Robots and Intelligence

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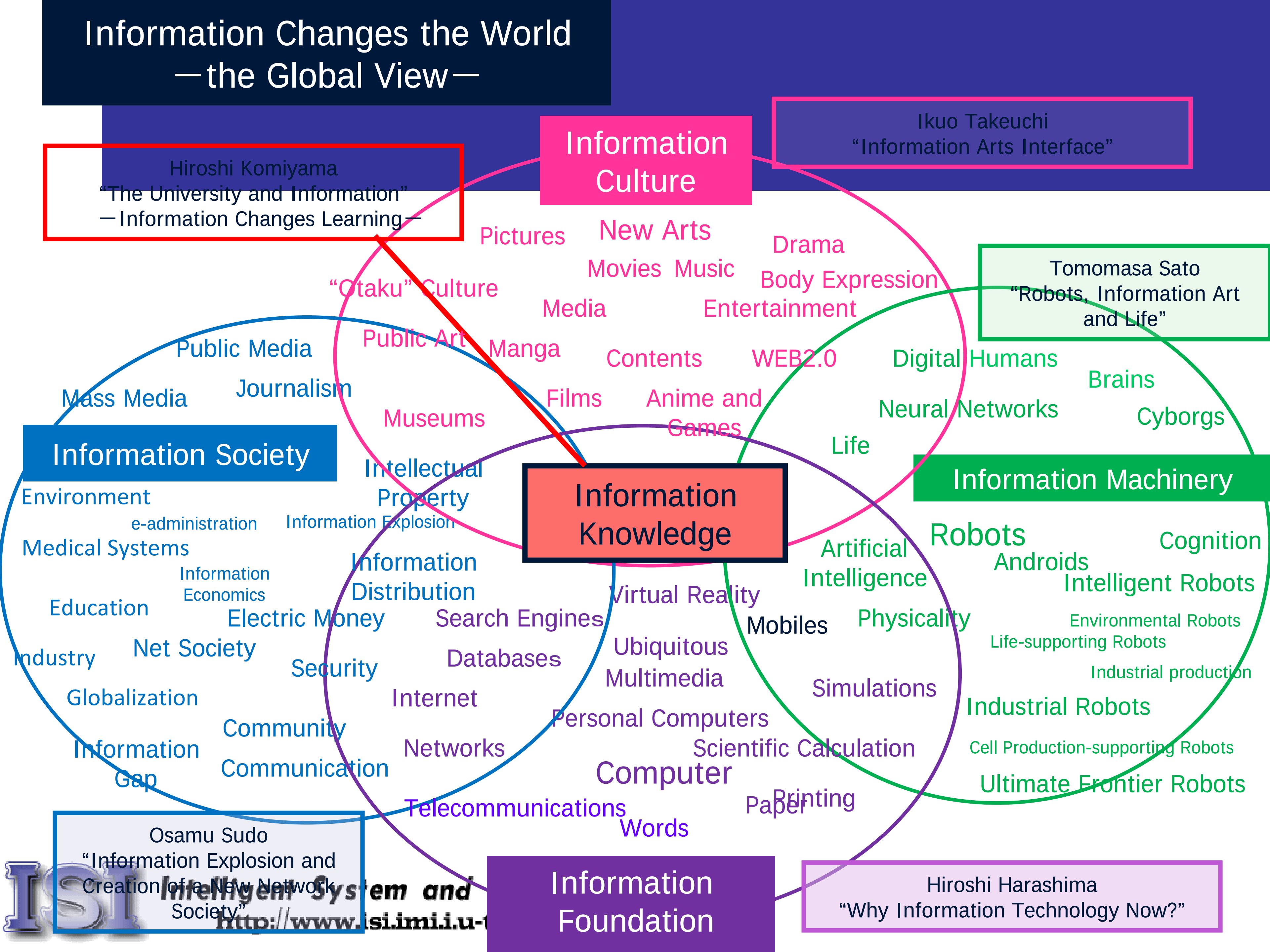
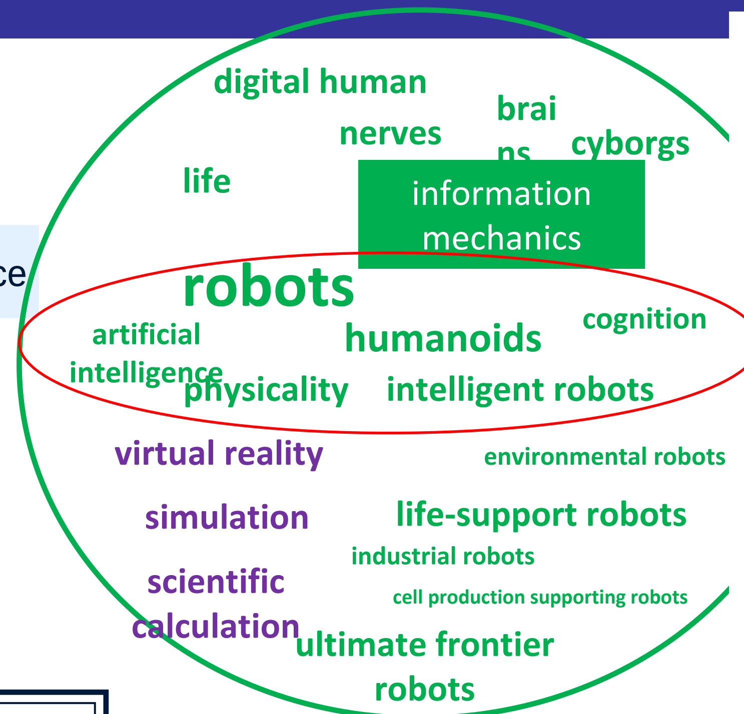

Information Changes the World
—the Global View—
Hiroshi Komiyama
"The University and Information"
—Information Changes Learning—
Information Culture
Ikuo Takeuchi
"Information Arts Interface"
Pictures
New Arts
Drama
Movies Music
Body Expression
"Otaku" Culture
Media
Entertainment
Tomomasa Sato
"Robots, Information Art and Life"
Public Media
Public Art
Manga
Contents
WEB2.0
Digital Humans
Brains
Mass Media
Journalism
Films
Anime and Games
Neural Networks
Cyborgs
Museums
Life
Information Society
Intellectual Property
Information Knowledge
Information Machinery
Environment
e-administration
Information Explosion
Robots
Cognition
Medical Systems
Artificial Intelligence
Androids
Information Economics
Information Distribution
Intelligent Robots
Education
Virtual Reality
Electric Money
Search Engines
Mobiles
Physicality
Environmental Robots
Life-supporting Robots
Industry
Net Society
Ubiquitous
Security
Databases
Multimedia
Industrial production
Simulations
Globalization
Internet
Industrial Robots
Personal Computers
Community
Information Gap
Networks
Scientific Calculation
Cell Production-supporting Robots
Communication
Computer
Ultimate Frontier Robots
Telecommunications
Paper
Printing
Words
Osamu Sudo
"Information Explosion and Creation of a New Network Society"
Information Foundation
Hiroshi Harashima
"Why Information Technology Now?"

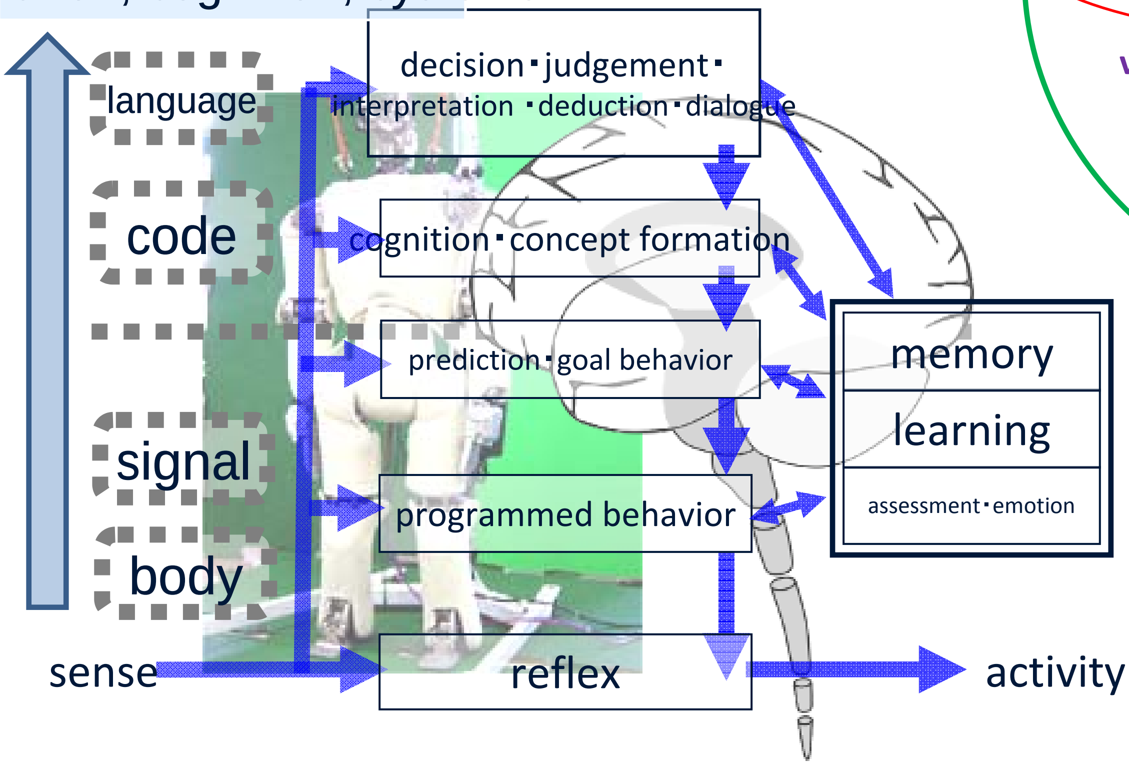
～Yasuo Kuniyoshi～

Robots and Intelligence
(Information Science in Robots that Learn and Develop)

cognitive development robot ⇔ human cognitive science



evolution, cognition, systems



Roots of information ＝ physics

- Entropy ：The Second Law of Thermodynamics. Quantity of state to show complexity in the air. (Clausius) $S = k_B \ln \Omega$
- ＝Amount of information measured by observing physical states（Szillard).
- Amount of information in probability events (Shannon)

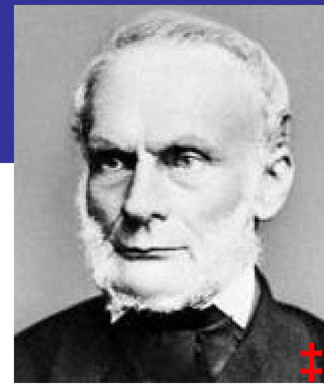
$$H(P) = -\sum_{A \subset \Omega} P(A) \log P(A)$$

$1bit = k_B \ln 2$ （k_B ： Boltzmann constant

Szilard, L. (1929) "Über die Entropieverminderung in einem Thermodynamischen System bei Eingriffen Intelligenter Wesen", *Zeitschrift für Physik* **53**:840–856

Claude Shannon, "A Mathematical Theory of Communication", *Bell System Technical Journal*, vol. 27, pp. 379–423 and 623–656, 1948

Rudolf Clausius (1822-1888)



http://en.wikipedia.org/wiki/Rudolf_Clausius

Leo Szilard, near Oxford, spring 1936.

Photo removed due to copyright restrictions

http://www.dannen.com/szilard.html

Claude Shannon (1916-2001)

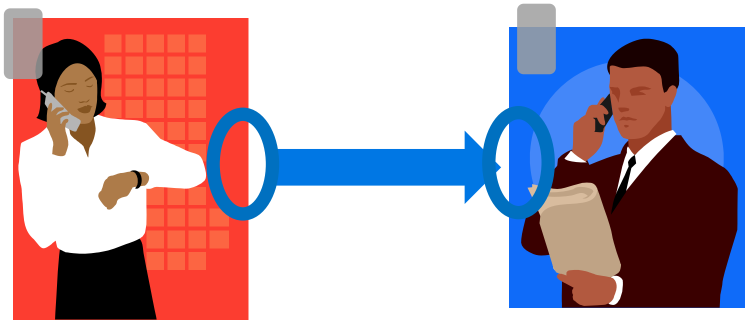
Photo removed due to copyright restrictions

http://en.wikipedia.org/wiki/Claude_Shannon

Information ≠ Information Bundles

- Shannon defined “bundles of information”, but he did not define “what information is”. So, as a consequence ...
- The basic concept of pure information science /communication：”How can information be sent to receivers without incurring losses.”

Bundles of sent and received information

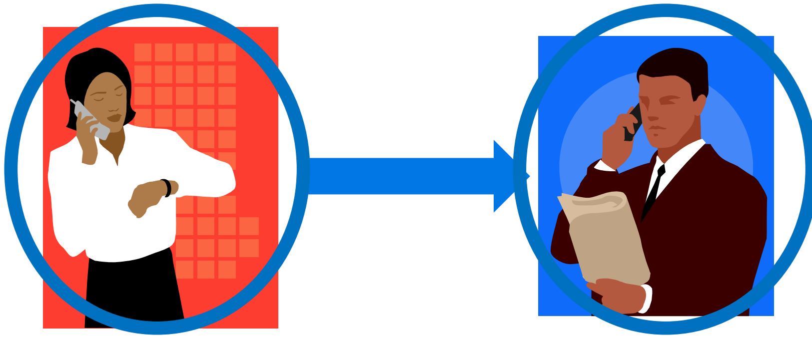


- Is this OK？
- To know the meaning of “information”,

we must think about how it is generated and what it would cause (or how it is used).

real phenomena：object→ object‘：real phenomena

Aim for a re-fusion with physics



Intelligent Robots in the Past

- They understood languages, recognized sounds, made sounds, synthesized voices, contained conceptual dictionaries・・・had locomotive capability. They didn't understand "meaning".
- Cognition・judgment・activity：Humans previously assigned rules to robots.
- Learning：Robots only matched given behavioral elements to fit criteria for evaluation which humans established. They cannot deal with situations which were not previously envisioned.

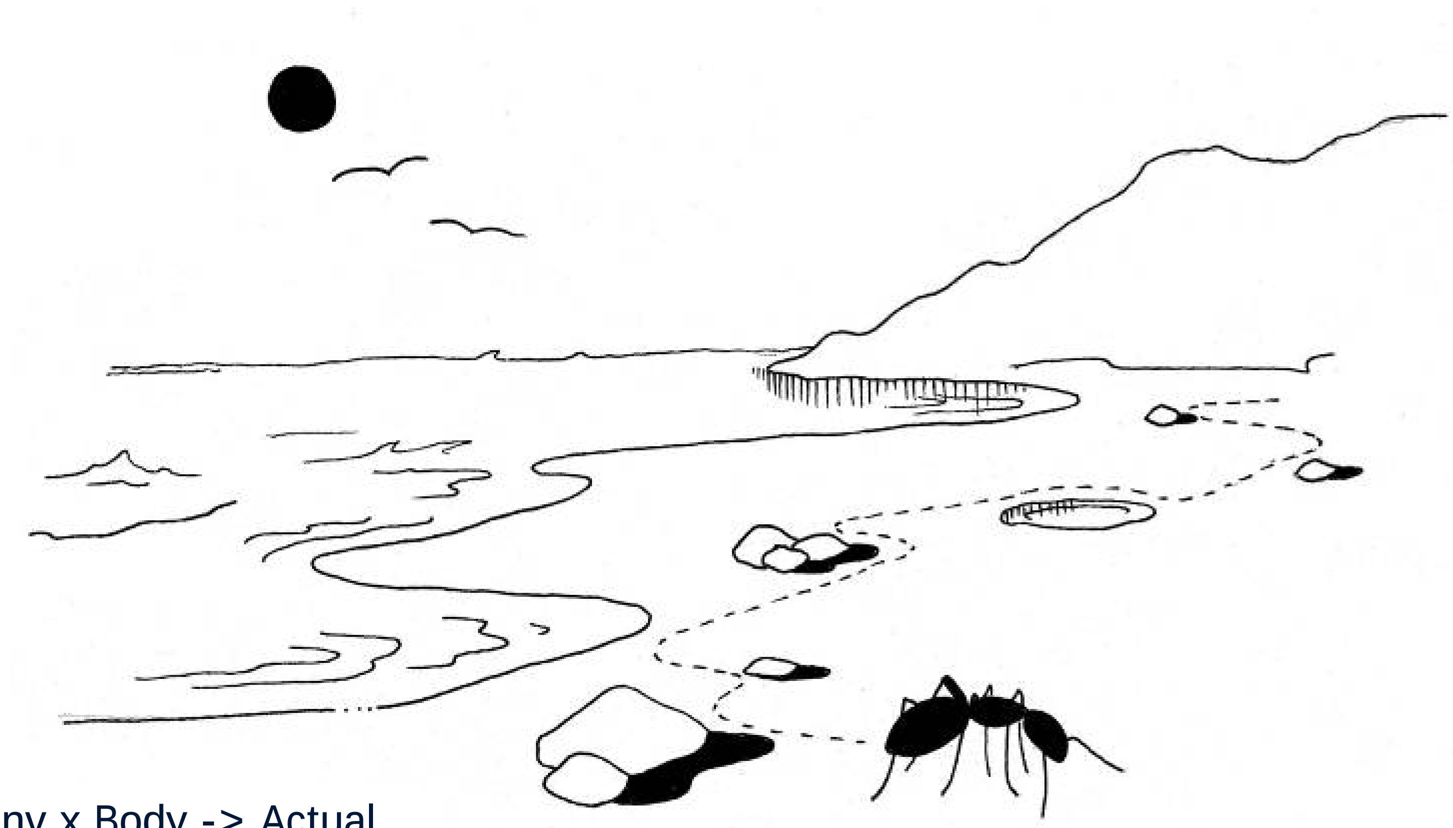
⇒"Demonstration" within the scope of their pre-programmed activity was possible, but when something unexpected occurred, robots reacted absurdly.

