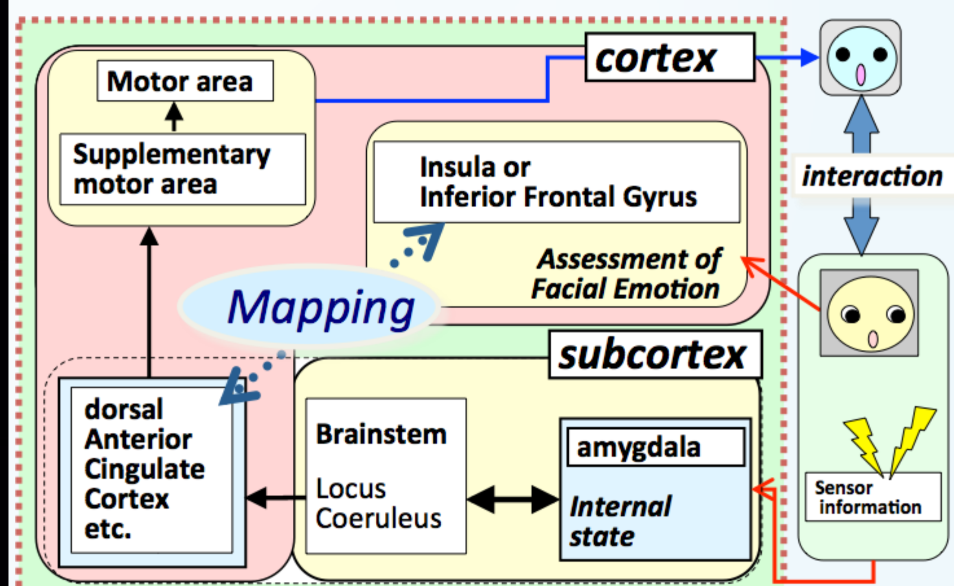

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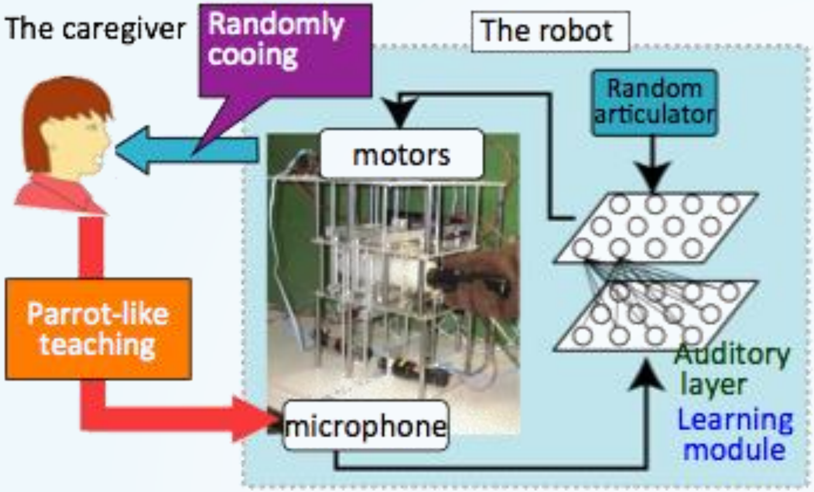
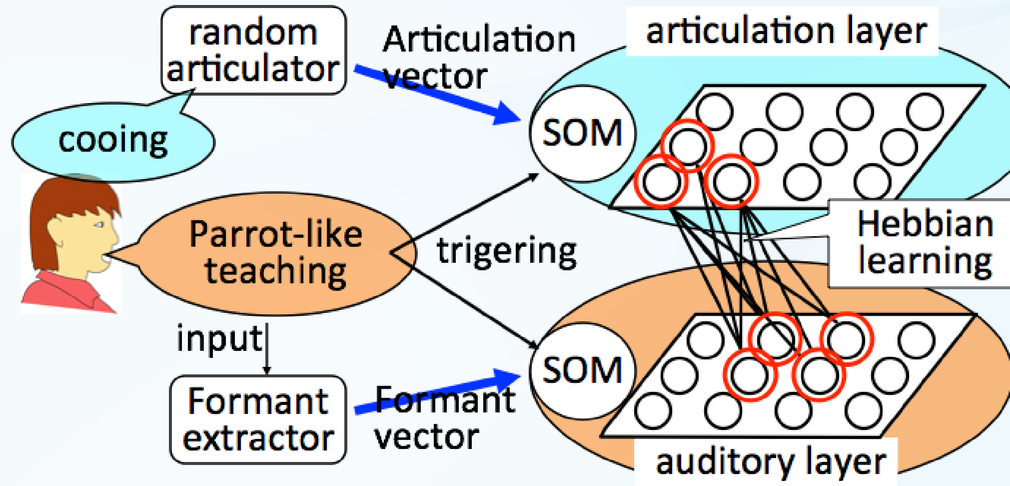
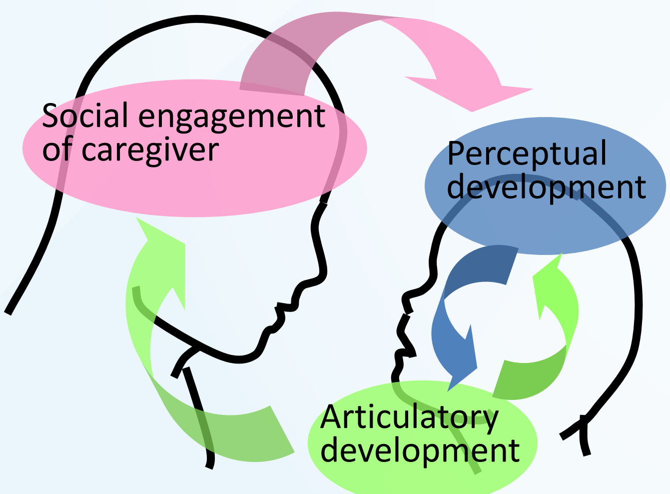
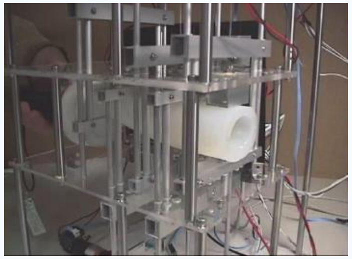
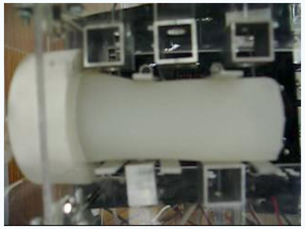
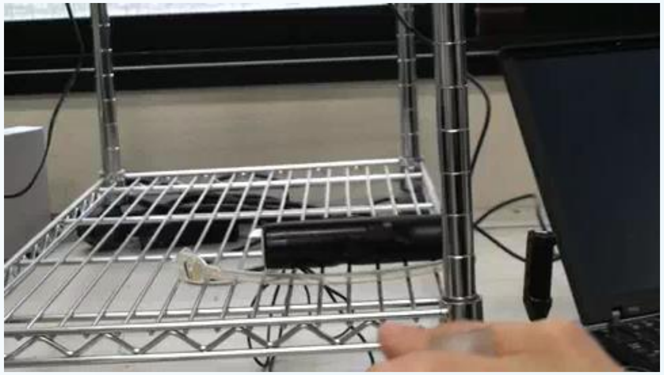






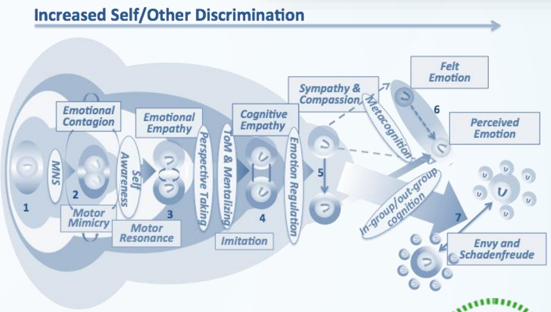


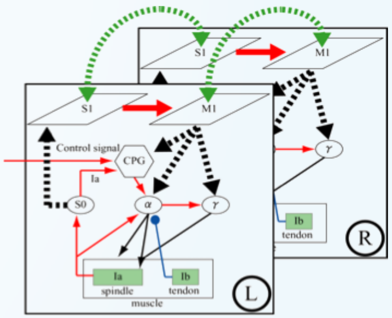


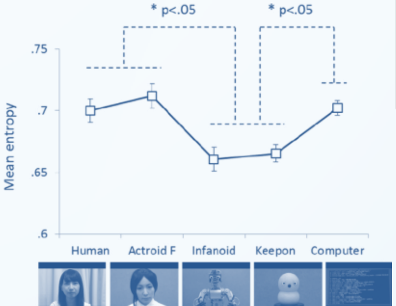


Outline of my talk

1. Cognitive Developmental Robotics
   - What's development?
   - Developmental Robotics, Cognitive Developmental Robotics
2. Towards Artificial Empathy
   - Self/other cognition
   - A developmental model
   - Cognitive vs. Affective
3. **Brain-Body Interaction**
4. Mind Holder and Mind Reader
5. Future issues

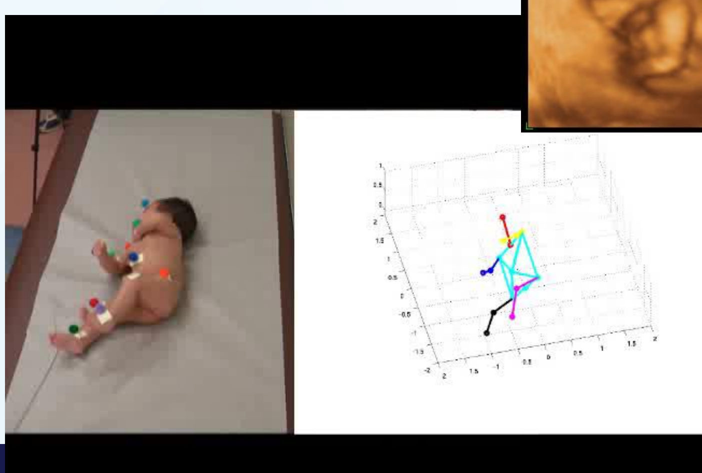


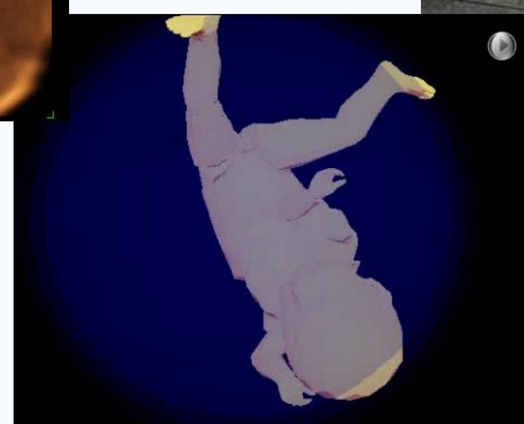
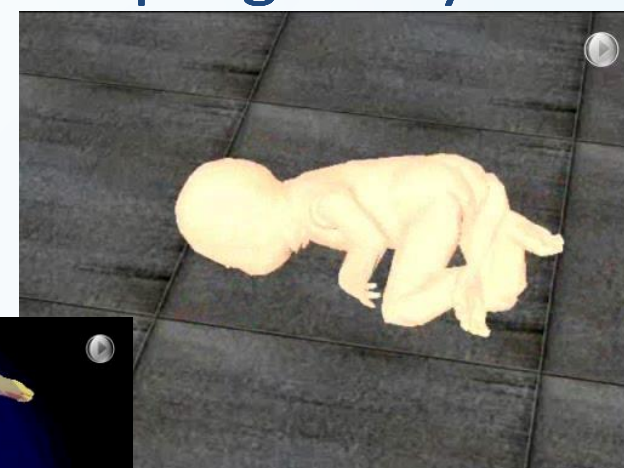




Constructive approach toward human development from fetus to infant

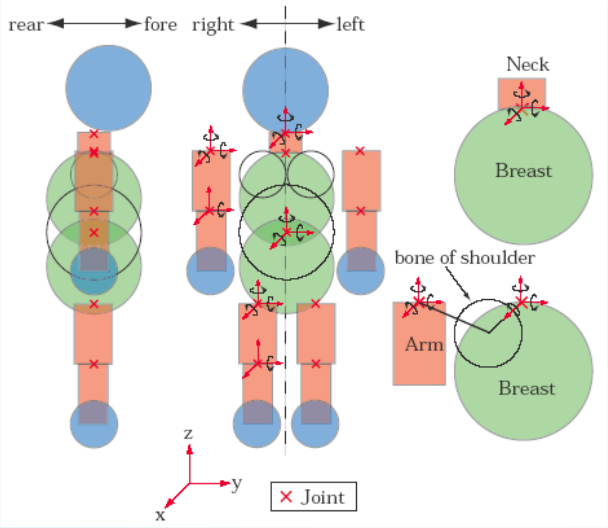
- Fetus and infant whole body musculoskeletal model [Kuniyoshi and Sangawa, 2006, Mori and Kuniyoshi 2010]
- The fetus simulation → reflexive human fetal behavioral development in first half of pregnancy.

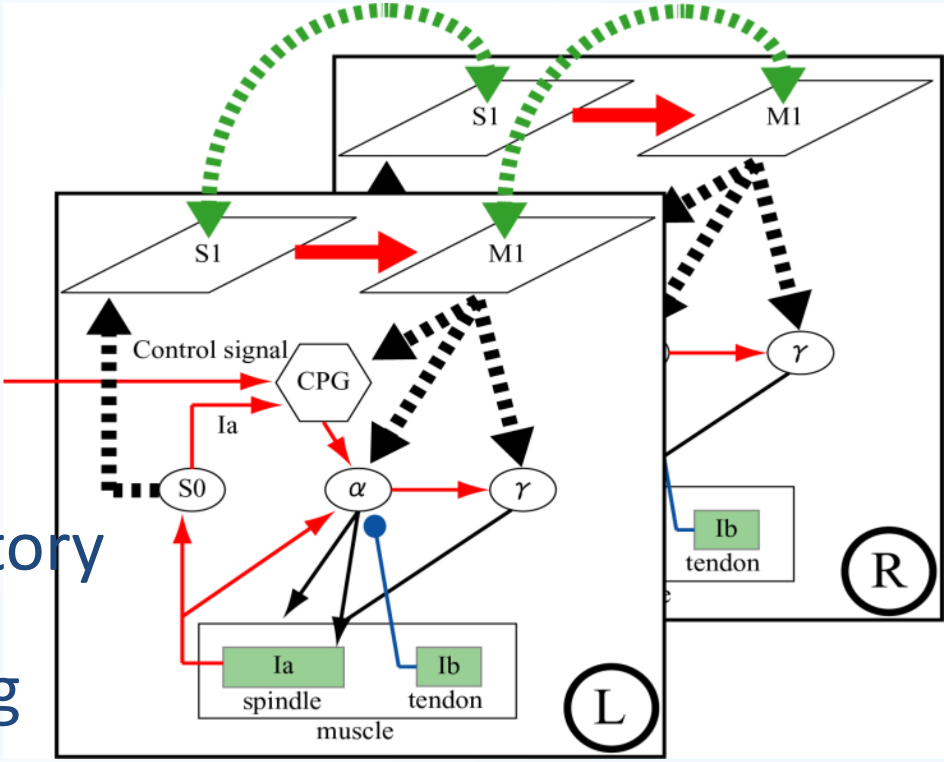


Fetal Brain Development (1)

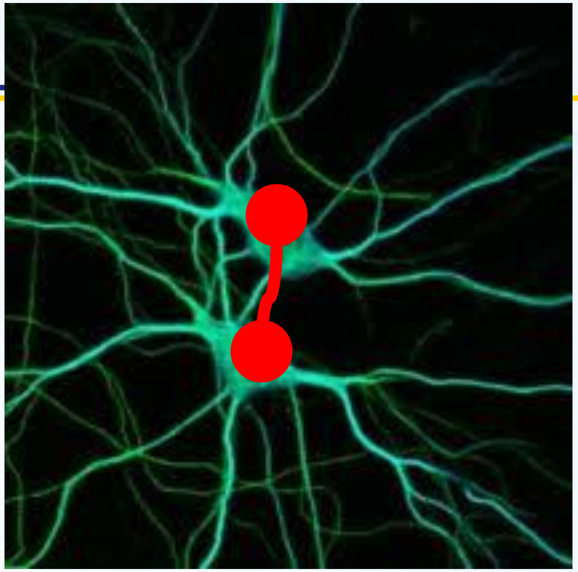
- Mori and Kuniyoshi (2010) → behavior generation through the interaction among (1) neural oscillators, (2) a muscleskelton system of the whole body, and (3) the external world based on [Kuniyoshi and Sangawa, 2006].





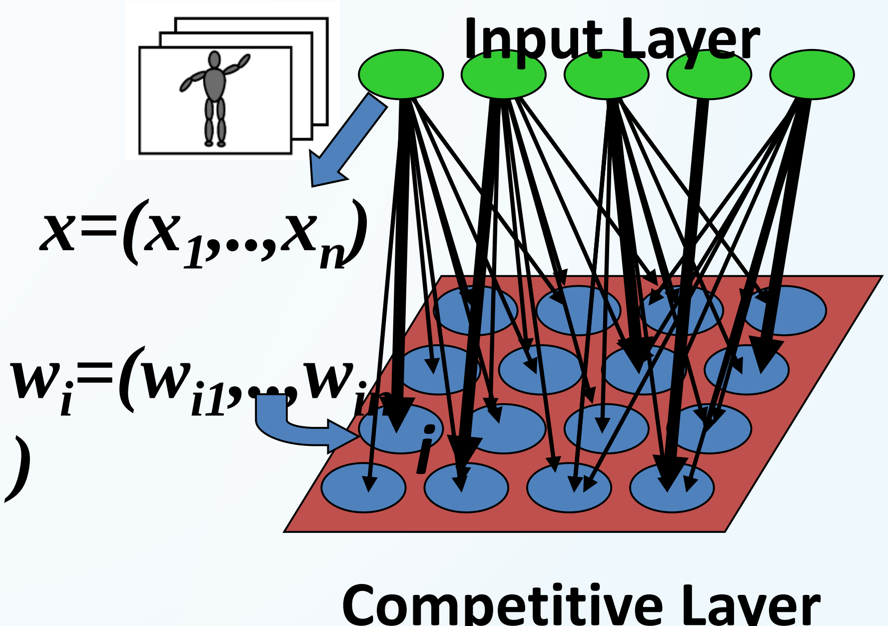
- Arrow (filled circle) → excitatory (inhibitory) connection.
- Thick broken lines → learning targets.

