



Information Changes the World Informatics, Robots, and Life

Robotic Informatics Used to Understand Life

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Ryohei Kanzaki

Graduate School of Information, Science and Technology
Research Center for Advanced Science and Technology

the World

— the Global View —

Hiroshi Komiya
“The University and Information”
— Information Changes Learning —

Information Culture

Ikuo Takeuchi
“Interface of Information and Art”

Tomomasa Sato
“Robot, Information and Life”

Information Society

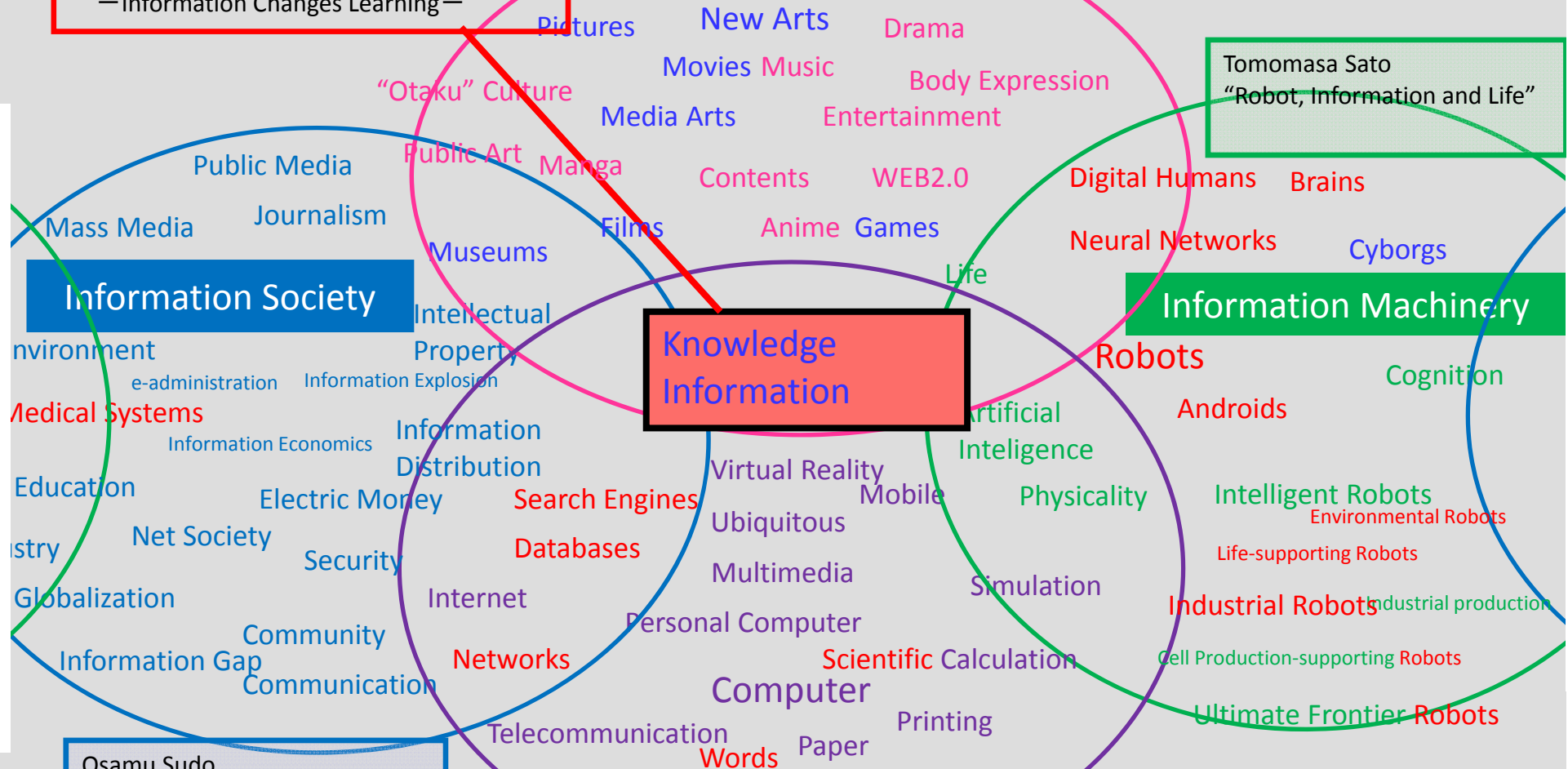
Knowledge Information

Information Machinery

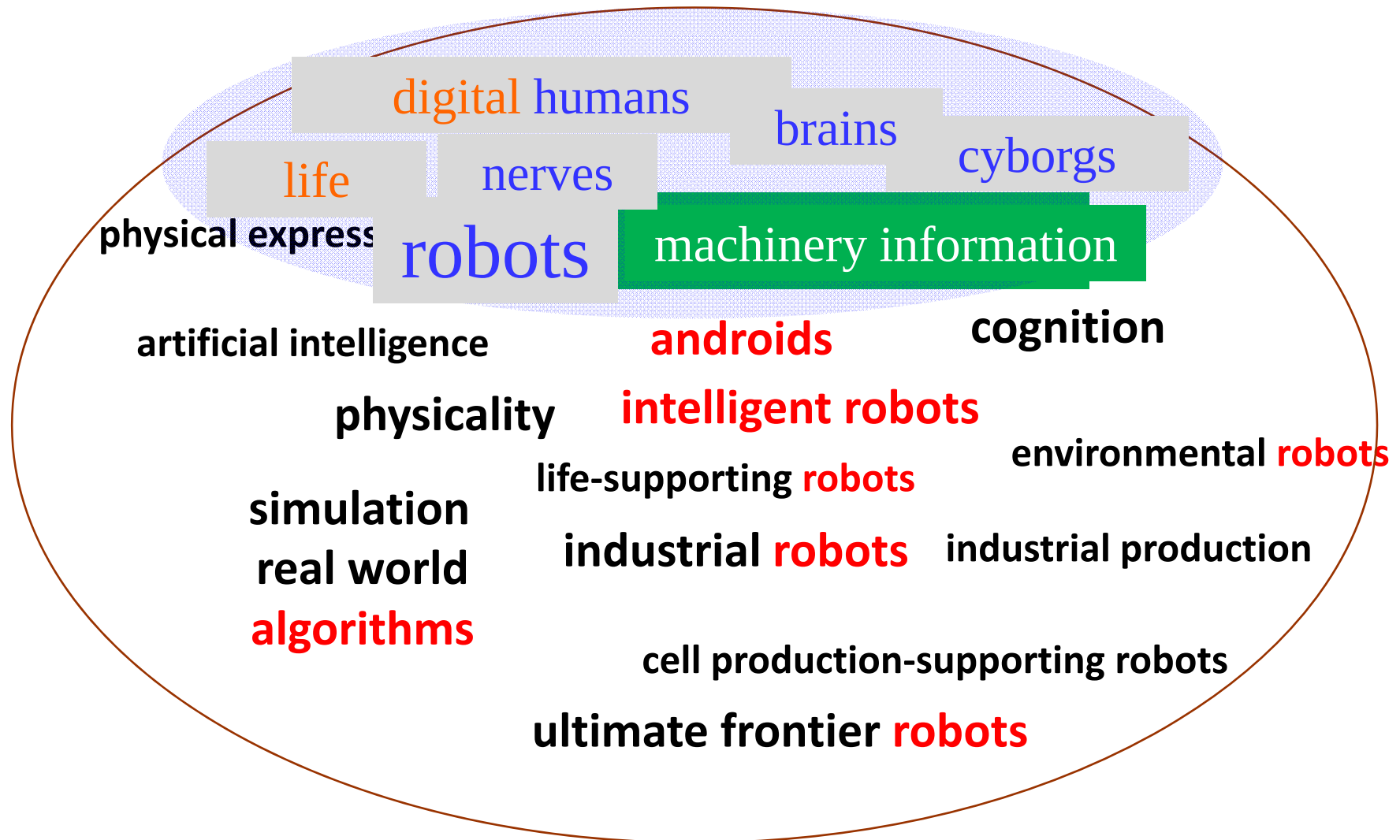
Information Foundation

Osamu Sudo
“Information Explosion and
Creation of a New Network
Society”

Hiroshi Harashima
“Why Information Technology Now?”



Covering **the** Range of Robotics (**a close-up**)



Informatics, Robots, and Life

Robotic Informatics to Understand Life

vision

olfaction

tactile

senses

auditory
perception

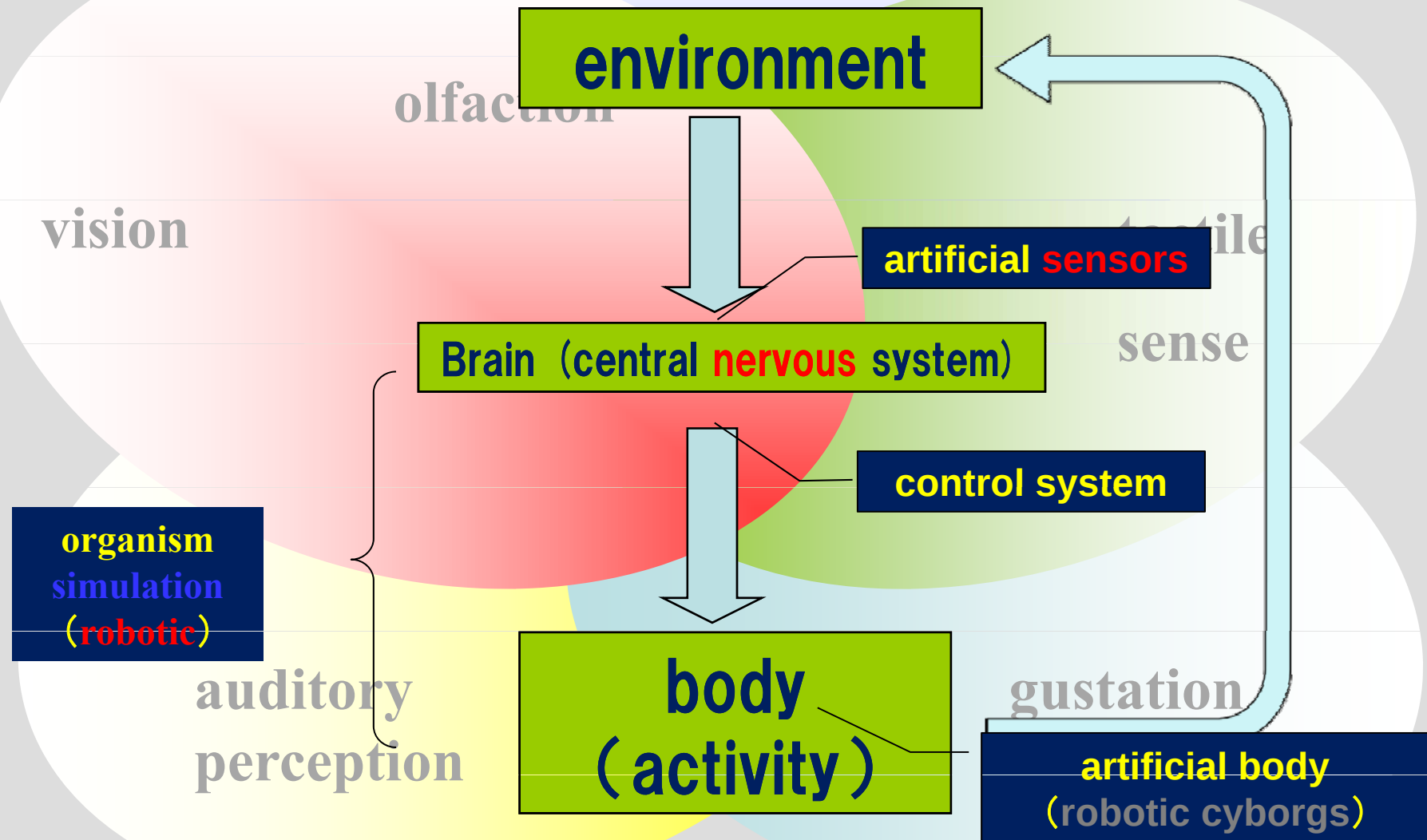
others

gustation



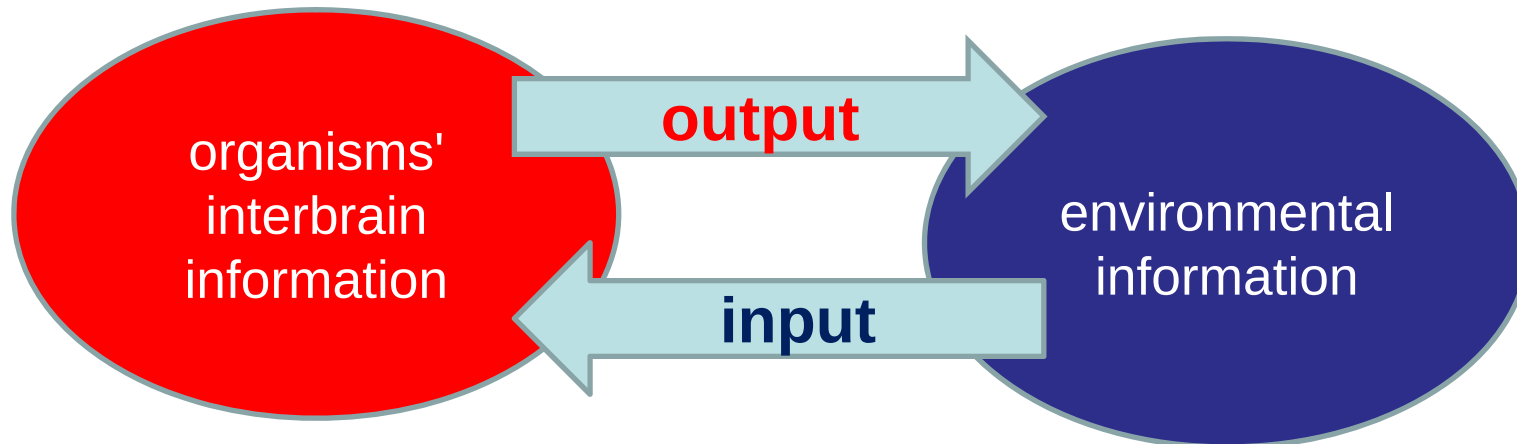
Informatics, Robotics, and Life

Robotic Informatics to Understand Life



Brain – Machine Interface that Links Organisms (Brain) and the Environment

Brain Machine Interface (BMI) is a technology that enables direct input and output between **the brain and the environment**.