Today, this is treated by broadening the range of possible robotic behavior.

Symbol grounding problem：interpretation, utility

Simon’s Ant on the Beach

Slides by Rolf Pfeifer (from AI Lectures in Tokyo)



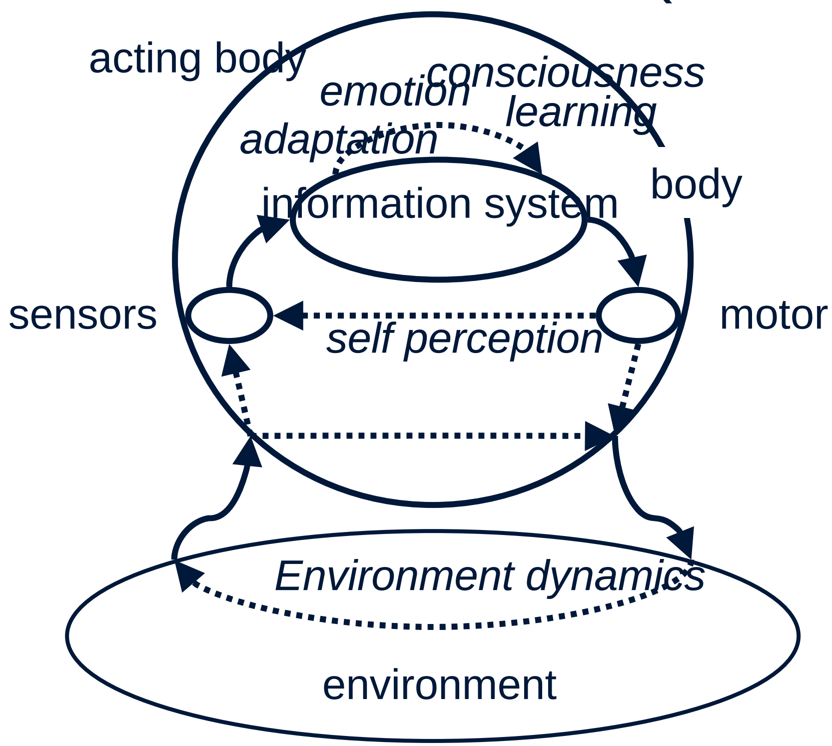
Goal x Env x Body -> Actual motion

‡

Herbert A. Simon

Information is generated from interactions between subjects and environment.

- Information is generated from interactions between the nervous system⇔body⇔environment.
- Physicality：constrains these interactions (meaningfully) and structures them.



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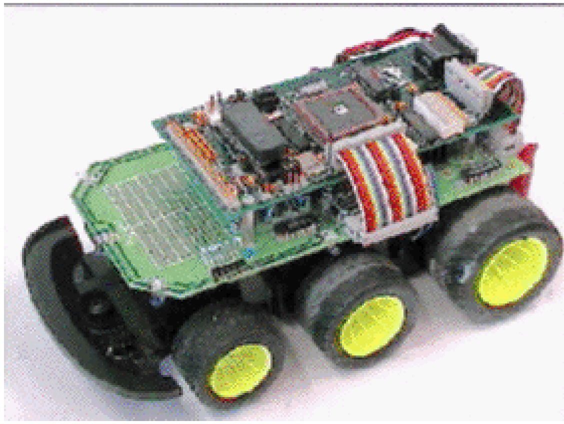
Minoru Asada, Yasuo Kuniyoshi “Robot Intelligence”, Iwanami Lectures on Robotics，Iwanami Shoten, 2006.(p18）

The „Didabot“ experiment

Slides by Rolf Pfeifer (from A Lectures in Tokyo)



‡

“Didabot”:
A simple robot for didactic purposes

‡

An arena with Styrofoam cubes
Experiment by René te Boekhorst and Marinus Maris

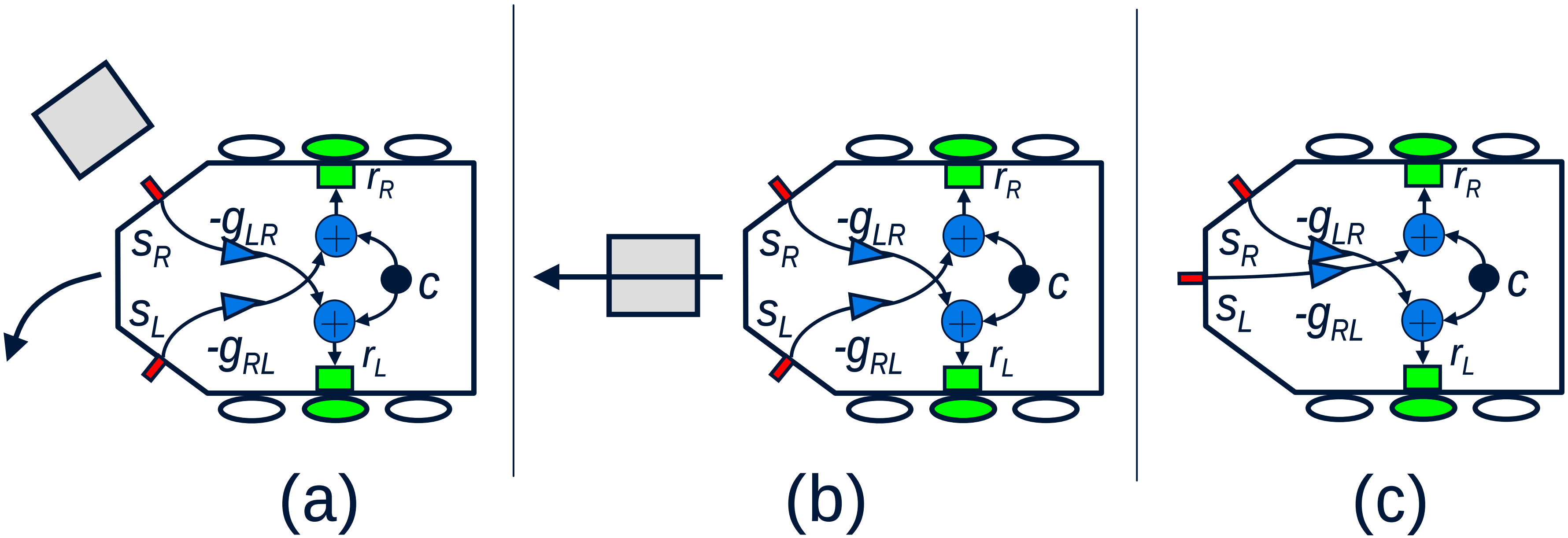
„Didabot“ experiment – overview

Slides by Rolf Pfeifer (from AI Lectures in Tokyo)

What are the robots doing?

Slides by Rolf Pfeifer (from AI Lectures in Tokyo)

Didabots



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Minoru Asada, Yasuo Kuniyoshi "Robot Intelligence", Iwanami Lectures on Robotics , Iwanami Shoten, 2006.(p59)

Didabots – real ants

Slides by Rolf Pfeifer (from AI Lectures in Tokyo)

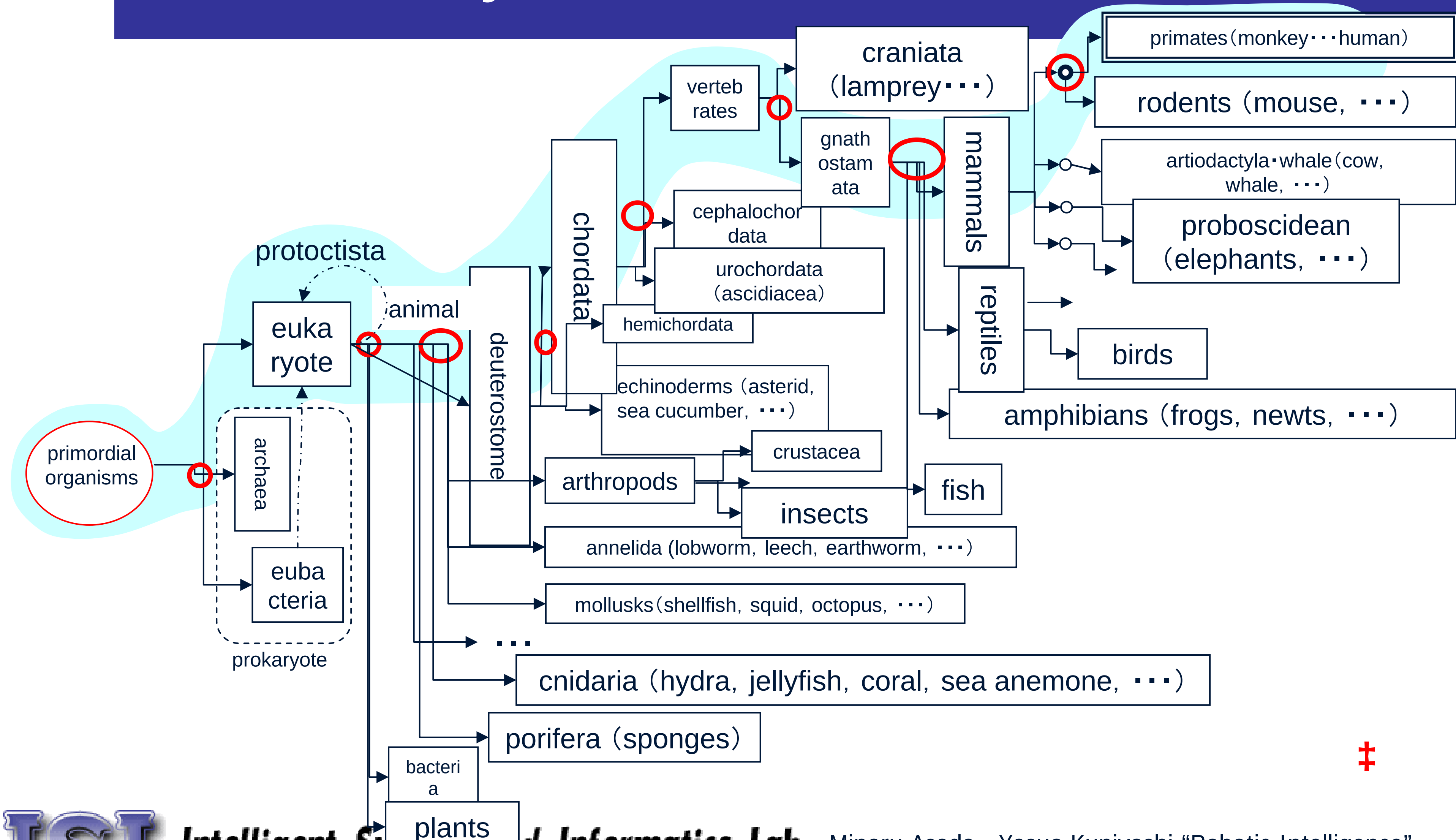
styrofoam cubes

‡

dead ants

‡

How the brain has evolved ：an evolutionary tree



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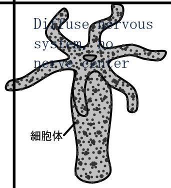
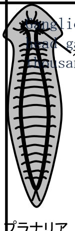
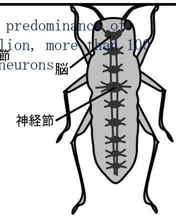
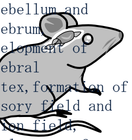
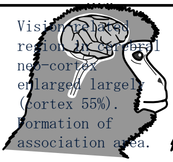
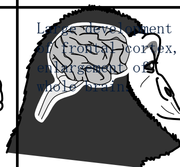
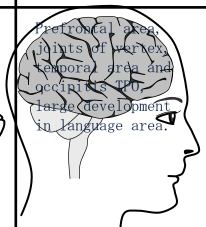
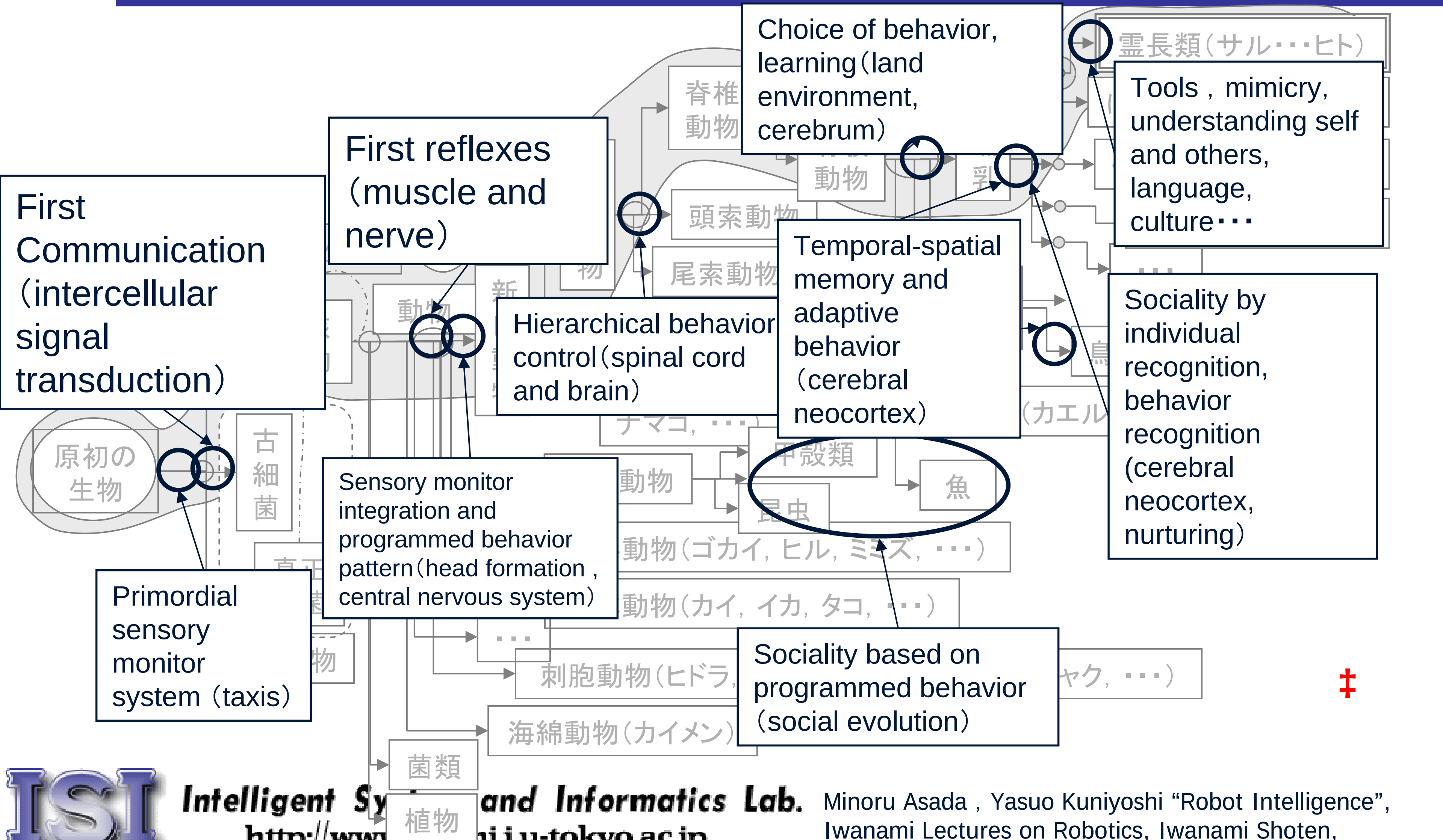
Minoru Asada，Yasuo Kuniyoshi “Robotic Intelligence”, Iwanami Lectures on Robotics, Iwanami Shoten, 2006.(p28）