Learning methods



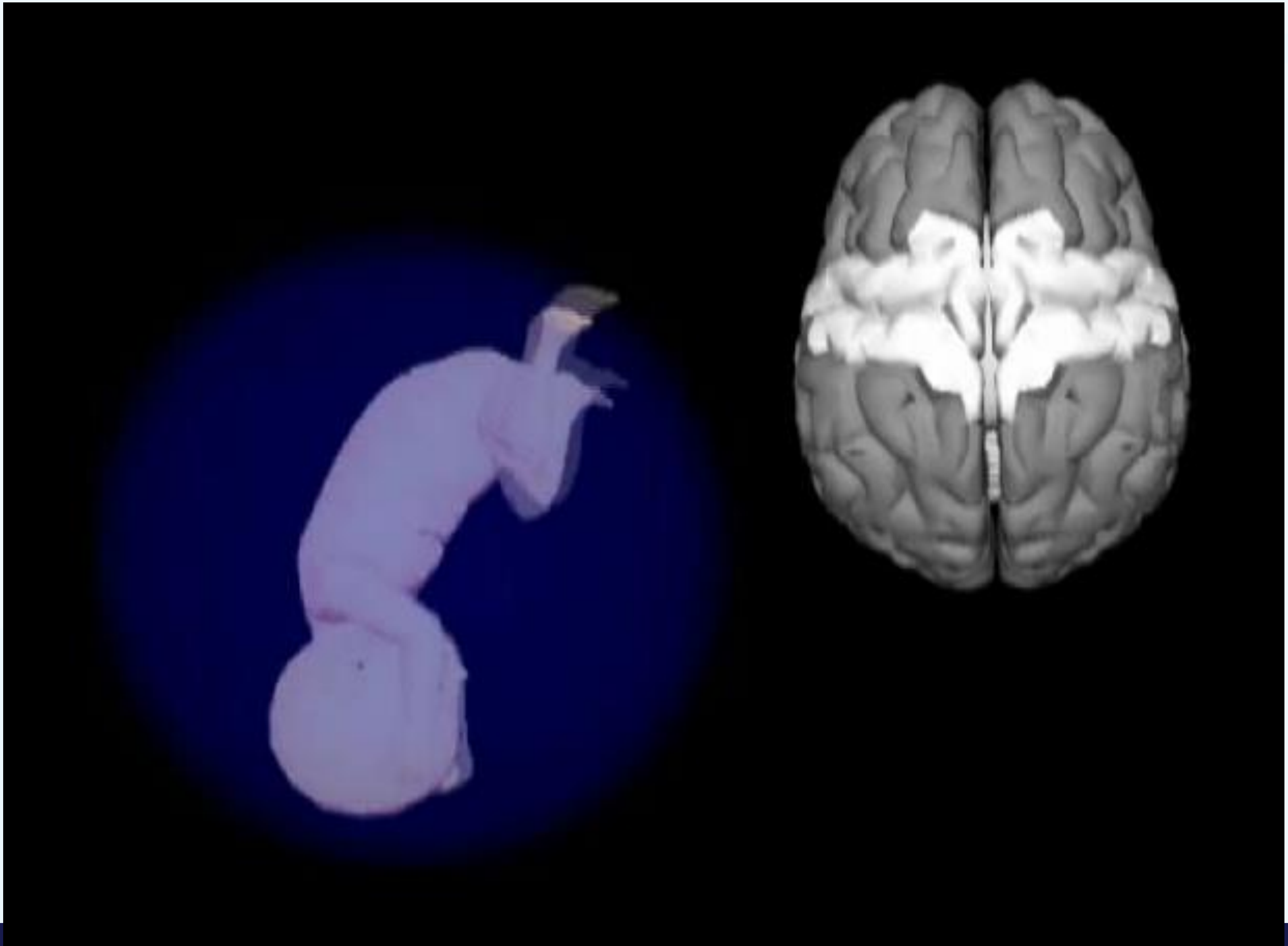
- **Hebbian learning:**
  - Fire together,
    Wire together!

- **Self-organizing map:**
  - Data reduction, usually 2-D map like cerebral cortex
  - As a result, clustering is done.



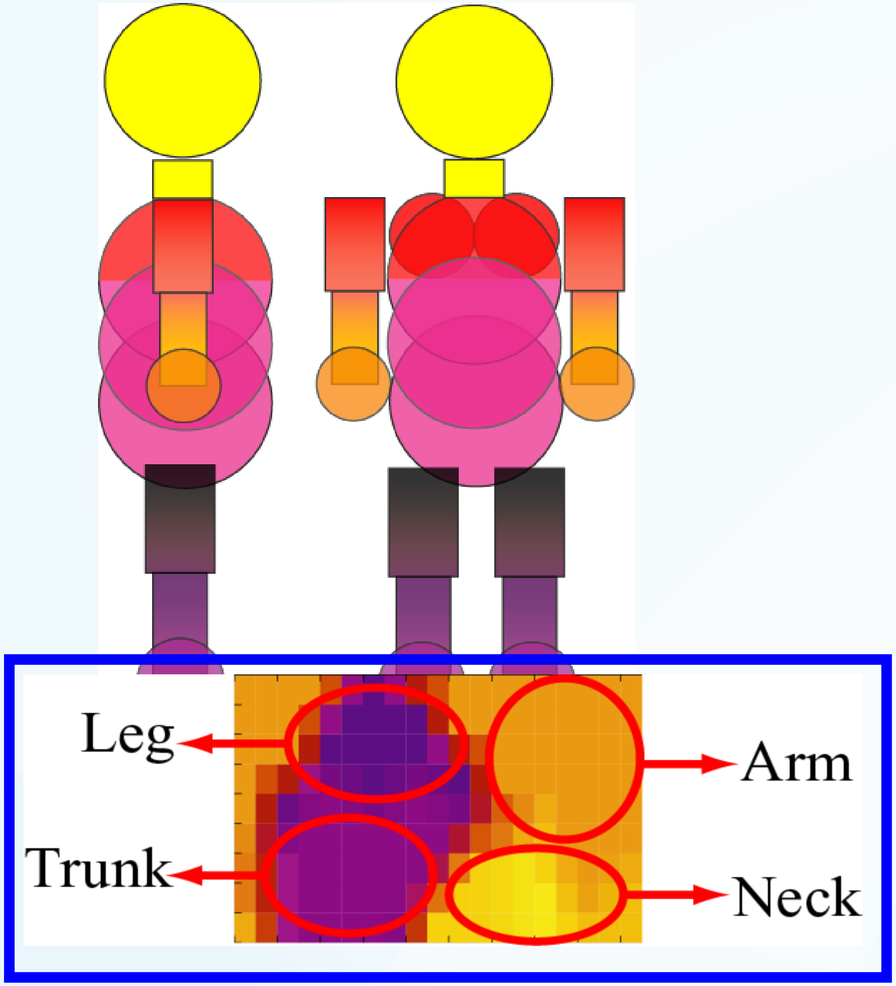
Fetal Brain Development (2)

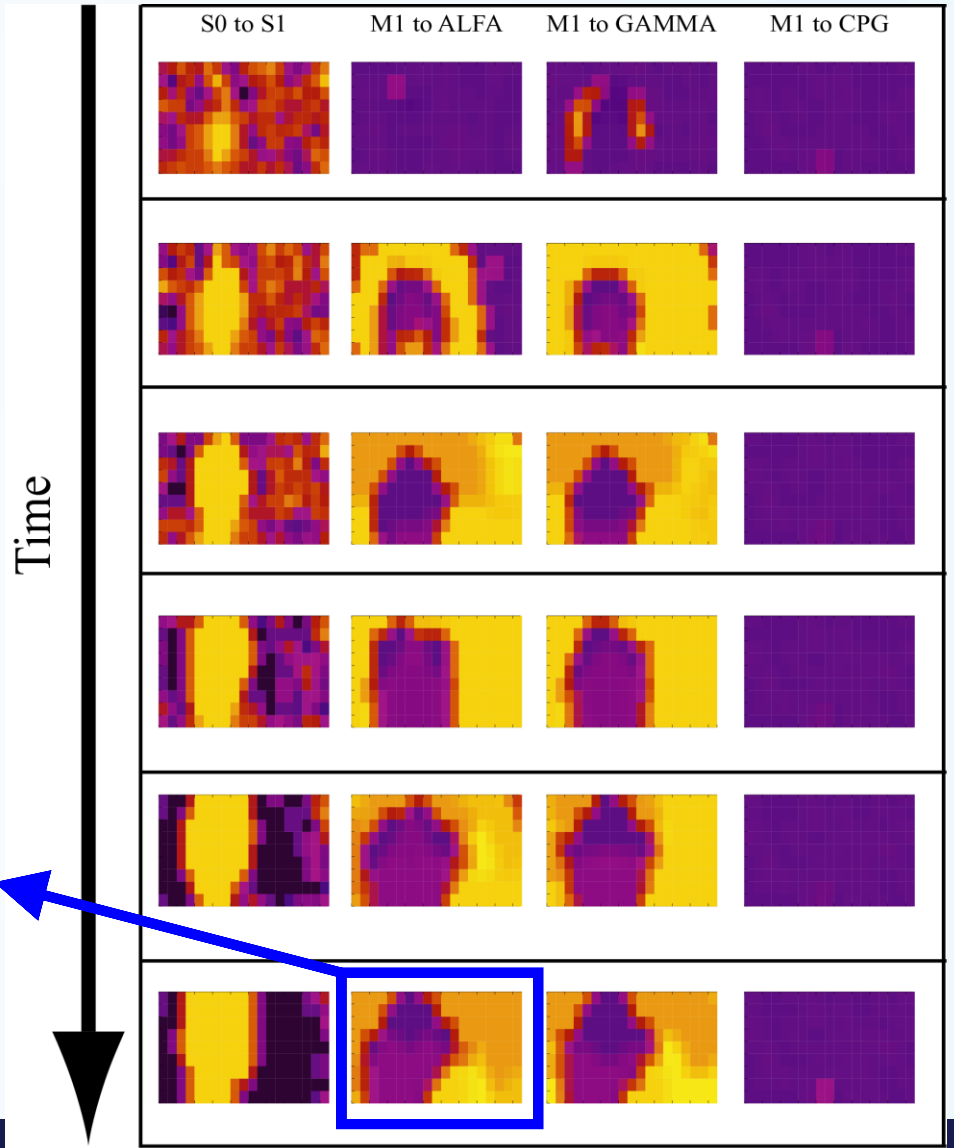
[Kuniyoshi et al., 08]



Fetal Brain Development (3)

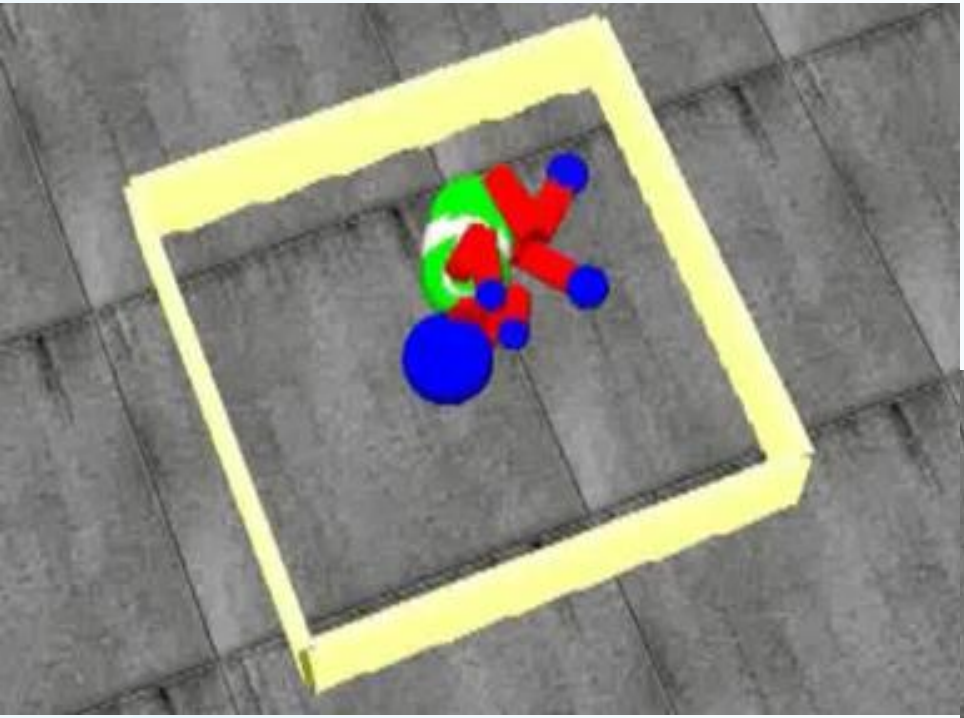
[Kuniyoshi and Sangawa 06]

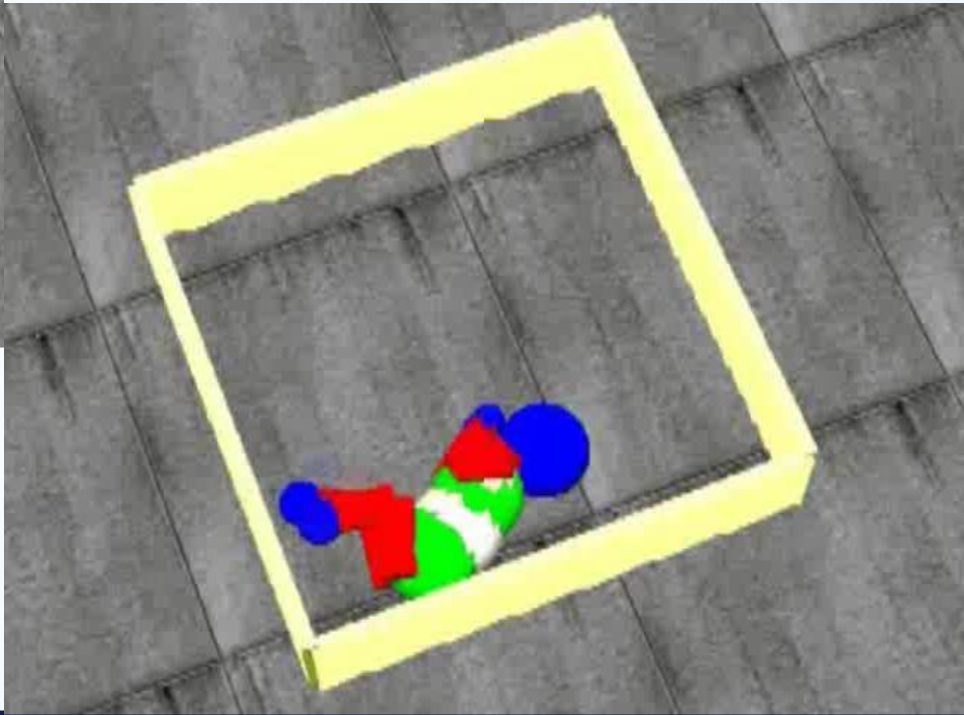




Fetal Brain Development (4)

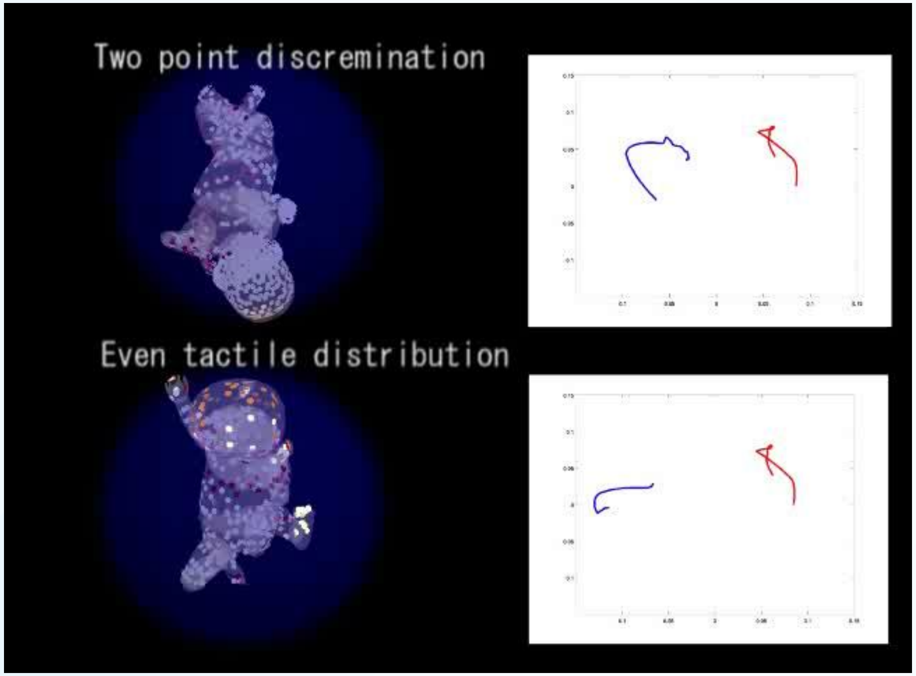
[Kuniyoshi and Sangawa 06]

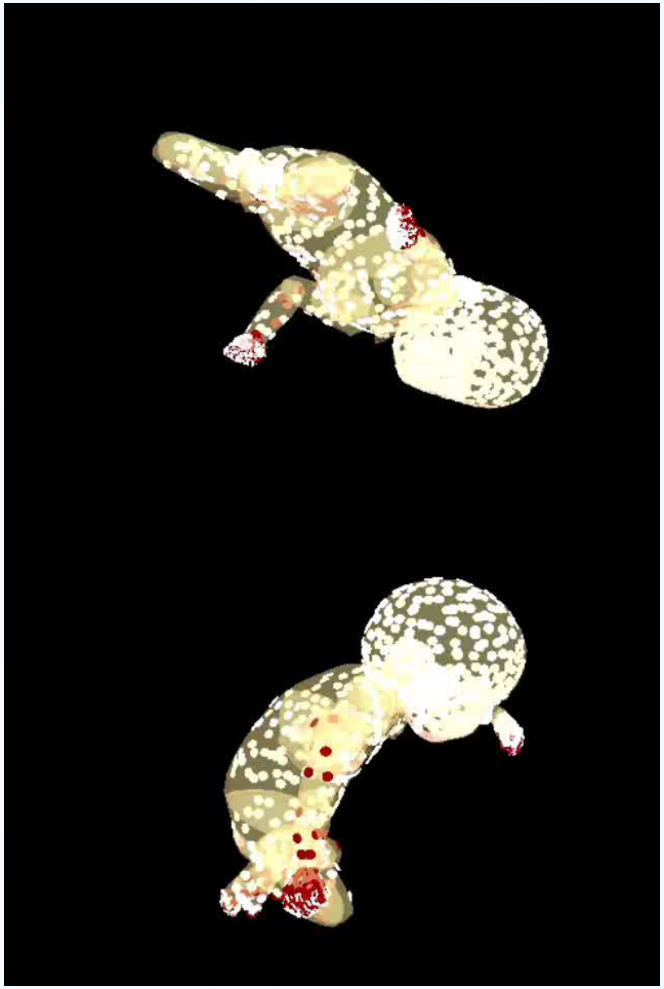




Fetal and neonatal simulations

- Top: normal fetus with heterogeneous tactile distribution.
- Bottom: abnormal on with homogeneous one which biologically dose not exist.