Global view of **the** information world brought **about by the** fusion of biology, informatics and **engineering**.

Informatics, Robots, and Life

Robotic Informatics Used to Understand Life

1. Information That Links Organisms and their Environment

- senses and behavior

2. The World as Environment

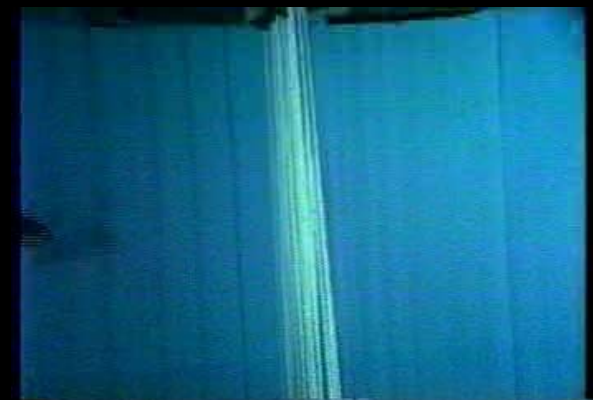
- senses, time, size information

3. Information That Links the Environment, Brain and Body

- nerves and the brain
- a fused system of organism and machinery (BMI, cyborgs)



Various Animals Living on the Earth



Resources : The Open University of Japan, Mobiligence, Kanzaki Lab.

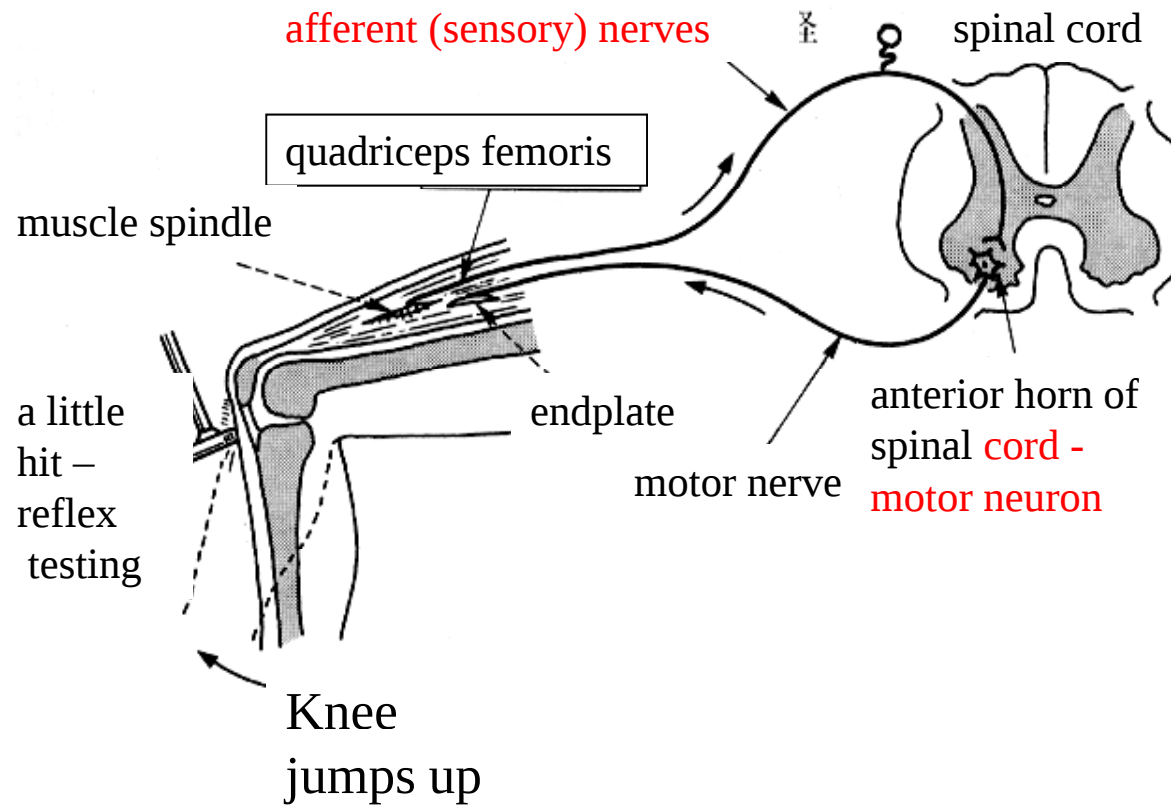
Animal Behavior

What is “behavior” ?

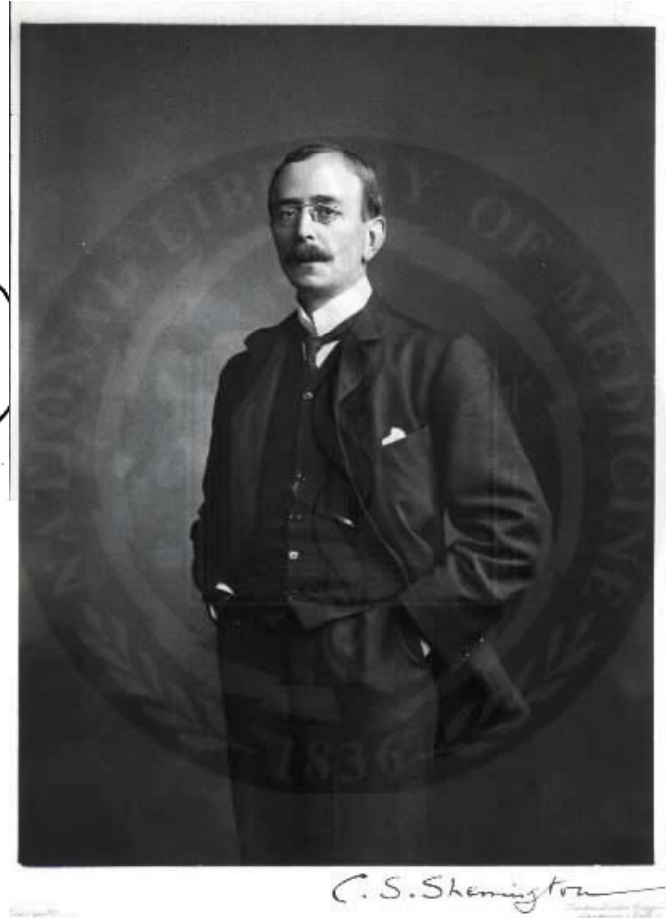
Motions that an individual animal **performs** actively in the environment (**activities which play some role in the animal's adaptation to life.**)

What is **a** unit of behavior?

Units of Behavior: Reflexes



**Reflex
reaction**



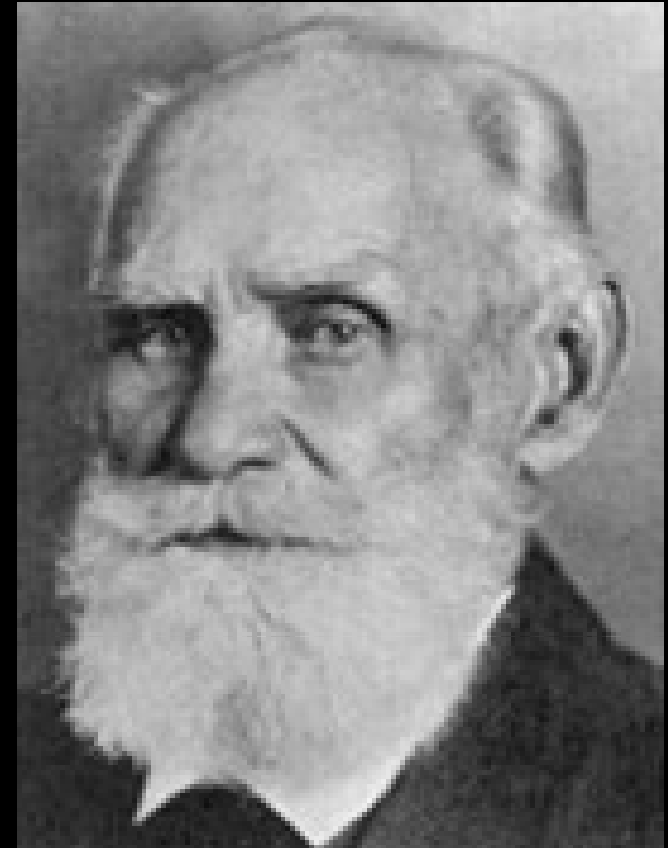
**Charles Sherrington
(1857~1952)**

Ivan Pavlov

(1849~1936)



conditioned reflexes



A Behavior-Based Robot

According to perceived sensor information, a module which outputs simple reflex behavior is executed paratactically. By performing small paratactic processes, quick judgments and flexible behavior suited to a real environment are possible.

Complex behavior can be created by the interactions of simple behaviors.



Units of Behavior : Inherent Behavior Patterns

3 Researchers Who Established Animal Behavior Studies

1930-50



Tinbergen

(1907-1988)

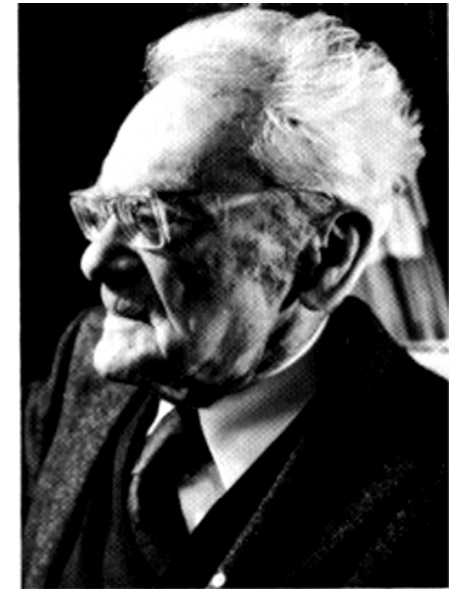
“The Study of Instinct”



Lorenz

(1903-1989)

The imprinting of geese

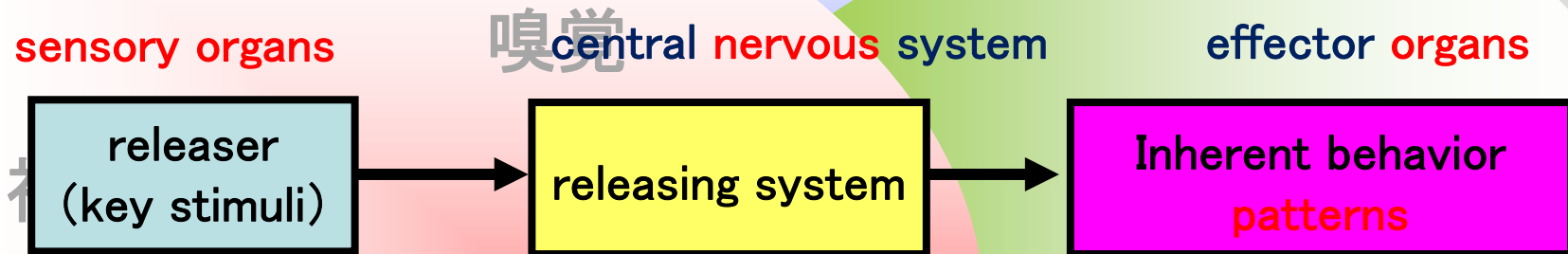


Frisch

(1886 - 1982)

The waggle dance of
the honey bee

Units of Behavior: Inherent Behavior Patterns



1. Sensory organs(releaser, key stimuli)
2. Central nervous system (releasing system)
3. Effector organs(inherent behavior patterns)