6	single-cell organisms, Primordial sensory systems and social st5ructures	Multi-cell stimuli reactivity	Acquisition of muscles and nerves primordial reflexes	formation of the head formation of sacomeres Primordial sensory integration	Spinal cord, central nervous system, complex instinctive behavior. hierarchical regulation.	Land animals, mammals, cerebral cortex, memory, expressive ability.	Primates appear. Cognition of complex situations, judgment	Apes appear. Analogy, deduction, social intelligence	Humans appear Abstract thinking, language, education, culture
Examples of existing creatures	*E. coli*, euglena, slime mold	sponge	hydra, jellyfish	earthworm, sea hare , squid, octopus, (insects)	fish, frog, crocodile	mouse, cat, pig, (bird)	monkey	gorilla, chimpanzee	human (early people, modern people)
Autonomous behavior, cognitive function	Toxic reaction to chemicals, temperature, light, approach to nutrients, avoidance of toxins, preference for light	Origin of reflexes, activities of cilia over the whole body stops in response to stimuli, stops in water flow.	Primitive reflexes, capture of prey that touches tentacles, swimming.	reflexes, releasing mechanisms and programmed behavior, nerve-controlled body movements. Insects have an ability to adapt to the environment, memorize, and learn.	Various instinctive behaviors : mating, nesting, territorial, warming eggs, etc.	Behavior based on memory, map cognition, sophisticated memory, learning ability	Sophisticated spatial perception and motor control for arboreal life, integration of information.	Making and using tools, limited mimicry, self - cognition, reading others' mind.	Erect bipedalism, mimicry, abstract thinking, language, creativity, science, technology, art
sociality	Communication by transmitter substance, population synchrony,aggregat ion	none	none	Genetically-controlled social insects, programmed communication between individuals, pheromona etc. .	Control by instinctive behavior is predominant..	Instinctive behavior is predominant. Mating, nurturing, troops, group hunting, orders.	Recognition of social relationships, identification of individuals,social hierarchy, grooming.	Communication by eye contact, dynamic partnerships	hierarchy. education, culture , social system, economy
Basic structure of body, ecologic traits	Single-cell, prokaryote/eukaryo te, nutrient intake from cell membranes.	Undifferentiate d multi-cell, amorphous, many pores on body wall, sessile	coelenteron (eating and excreting by mouth)	Digestive tract, distinction between mouth and anus, head part can be clearly identified.	Spinal cord, inner skeletal structure	Terrestrial life, development of 4 limbs, viviparity, homeothermism, many are nocturnally active	Hands and fingers that can grasp things (Thumbs are placed opposite) . Face. Many live on trees.	Enlargement of the body, omnivorous (fruits, plants, insects, animals)	Curving spinal cord adopted to erection.
motion mechanism, sensory organs	Flagellum motor, cilia, vermiculation, sensor such as chemical/light receptor	No nutrient intake by flagellum in a pore, generation of water flow to take up nutrients	Plain muscles, no skeleton.	Striated muscle (rapid),arthropods have an outer skeleton link system. Sensory organs are centered on head (eyes, antennas) , sensory organ to extract specific information.	4 limbs. Inner skeleton is surrounded by muscles. Dynamic coordination is needed to keep balance. Eyeballs are developed.	Sophisticated alertness (activity improved by homeothermism) , keen senses (especially, olfactory and auditory senses)	Development of fingers, Sophisticated eyesight	Cleverness of fingers, various vocalizations.	Development of sound producing organ (language sounds). Development of facial muscles.
Nervous system	None, some times chemical signal transmission from receptor to moving organ.	none. Intercellular transmission by membrane potential in glass sponge 	Diffuse nervous system, no nerve center 	Ganglion, predominance of head ganglion, more than 100 thousand neurons  	Myelin sheath, faster transmission, brain-spinal cord system is established, CPG, brain stem, cerebellum, limbic cortex 	Development of cerebellum and cerebrum, development of cerebral cortex,formation of sensory field and motion field, development of regions related to auditory and olfactory 	Vision related region in cerebral neo-cortex enlarged largely (cortex 55%). Formation of association area. 	Large development of frontal cortex, enlargement of whole brain. 	Prefrontal area, joints of vertex, temporal area and occipitis TPO, large development in language area. 

Minoru Asada , Yasuo Kuniyoshi “Robot Intelligence”, Iwanami Lectures on Robotics, Iwanami Shoten, 2006.(Chapter 1)

Evolution of Intelligence：information structure that environment×body create (possibility)⇔nerve system



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Minoru Asada，Yasuo Kuniyoshi “Robot Intelligence”, Iwanami Lectures on Robotics, Iwanami Shoten, 2006.(p30）

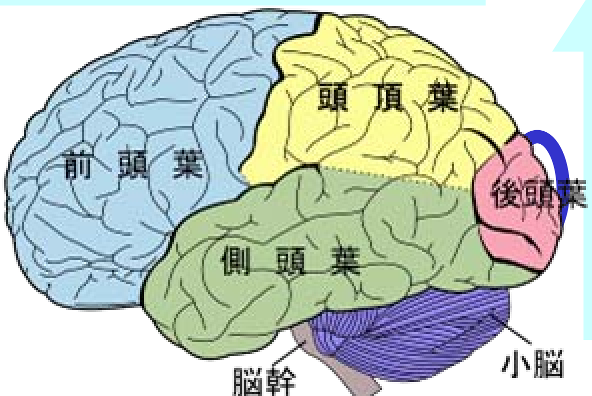
he body makes the brain !

Creation and Development of Cognitive Structures

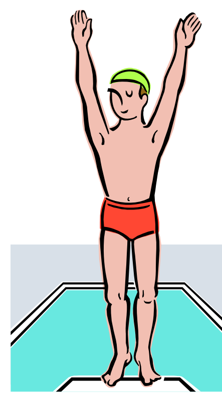
Plasticity &
Early Development

Information-Driven
Self-Organization
Esp. Cerebral Cortex

Emergent Information Structure
from Embodied Interaction



Brain ‡



Body

Environment

http://ja.wikipedia.org/wiki/%E7%94%BB%E5%83%8F:Brain_diagram_ja.png

Creative/Developmental Structuring Theory

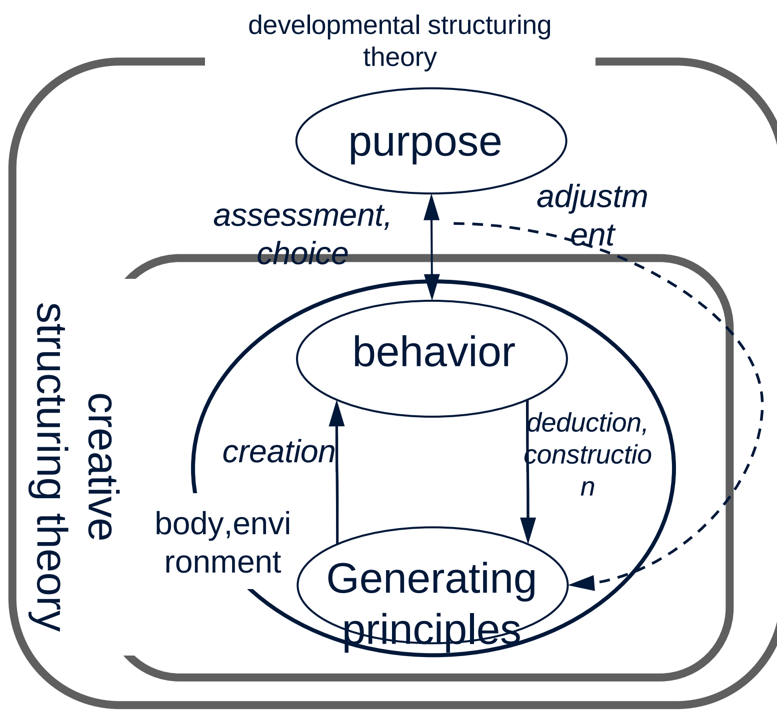
Minoru Asada，Yasuo Kuniyoshi “Robot Intelligence”, Iwanami Lectures on Robotics, Iwanami Shoten, 2006.(Chapter 1）

Find out the most basic principle of generation and changes of intelligent behaviors, not by making a complete model of an intelligent behavior, but by removing unimportant things from it. Construct this in a real environment , monitor how it behaves and develops, and scale it up by feeding back to the principle.

Basic principles of intelligence creation and development：

1. physicality＝information structure formed by a body
2. A system to discover, obtain and use that information structure

Understand the mechanism to create intelligence



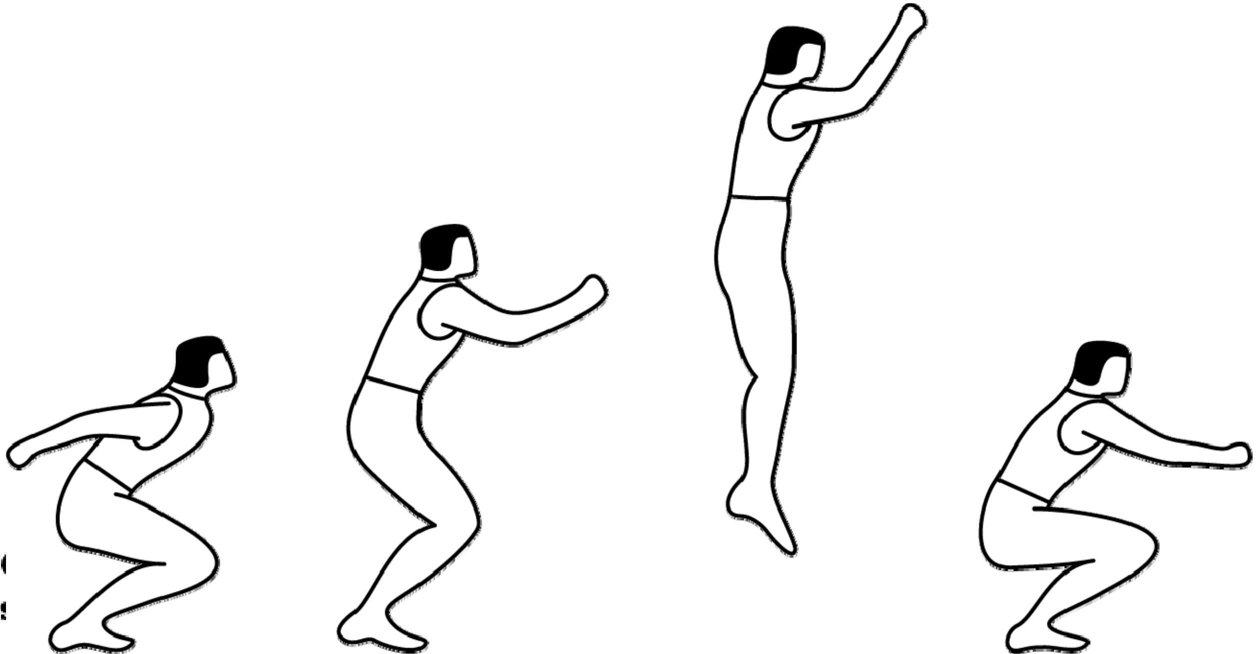
“Wisdom” of a Body With Brain Completely Removed

Jumping and Landing：Physical Intelligence

Niiyama・Kuniyoshi 05-06

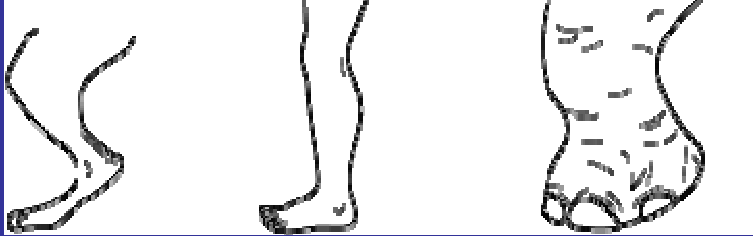
- Jumping and landing
  - Extremely fast & dynamic – Feedback control is difficult.
  - Interactions with ground – Modeling and prediction are difficult.
  - Role of body dynamics is important. Utilization is essential.
- Wisdom：With factors above, jump and land stably.

Ryuma Niiyama, Akihiko Nagakubo, Yasuo, Kuniyoshi: “Mowgli: A Bipedal Jumping and Landing Robot with an Artificial Musculoskeletal System”, Proc. 2007 IEEE International Conference on Robotics and Automation, ThC5.2 , 2007/4/12 , Rome, Italy. Fig.1

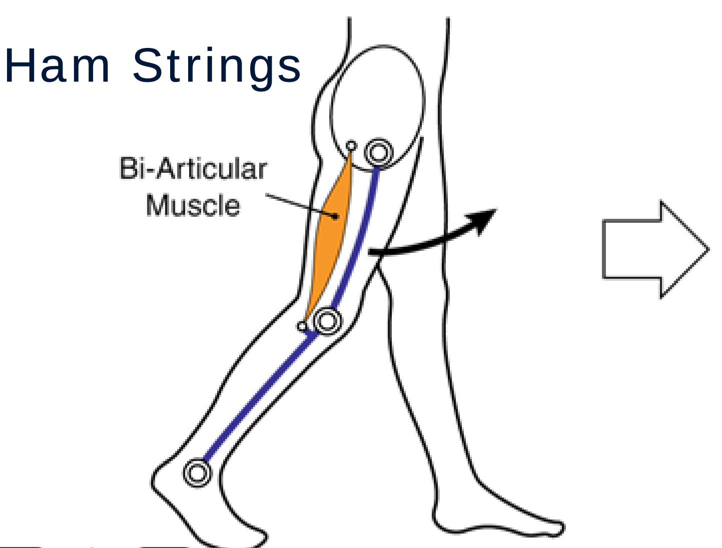


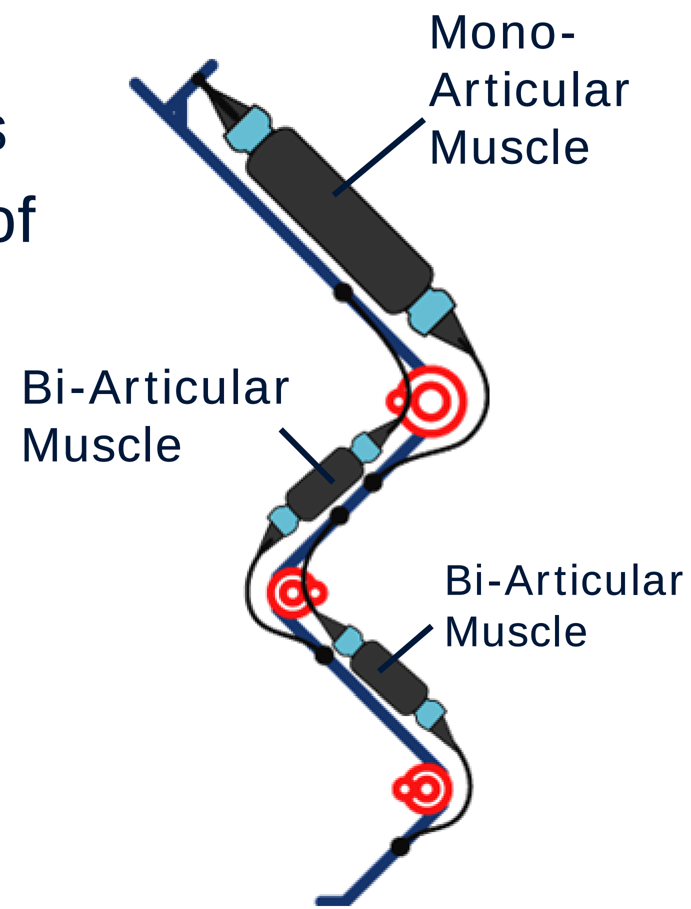
Bio-mechanism of Legs

Niiyama･Kuniyoshi 05-06



- Body structure ⇒ natural movements
  - Bi-Articular Muscles
  - McKibben pneumatic actuators
  - Size of each part･distribution of mass





Jumping & Landing: MOWGLI

Niiyama & Kuniyoshi 05-06

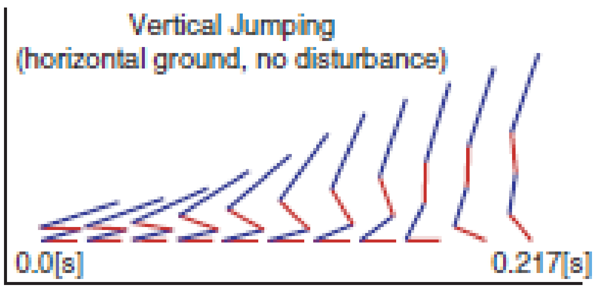
Ryoma Niiyama, Yasuo Kuniyoshi：Development of Jumping and Landing Robot Based on Muscular-skeletal Bio-Mechanics, the 11th Robotics Symposium, 1C1, pp.50-55, Saga, March, 2006.