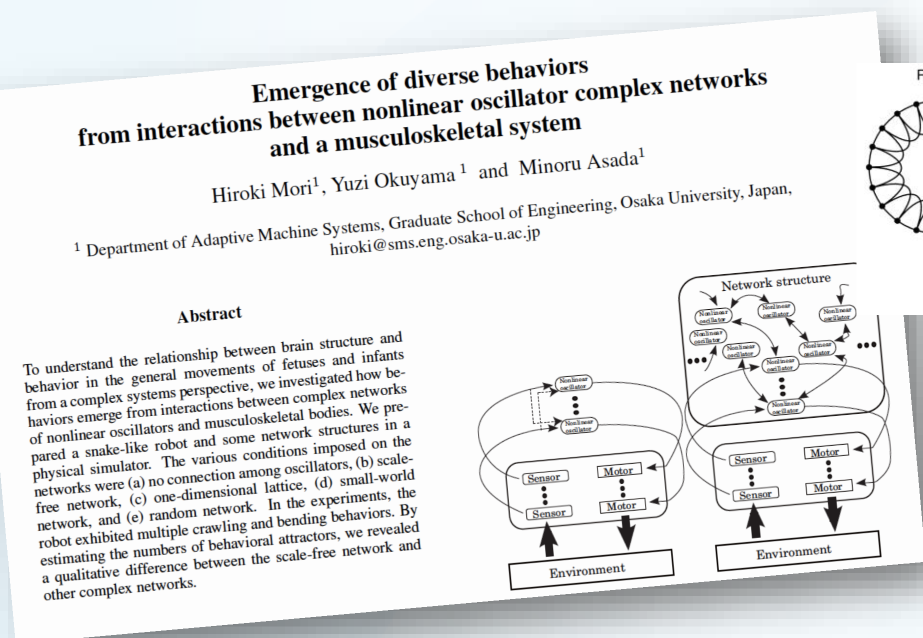


[Mori & Kuniyoshi 10]

Neural dynamics vs. Body dynamics?

[Mori et al., 2013]

- Observe and analyze the interaction between complex nonlinear oscillator networks and a musculoskeletal system from a perspective of emergence of diverse behaviors.



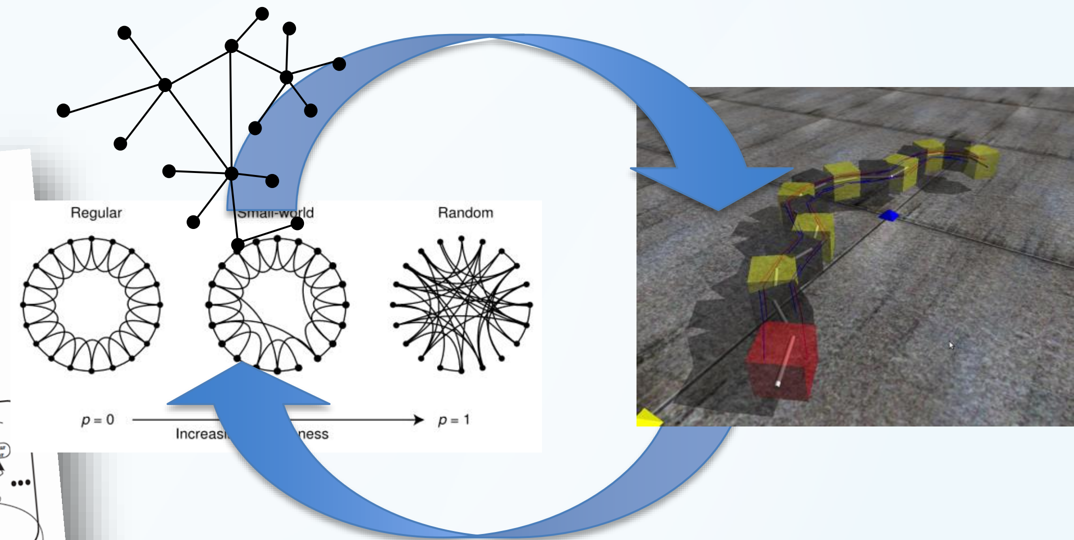
Emergence of diverse behaviors from interactions between nonlinear oscillator complex networks and a musculoskeletal system

Hiroki Mori[1], Yuzi Okuyama [1] and Minoru Asada[1]

[1] Department of Adaptive Machine Systems, Graduate School of Engineering, Osaka University, Japan, hiroki@sms.eng.osaka-u.ac.jp

Abstract

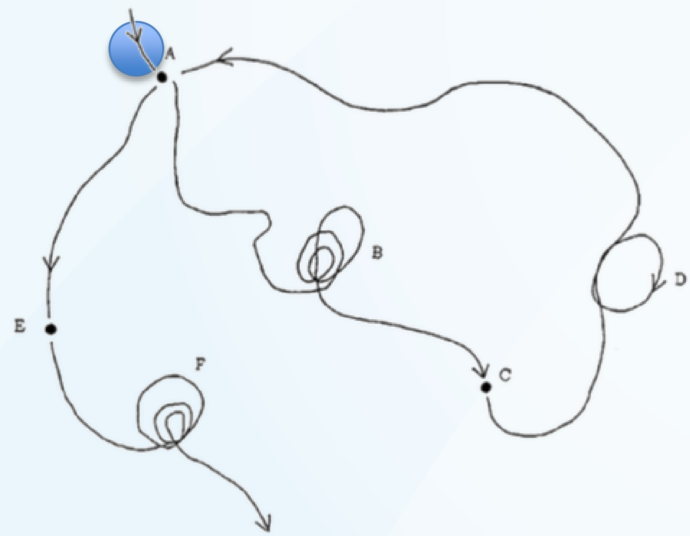
To understand the relationship between brain structure and behavior in the general movements of fetuses and infants from a complex systems perspective, we investigated how behaviors emerge from interactions between complex networks of nonlinear oscillators and musculoskeletal bodies. We prepared a snake-like robot and some network structures in a physical simulator. The various conditions imposed on the networks were (a) no connection among oscillators, (b) scale-free network, (c) one-dimensional lattice, (d) small-world network, and (e) random network. In the experiments, the robot exhibited multiple crawling and bending behaviors. By estimating the numbers of behavioral attractors, we revealed a qualitative difference between the scale-free network and other complex networks.



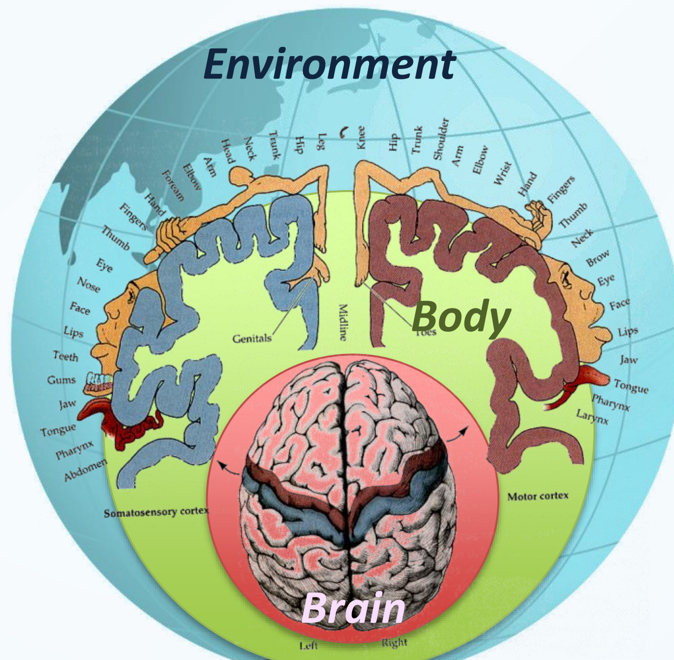
More conceptually, ...

Chaotic itinerancy to understand mechanism to emerge versatile behaviors from a interaction between body, brain and environment

- Sequence of quasi-attractor in a high-dimensional state space of neural activity [Tsuda, 2001]



[Tsuda, 2001]



www.flickr.com/photos/46006858@N05/8641421501

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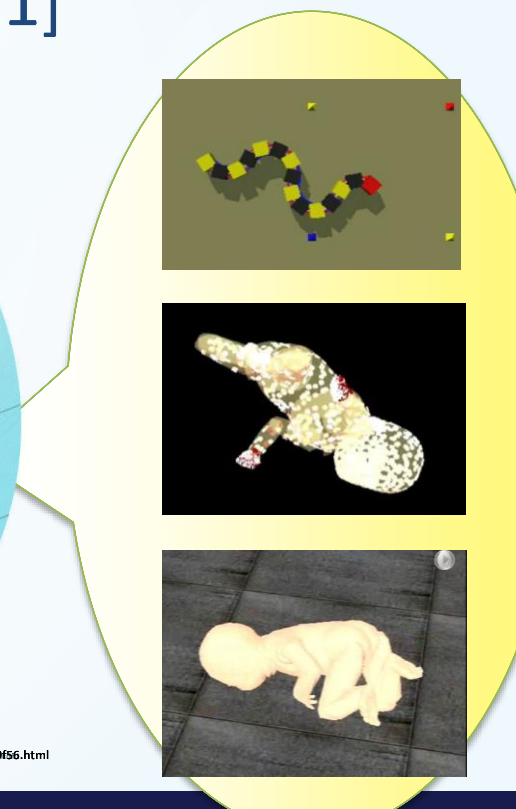


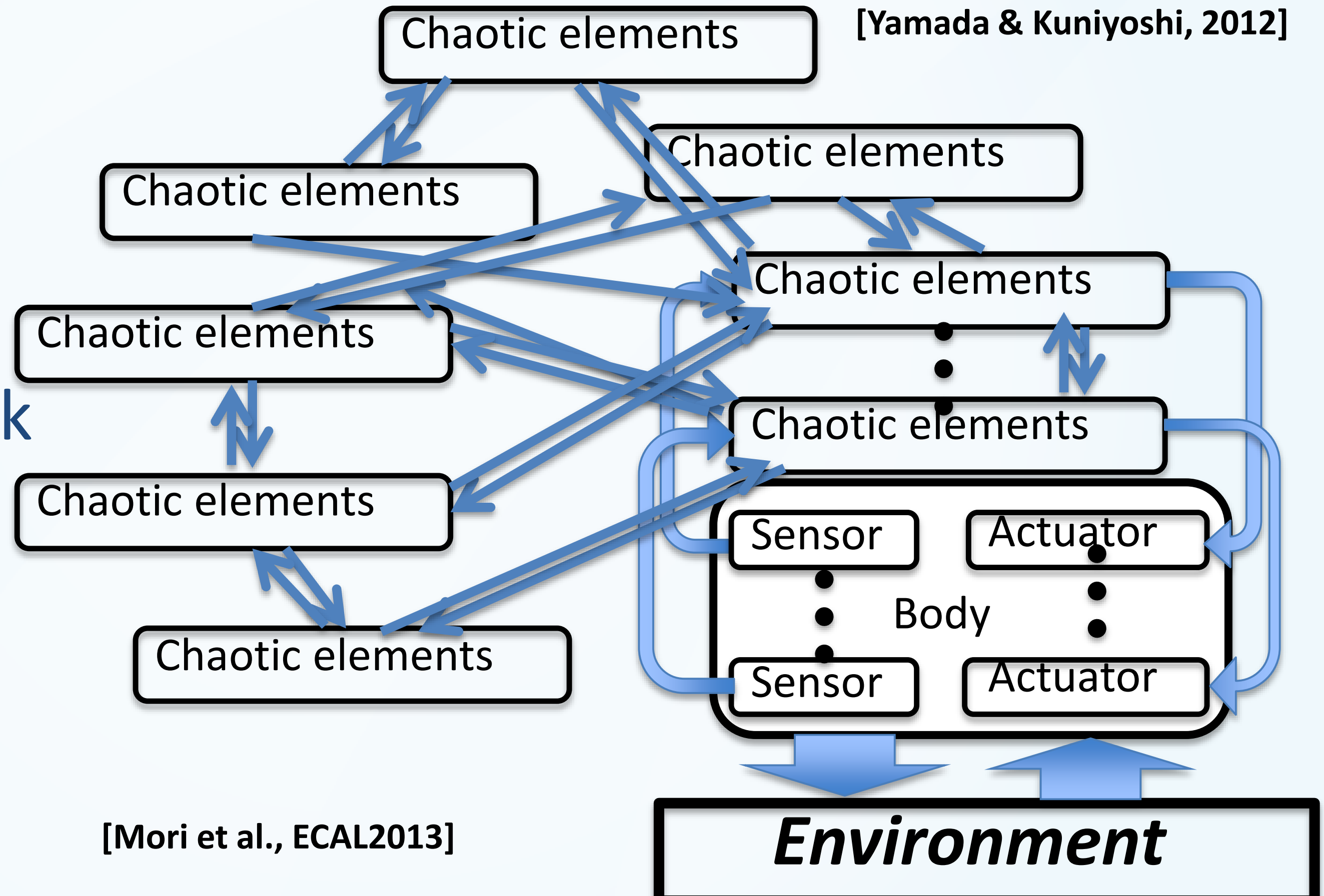
Previous studies

- Adaptive behaviors are emerged from a interaction between environment and body using body constraint as chaotic itinerancy.

[Kuniyoshi & Suzuki, 2004]

[Yamada & Kuniyoshi, 2012]

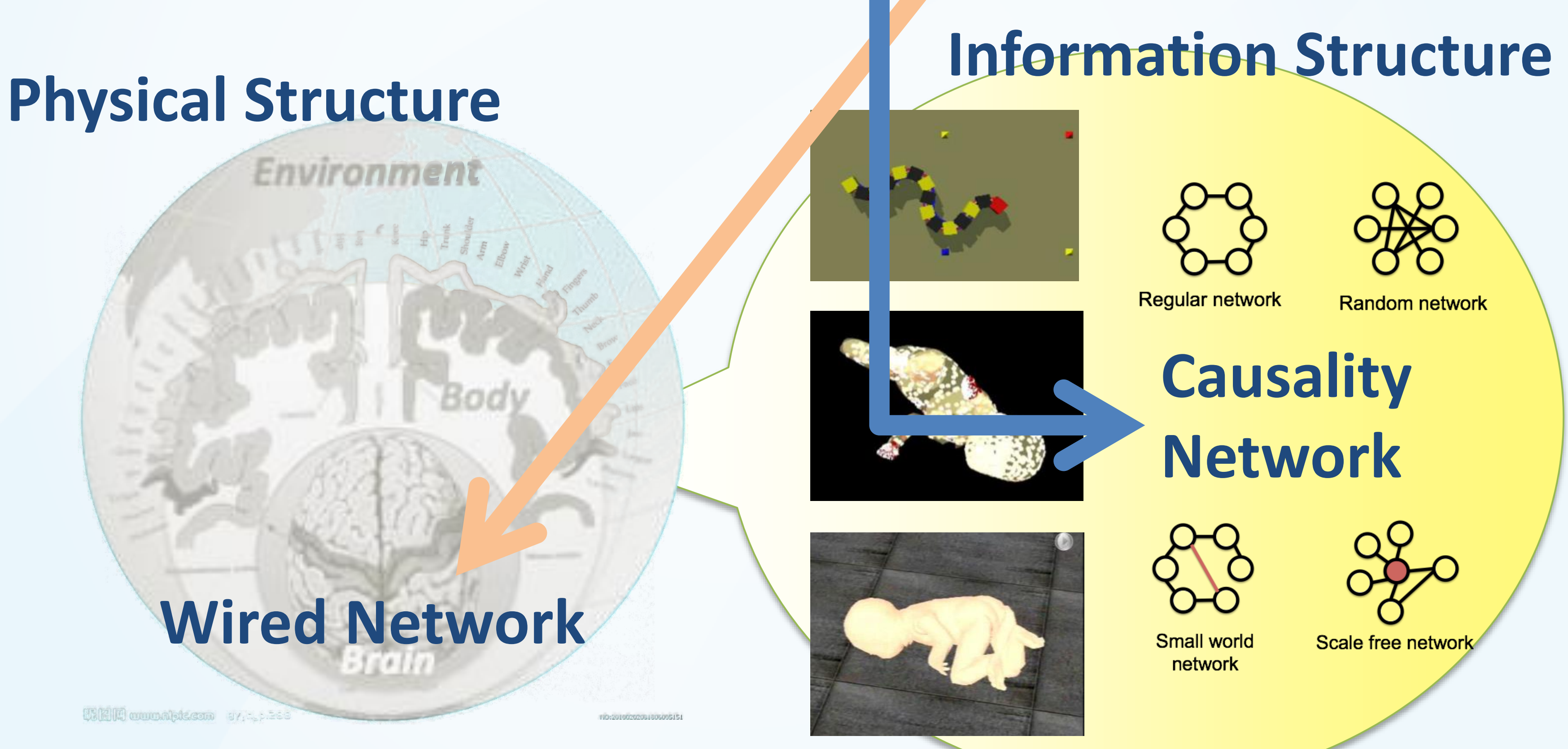
- Diverse behaviors are spontaneously emerged by complex network connected to a musculoskeletal body according to topology of network.



[Mori et al., ECAL2013]

Approach

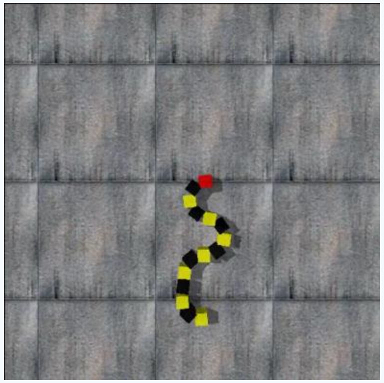
- Conduct a simulation using nonlinear oscillator network and musculoskeletal body
- Estimate an emerged network structure within behaviors by causality between neurons.