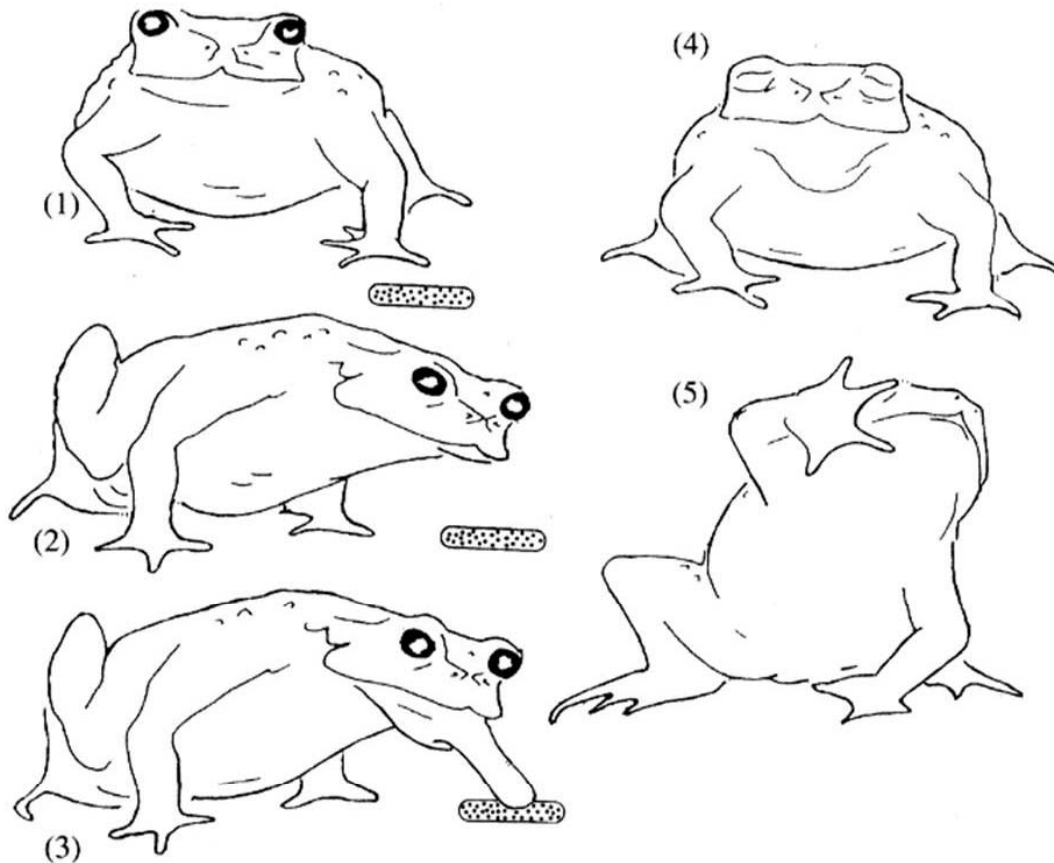
Supply information on how to move in the environment.
Environmental information (key stimuli) determines movements.

The Escape Behavior of a Sea Slug



Gastropoda, Orthogastropoda, Heterobranchia resource : BBC Nerve studi

Unit of Behavior: **Reflexes** and **Programmed Behavior**



The Hunting behavior of a toad

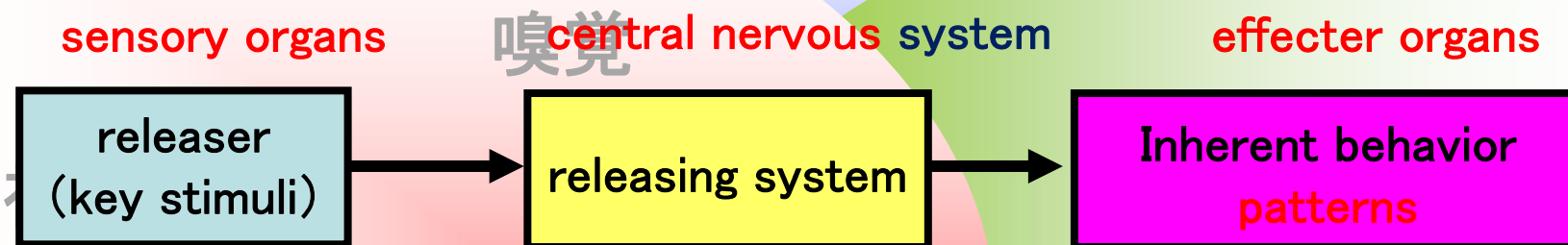
[J.-P.Ewert, *NEUROETHOLOGY*, Fig.41, Springer (1976)]

- 1) **Detects** motions of a prey
- 2) **Turns** toward the prey, **focuses** on the prey within their field of view
- 3) **Holds out its tongue and tackles** the prey
- 4) **Swallows**
- 5) **Wipes** the mouth with a front limb

These are chained behaviors from 1) to 5). However, even if a prey is taken away before a toad swallows it, a toad **will wipe its** mouth.

1) 2) are **reflex behaviors**
3) to 5) are **programmed behaviors**

Environment Information (Key Stimuli)



1. **Sensory organs**(releaser, key stimuli)
2. **Central nervous system** (releasing **systems**)
3. **Effector organs**(inherent behavior **patterns**)

聴覚

その他

味覚

This is information on how to move in the environment.

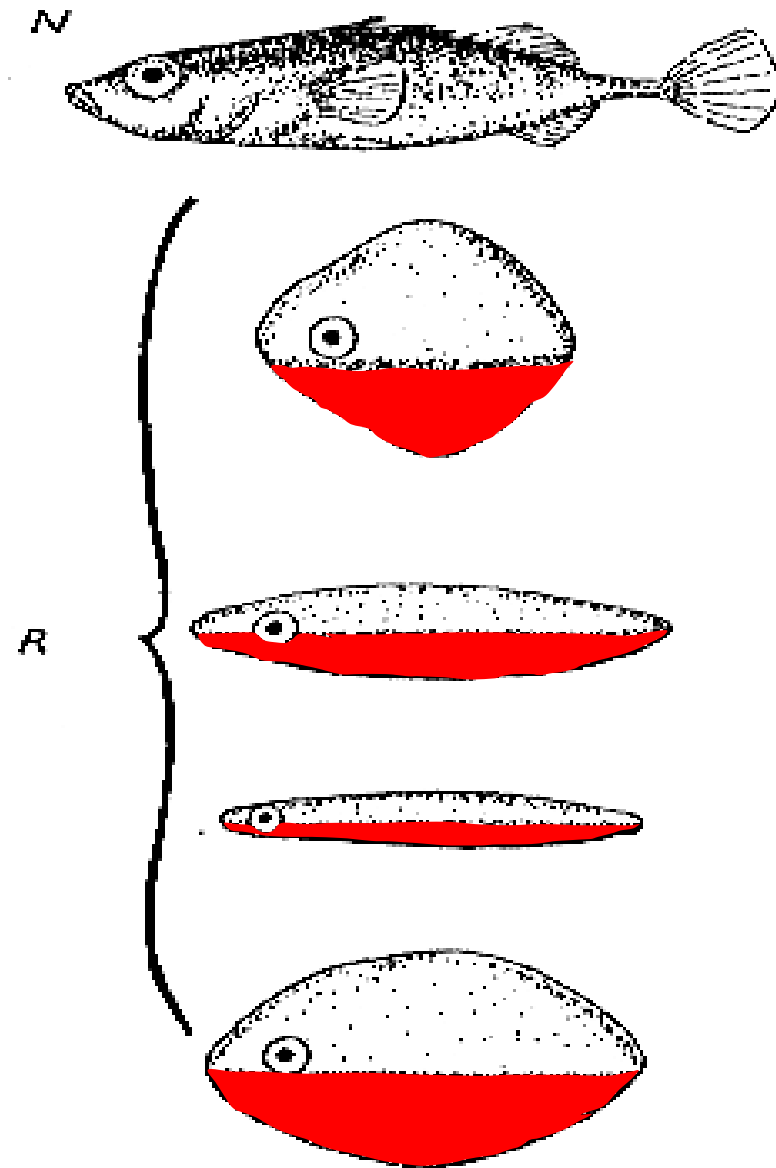
Some of this environmental information (its key stimuli) determines movement.

Mating Behavior and Aggressive Behavior of the Three- Spined Stickleback



Resources : The Open University of Japan

Key Stimuli



Aggressive Behavior of a Male Three-Spined Stickleback

Bristlings do not always need a red stomach. The color red is a key stimulus for them. If a rival male has a red back instead of a red stomach, it is meaningless.



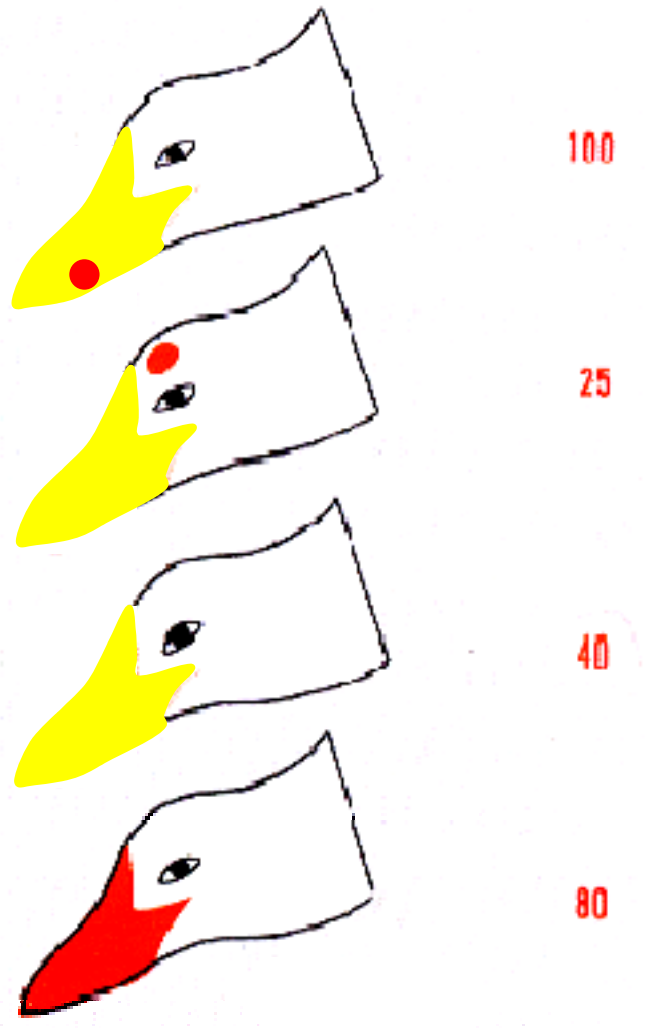
Teasing Behavior of Feeding Herring Gulls



Tinbergen and Perdeck, 1950

Resources : The Open University of Japan

Key Stimuli

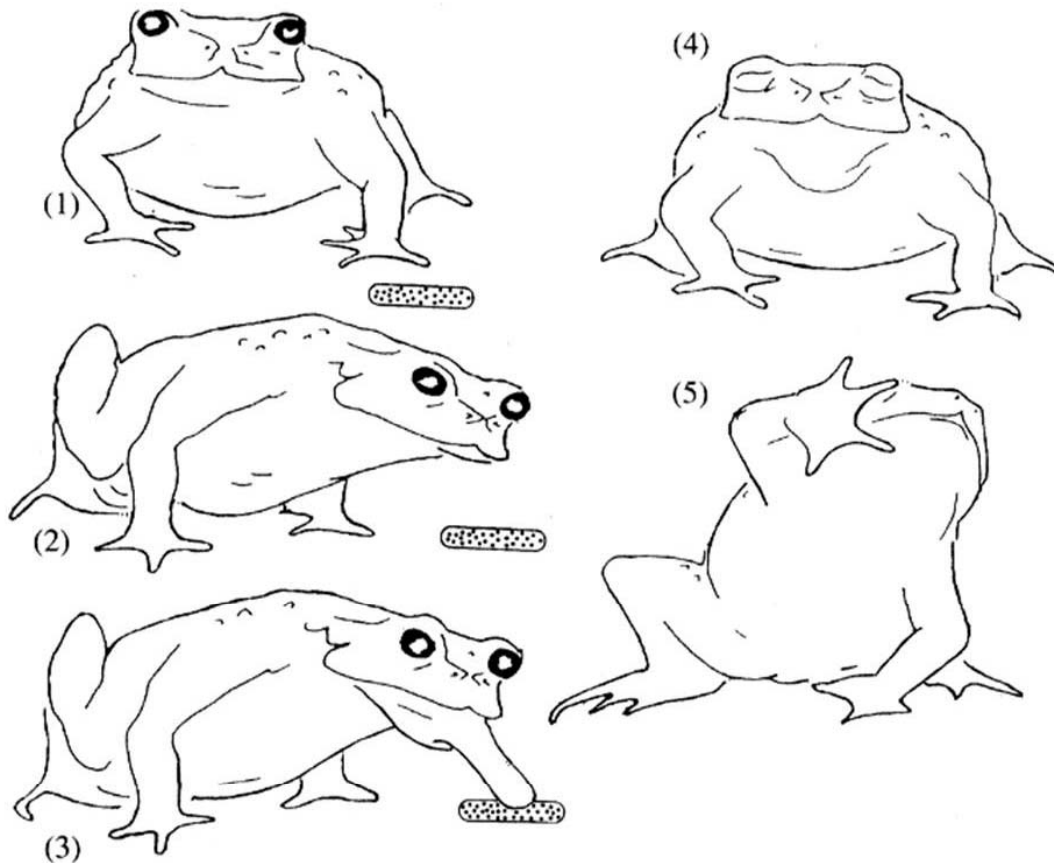


Gulls stuff their crops with food. They feed their mates and chicks from their crop.