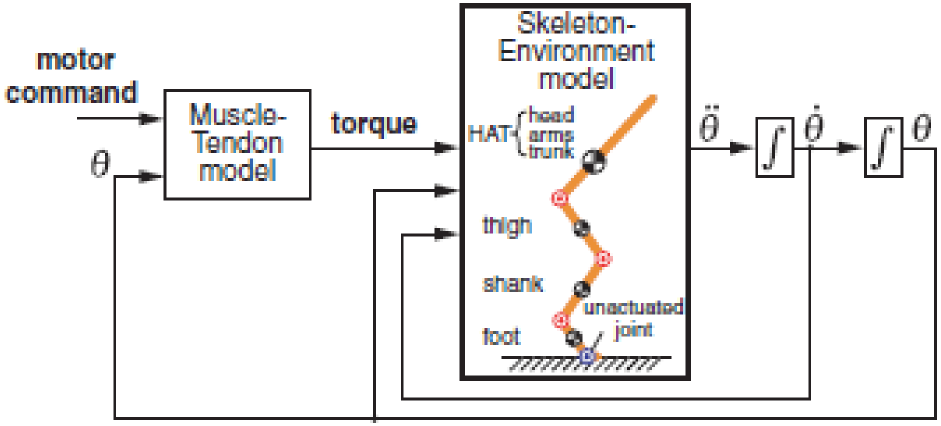
The Body's Wisdom

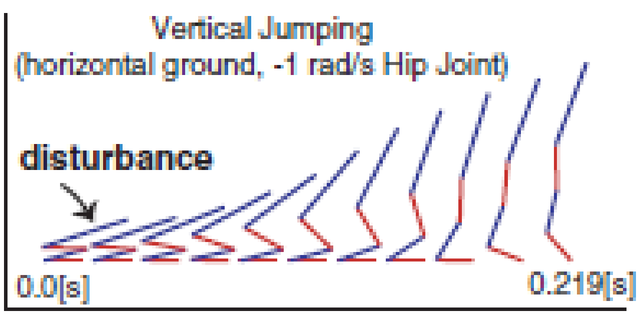
Ryuma Niiyama, Akihiko Nagakubo, Yasuo, Kuniyoshi: "Mowgli: A Bipedal Jumping and Landing Robot with an Artificial Musculoskeletal System", Proc. 2007 IEEE International Conference on Robotics and Automation, ThC5.2 , 2007/4/12 , Rome, Italy. Fig.10, 11 ‡

- Adaptation to Disturbance

Movements without disturbance（muscle＝motor）

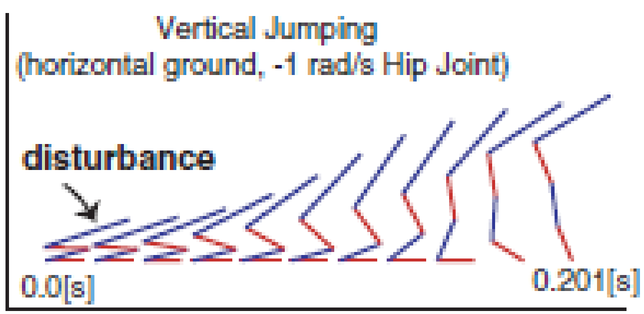






muscles（including bi-articular muscles）

With Disturbance



Articular motor（not including bi-articular muscles）

A Knack and Eye for the Good
―the information structure of physicality―
What is an information structure shared by objects with humanoid bodies？

Information structure created from interactions between the body and the environment

Information structure controlled by the brain

Information transmitted by mimicry or teaching

“Once you get the hang of it, the work can be done very easily and securely. ”
“A person with a good memory knows a good thing when he/she sees it.”
→Popular sayings, but they signal the most important phenomenon related to the principle of human intelligence.

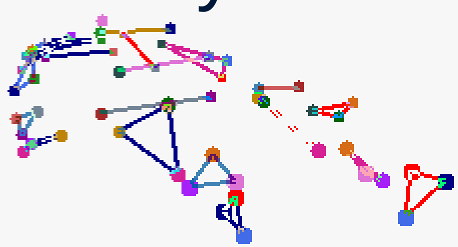
“Roll-and-Rise” Motion
-- An example emphasizing ”getting the knack”

Yasuo Kuniyoshi,Yoshiyuki Omura, Kohshi Terada, Akihiko Nagakubo

Journal of RSJ vol.23, no.6, pp.706-717, sep.2005. Fig.1

‡

- Body dynamics are activated. A skill is needed.
- Perfect modeling is impossible（a minor impetus creates a major reaction）
- Control switching is needed（multiple dynamics）
- Not a limited cycle. Includes divergence. Aspires to a goal.



A Non-Uniform Trajectory Bundle

T. Yamamoto and Y. Kuniyoshi 02

There are regions where phased spatial (knee-waist articular space) orbits converge or diverge.

Sole-landing
(convergence)

Lifting and lowering legs
(divergence)

Figure removed due to copyright restrictions

Standing position
(convergence)

Non-uniform Points of Convergence

K. Terada and Y. Kuniyoshi 04

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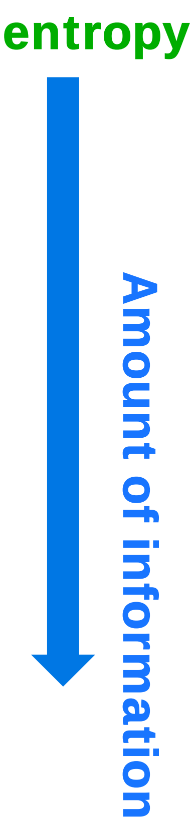
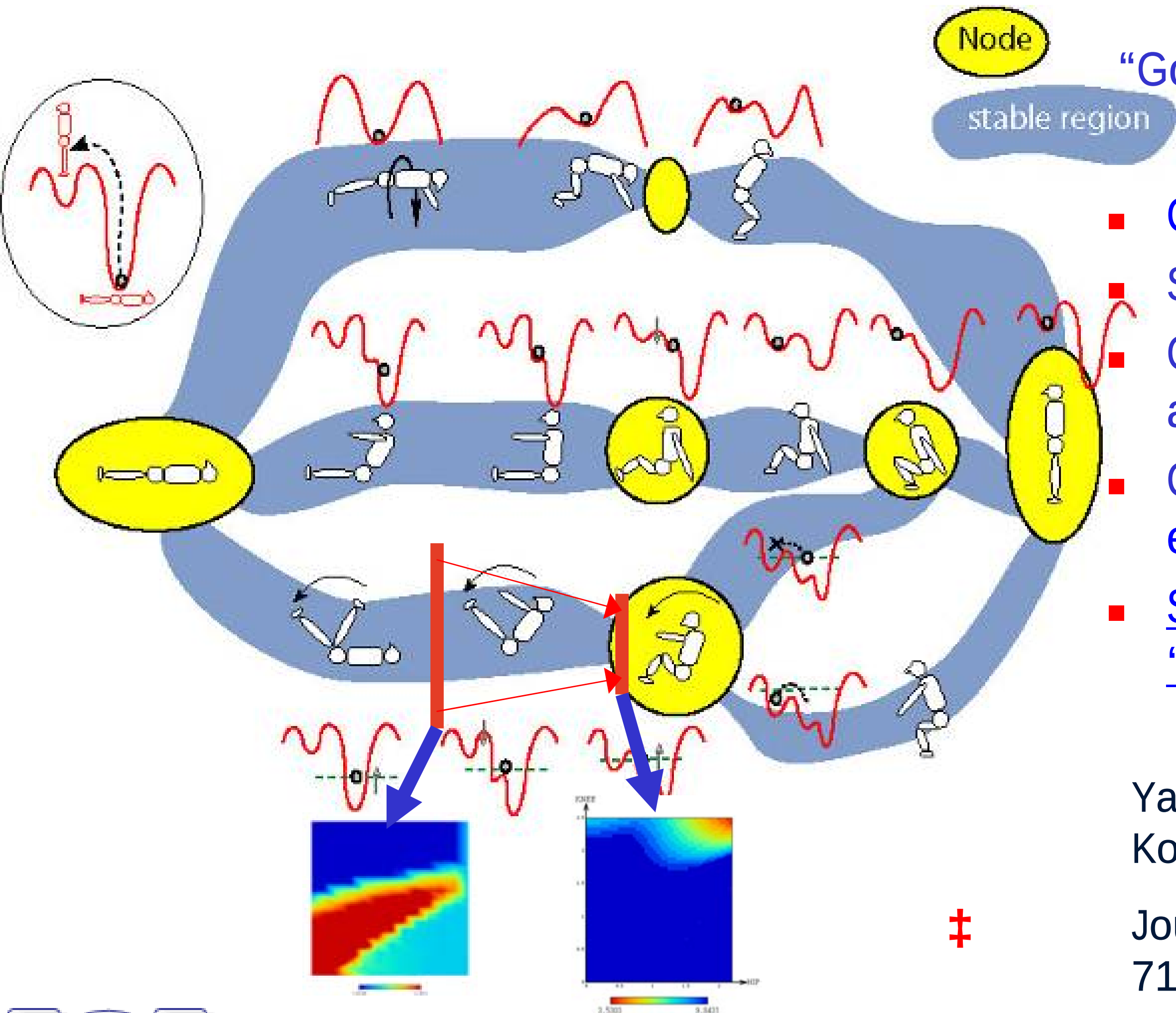


Global Dynamics → **Good Point** (physical information structure)



"Good point"

● ←"getting the knack"

- Centered point of information
- Stable to disturbance
- Compatibility of adaptation and assurance
- Creation using the body, environment, purposeful action
- Symbolic information shared by "humanoids".

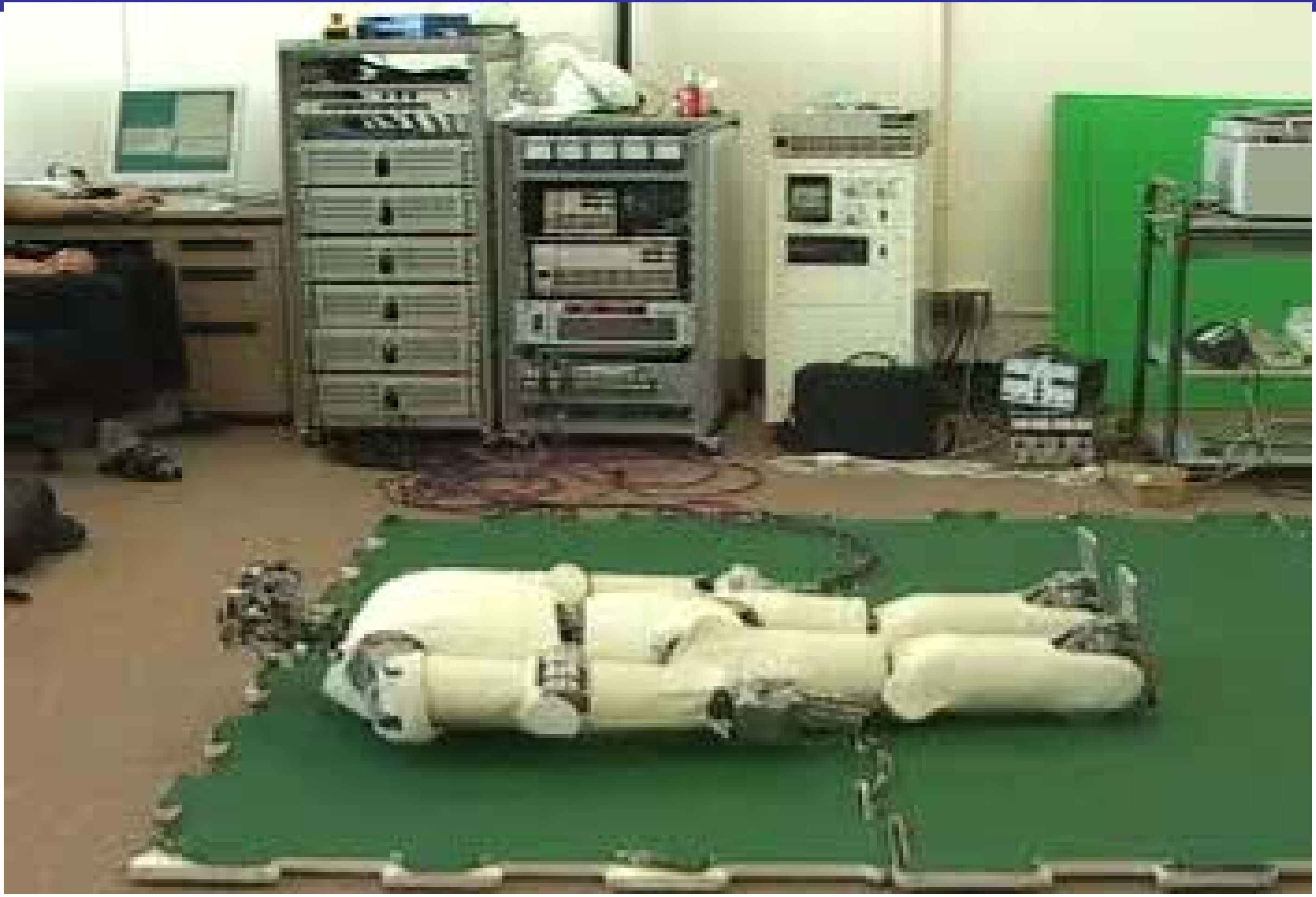
‡

Yasuo Kuniyoshi, Yoshiyuki Omura, Kohshi Terada, Akihiko Nagakubo

Journal of RSJ vol.23, no.6, pp.706-717, sep.2005. Fig.3

Success! – Rising in 2secs.