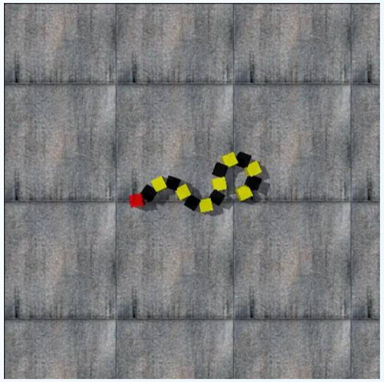


Analysis of Causality Network

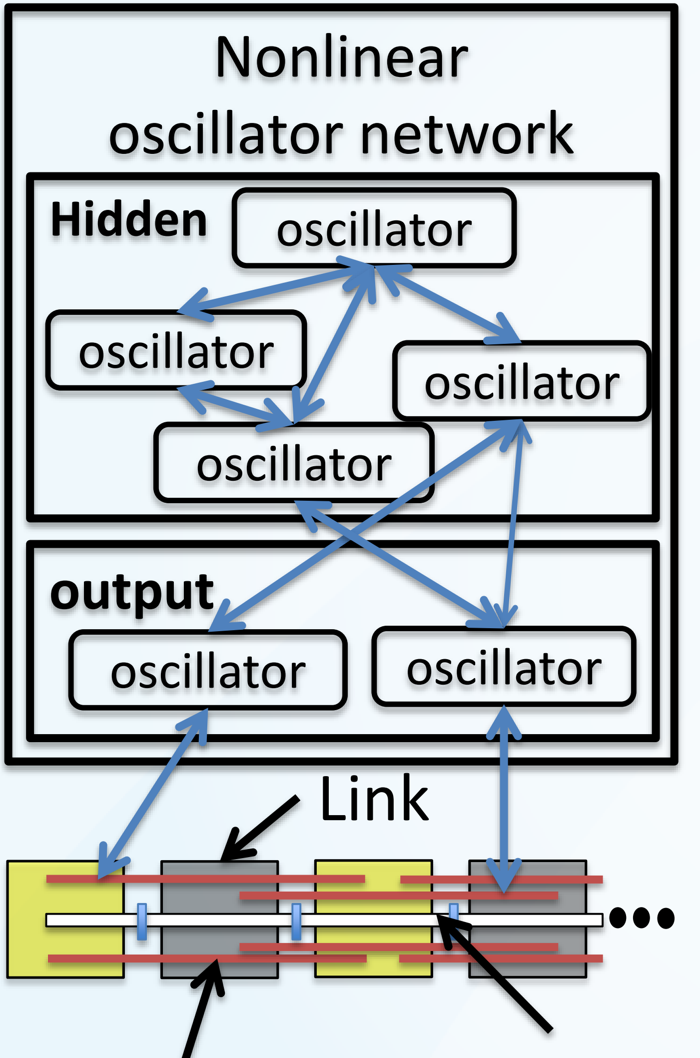
[Park et al., ECAL2015]

Three major questions:	Stable Motion	Unstable Motion
1. How and what type of neurons are interacted?	Local Interaction	Global Interaction
2. What’s structural property of causality network?	Less Complex Network	More Complex Network
3. How much Influence from the body?	Weak Influence	Strong Influence





A nonlinear network and a musculoskeletal model



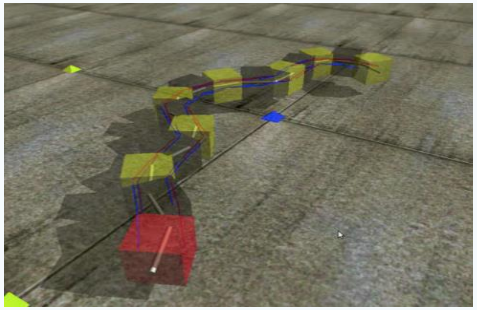
Bonhoeffer–van der Pol (BVP) equations as neuron

$$\tau \frac{dx}{dt} = c\left(x - \frac{1}{3}x^3 - y + z\right) + \boxed{\delta(S_f - x)}$$

$$\tau \frac{dy}{dt} = \frac{1}{c}(x - by + a) + \boxed{\epsilon S_f}$$

$$S_f = \begin{cases} \alpha I + (1-\alpha)\frac{1}{K}\sum_{j=1, j\neq i}^{N} w_{ji}x_j & \text{if output neuron} \\ \frac{1}{K}\sum_{j=1, j\neq i}^{N} w_{ji}x_j & \text{else} \end{cases}$$

$$w_{j,i} = \begin{cases} 0 & \text{if no connection} \\ 1 & \text{else} \end{cases}$$

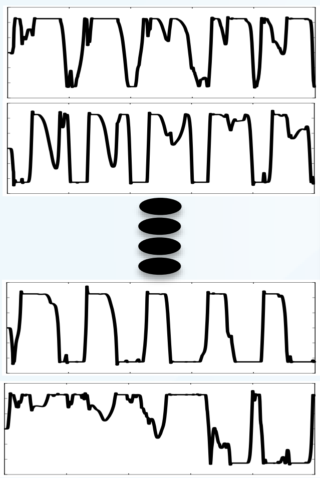


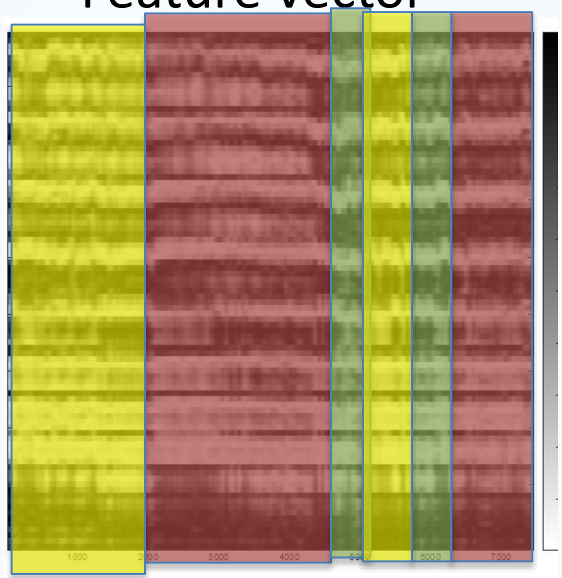
Sensor value (length of muscle fiber) is used as input to neurons

Behavior Analysis

To find repetitive movement patterns

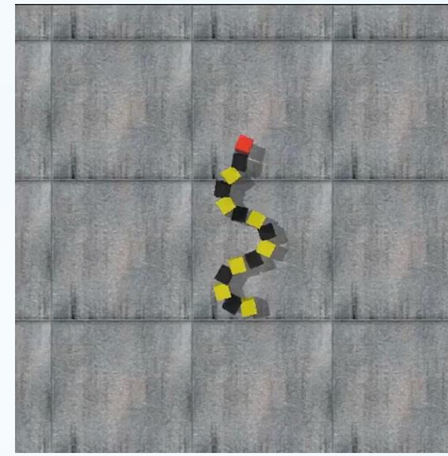
Joint angles





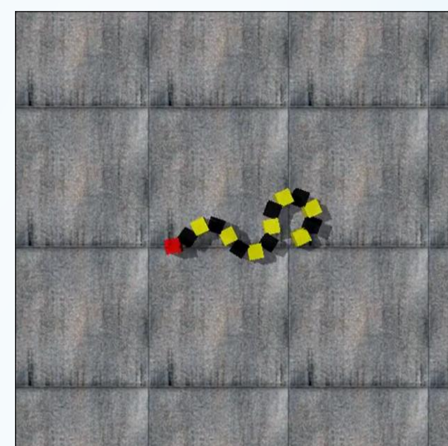
Correlation between joint angles within time window

Stable movement



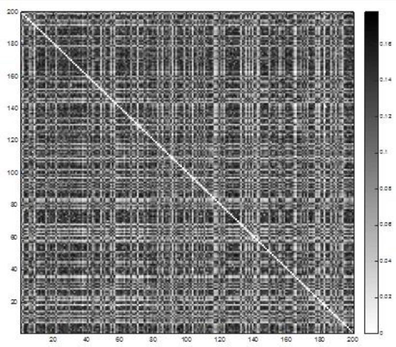
Duration: 430[sec]

Unstable movement



Duration: 11[sec]

Causality Network Analysis



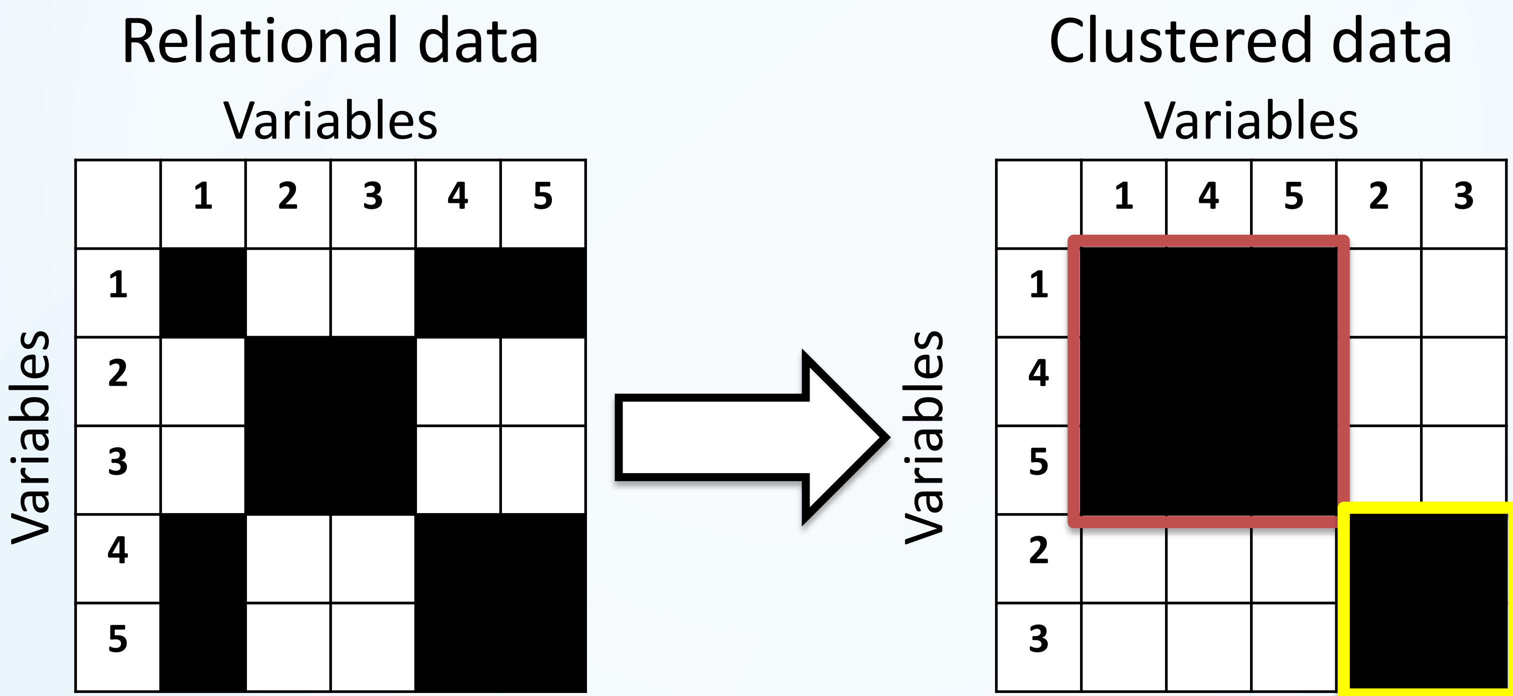
Estimate a causality network by transfer entropy using neuron's activation for each movement pattern

1. Cluster and extract subnetworks by IRM: To know and visualize an interaction in a causality network

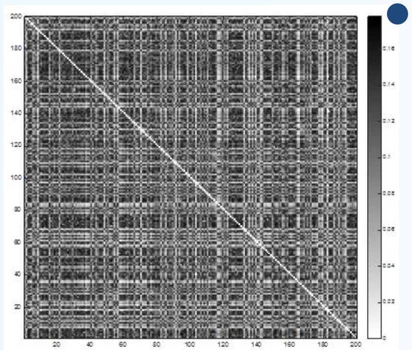
Infinite Relational Model (IRM)

[Kemp et al., 2006]

- Nonparametric Bayesian model that discovers system of related concepts
- Rearrange matrix which consist of relational data to make clusters

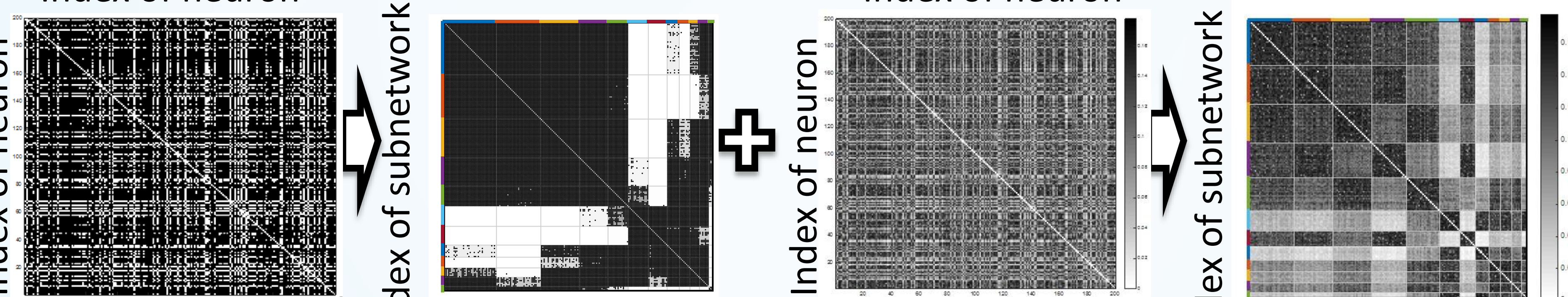


Causality Network Analysis



- Estimate a causality network by transfer entropy using neuron's activation for each movement pattern

1. Cluster and extract subnetworks by IRM: To know and visualize an interaction in a causality network

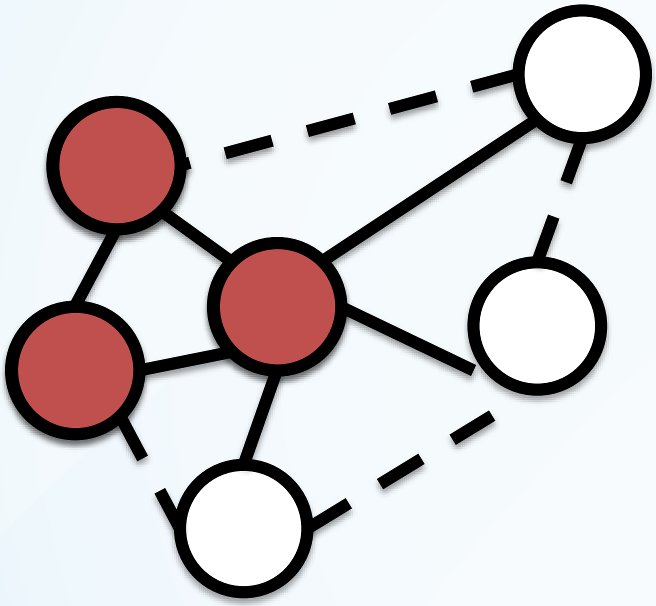


Binaries mutual information → Extract subnetwork + Causality network → Clustered causality network

2. Complex network theory: Topological property

Index of Complexity: Clustering coefficient and shortest path length

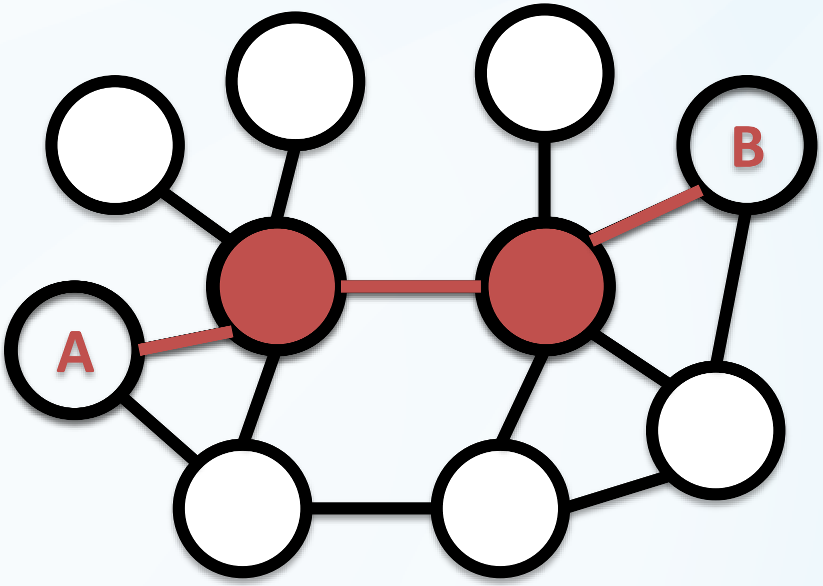
Clustering coefficient



Density of groups in a network

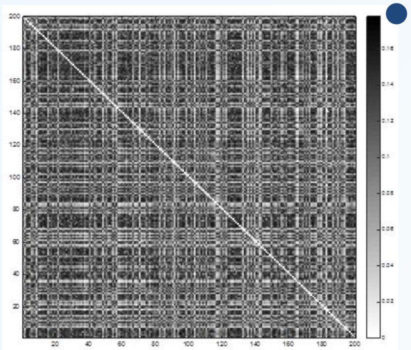
$$C = \frac{\text{Number of closed triangles}}{\text{Number of possible triangles}}$$