A key **stimulus** for this behavior is the red spot on a gull's yellow beak.



Meaning of **the** Environment (Stimuli)



The Hunting behavior of a toad

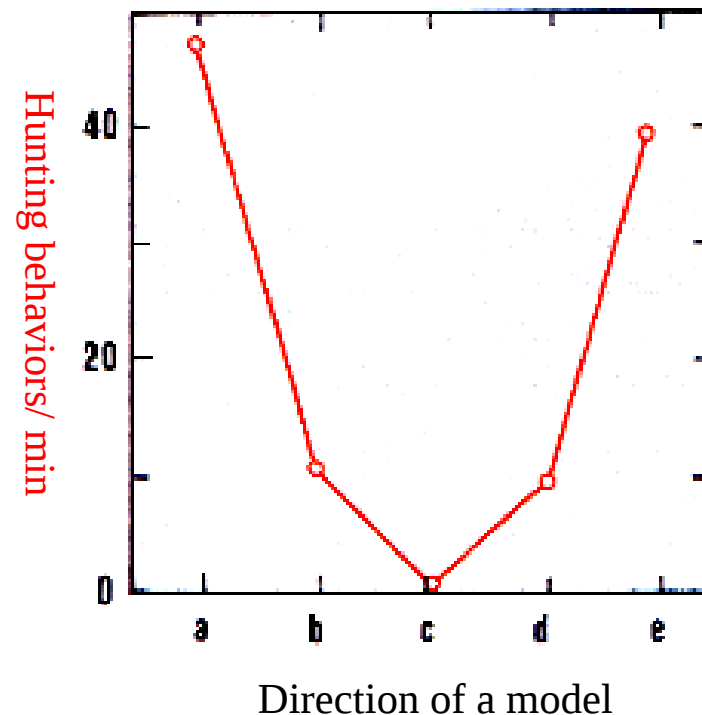
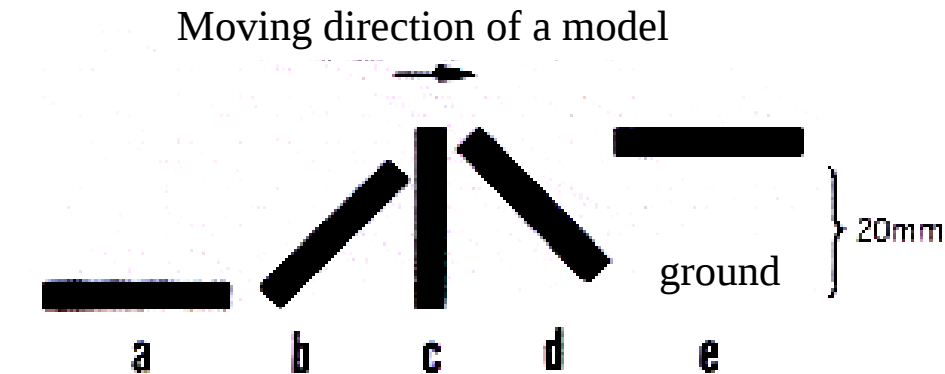
[J.-P.Ewert, *NEUROETHOLOGY*, Fig.41, Springer (1976)]

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These are chained behaviors from 1) to 5). However, even if a prey is taken away before a toad swallows it, a toad **will wipe its** mouth.

- 1) 2) are **reflex behaviors**
3) to 5) are **programmed**

The Meaning of the Environment (Stimuli)



Hunting behavior for small moving objects:

When a model moves in a transverse direction like an **insect**, a toad recognizes it as food.

When a **standing model moves** in a transverse direction:
a toad fears it as if it **were** a snake.

Example of a Gestalt receptive model
Toad hunting behavior

Informatics, Robots, and Life

Robotic Informatics to Understand Life

1. Information that Links Organisms and the Environment

- senses and behavior

2. The World as Environment

- senses, time, size information

3. Information that Links the Environment, Brain and Body

- nerves and brain
- fused systems of organism and machinery (BMI, cyborgs)





The World as Environment

- **World of Senses**
- **World of Time**
- **World of Size**

From “Dream of an Insect Robot” written by Ryohei Kanzaki, illustrated by Katsuhiko Shigeri

World of Senses

sense

A response to a stimulus generated when a stimulus received by any receptor (sensory organ) in an animal body is transmitted to the brain by a sensory nerve.

Summary of Iwanami's Dictionary of Biology the 4th Edition

Parameter of Senses

modality

visual, auditory, olfactory, gustation, tactile perceptions

quality

wavelength (color), frequency (rhythm), waveform (tone)

quantity

power, amplitude, concentration

The Different Sensing Ability of Animals

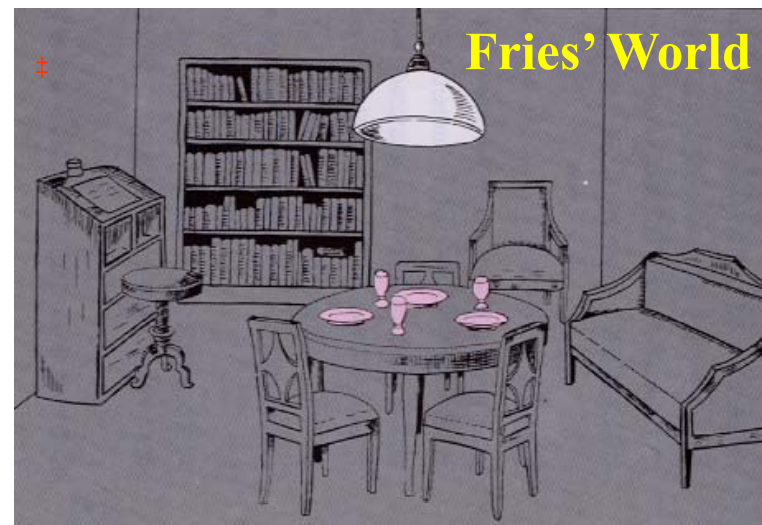
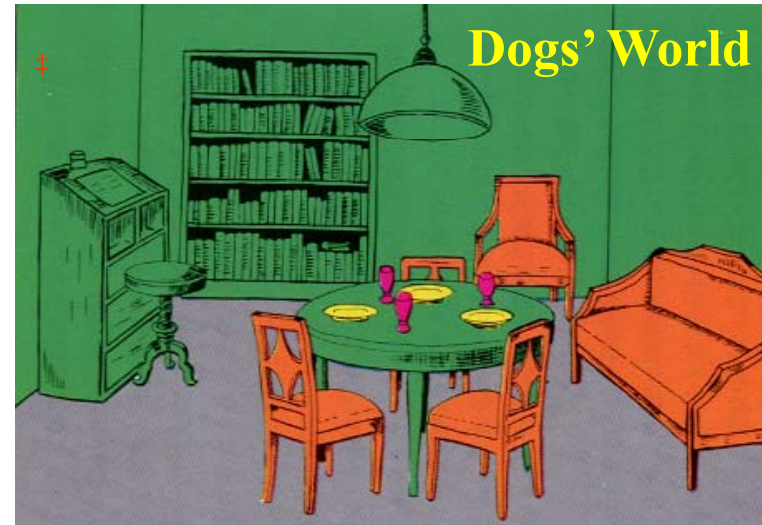
1. Honey bees sense ultraviolet rays and polarization **using their** compound eyes.
2. Elephants sense **sounds** of 1 Hz.
3. Rats sense **sounds** of 80 thousand Hz.
4. **Dogs sense of smell is a million times stronger than humans** (acidum tartaricum contained in **their** sweat).
5. A scallop has 100 eyes.
6. Woodcocks have **a 360° field of vision**. (Humans **have a 260° field of vision**)

Jakob Johann Baron von Uexküll (1864– 1944)

**“Uexküll’s
photograph”** inserted here
was deleted according to
copyright issues.



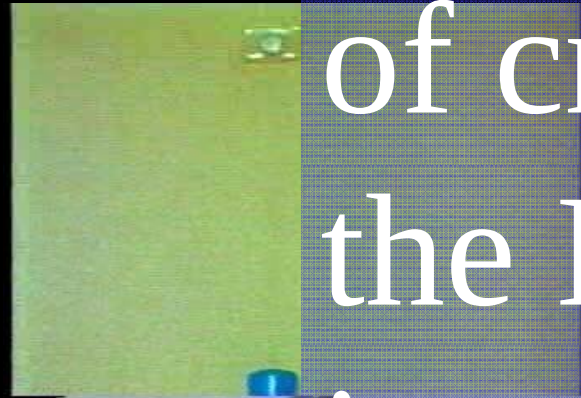
World of Senses



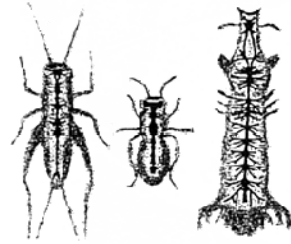
“The World Seen by Animals” Uexküll, 1933, Shin-Shisaku Sha

Various Animals Living on the Earth

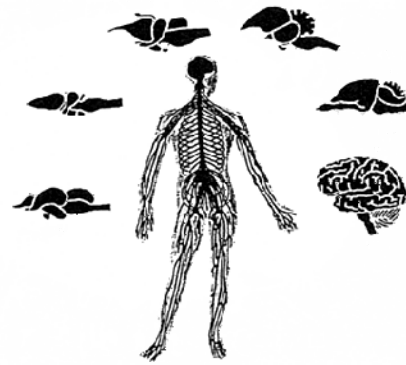
More than 70%
of creatures on
the Earth are
insects.



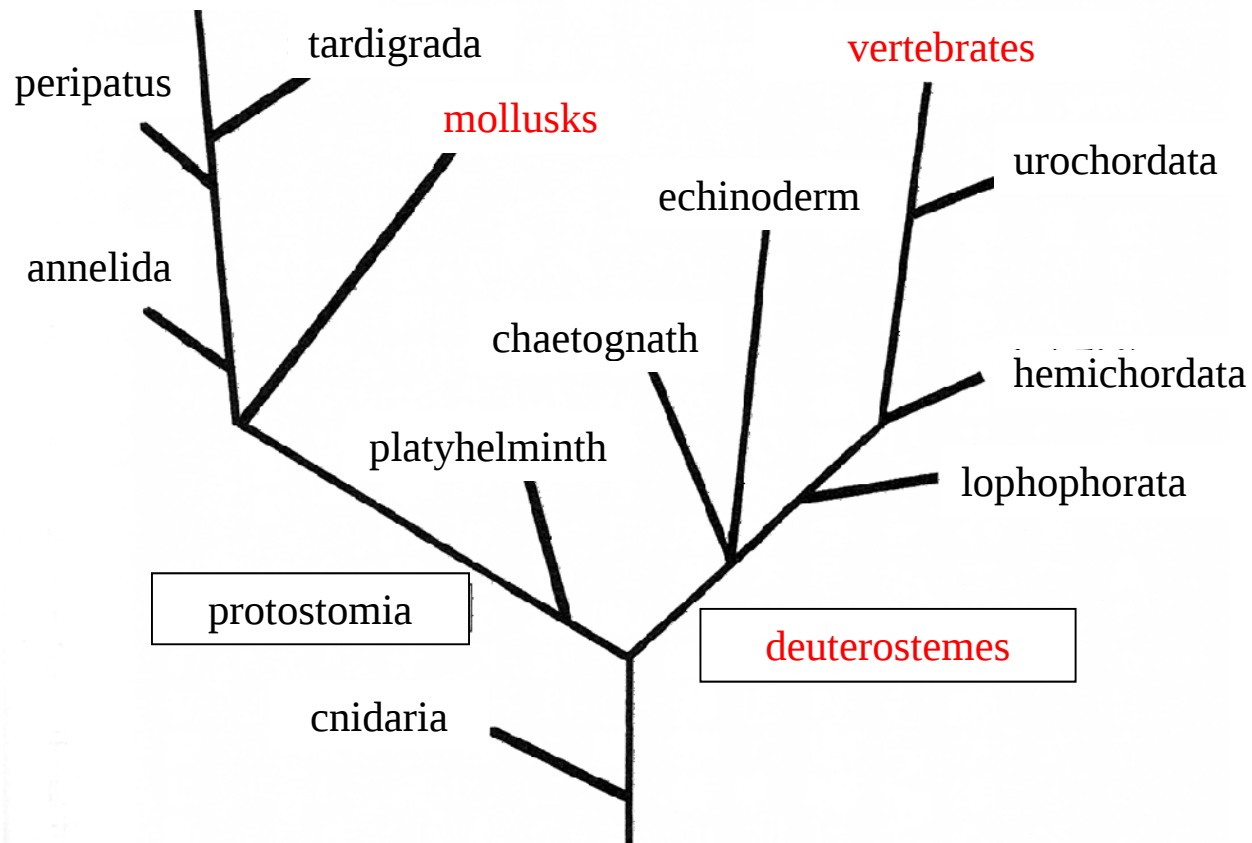
Insects **have experienced an** utterly different phyletic evolution **than** humans.