Ohmura, Terada & Kuniyoshi 03



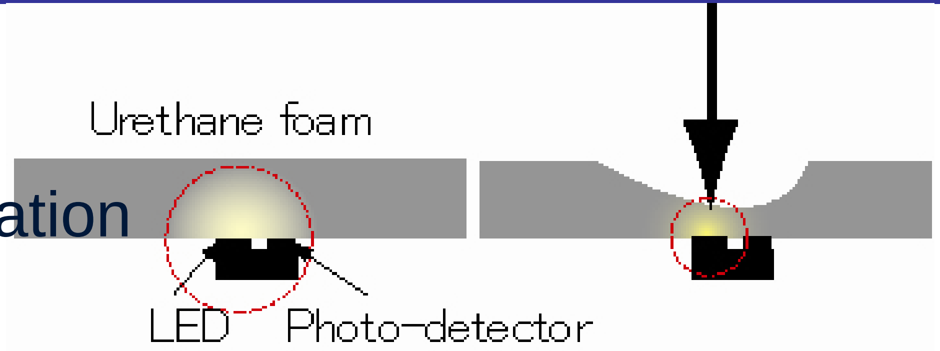
Yasuo Kuniyoshi, Yoshiyuki Ohmura, Koji Terada, Akihiko Nagakubo: Dynamic Roll-And-Rise Motion By An Adult-Size Humanoid Robot, International Journal of Humanoid Robotics, vol.1, no.3, pp.497-516, 2004.

Tactile Sensor

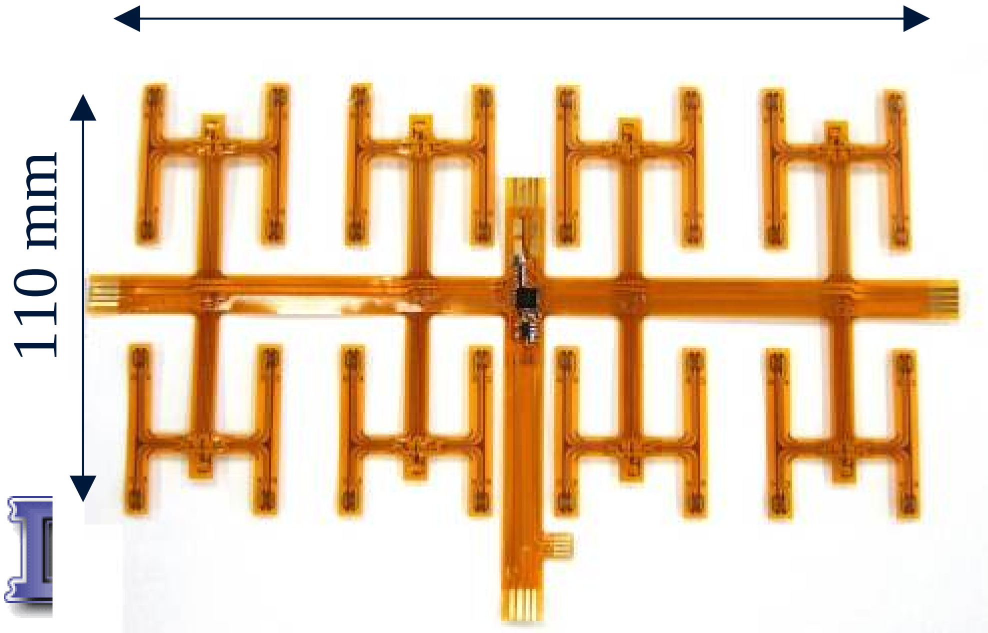
Ohmura, Nagakubo, Seta, Kuniyoshi 2005

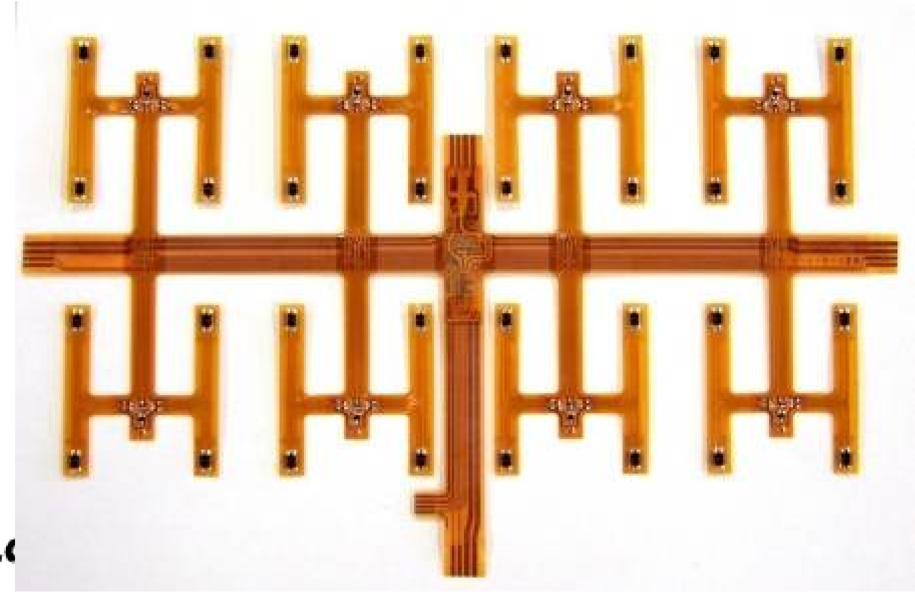
Yoshiyuki Ohmura, Yasuo Kuniyoshi, Akihiko Nagakubo:Conformable and Scalable Tactile Sensor Skin for Curved Surfaces, Proc. IEEE Int. Conf. on Robotics and Automation, pp.1348-1353, 2006. Fig.1(p1349), 6(1351)

Small tactile sensors
Cut-and-paste implementation



Light diffusing method





Implementation to Humanoid
Soft touch skin

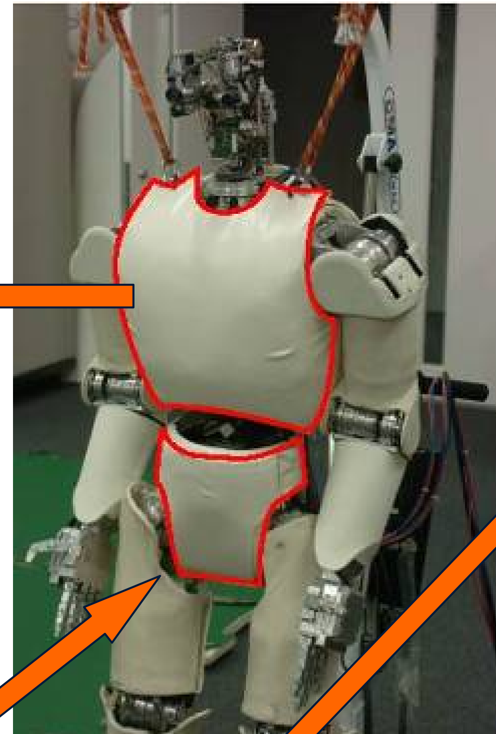
(a stepping-stone to closer contact with humans …)

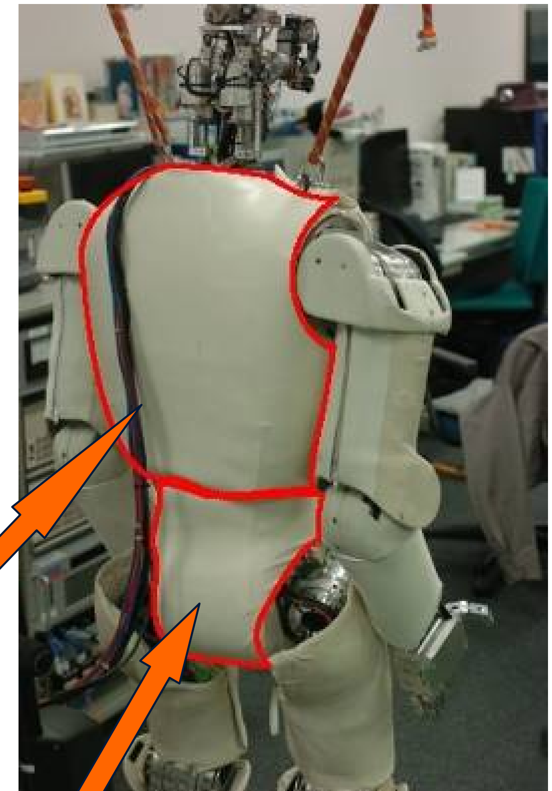
Ohmura,
Kuniyoshi 2006

400mm

400mm

Soft touch skin for body
(192 points)





groin
(62 points)

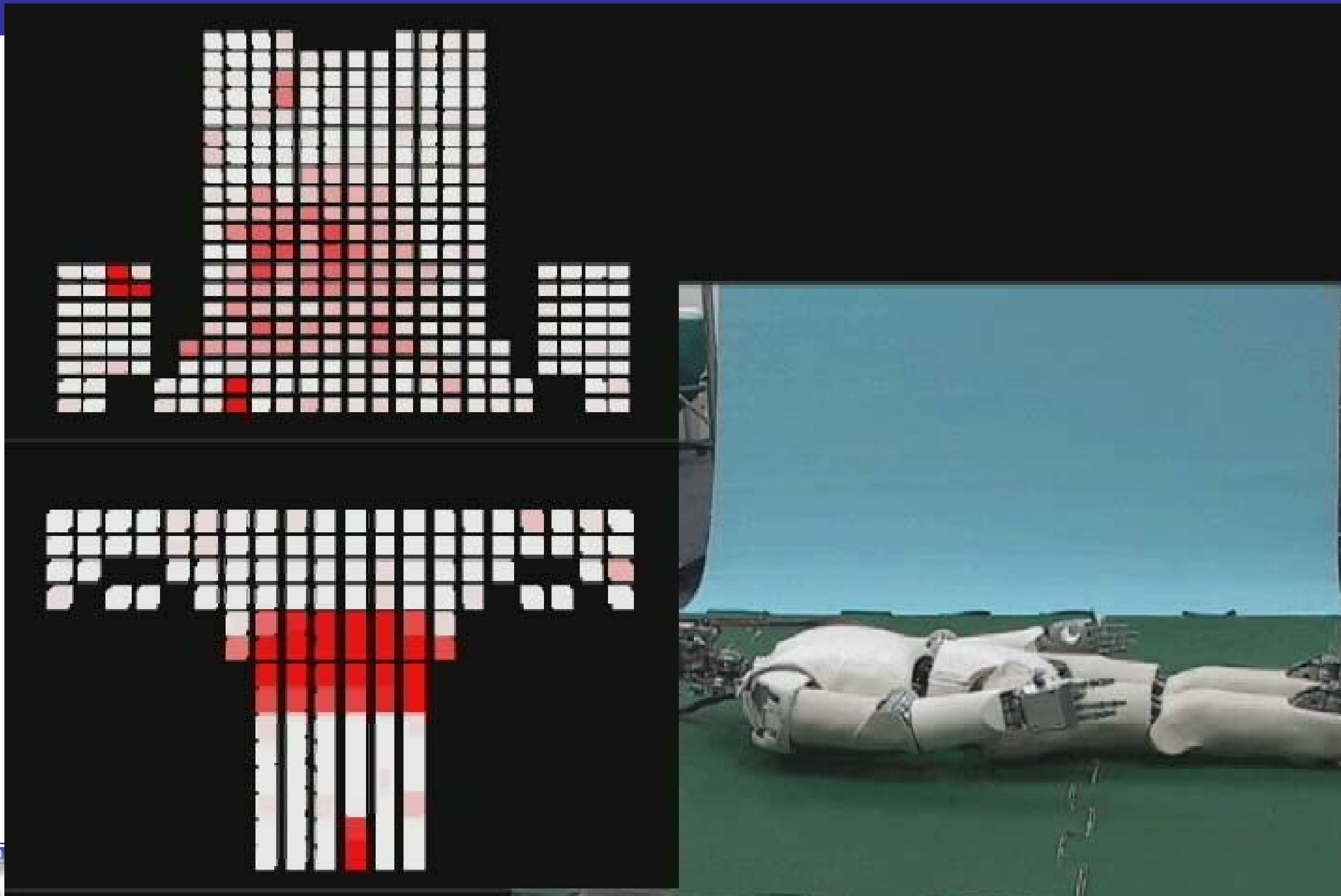
back
(308 points)

hip
(150 points)

sole
56 points each

Rising Motion Experiment

Yoshiyuki Ohmura, Yasuo Kuniyoshi: Physical rising motion of a humanoid using distributed tactile senses, the Robotics Society of Japan, the 24th Academic Lecture, CD-ROM, 2H22, 2006.



Temporal focus in understanding Action

Yasuo Kuniyoshi, Yoshiyuki Ohmura, Koji Terada, Akihiko Nagakubo, Shin'ichiro Eitoku, Tomoyuki Yamamoto: Understanding Invariant Features in Execution and Whole Body Dynamic Action --- Getting the Knack of Roll-and-Rise Motion in Robotics and Autonomous Systems, vol.48, no.4, pp.189-201, 2004.

When do you know it's X action?
Temporal localization of action information

Figure removed due to copyright restrictions

When do you know it's "X" action?
Temporal localization of action information

Eitoku&Kuniyoshi 04

- 30 S's（M23,F7)
- 64 trials

=2 performers x (2 successes, 2 failures) x 8 samples (diff. Length).

- Random display
- Guess success/failure

Figure removed due to copyright restrictions

Flow of Information ⇒ Percentage of correct answers increases.（entropy decreases）

Figure removed due to copyright restrictions

First Summary

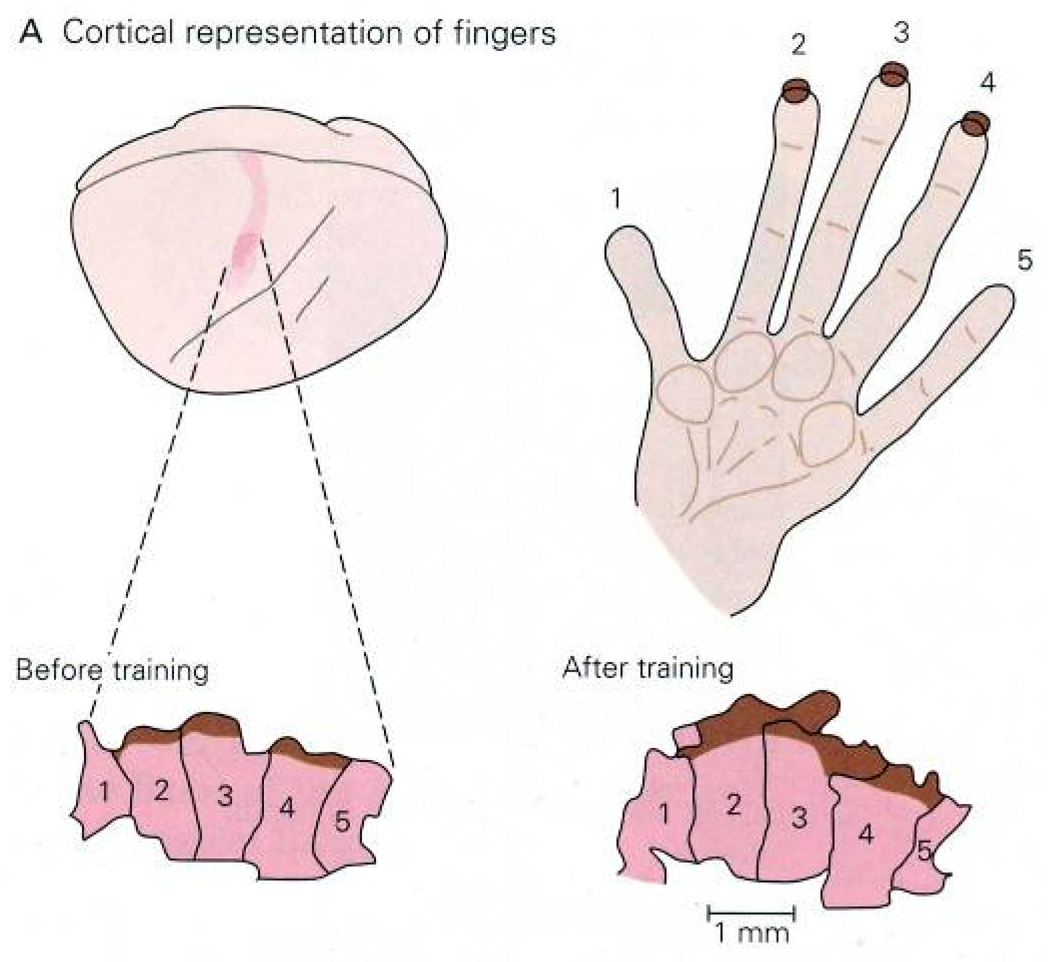
- Physical interactions between the body and the environment generate information.
- Why do humans understand each other's behavior? Why can we communicate with each other by words? A search for basic principles leads to the question of why certain behavior and concepts are common to all people. Now, it is being understood that similarity of our bodies play a key role in our commonality.