Shortest path length



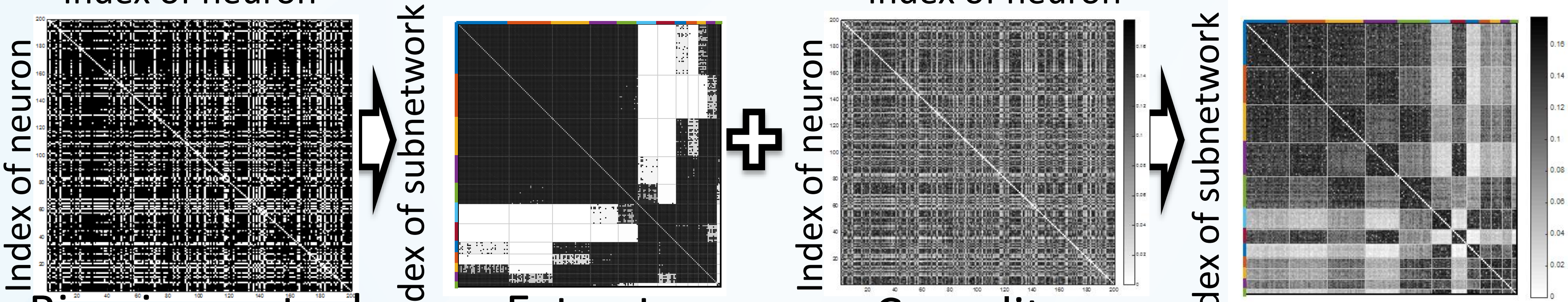
Distance among the nodes

Causality Network Analysis



- Estimate a causality network by transfer entropy using neuron's activation for each movement pattern

1. Cluster and extract subnetworks by IRM: To know and visualize an interaction in a causality network



Binaries mutual information

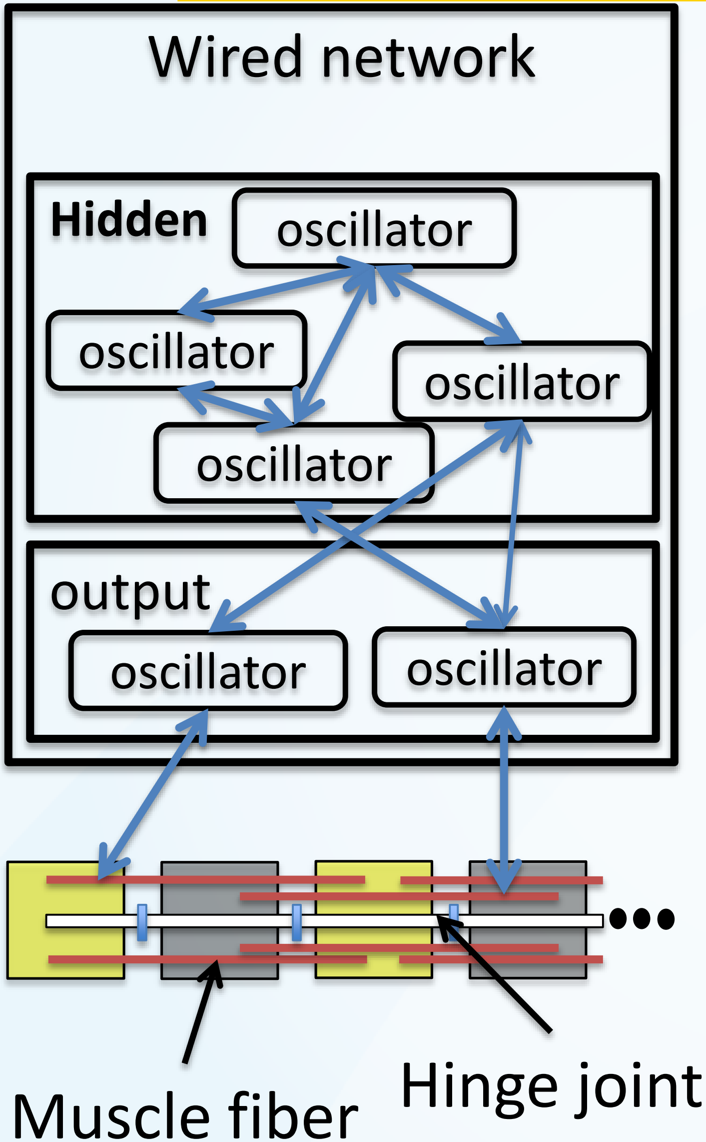
Extract subnetwork

Causality network

Clustered causality network

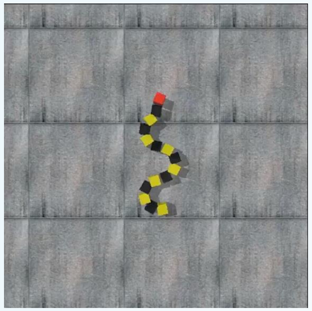
2. Complex network theory: Topological property
3. Average transfer entropy: Influence from a body to network

Experimental setting

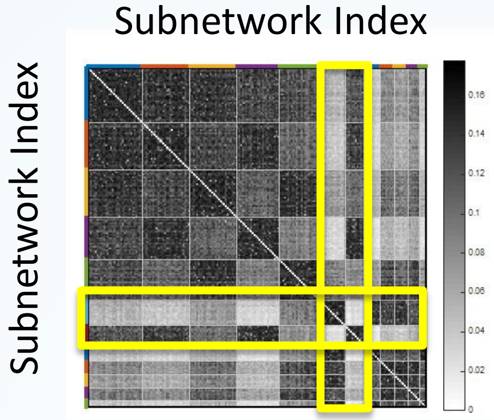


- Snake-liked robot
- Number of link: 15
- Number of output neurons: 26
- Number of hidden neurons: 174
- Topology of wired network: Randomly distributed network
- Simulation time: 2000[sec]
- No learning mechanism

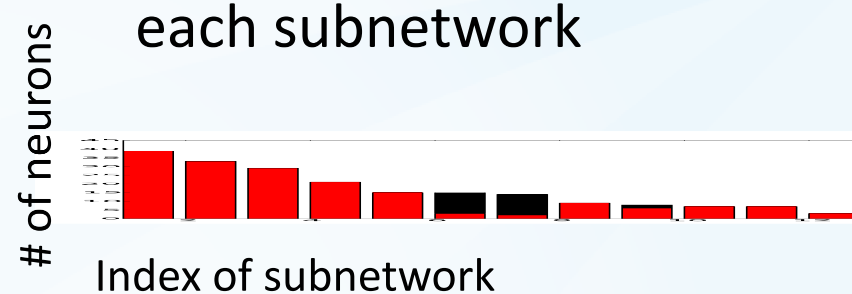
(a) Causality network: How and what type of neurons are interacting?

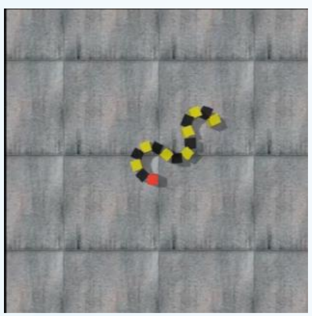


Duration: 430[sec]

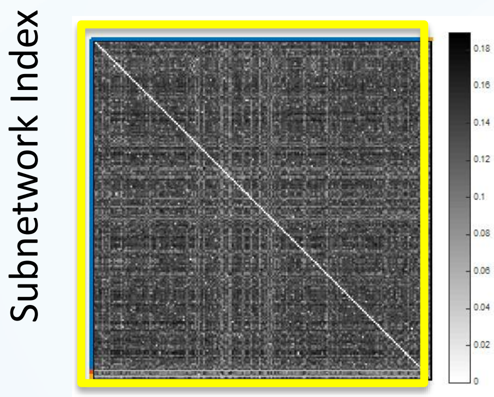


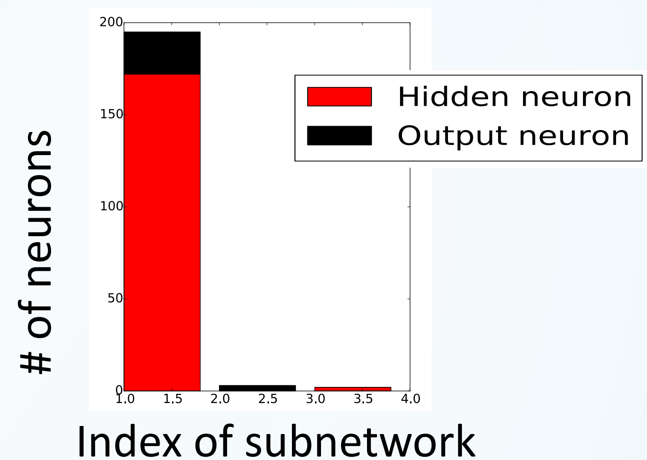
Number of neurons in each subnetwork





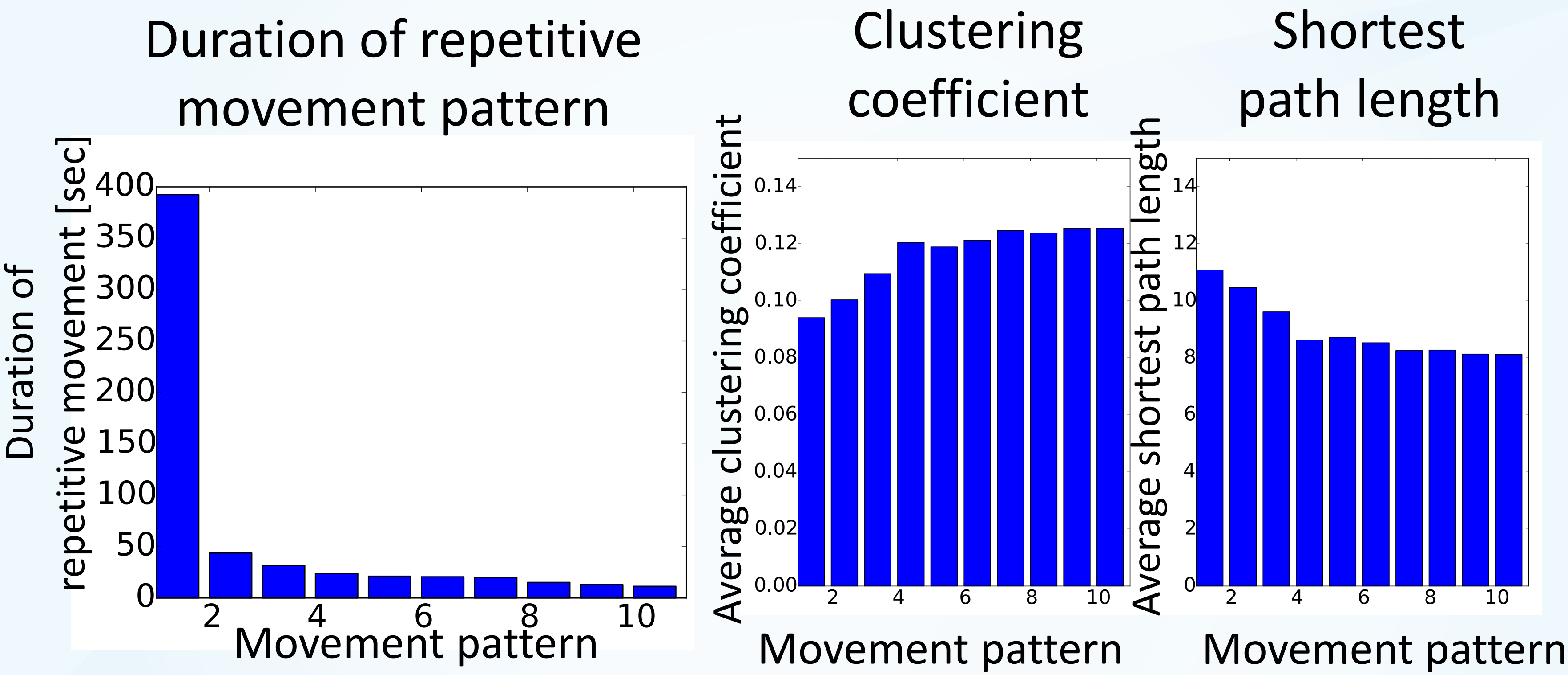
Duration: 11[sec]





- Causality networks when the most stable movement pattern has the least and local interaction with a subnetwork that has many output neurons to another subnetwork.

(b) Complex network properties: Structure property in a causality network?



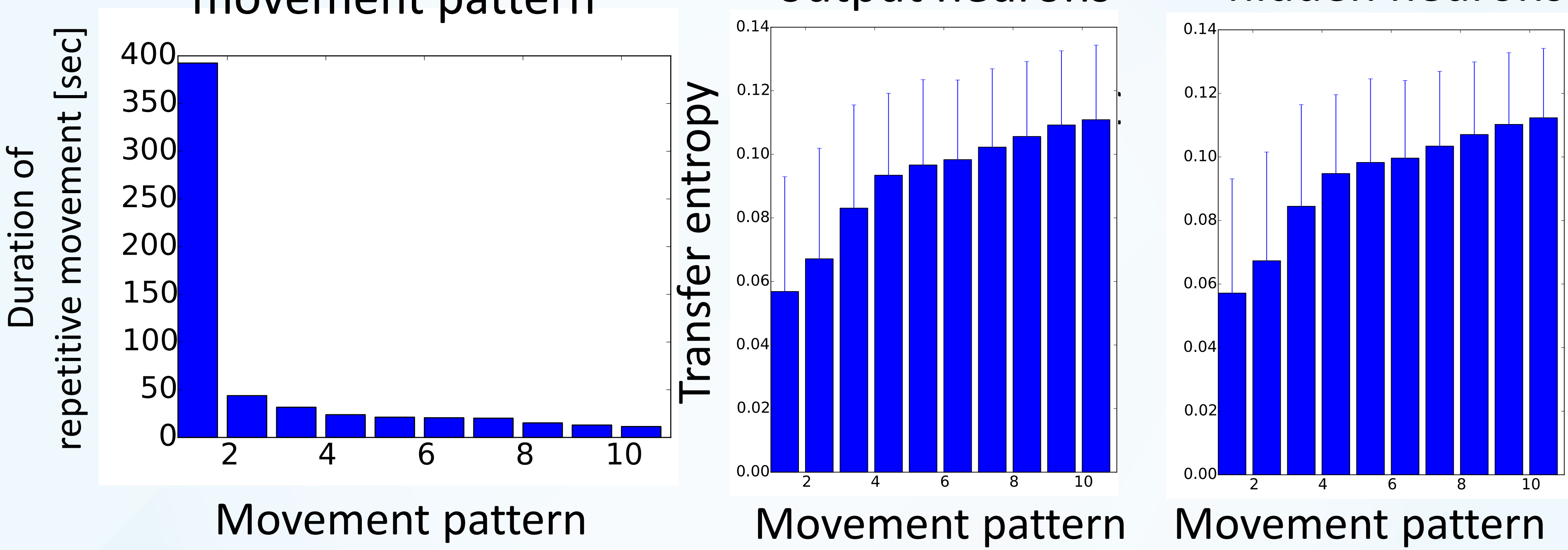
- Causality network during longer stable repetitive movement has a smaller clustering coefficient and longer shortest path.

(c) Average of transfer entropy between hidden and output neurons: Influence of body?

Duration of repetitive movement pattern

hidden neurons -> output neurons

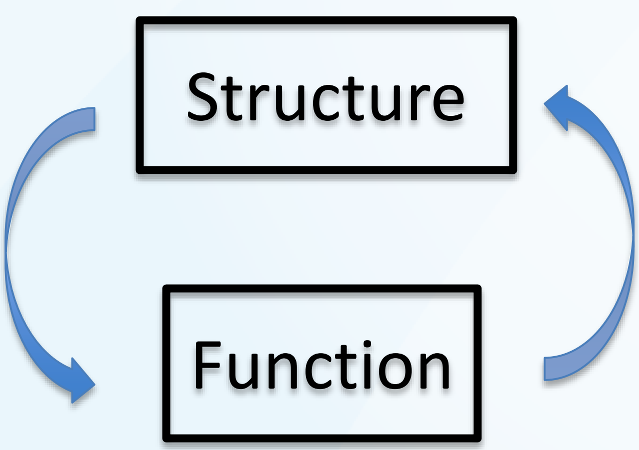
Output neurons -> hidden neurons

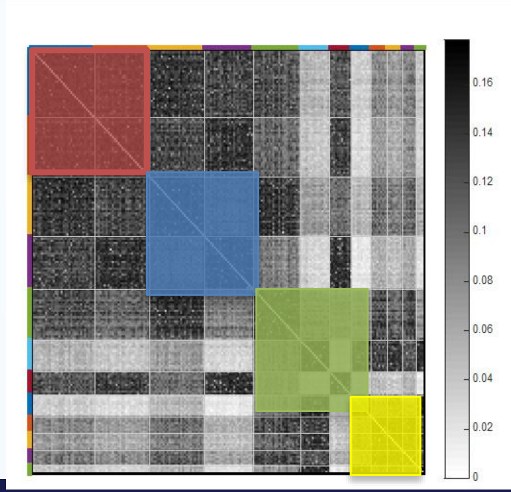


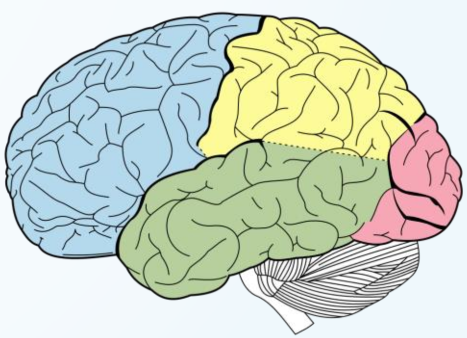
- Lower values of transfer entropy between hidden neurons and output neurons are observed during longer repetitive movements

Discussion

- Emergence of functional module in a subnetwork
  - Role of body and wired network to make functional module
    - Goal oriented movement patterns are emerged by constraint of body [Kuniyoshi and Suzuki, 2004]
    - More complex structure? Appropriate constraint?
  - Other type of sensor
    - Emergence of visual, sound, tactile sensor area?







https://en.wikipedia.org/wiki/Cerebral_cortex

Summary of network analysis

- We estimate a emerged causality network within behaviors and analyze interaction and structure property of the causality network
- Stable (unstable) movements are emerged from
  - Local (global) interaction in subnetworks that had more output neurons
  - Less (more) complex network property
  - Weak (strong) interaction between body and network

Future issues

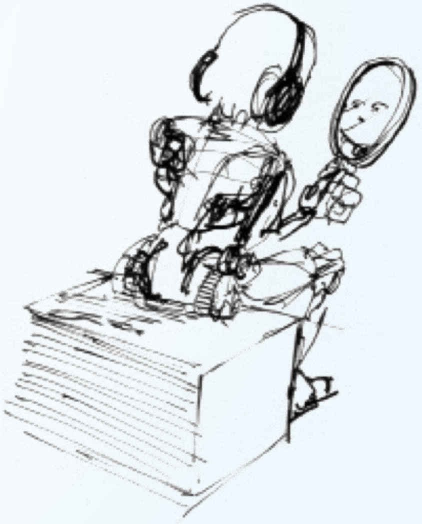
- Different body structure and wired network
- Other sensors
- Other property of complex networks

My desire or speculation is ...