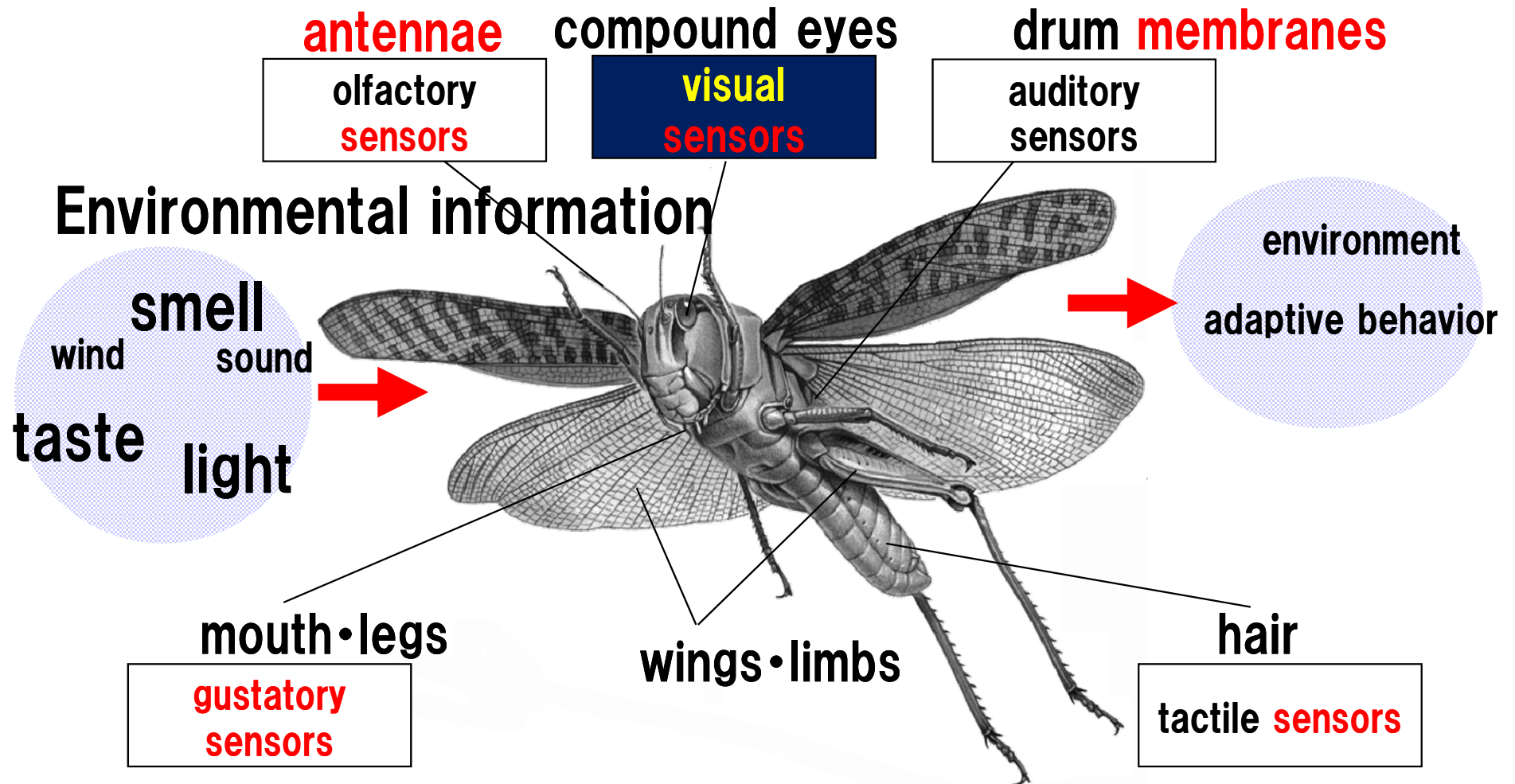
arthropods



vertebrates



Insects' Sensory World (visual **sensors**)



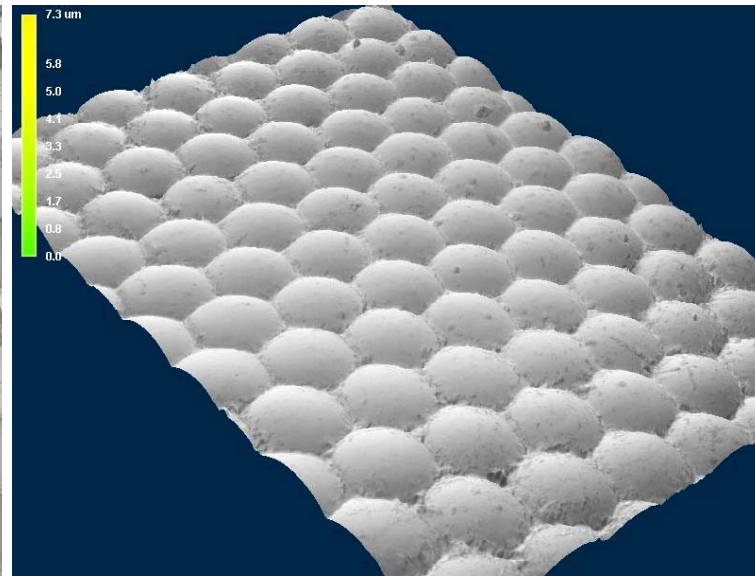
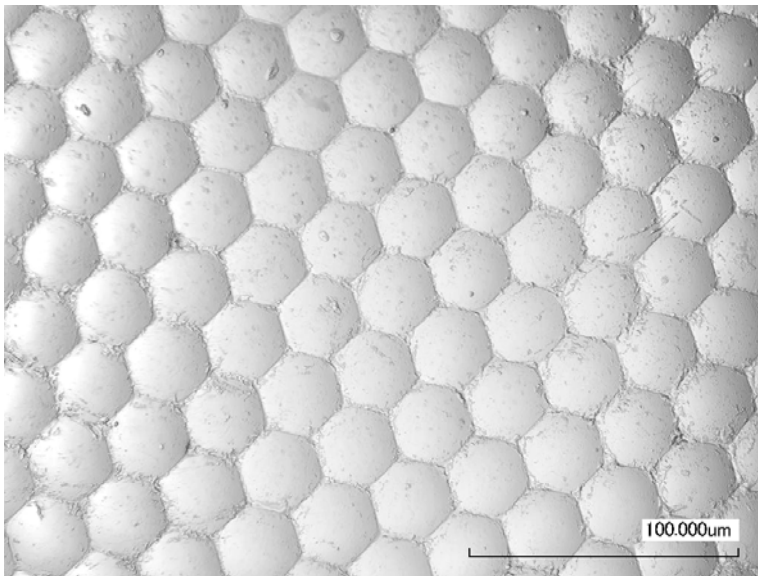
Insects' Visual **Sensors** (Compound Eyes)



A bumblebee 's compound eye



A bumblebee



Insects' Visual **Sensors** (Compound Eyes)



“Diagram of a compound eye“ inserted here was deleted in compliance with copyright issues.

Hunting • Avoiding Obstacles: Information Processing using Compound Eyes

High-speed Adaptive Processing using Low Space Resolution Sensors

View angle: 2° (eyesight < 0.01)

- 1) Optical flow
- 2) Subject detection
- 3) Visual action **reflexes**



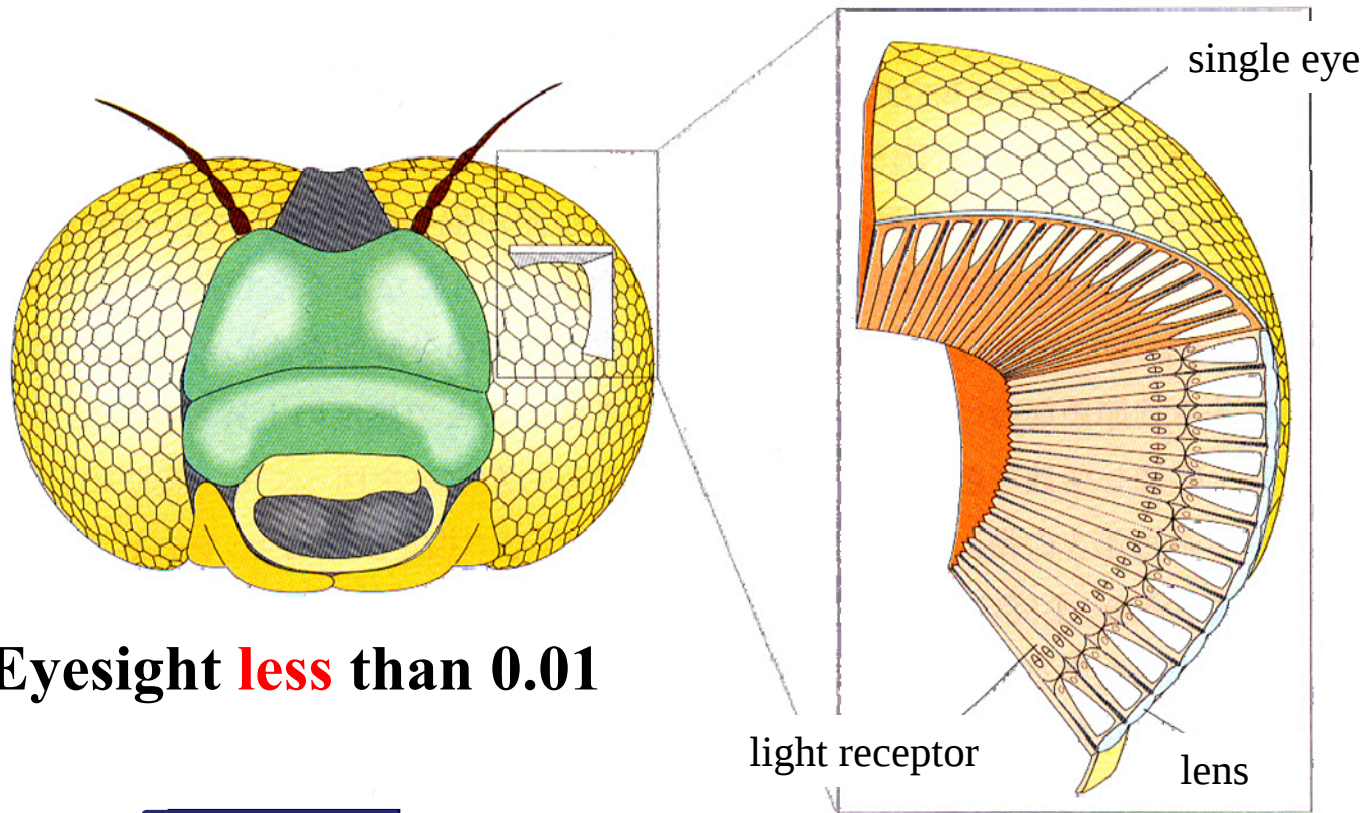
Low-space resolution

Distance information: Stereovision cannot be used structurally

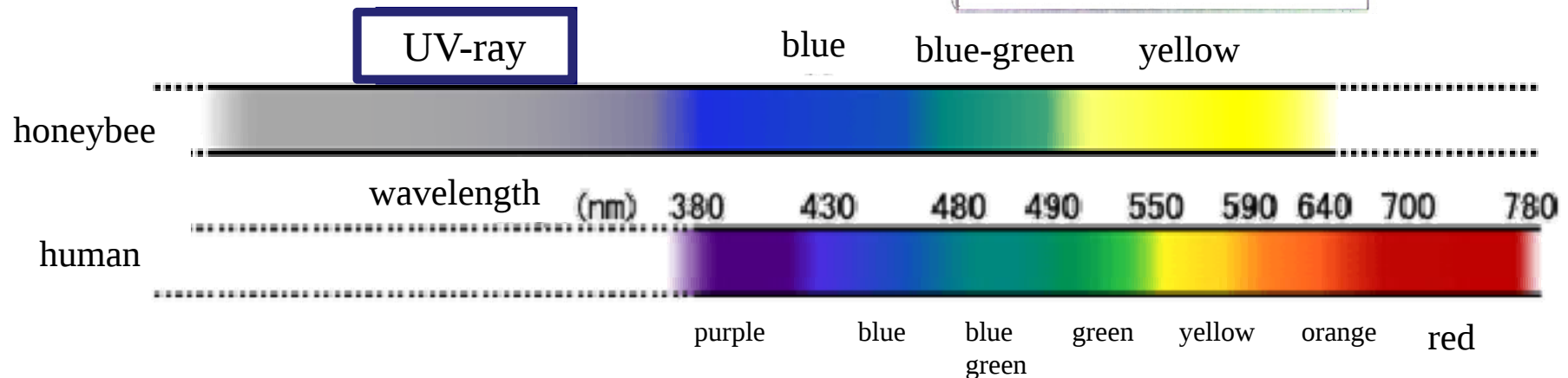


Dragonflies have a **different optical structure than** humans

Range of Detectable Wavelength (Properties of Wavelength Distribution)