The Body Makes the Brain

- Neuron projection at the early stage of development is activity-dependent. [Crair 1999]
- The column structure of the cerebral cortex can be explained by a self-organizing model.
- The plasticity of various inner brain expressions such as in the somatosensory area
- Environmental factors and gene expression interact with each other through regulatory gene network. There is no one-sided control by a gene program.[Ridley 2004]. Behavior and learning of an individual take part in these interactions, and consequentially, they control development.
- FOXP2 which became known as a “language gene” is thought to be a gene for controlling activity, which also affects language development.[Johnson 2005].
- There are studies that point out that retarded development of motor control might be a cause in autism.

Plasticity of a Somatic Sense Map

- Monkeys：The map changes due to amputation of a finger or a nerve：adjacent regions come to the rescue.
- By suturing 2 fingers, boundaries disappear.
- Humans：10 days after separating a congenital adhesion, the map of the fingers change.（a brain-inducing map）
- Monkeys：After training to use the fingertips, the region widens（right）
- String musicians have larger regions for their left fingers.



Kandel, et al.: Principles of Neural Science, McGraw-Hill, 2000.

Hypothesis

- Structures of body-environment interactions guide self-organization of nervous systems, and are deeply related to the construction of cognitive mechanisms.
  - General structures of body and nerve systems are controlled by genes, and cognitive functions are controlled by information-driven self-organizations.
  - By detecting such structures and exposing them, mechanisms reflected in learning and self-organization are studied.
- Development of motor function is a basis for all cognitive functions.
  - Coherent learning information is generated from movement.
  - Senses accompanying motion have ultra-modal consistency.

Perception, Behavior and Learning During the Embryo Period

- Generalized movement:
  - Starts 2 months after impregnation (Kisilevsky&Low98,Joseph00).
- Vision:
  - Eye opening:20 weeks after impregnation (Lecanuet&Schaal96), 40% time rate 34 weeks after impregnation (Birch&O' Conner01).
  - light:10% of outer light (red) reaches the womb(by animals, Jacques et al.87)
  - retina:All cell layers are formed 7 months after impregnation, middle peripheral vision occurs 30 weeks after impregnation.
  - optic nerve:forms before 28 weeks.
  - cognition:preferential looking starts at 32 weeks (8months).
- Adaptation(learning) :
  - Naturalization and denaturalization:observation by body movements – reaction of the embryo to sound signals (Madison et al 86).
  - Stimuli received during the embryo period are in effect after birth (Lecanuet&Schaal96).
- Mutual bonding of the nerve circuit network:
  - There are many random bondages in an embryo brain. There is a peak shortly before birth. (Rakic et al.86)

Body Models of Embryo and Neonate

Sangawa & Kuniyoshi 05

- Musculoskeletal system (198 muscles)
- Muscle kinetics model (He et al. 01, Hill 38)
- Size, mass, inertia are set based on papers
- Movable limit of joints, setting of a natural position
- Growth (parameters: gestational age).

$$\frac{dq}{dt} = 18.8496(m - q)$$

$$u = \frac{q^2}{30^2 + q^2}$$

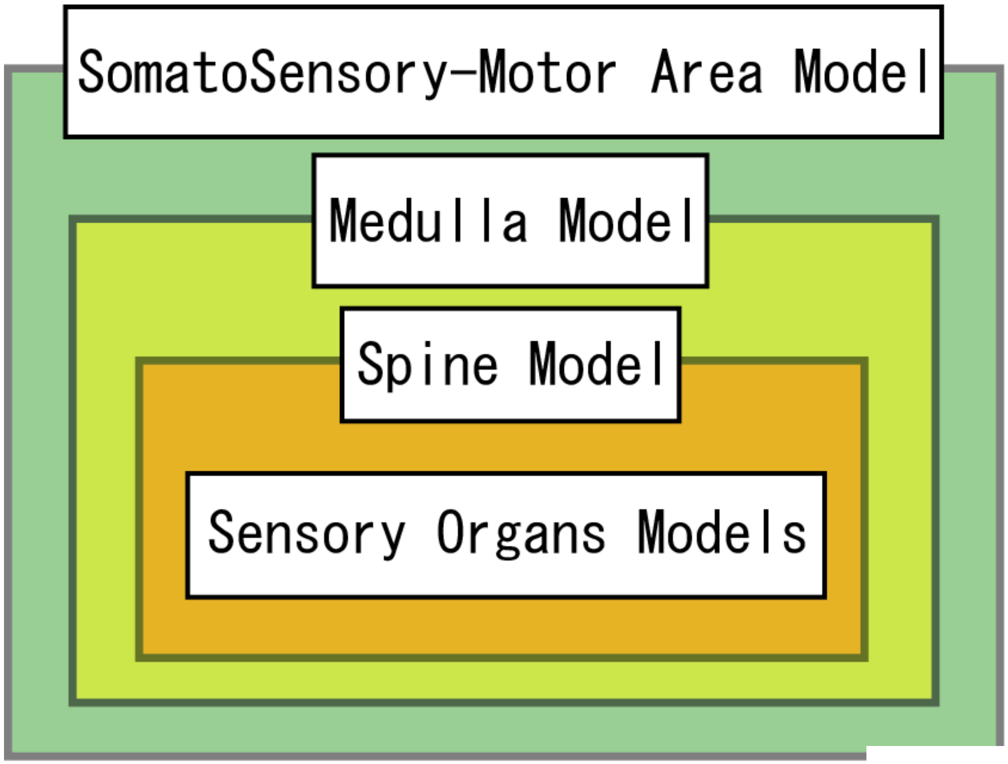
$$\frac{da}{dt} = 22(1 - 0.51a)^2(u - a)$$

Figure removed due to copyright restrictions

Touch sensor: 1448 points

Partial Model of the Central Nervous System

Sangawa & Kuniyoshi 06



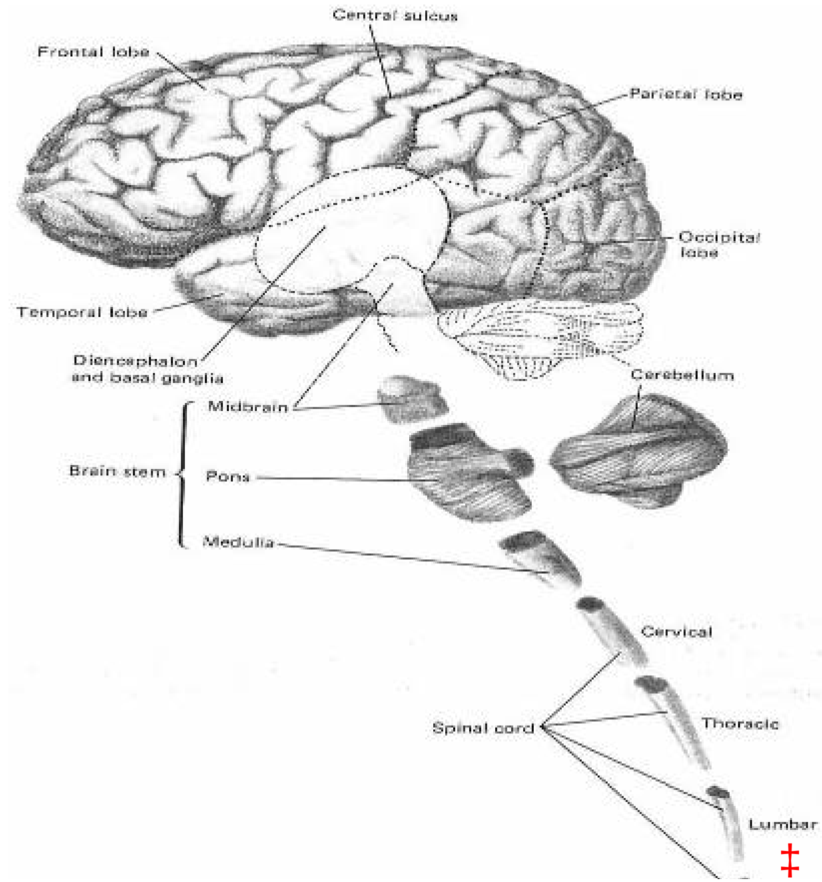


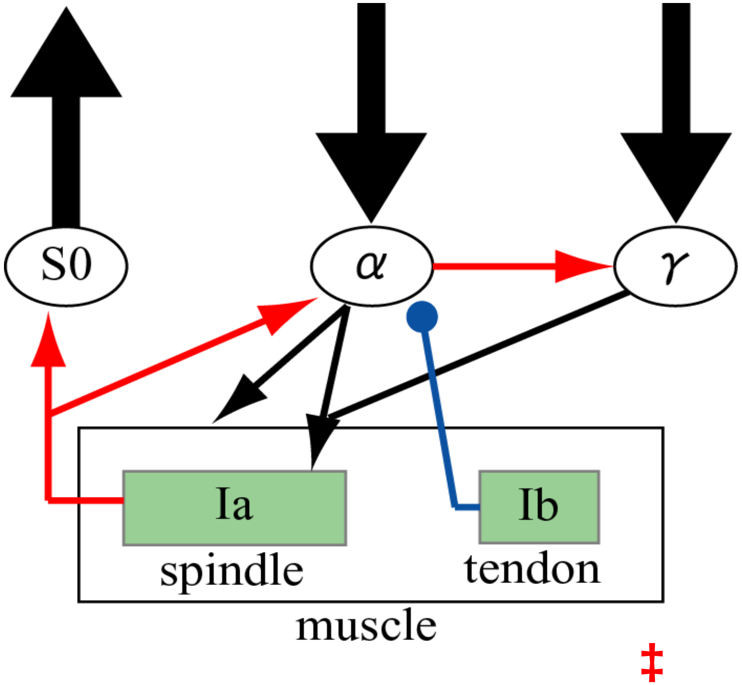
Fig. 1-2 The parts of the central nervous system.
Eric R. Kandel (Editor), James H. Schwartz (Editor), B. Andrew Mudryk : Principles of Neural Science, London : Edward Arnold , 1981, ISBN: 0-444-00651-6.

Spine Model

Sangawa & Kuniyoshi 06

Yasuo Kuniyoshi and Shinji Sangawa, Early Motor Development from Partially Ordered Neural-Body Dynamics -- Experiments with A Cortico-Spinal-Musculo-Skeletal Model, Biological Cybernetics, vol. 95, no. 6, pp. 589-605, Dec., 2006. Fig.7 の一部(p.597)

- Stretch Reflex（Spindle→Ia→α→Muscle→Spindle）
  - Regulates muscle length.
  - Postural control.
- Ib inhibition（Tendon→Ib→α→Muscle→Tendon）
  - Regulates muscle tension.
- α-γ linkage
  - Simultaneous activation of α and γ.
  - Override feedback loop of stretch reflex.
  - More force on contracted muscles.
    →**Voluntary motion.**



Spinal neurons transfer function (He et al. 01):

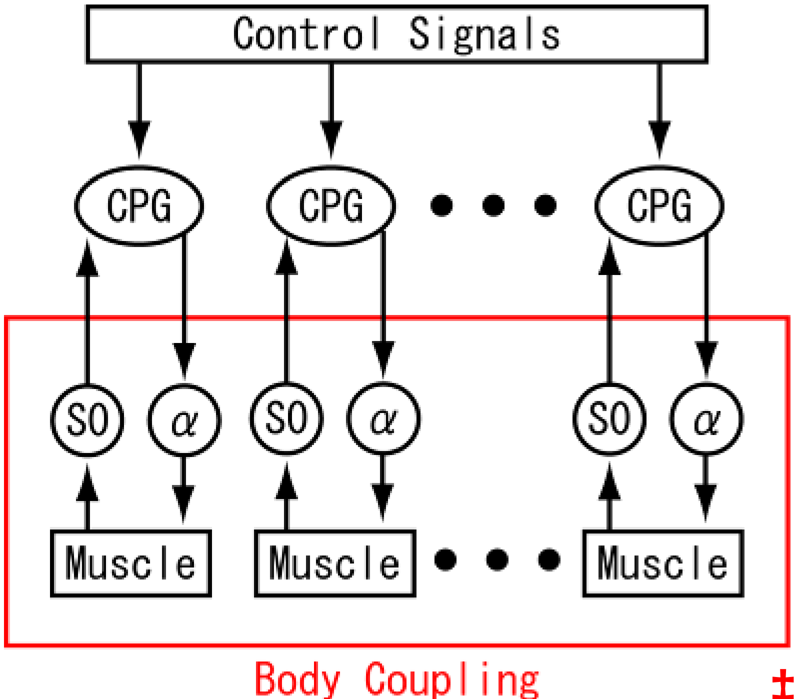
$$\frac{o(s)}{i(s)} = \frac{1.5 \cdot \left(1 + s/33 + (s/33)^2\right)}{1 + 2(s/58) + (s/58)^2}$$

Medulla Model

Sangawa & Kuniyoshi 06

Yasuo Kuniyoshi and Shinji Sangawa, Early Motor Development from Partially Ordered Neural-Body Dynamics -- Experiments with A Cortico-Spinal-Musculo-Skeletal Model, Biological Cybernetics, vol. 95, no. 6, pp. 589-605, Dec., 2006. Fig.3(p.593)

- Each neuron controls 1 muscle.
- No direct coupling between CPG's.
- CPG coupling throughout the body.
- Periodic/chaotic movement depending on input (constant + M1 signal).



‡

$$\frac{dx}{dt} = c \cdot \left(x - \frac{1}{3}x^3 - y + in_{control}\right) + \delta \cdot (Ia - x)$$

$$\frac{dy}{dt} = \frac{1}{c} \cdot (x - b \cdot y + a) + \varepsilon \cdot Ia$$

$in_{control}$: Control input.

Ia : Spindle output.

x : Muscle activation,

Chaotic motor exploration

Sangawa & Kuniyoshi 06

- Coupled CPG's generate periodic / chaotic signals (Asai 03).
  - Periodic: for uniform control inputs.
  - Chaotic: for non-uniform control inputs.
- Motor exploration by couple chaotic system(Kuniyoshi&Suzuki 04)
  - Coupling of chaotic elements via embodiment.

$$\frac{dx_1}{dt} = c \cdot (x_1 - \frac{1}{3}x_1^{\ 3} - y_1 + z_1) + \delta \cdot (x_2 - x_1)$$

$$\frac{dy_1}{dt} = \frac{1}{c} \cdot (x_1 - b \cdot y_1 + a) + \varepsilon \cdot x_2$$

1CPG

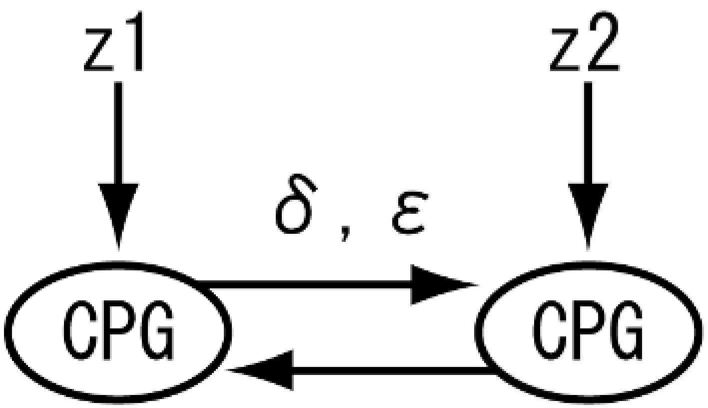
$$\frac{dx_2}{dt} = c \cdot (x_2 - \frac{1}{3}x_2^{\ 3} - y_2 + z_2) + \delta \cdot (x_1 - x_2)$$

$$\frac{dy_2}{dt} = \frac{1}{c} \cdot (x_2 - b \cdot y_2 + a) + \varepsilon \cdot x_1$$

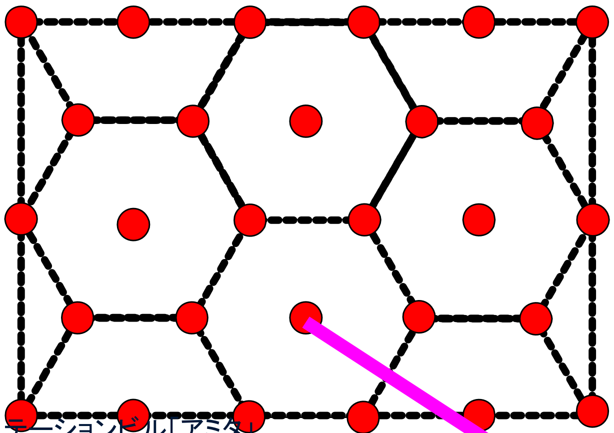
1CPG

BVP eq.

z_1, z_2 : Control inputs.