- Consciousness comes from unstable state → more interaction with physical environment through sensorimotor systems. → Exploration → Motivation

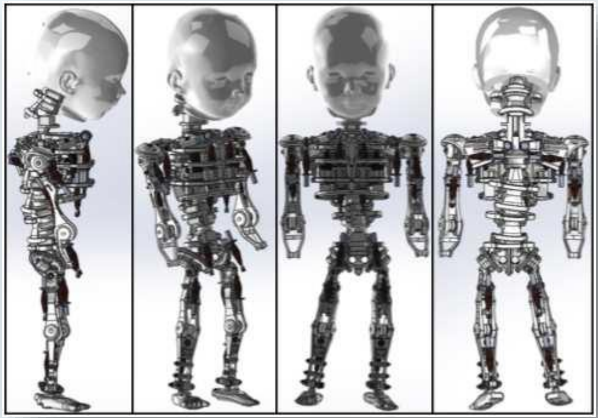
- Unconscious level is at stable state → less interaction with physical environment through sensorimotor systems. → DMN?

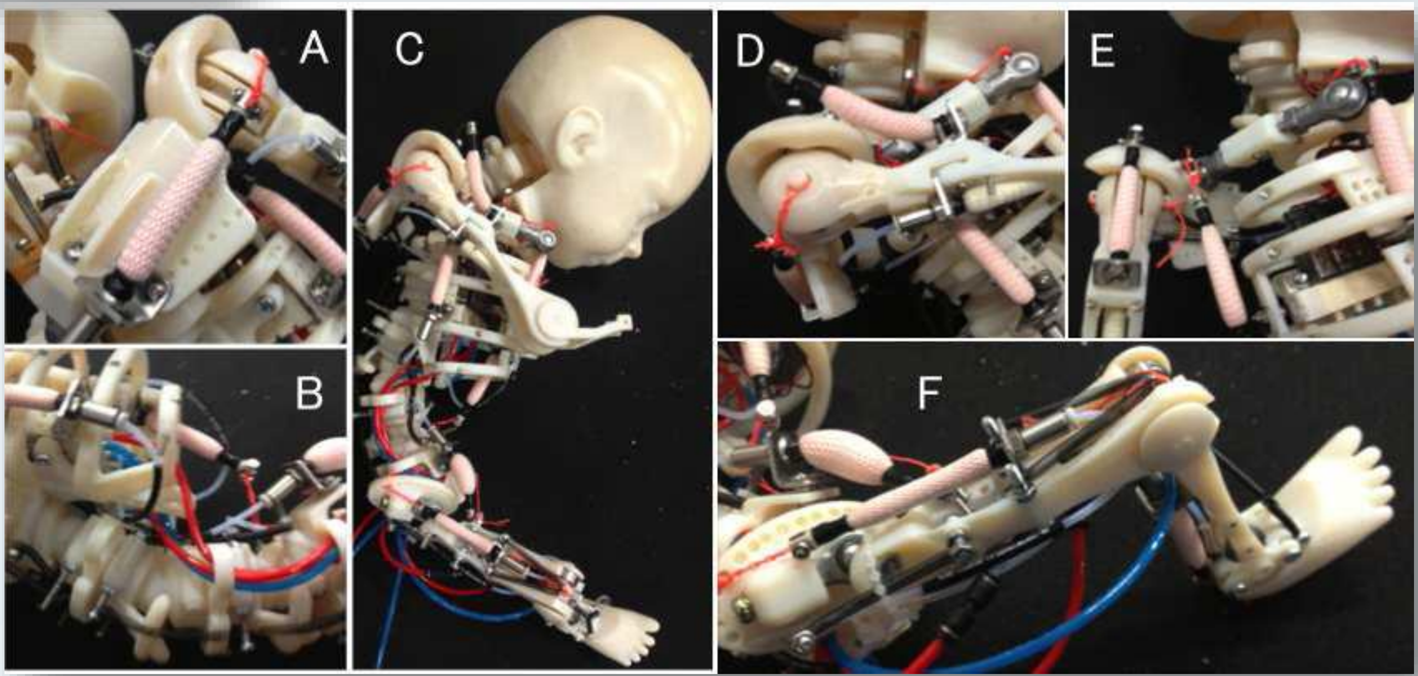
- Chaotic itinerancy between both states with a huge diversity of behaviors is a phenomenon of robot self?



Fetusoid

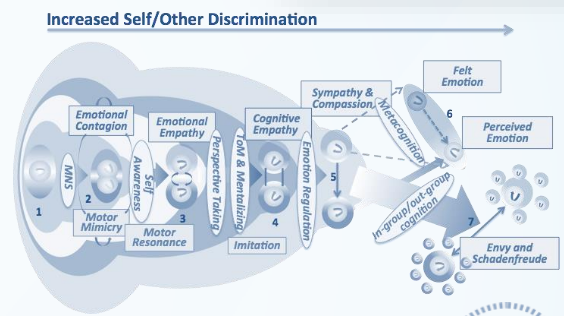
[Mori et al., 2014 (to appear)]

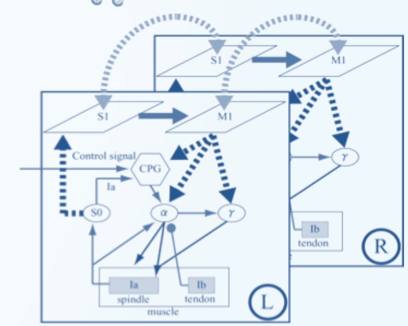


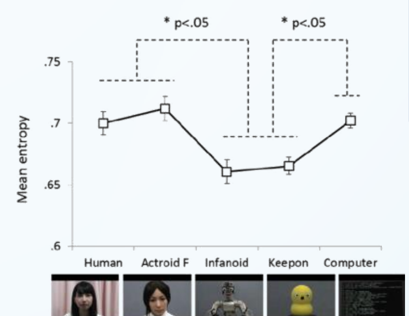


Outline of my talk

1. Cognitive Developmental Robotics
   - What's development?
   - Developmental Robotics, Cognitive Developmental Robotics
2. Towards Artificial Empathy
   - Self/other cognition
   - A developmental model
   - Cognitive vs. Affective
3. Brain-Body Interaction
4. **Mind Holder and Mind Reader**
5. Future issues







Social Brain Analysis

[Takahashi et al., 2014]

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CORTEX XXX (2014) 1–12

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Journal homepage: www.elsevier.com/locate/cortex

ELSEVIER

Special issue: Research report

Different impressions of other agents obtained through social interaction uniquely modulate dorsal and ventral pathway activities in the social human brain

Hideyuki Takahashi [a,b,c], Kazunori Terada [d], Tomoyo Morita [a,c], Shinsuke Suzuki [e,f], Tomoki Haji [b,c], Hideki Kozima [g], Masahiro Yoshikawa [h], Yoshio Matsumoto [i], Takashi Omori [b], Minoru Asada [a] and Eiichi Naito [c,j,]*

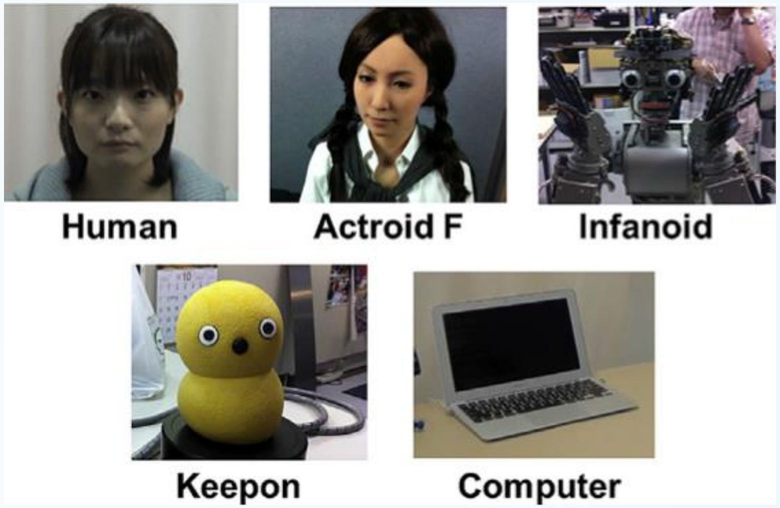
Abstract

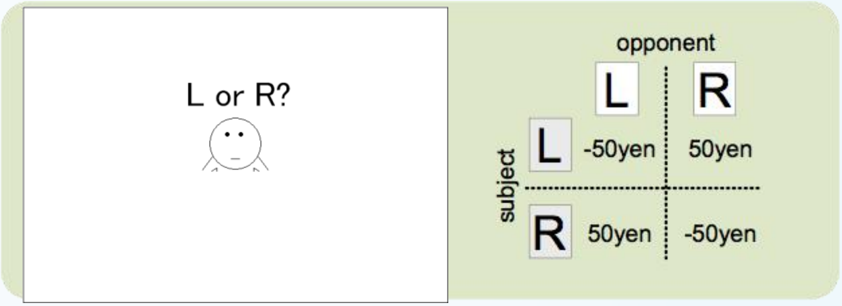
[Takahashi et al., 2014]

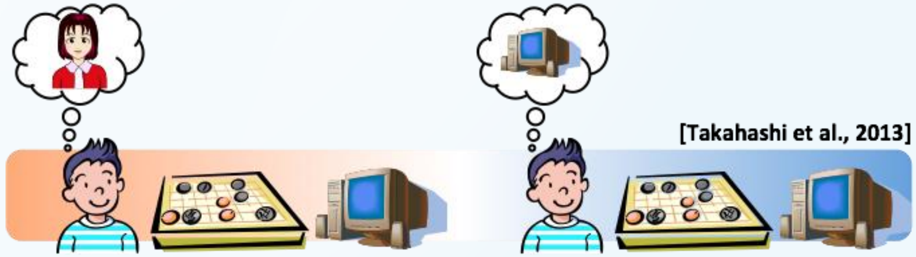
1. Social interaction with five kinds of different opponents (16 subjects).
2. Matching-pennies game in fMRI scanner.
3. Analysis of impressions and brain activities affected by 1.

→ Mind holderness

→ Mind readerness







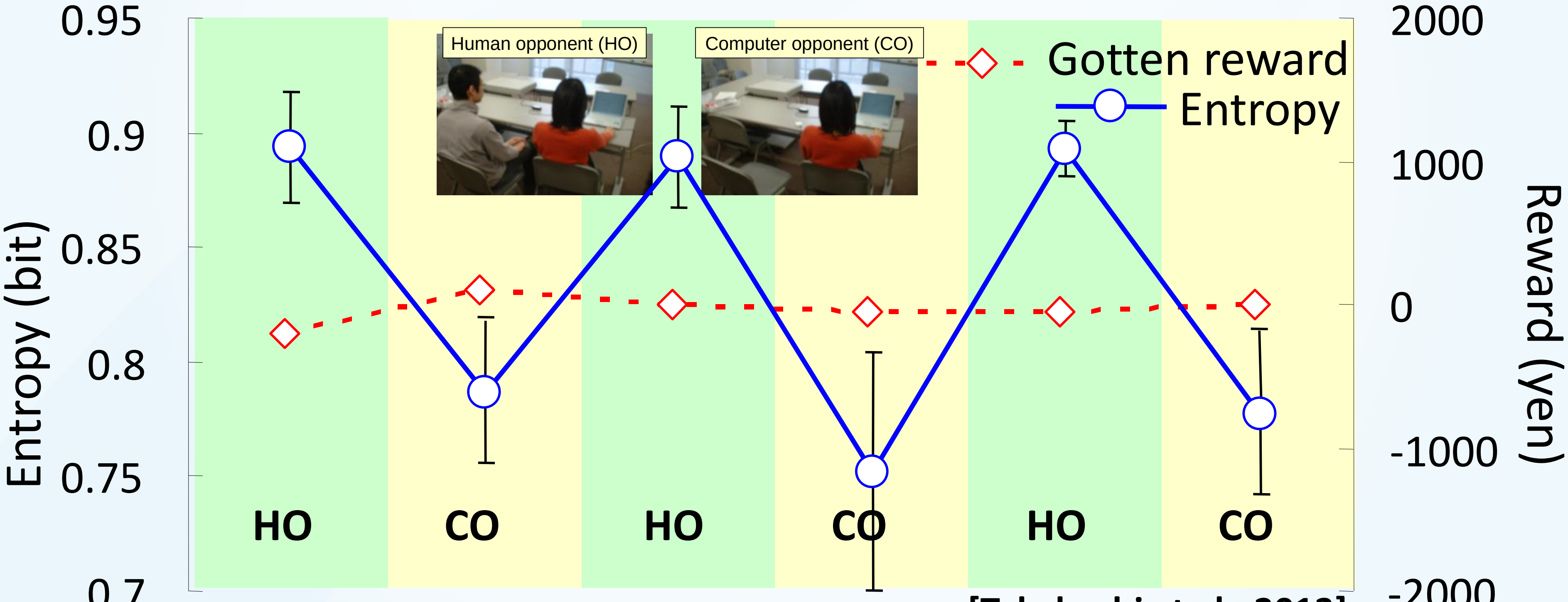
Basic idea of behavior Analysis

[Takahashi et al., 2014]

- Evaluation of decision-making tactics → entropy

$$H_S = -\frac{1}{N_s} \sum_{s \in S} \sum_{d \in \{L,R\}} P(d|s) \log_2 P(d|s)$$

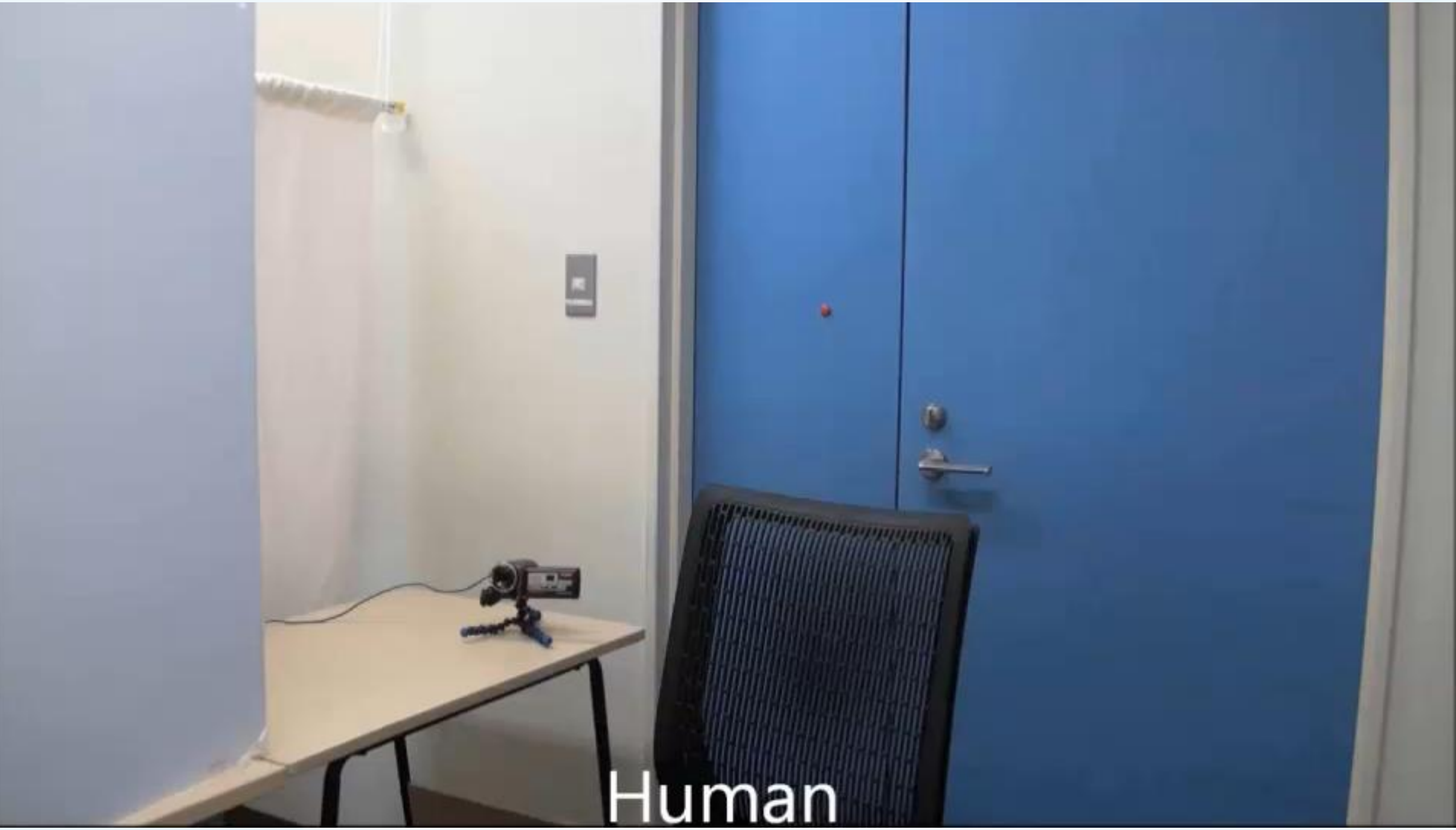
- Larger H_S → complex! Smaller H_S → simple!