Eyesight **less** than 0.01



Rapeseed Flower as seen by a Honeybee



Resources : The Open University of Japan

Mating Behavior of **the** Small Cabbage White



Resources : The Open University of Japan

The World of Time

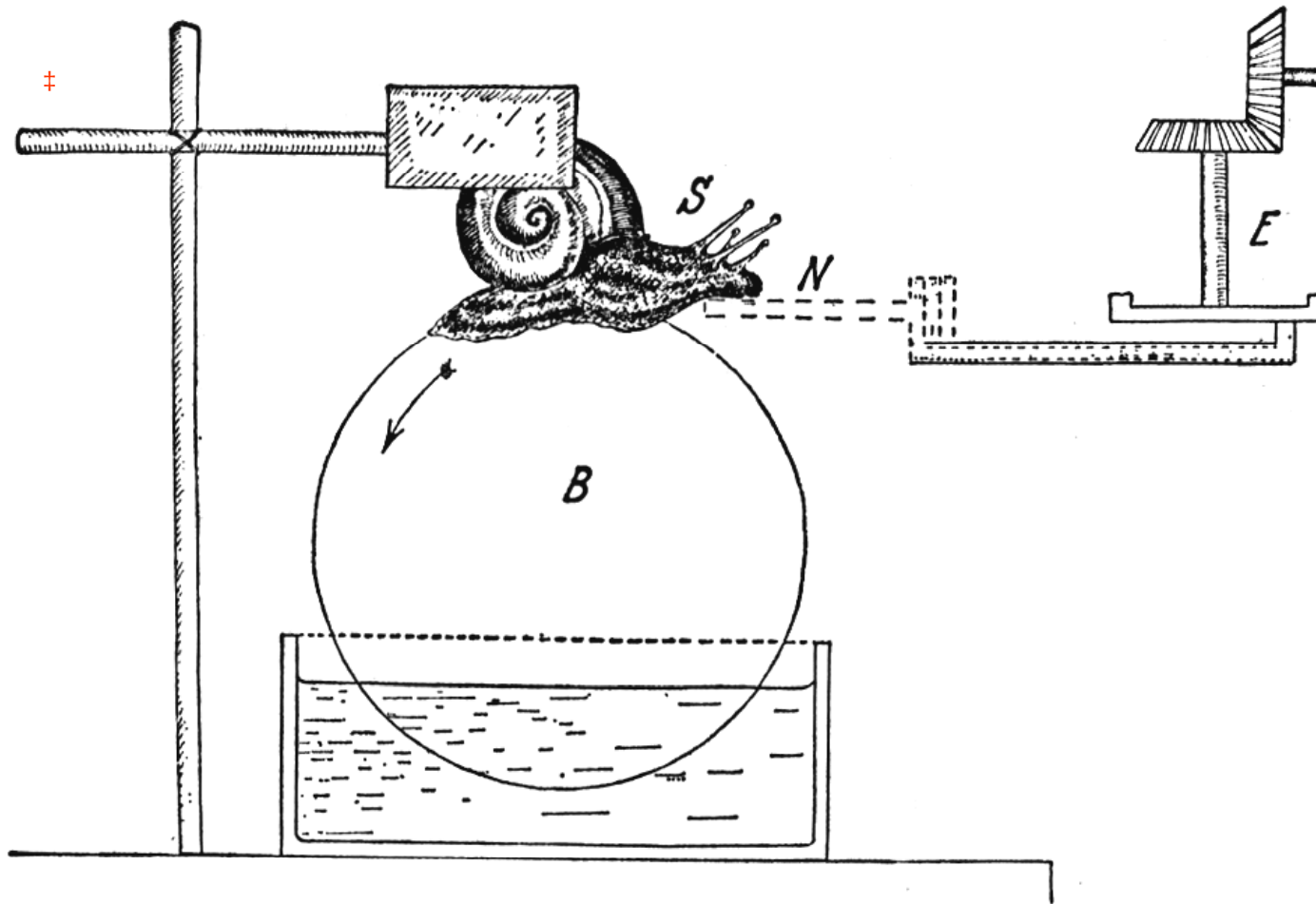


Fig.16 **At a Snail's Pace** B: rubber ball E: eccentric wheel N: stick

S: snail

“The World Seen by Animals” Uexküll, 1933, Shin-Shisaku Sha

Instance

Uexküll (Biological Instance)

Each animal **has a** different length of instance

.

CFF

frequency of critical

fusion :

**time resolution of
vision**

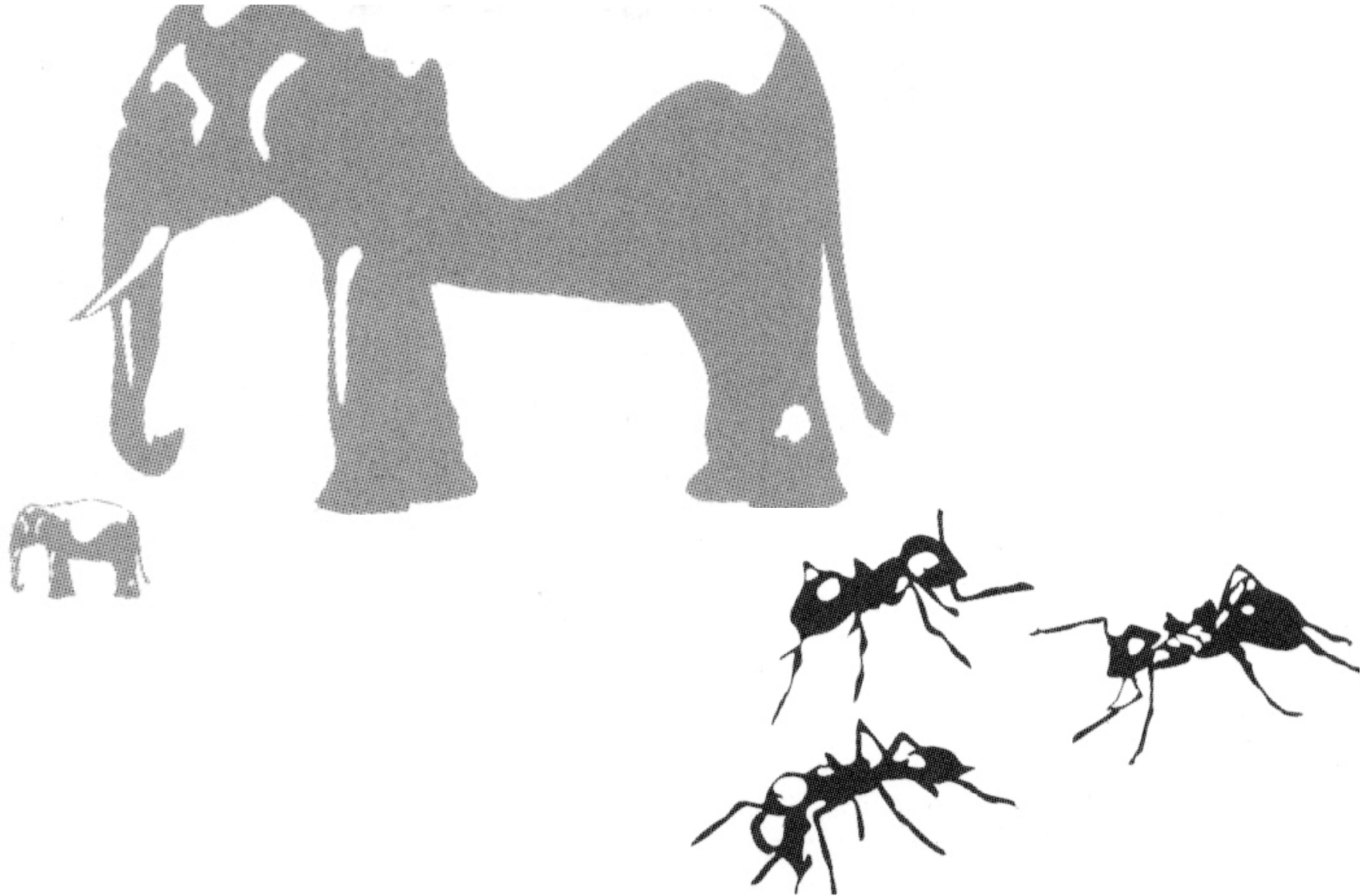


The CFF of Various Animals

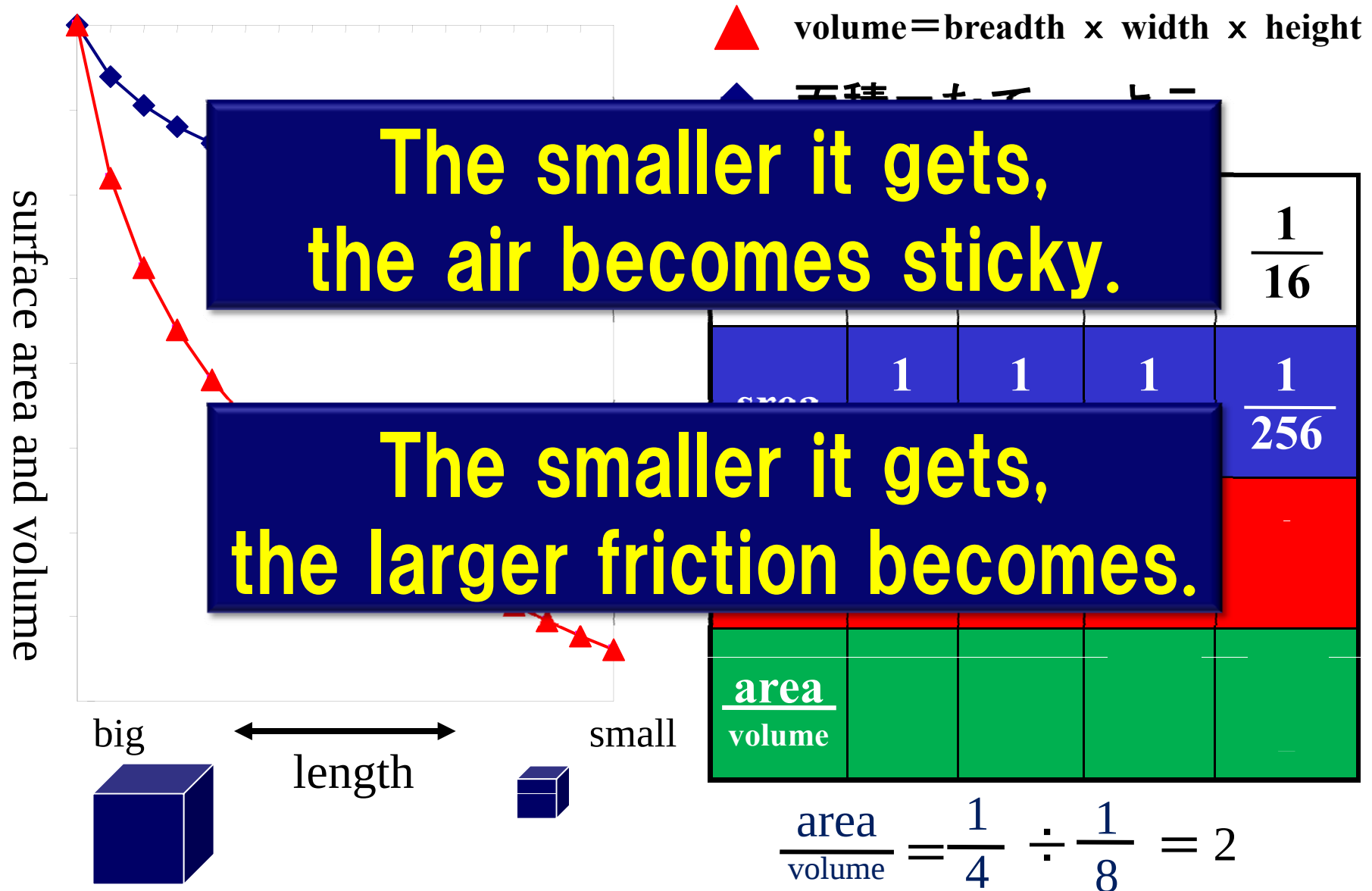
(weak light — strong light. Animals with only one value were exposed to strong light.)