Dynamics of S1 and M1



•三田ステーションビル「アミタ」

S1

$$\frac{du_i}{dt} = G_u \left(-C_u \cdot u_i + \frac{\prod_{j \in S0} in_{ij}}{\sum_{k \in S1} \prod_{j \in S0} in_{kj}} + \sum_{k \in S1} inn_{ik} \right)$$

$$in_{ij} = \begin{cases} 1 - |y_j - w_{ij}| & (|y_j - w_{ij}| < 1.0) \\ 0.0 & (|y_j - w_{ij}| \geq 1.0) \end{cases}$$

u_i : Active potential of an S1 neuron *i*

in_{ij} : Input from an S0 neuron *j* to an S1 neuron *i*

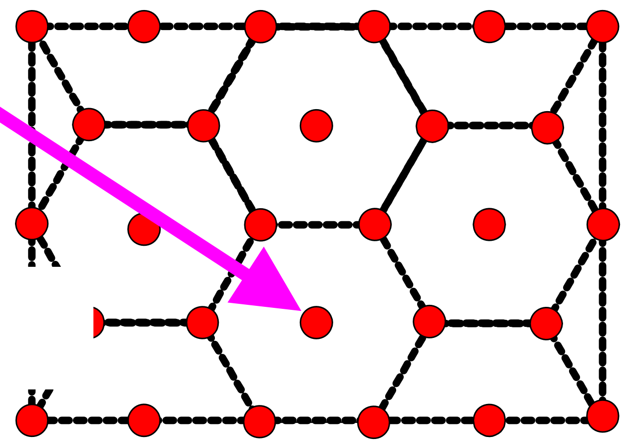
inn_{ik} : Input from an adjacent S1 neuron *k*

$$\frac{du_i}{dt} = G_u \left[-C_u \cdot u_i + w_{S1toM1} \left(y_j + \sum_{k \in S1} y_k \right) \right]$$

u_i : Active potential of an M1 neuron *i*

y_j : Output of an S1 neuron *j* corresponding to an M1

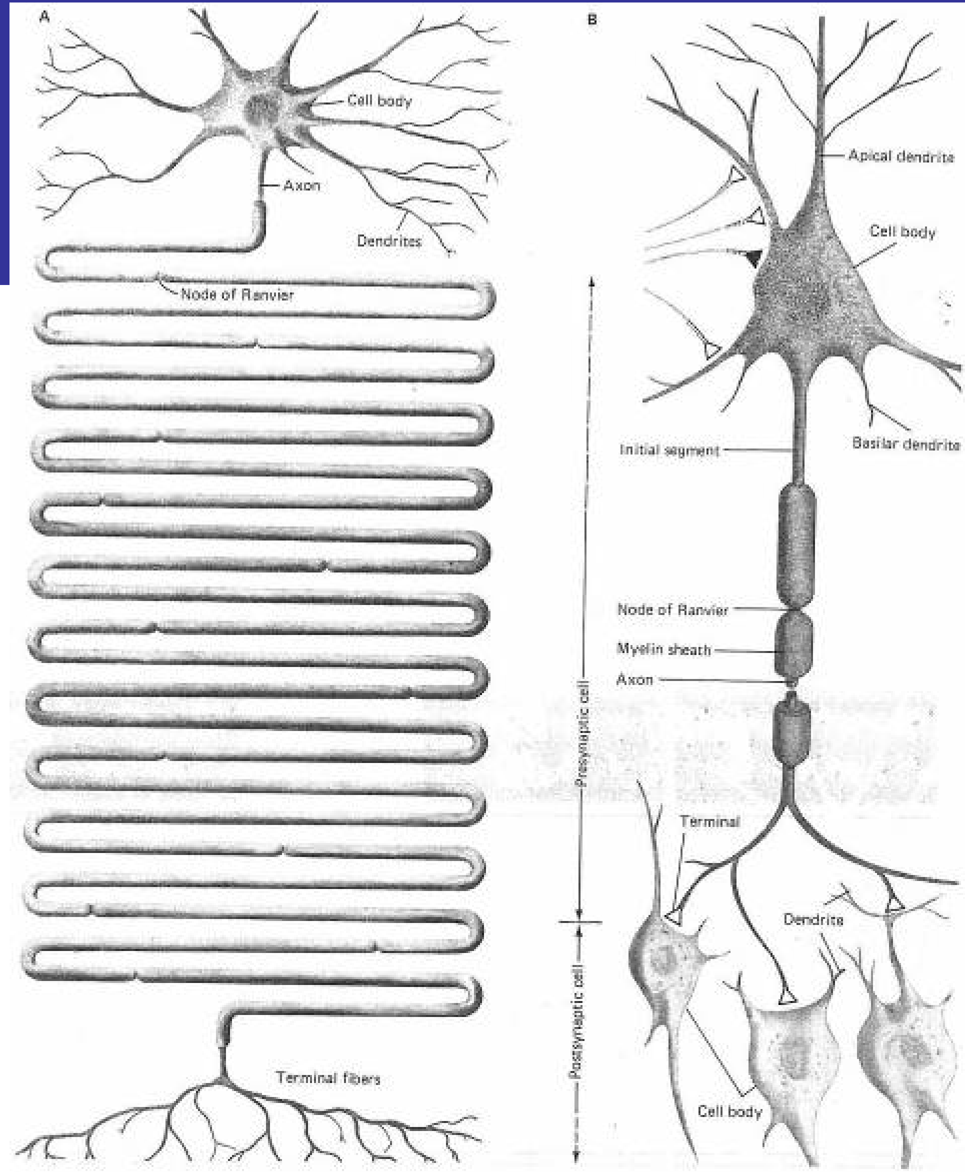
y_k : Output of an adjacent neuron to an S1 neuron *j*



M1

Basic Activities of the Neuron

- input：
  - synapse→dendrite
  - synaptic efficacies, weight
- integration：
  - total
  - cell body
  - membrane potential
- output：
  - threshold
  - axon
  - action potential



Eric R. Kandel (Editor), James H. Schwartz (Editor), B. Andrew Mudryk：Principles of Neural Science, London : Edward Arnold , 1981, ISBN: 0-444-00651-6. Fig.2-2 ‡

Neuron Model

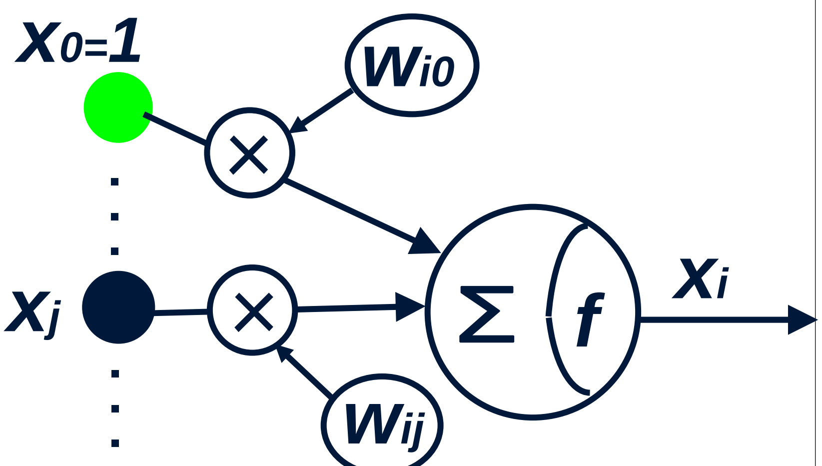
x_j : Output value of a neuron *j* , (x_0: Bias node for a neuron *i*)

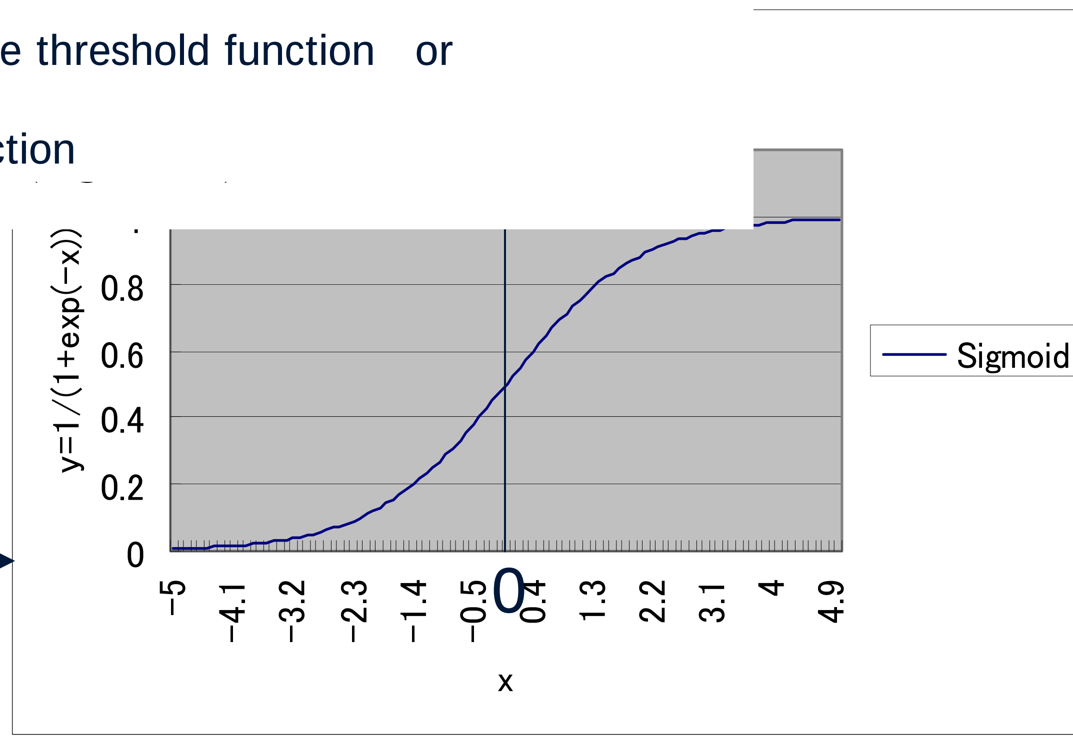
w_{ij} : Bonding load from a neuron *j* to *i* (synapse load)

$u_i = \sum_j w_{ij} x_j$: Inner potential of a neuron *i*

$$x_i = f_i(u_i)$$

$$f_i(u) = \begin{cases} \alpha u & \text{: Linear or} \\ 1(u - \theta_i) & \text{: Simple threshold function or} \\ \dfrac{1}{1 + e^{-\beta_i u}} & \text{: Sigmoid function} \end{cases}$$



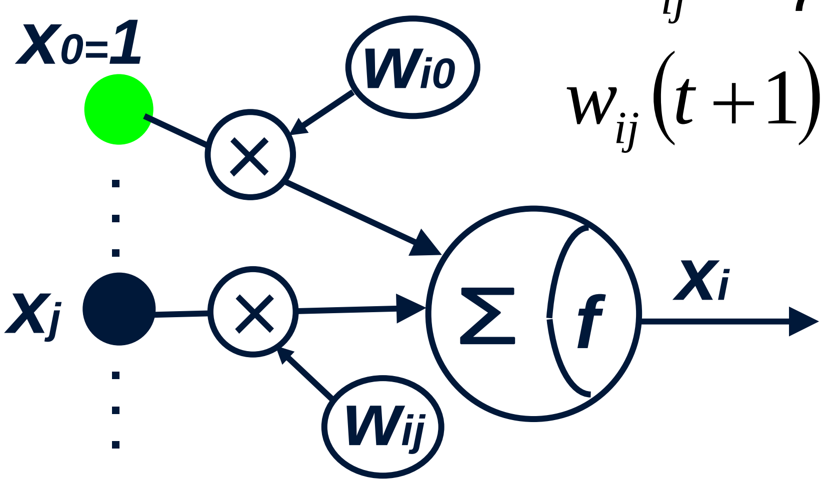


Neuron Model and Learning

- Hebb learning：When 2 neurons are activated at the same time, the bond between them is enhanced.
- Correlated learning

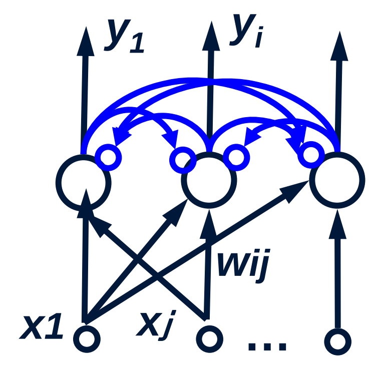
$$\Delta w_{ij} = \eta \cdot x_j \cdot x_i, \quad 0 < \eta = \text{Learning efficiency}$$

$$w_{ij}(t+1) = w_{ij}(t) + \Delta w_{ij}$$



Lateral Inhibition

- Mexican-hat function
- Promotion of clusters（gathering similar things）



$$w_{ji} = (E+1)\exp\left(-\frac{|i-j|^2}{2r_E^2}\right) - I\exp\left(-\frac{|i-j|^2}{2r_I^2}\right)$$