[Takahashi et al., 2013]

Social interactions with five kinds of different opponents

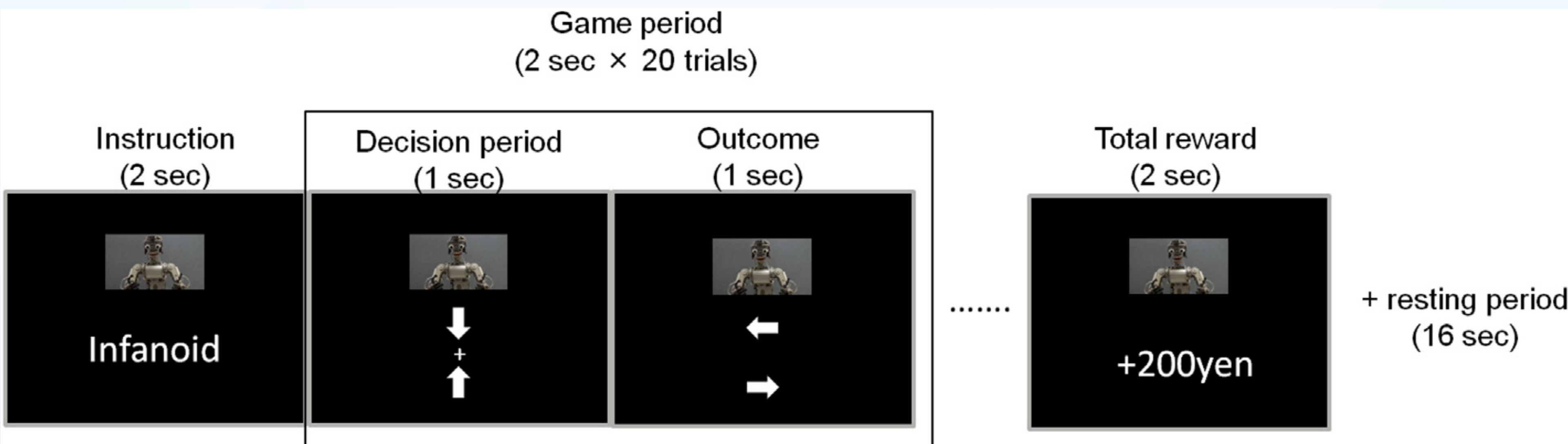
[Takahashi et al., 2014]



Task: procedures

[Takahashi et al., 2014]

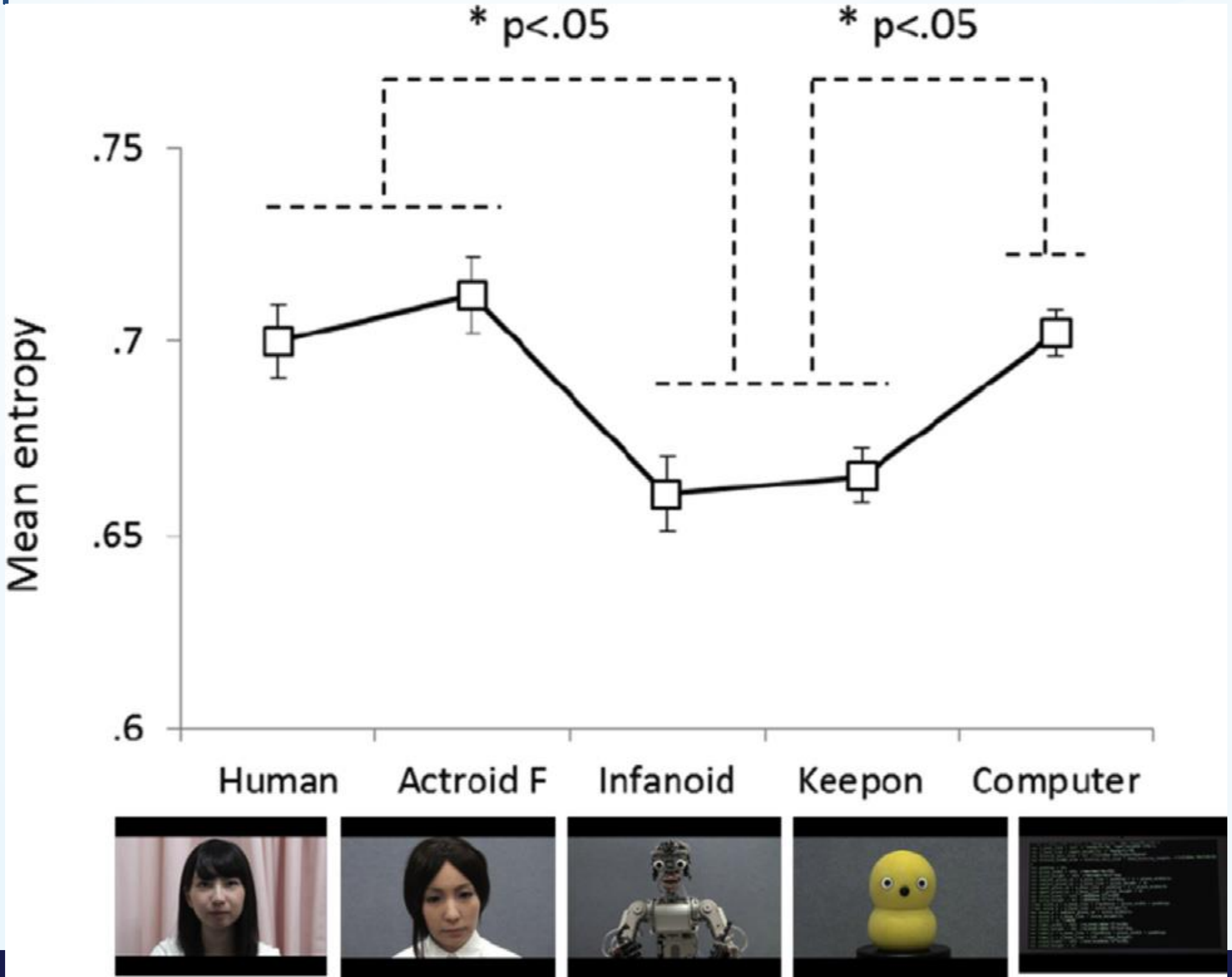
- Participants were required to select either left or right.
- The panel: the opponent → its "right" and the participant → his/her "right", →→→ the participant lost this game.
- 20 times in each block, 16-sec break before next block where participants played with a new opponent.



Behavior Analysis

[Takahashi et al., 2014]

- Grand means of entropy for the five opponents across participants. Error bars indicate standard errors of means.



Questionnaire Analysis: PCA

[Takahashi et al., 2014]

The impression questionnaire from all participants.

1. a mental function score →How much the participants explicitly attributed mental functions to each opponent
2. Correlation between PCA values obtained from the two questionnaires across the five opponents.
3. Correlation between the PCA and entropy values.
4. Transform the correlation to z-scores within each participant.
5. Determine which PCA component better reflected
    1. the mental function
    2. Entropy

Questionnaire Analysis: PCA

[Takahashi et al., 2014]

Table 1 – Loads of questionaries' items for each PCA component.

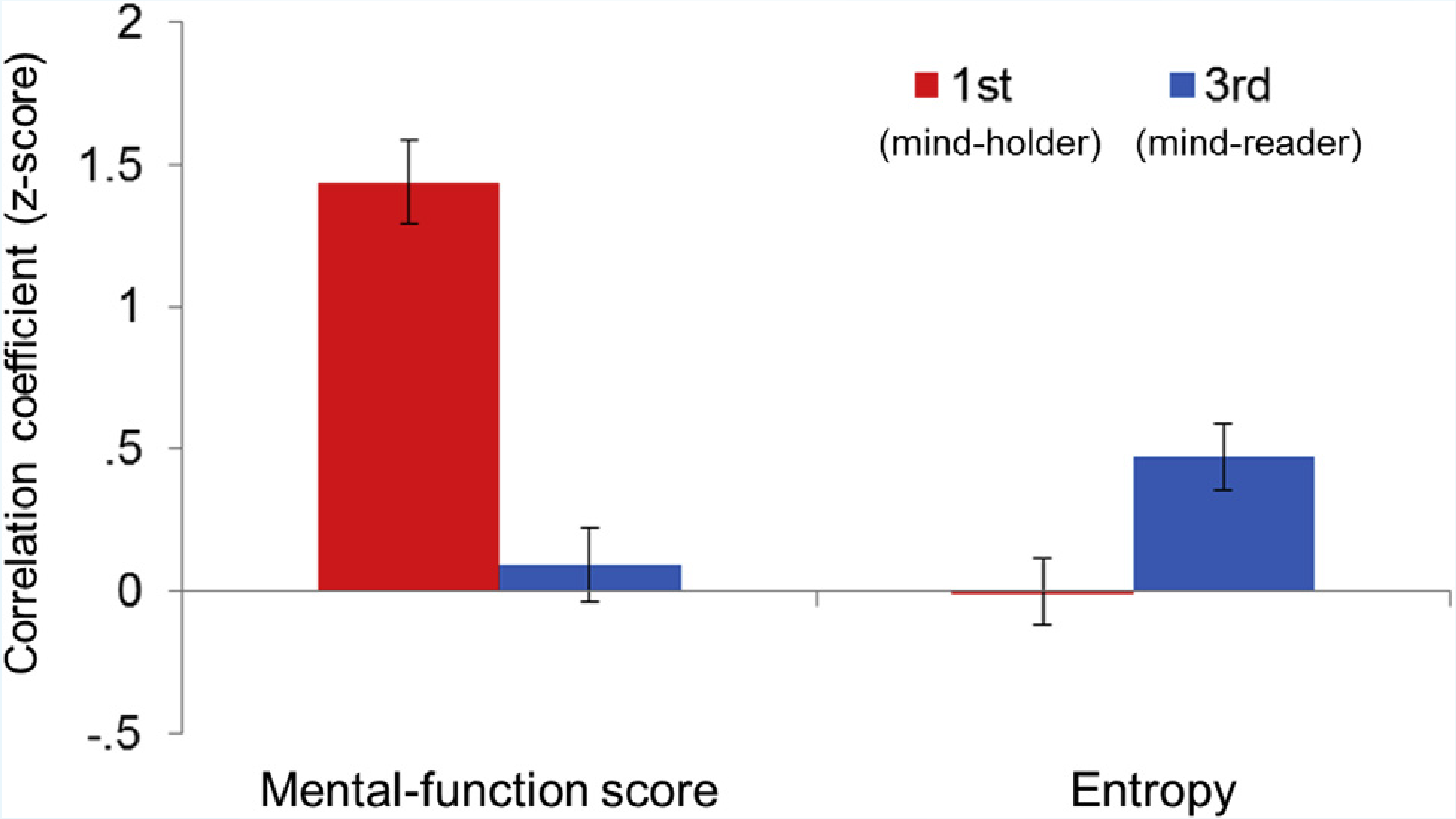
	1st	2nd	3rd
Human-like	.3345	−.0081	.3498
Intelligent	.0745	.4607	.2512
Ethical	.0398	.4523	.1508
Nice	.1751	.0867	.0029
Cute	.2846	−.0619	−.281
Friendly	.3243	−.0007	−.3127
Active	.2078	.166	−.3477
Positive	.1671	.1705	−.3017
Kind	.19	.042	−.0562
Warm	.2748	.0066	−.1688
Curious	.1749	.0718	−.2756
Thoughtful	.164	.127	.0819
Emotionally stable	.0231	.348	−.0972
Rational	−.0748	.4174	−.0638
Responsible	.108	−.026	.2067
Biological	.3322	−.1024	.412
Conscious	.329	−.1184	.1665
Regular	−.1018	.0284	−.0017
Natural	.2841	.0633	.0812
Simple	.1265	−.4033	−.1303
Emotional	.2838	−.0642	.1071

Questionnaire Analysis: PCA

[Takahashi et al., 2014]

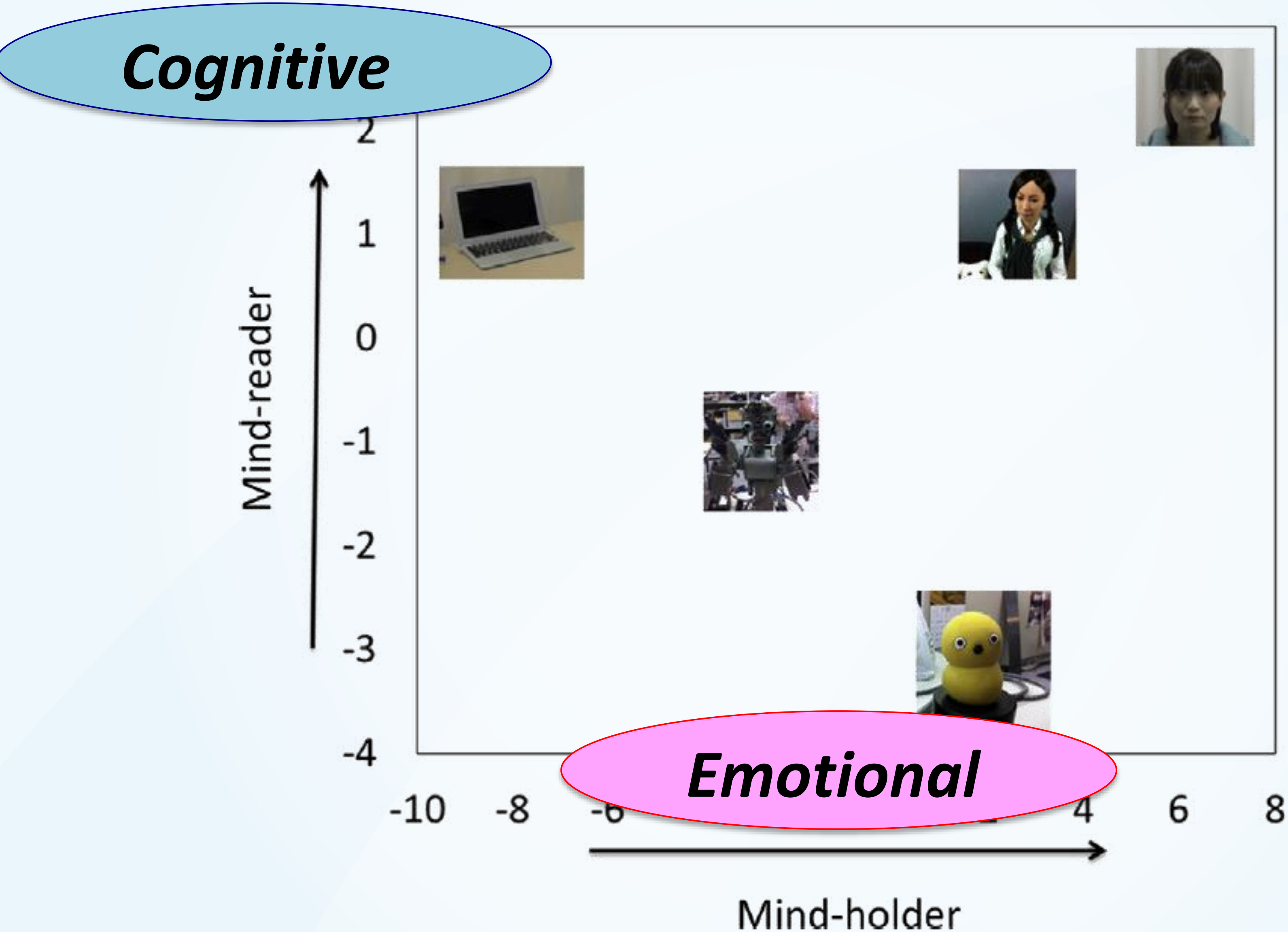
The 1st PCA component → the mental function score

The 3rd PCA component → entropy



Questionnaire Analysis: PCA

[Takahashi et al., 2014]



fMRI Scan

- We prepared four regressors per participant:
  1. one regressor was game-related used to specify the game period.
  2. the other three regressors, which were constructed based on the three PCA components.

- The parametric modulation analysis for each PCA component → each participant separately.

- The estimated blood oxygen level dependent (BOLD) signal change obtained from each of the 16 participants.

[Takahashi et al., 2014]

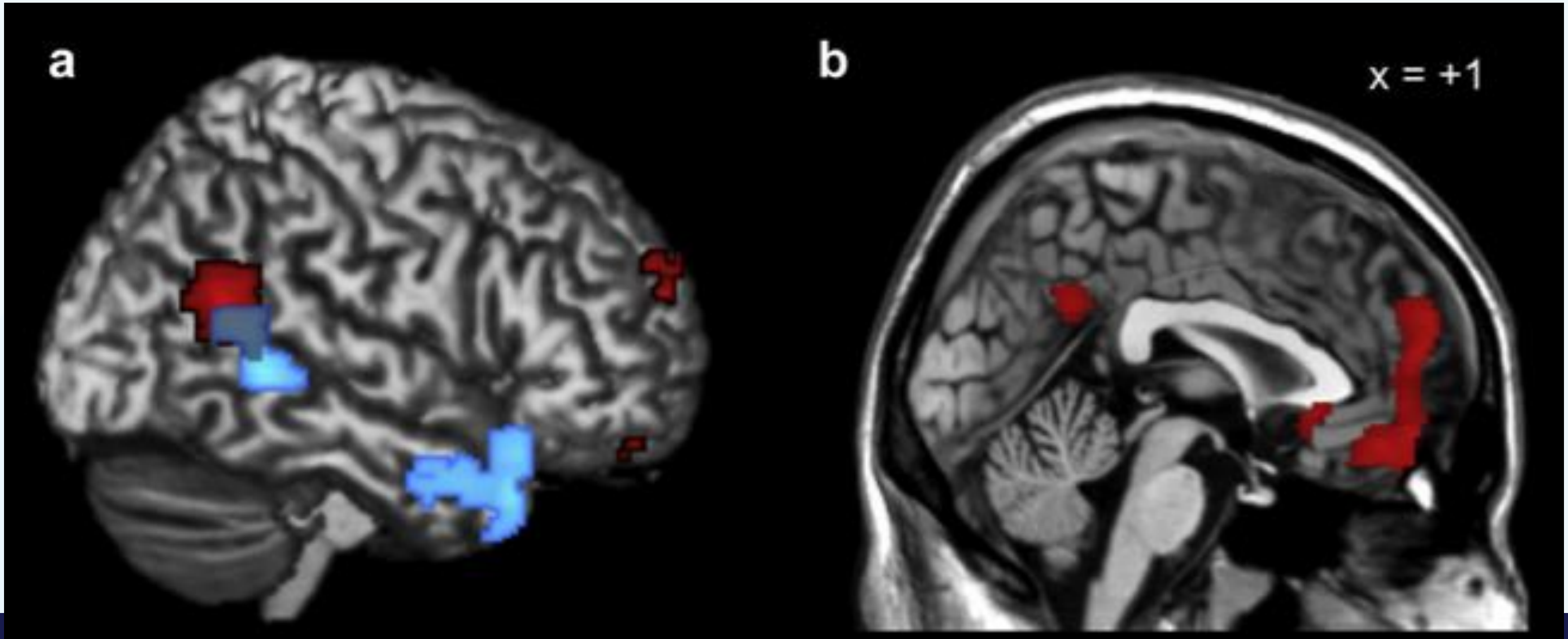
fMRI Scan

[Takahashi et al., 2014]

"mind-holderness" → red "mind-readerness" → blue)

a. regions are superimposed on a lateral view of the MNI standard brain.

b. regions are superimposed on a sagittal section, x=+1.