	C F F (Hz)
mammals	
humans	15—60 (around the retina)
	5—20 (15° surrounding the
cats	15—60 retina)
guinea pigs	10—40
birds	
pigeons	150
fish	
carp	14—18
osmerus	67
insects	
honeybees	60—310
flies	60—260
butterflies	150
(silver-washed fritillary)	
cricket s	5—40
cephalopoda	
octopuses	20—70

The World of Size



Scale Effects



Informatics, Robots, and Life

Robotic Informatics to Understand Life

1. Information That **Links** Organisms and **the** Environment

- **senses** and behavior

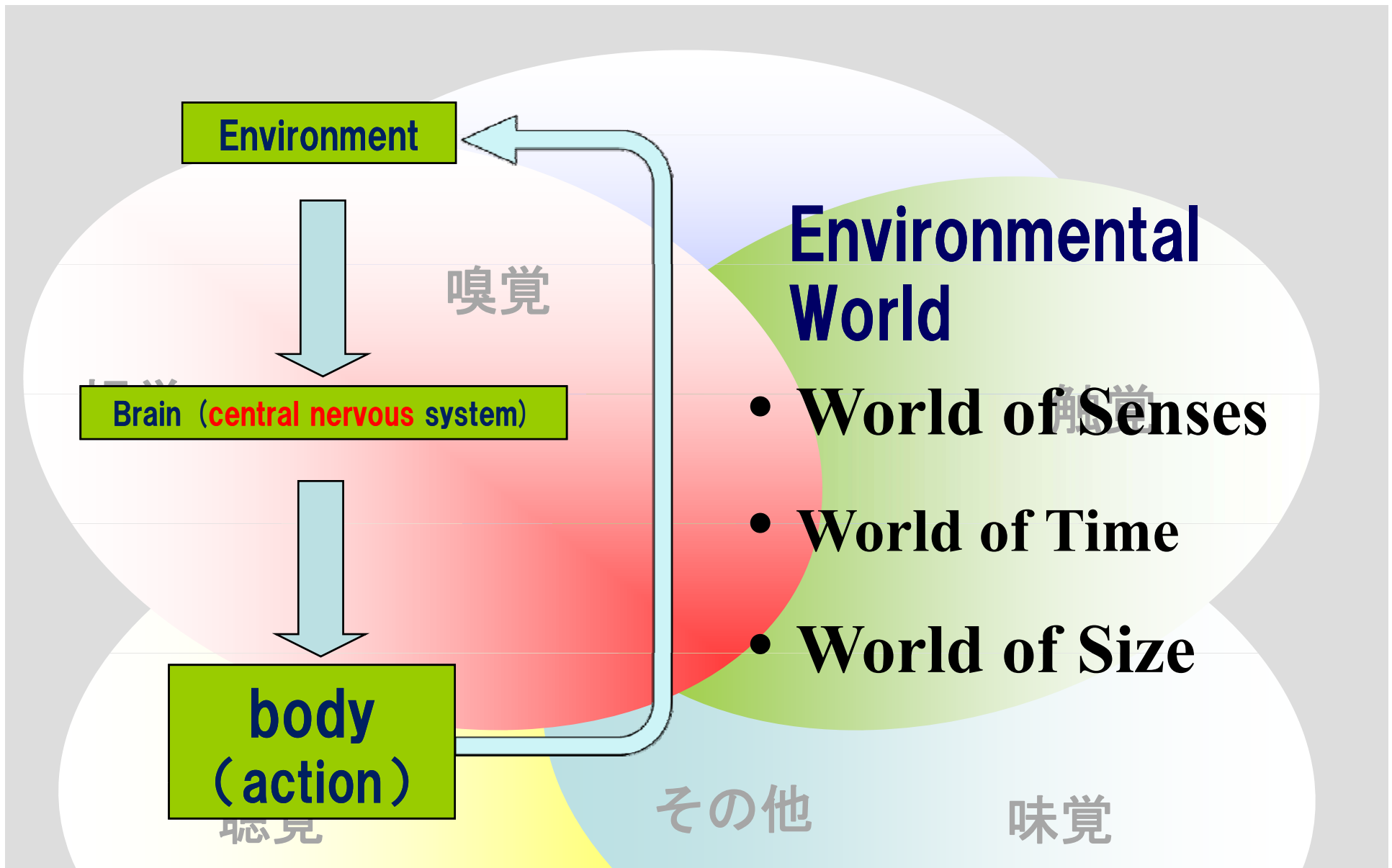
2. The World as Environment

- **senses**, time, size information

3. Information That **Links** the Environment, Brain and Body

- **nerves** and **brain**
- **fused system of organisms and machinery**
(**BMI**, **cyborgs**)





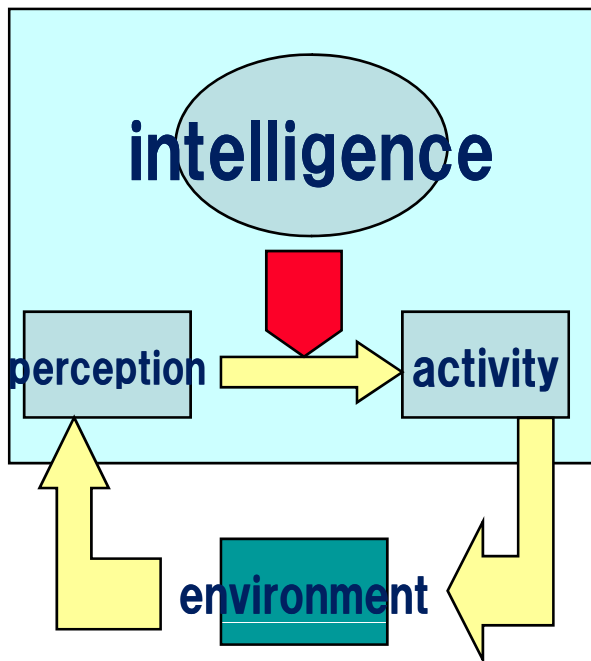
Information about how to move in an environment.

Some environmental information (its key stimuli) determines movement.

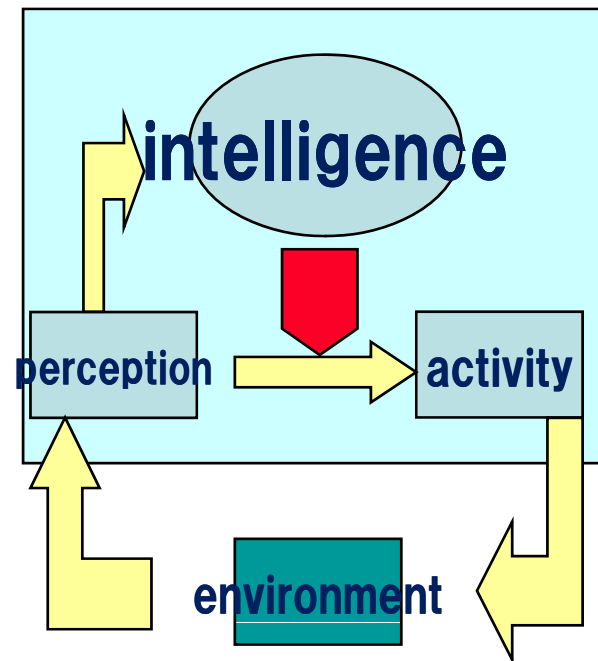
The Concept of Intelligence

robotics and mobiligence

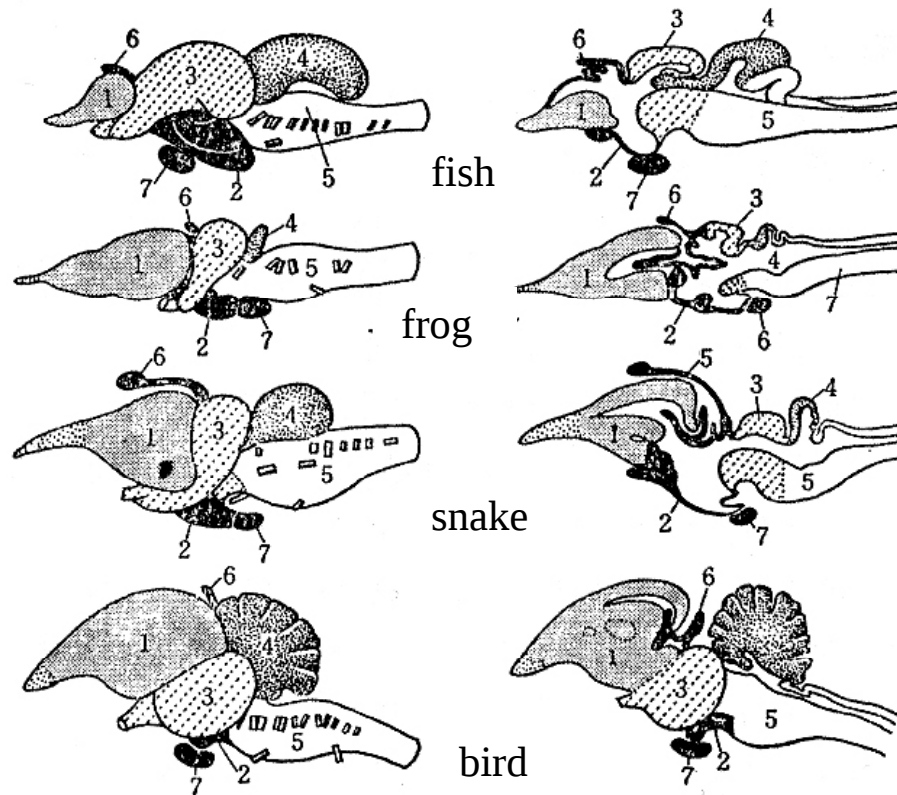
past robotics



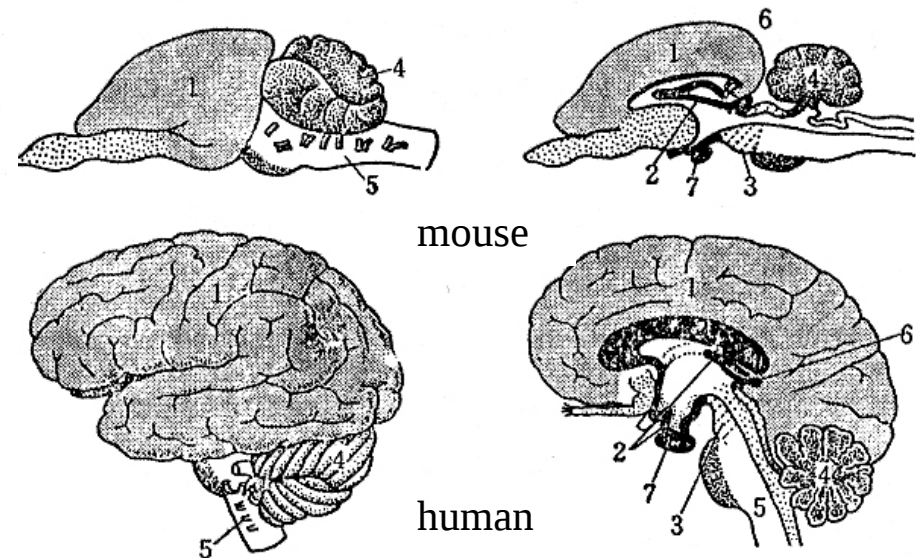
mobiligence



The Brains of Various Animals



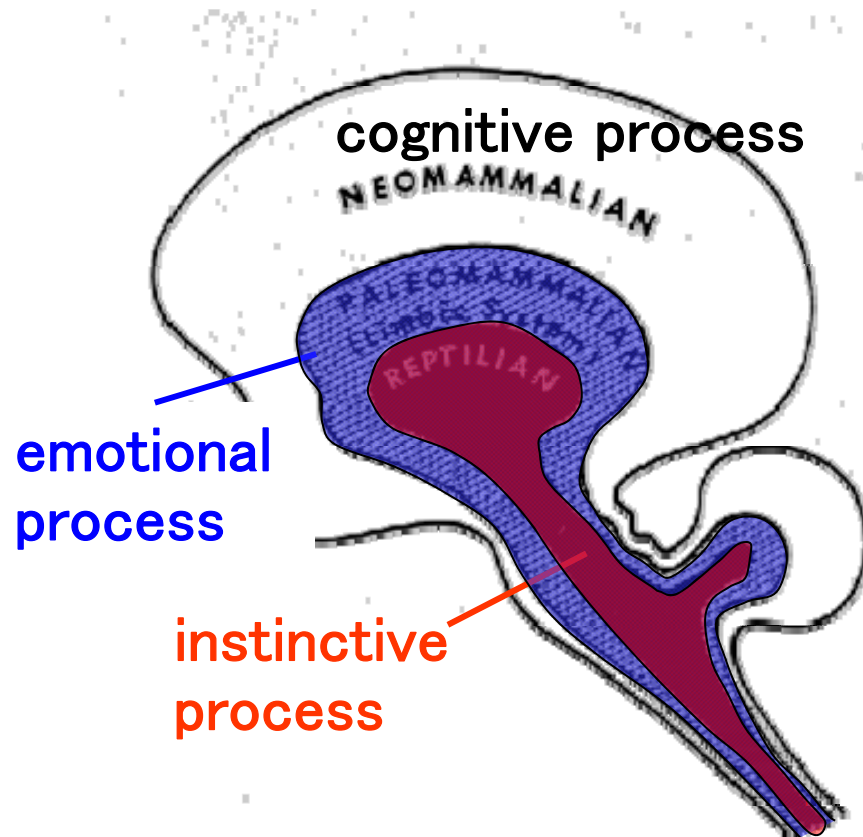
cerebrum (1)
 cerebellum (4)
 brain-stem (2, 3, 5)
 (medulla · bridge · midbrain · interbrain)