i, j : Position of neurons

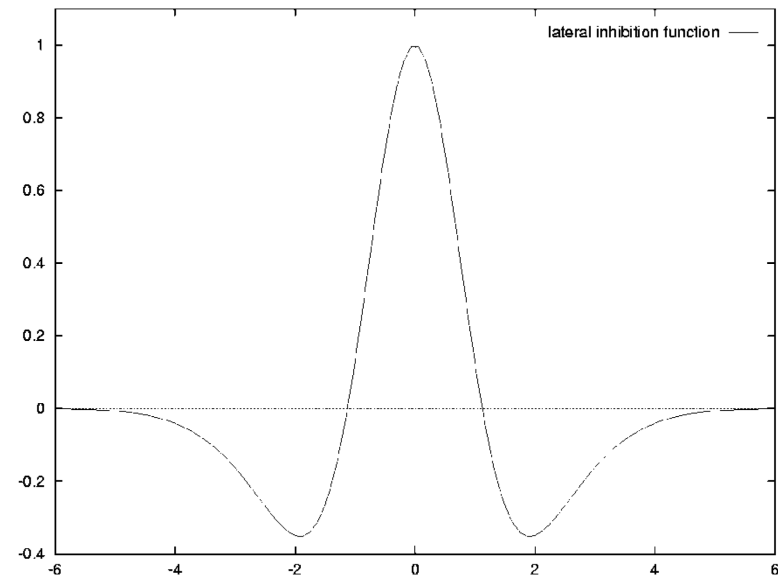
E : Strength of excitement

I : Strength of inhibition

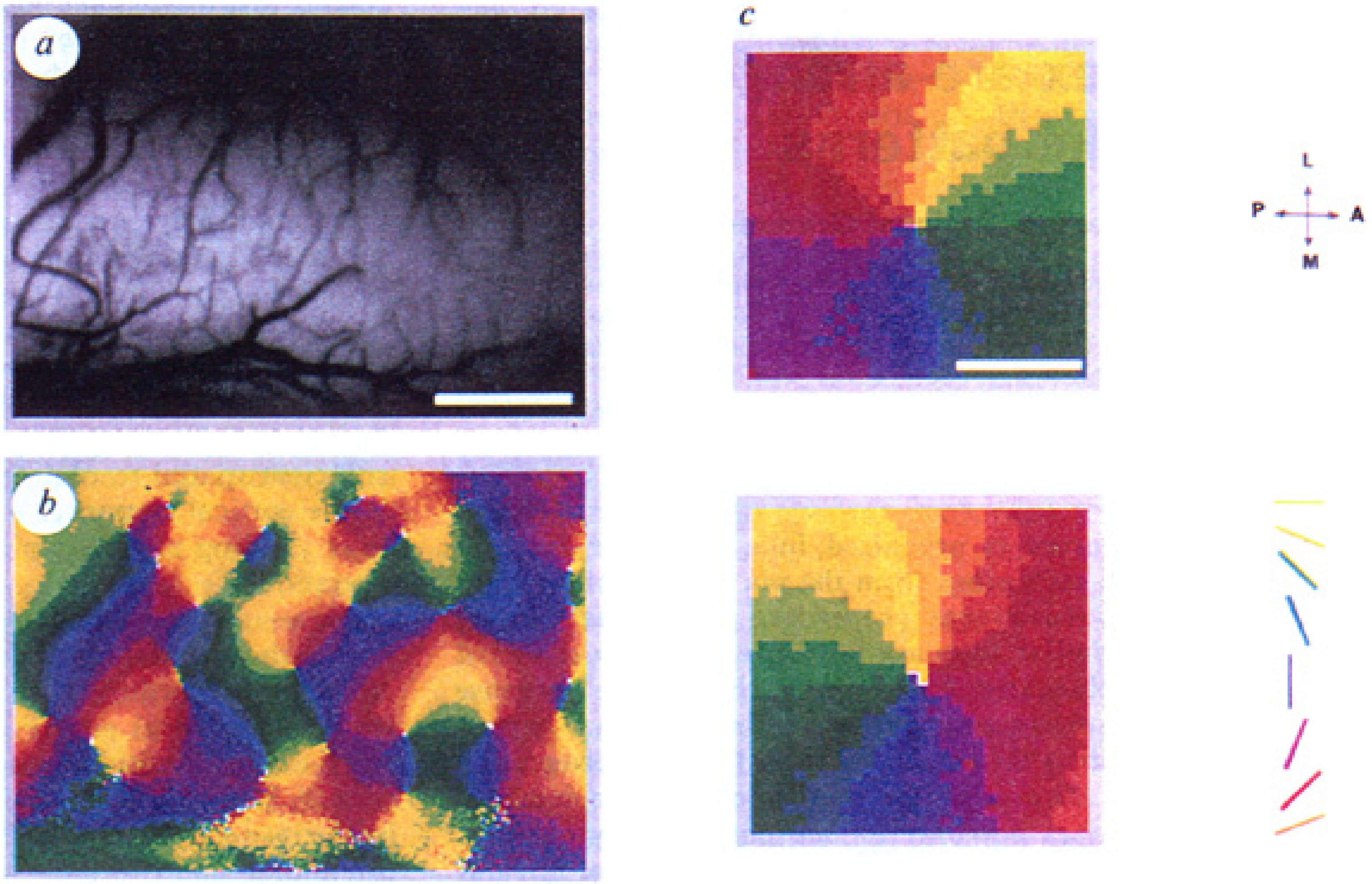
r_E : Excitement radius

r_I : Inhibition radius

When combined with Hebb learning, self-organization learning.



Character Map of the Primary Cerebral Visual Area



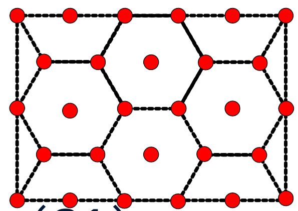
Bonhoeffer and Grinvald, 1991

Intelligent System and Informatics Lab.
http://www.isi.imi.i.u-tokyo.ac.jp

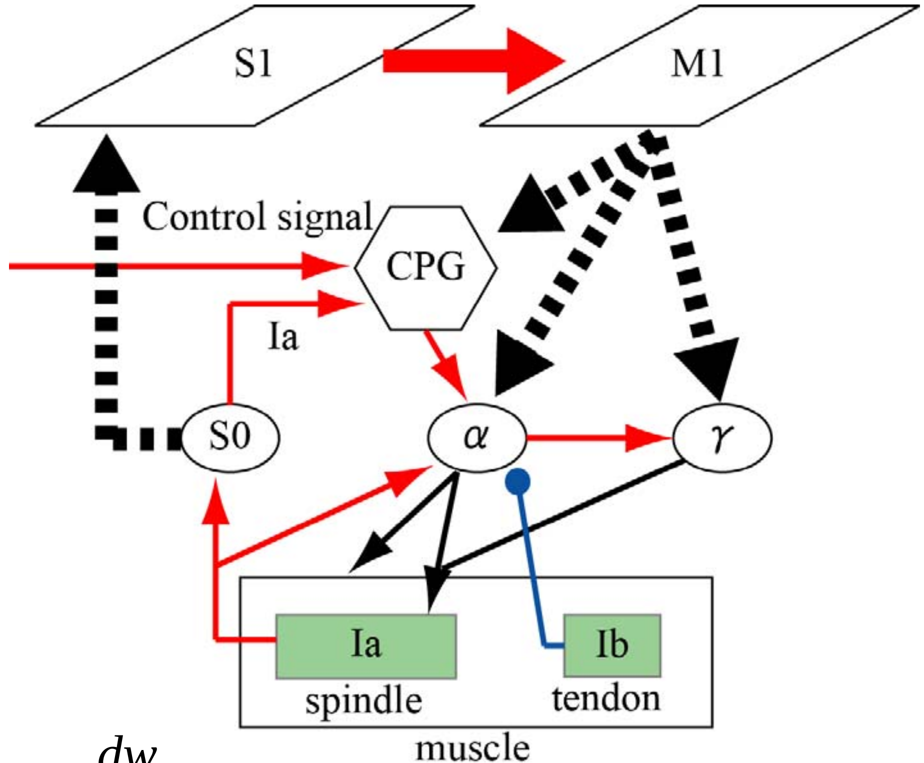
Motor(M1)- SomatoSensory(S1) Areas Model

Sangawa & Kuniyoshi 06

- A Self-Organizing Network with a spatial structure(Chen 97)



- Somatosensory area(S1)
  - Competitive SOM
  - S0-S1: Modified Hebbian, fully connected.
- Motor area(M1)
  - Receptive field around the corresponding point on S1
  - M1-α, M1-γ, M1-CPG Modified Hebbian



$$\frac{dw_{ij}}{dt} = \eta \cdot y_i \cdot (y_j - w_{ij})$$

y_i : Output of postsynaptic neuron i.

y_j : Output of presynaptic neuron j.

w_{ij}: Connection weight from j to i.

Left and Right Hemispheres

Sangawa & Kuniyoshi 06

- Left and right neural systems
  - S1, M1:20x10 each neuron
  - Spinal cord, medulla：99 neurons
  - Bridge：link left and right S1,M1
  - All bonds（excitement）
  - Hebbian rule（altered version）
- Restriction input
  - Constant value（0.5）
  - Smooth motion

Figure removed due to copyright restrictions

Intell

Shinji Samukawa, Yasuo Kuniyoshi：Body and Brain-Spinal Cord Model of Embryo and Neonate, Self-Organization of Somatic Sensory Area and Motor Area，the Robot Society of Japan, the 24th Academic Lecture，CD-ROM，2L24，2006.

Embryo and Neonate Environment

Sangawa & Kuniyoshi 06

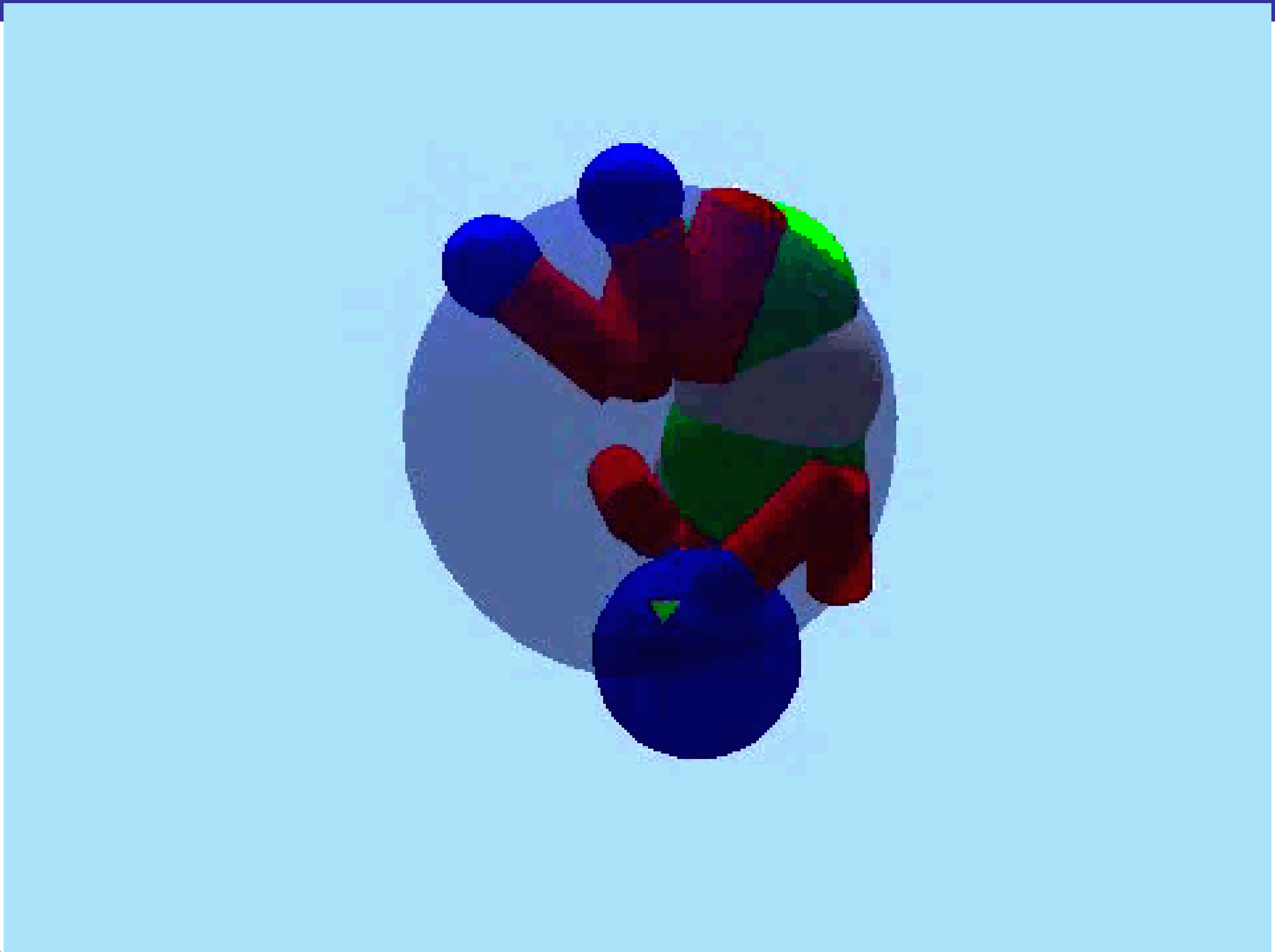
- embryo（35 weeks after impregnation)
  - Womb environment：gravity, buoyancy, fluid resistance, umbilicus (the fetus connects to the body at the umbilicus)
  - Uterine wall：non-linear spring, damper model
- neonate（0 weeks after birth）
  - Normally, gravity
  - Flat floor
  - Surrounded by a fence

Figure removed due to copyright restrictions

Shinji Samukawa, Yasuo Kuniyoshi：Body and Brain-Spinal Cord Model of Embryo and Neonate, Self-Organization of Somatic Sensory Area and Motor Area，the Robot Society of Japan, the 24th Academic Lecture，CD-ROM，2L24，2006.

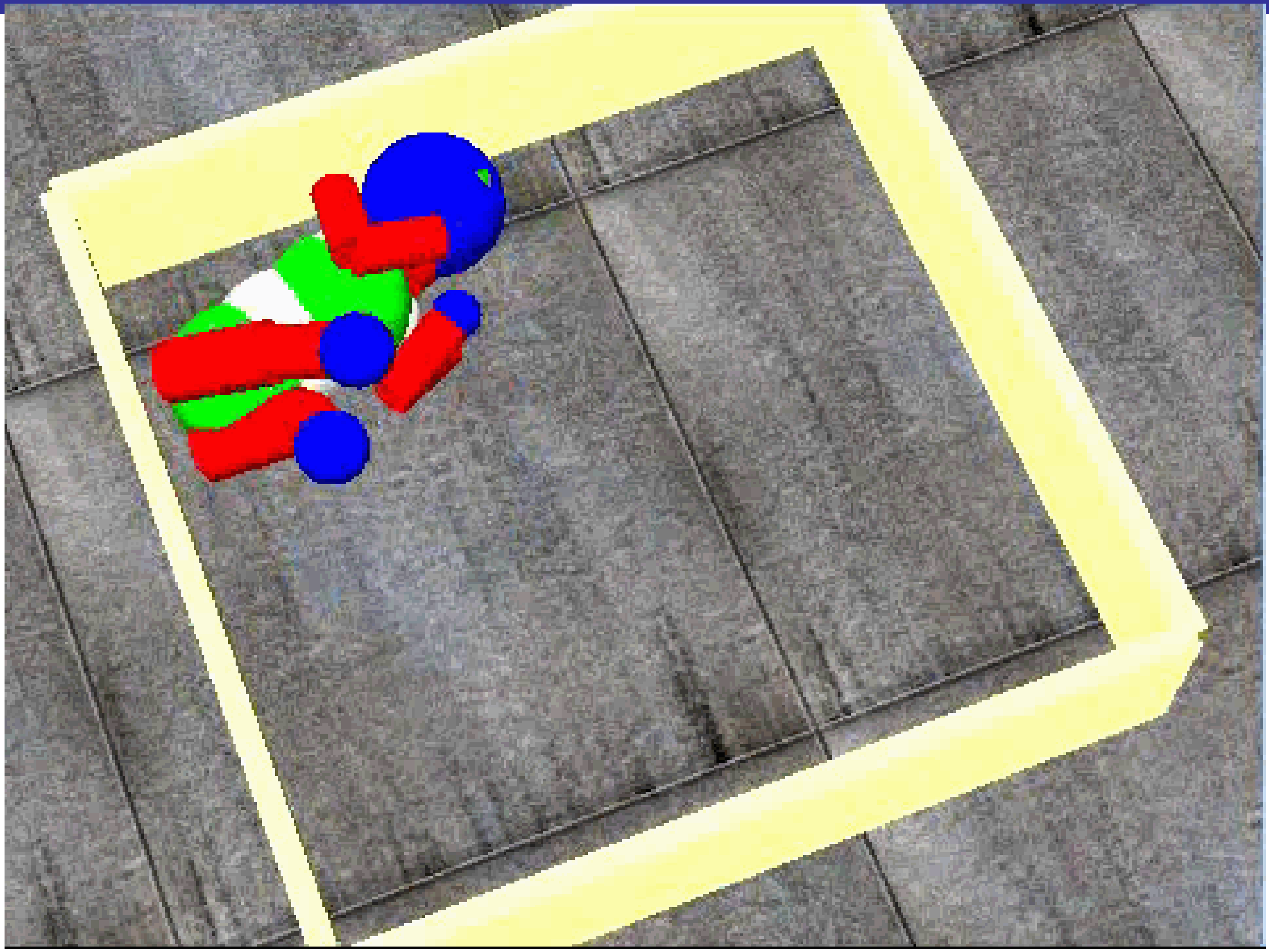
Movements of the Embryo – a Model

Sangawa & Kuniyoshi 06



Movements of an Embryo – a Model

Sangawa & Kuniyoshi 06



Steps from Motion to Cognition

- GM→structuralizing of the body and the environment dynamics → units of motion
- Body diagram, integration with view, body schema
- Prediction and segmentation of motions accompanied by sense, attention, consciousness
- Attention to other people's motions and turn-taking
- Others' body diagrams can be obtained by body diagrams.
- Motivation for identifying others, mimicry trial
- Stand holding on to something
- Language acquisition

Conclusion

- Information structure generated from interactions between nerve, body and environment.
- Neural system to drive and learn it.
- Self-organized information in the brain communicate with others, interpret information and decide what to do..
- By imagining developing robot, all procedures through the generation of information through interpretation and uses can be considered as a closed system.
- For a robot that can really communicate with humans. .