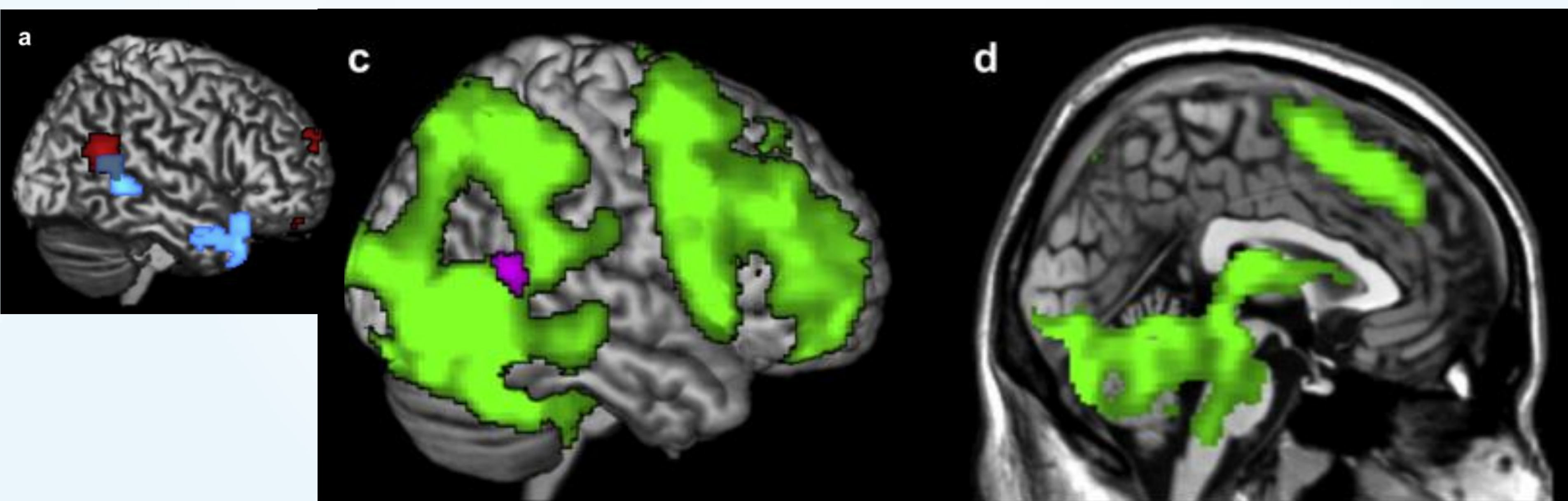


fMRI Scan

[Takahashi et al., 2014]

(c) and (d) → regions activated during the game.

The purple section in panel (c) represents a TPJ section where activity was modulated both by "mind-holderness" and by "mind-readerness".



Summary of social brain analysis

[Takahashi et al., 2014]

- The opponent = an anthropomorphic mind-holder, perspective taking to mentalize their intention, tactics, and even emotion ← the dorso-medial cingulum network.

- The opponent = categorized as a mind-reader, mindful of the possible gaze of the opponent ← the anterior-ventral TPJ/pSTS.

- Social interaction with mindholder or mind-reader may distinctly shape the internal representation of our social brain, which may in turn determine how we behave for various agents that we encounter in our society.

One more recent publication

[Hirata et al., 2014]

frontiers in
HUMAN NEUROSCIENCE

METHODS ARTICLE
published: 04 March 2014
doi: 10.3389/fnhum.2014.00118

Hyperscanning MEG for understanding mother–child cerebral interactions

Masayuki Hirata[1]*, Takashi Ikeda[1,2], Mitsuru Kikuchi[3], Tomoya Kimura[4], Hirotoshi Hiraishi[3], Yuko Yoshimura[3] and Minoru Asada[2]

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[2] *Department of Adaptive Machine Systems, Graduate School of Engineering, Osaka University, Suita, Japan*
[3] *Research Center for Child Mental Development, Graduate School of Medical Science, Kanazawa University, Kanazawa, Japan*
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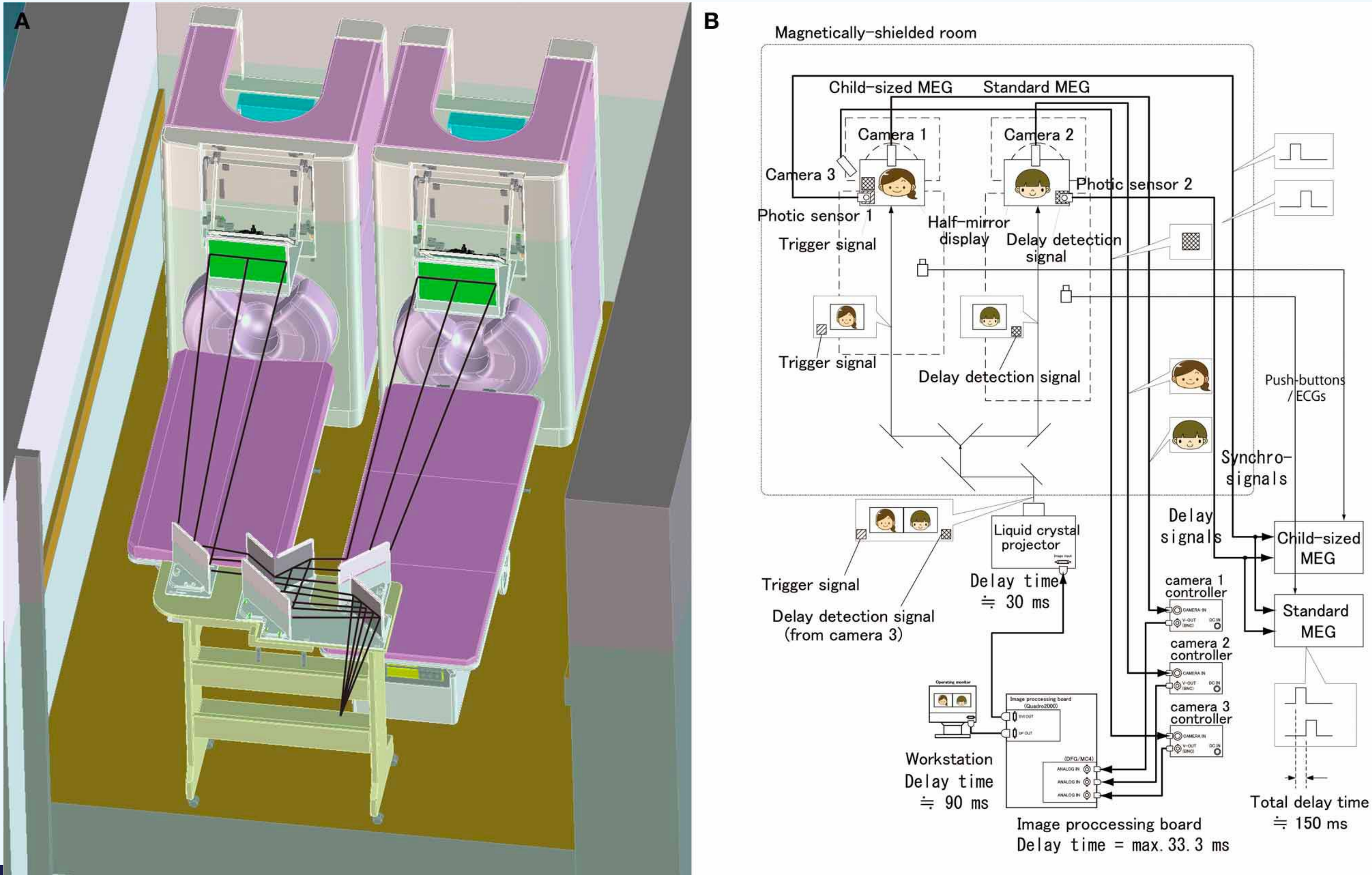
Child development is seriously affected by social interactions with caregivers, which may lead to forming social minds in our daily life afterward. However, the underlying neural mechanism for such interactions has not yet been revealed. This article introduces a magnetoencephalographic (MEG) hyperscanning system to examine brain-to-brain interactions between a mother and her child. We used two whole-head MEG systems placed in the same magnetically-shielded room. One is a 160-channel gradiometer system for an adult and the other is a 151-channel gradiometer system for a child. We developed an audio-visual presentation system, which enabled a mother and her child to look at each other in real time. In each MEG system, a video camera was placed behind a

Hyper Scanning MEG (1)

[Hirata et al., 2014]

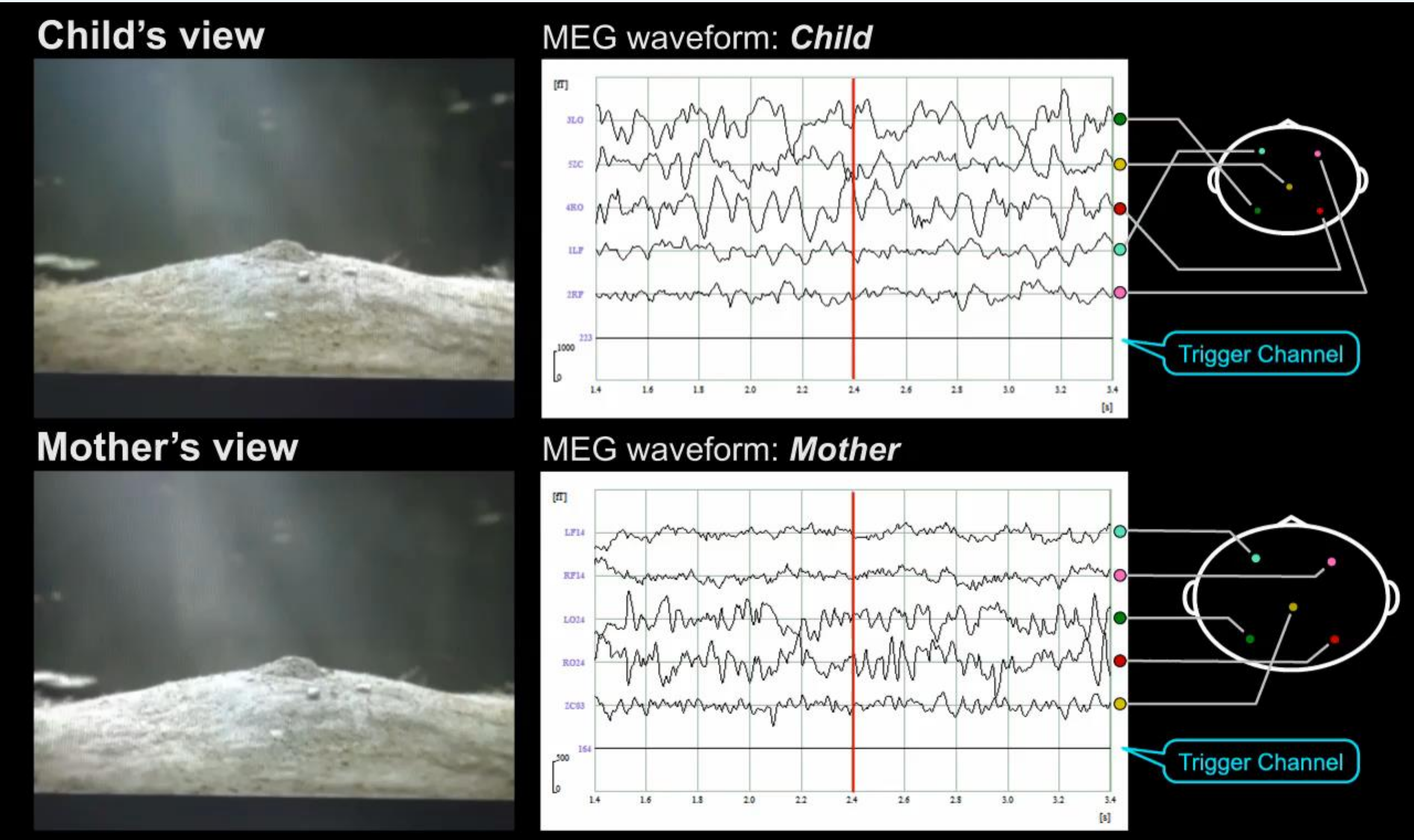


Hyper Scanning MEG (2)

[Hirata et al., 2014]

Hyper Scanning MEG (3)

[Hirata et al., 2014]



Outline of my talk

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   – What's development?
   – Developmental Robotics, Cognitive Developmental Robotics
2. Towards Artificial Empathy
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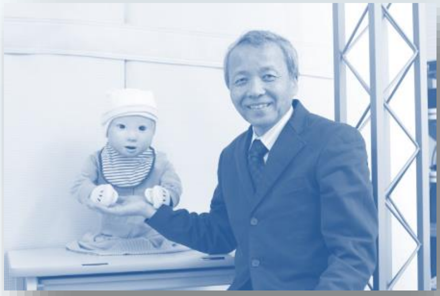
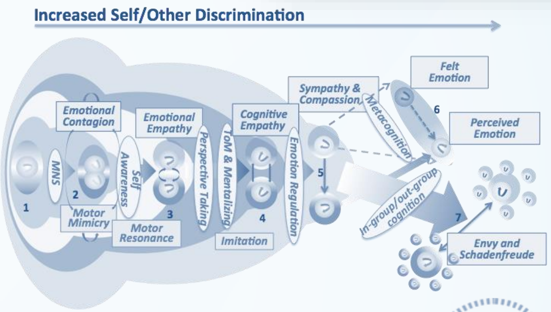
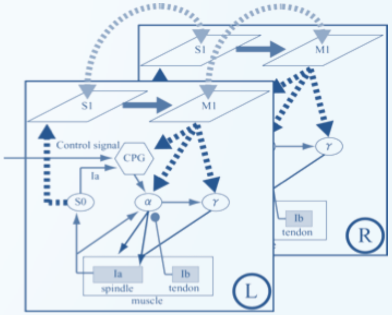
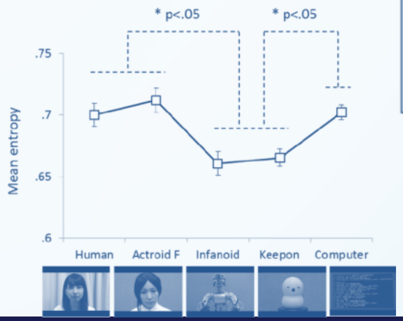
   – A developmental model
   – Cognitive vs. Affective
3. Brain-Body Interaction
4. Mind Holder and Mind Reader
5. **Future issues**









Future issues (1)

1. How to design robot emotion?
   - A lack of homeostasis in the body [Damasio & Carvalho, 2013] → adaptive behavior via brain networks
   - Robot homeostasis → self-preserving architecture → a pioneering work WAMOEBA [Ogata & Sugano, 1997]

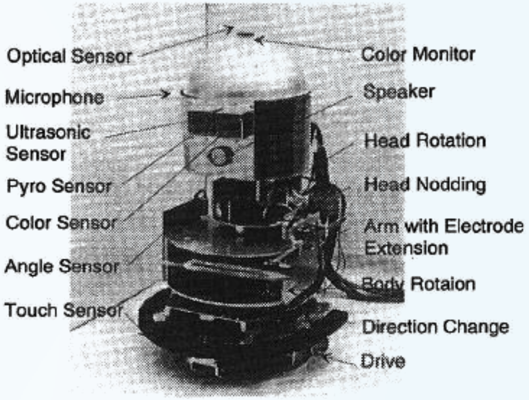


Fig. 2 WAMOEBA-1R

2. How to design intrinsic motivation?
   - Falling is a leading cause of accidental injury and death in children under five. [Joh & Adolph, 2006]
   - ML and developmental robotics communities [Lopes & Oudeyer, 2010]

Future issues (2)

3. Language?
   - Studies assessing severe aphasic patients have reported normal ToM processing. [Varley, 2001]
   - However, language faculty is needed in higher empathic social contexts. Rather, empathy and motivation may accelerate language learning.

4. Hormones and neurochemical compounds
   - oxytocin (OT) → emotional empathy, and dopamine (DA) → cognitive empathy [Gonzalez-Liencres et al., 2013]
   - EE sensitivity and CE capability to characterize empathic disorders → Gain control in our model.

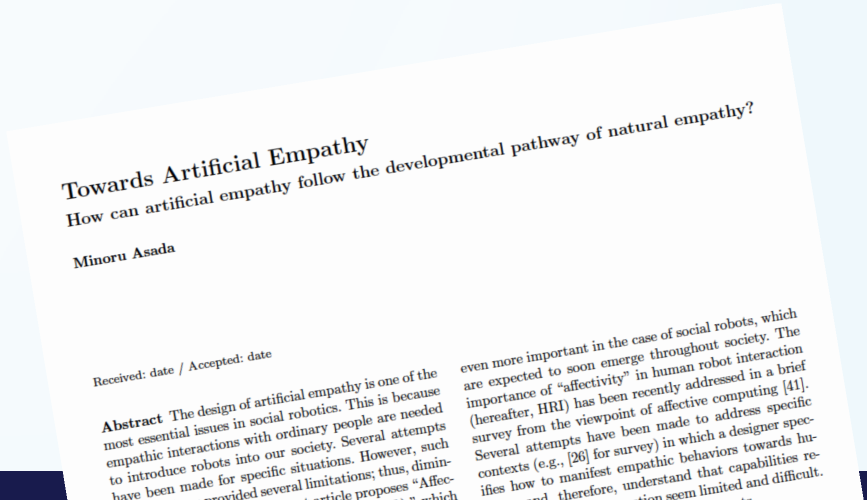
[Smith, 2006]

Future issues (3)

5. Expressions
   – Facial and gestural expressions are key aspect of artificial empathy.

[Ishihara and Asada, 2011, 2013]

6. Many more issues!
   – Towards Artificial Empathy (to appear in the Int. Journal of Social Robotics)



Towards Artificial Empathy

How can artificial empathy follow the developmental pathway of natural empathy?

Minoru Asada

Received: date / Accepted: date

Abstract The design of artificial empathy is one of the most essential issues in social robotics. This is because empathic interactions with ordinary people are needed to introduce robots into our society. Several attempts have been made for specific situations. However, such

even more important in the case of social robots, which are expected to soon emerge throughout society. The importance of "affectivity" in human robot interaction (hereafter, HRI) has been recently addressed in a brief survey from the viewpoint of affective computing [41]. Several attempts have been made to address specific contexts (e.g., [26] for survey) in which a designer specifies how to manifest empathic behaviors towards hu-


Thank you for your attention