Copyright: Iwanami Shinsho
 “Story of Brain”, p. 22, fig.8

fig. 1-1 systematic evolution of vertebrates 1. cerebral hemisphere 2. interbrain 3. midbrain 4. cerebellum 5. medulla 6. pineal apparatus 7. hypophysis

The Layered Structure of the Brain



Paul D. MacLean's
“Visceral Brain” “Limbic System”
and “evolutionary triune brain”
theory

neomammalian brain : neocortex
cognitive process

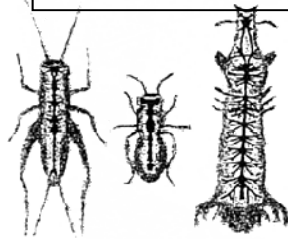
paleomammalian brain : limbic system
emotional processes

protoreptilian brain : brain stem
reflexes • programmed behavior

Evolutionary path
of new brains added
to the old brains
of animals

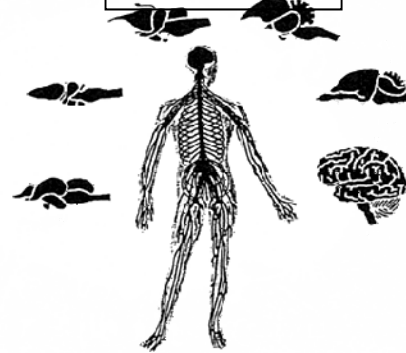
Phylogeny of Animals and Evolution of the Brain

micro brains

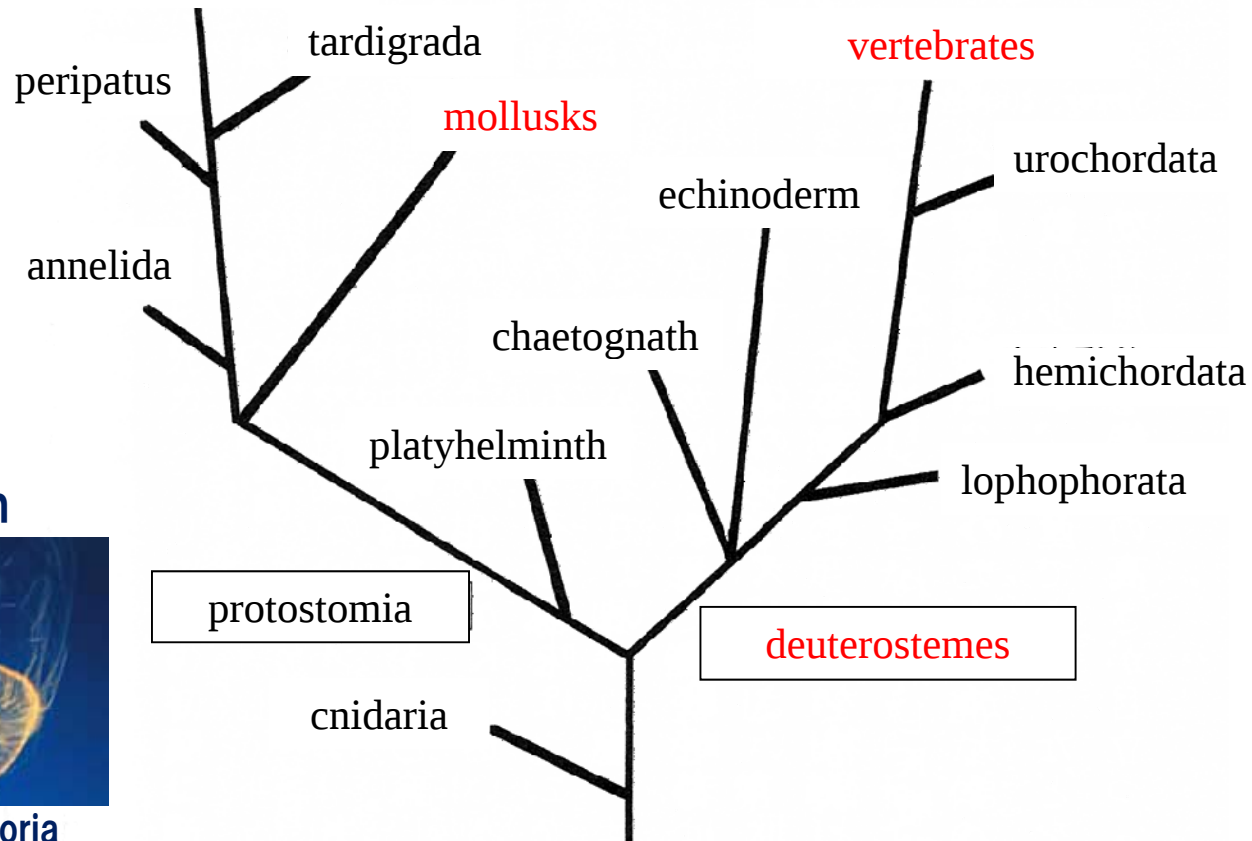


arthropods

giant brain



vertebrates



cnidarian



Aequorea victoria

Discovery of the Neuron

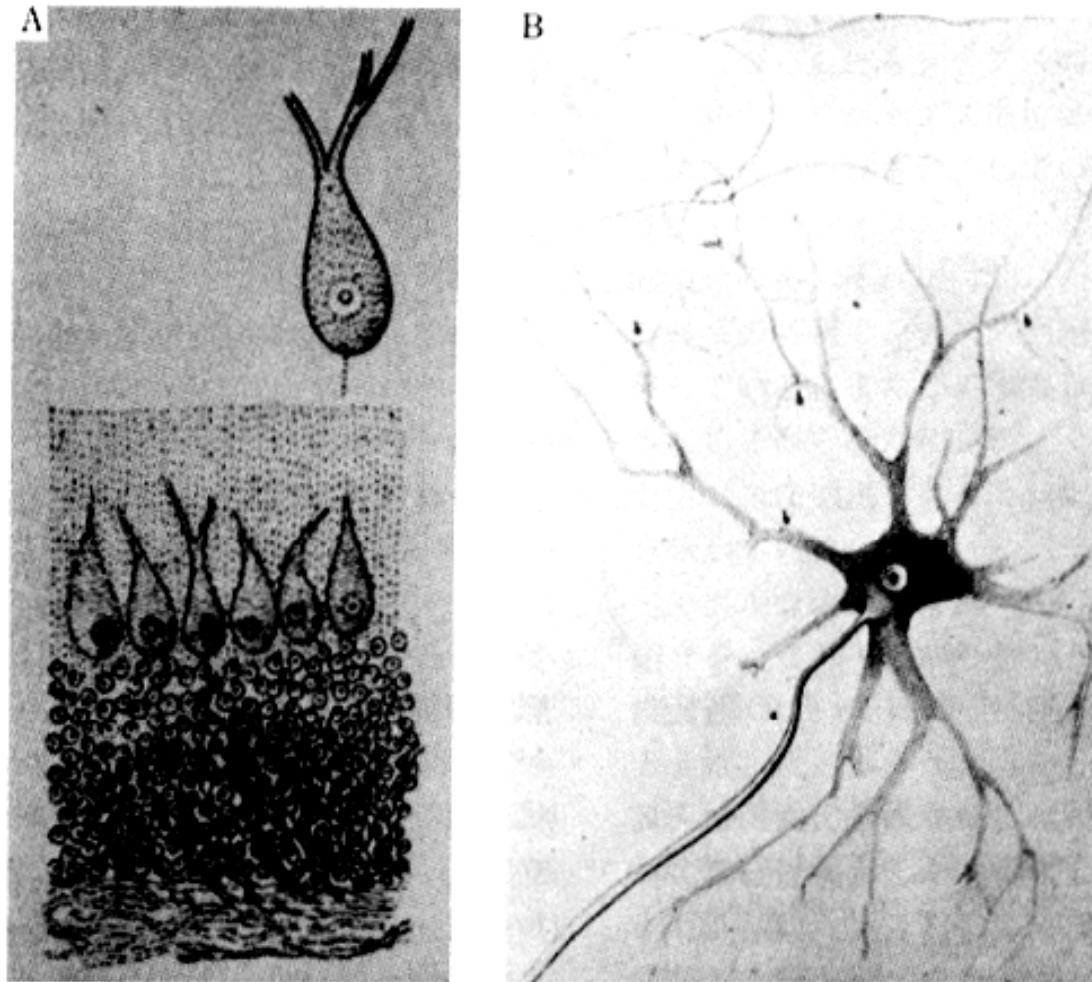


Fig 3.1 A. Neural cell in the cerebellum observed by Purkinje in 1837. Cells stuffed at the bottom are granule cells. The cerebellum will be discussed in Chapter 21. B. A large-size motor neuron in the spinal cord observed by Deiters in 1865. Focus on a long, smooth axon. This is clearly different from dendrites which repeat branching. The spinal cord is discussed in Chapter 20. (Liddell, 1960)

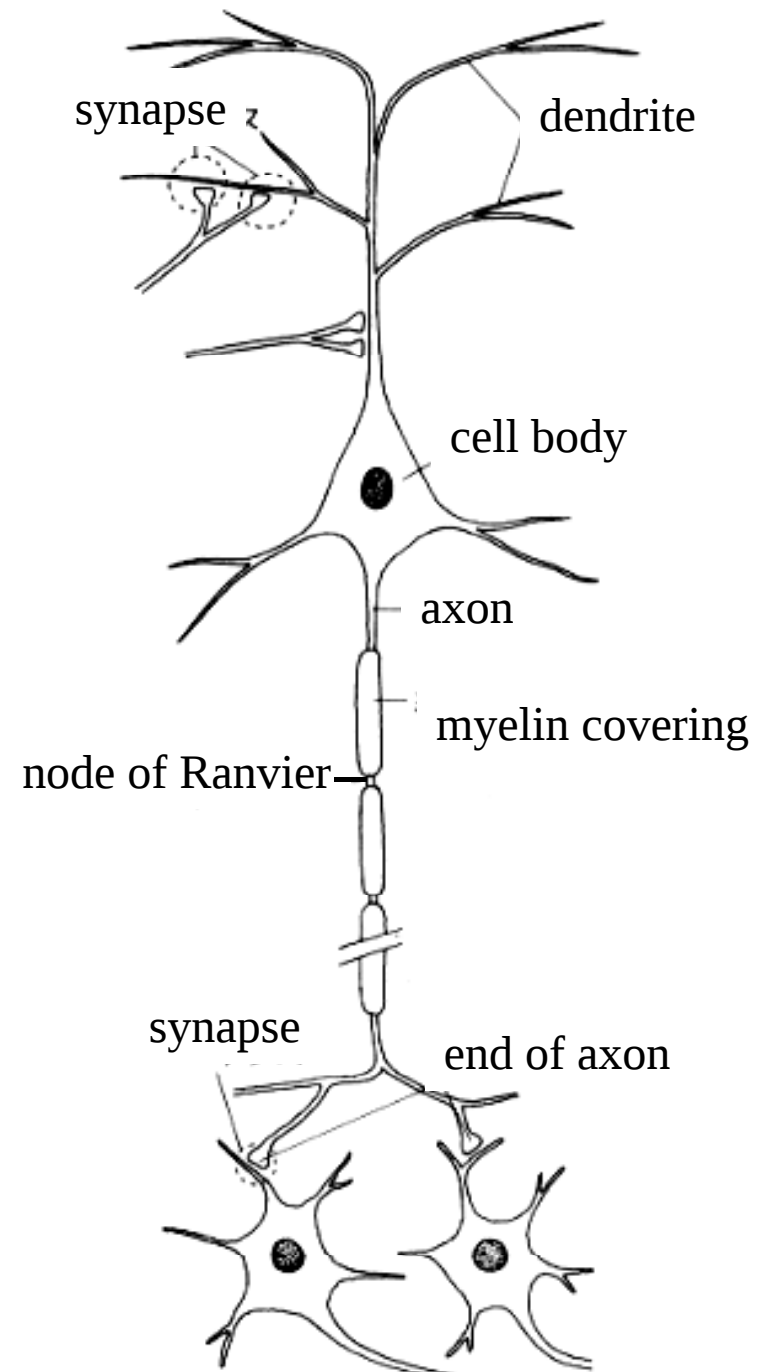
“Neurobiology” G.M.Shepherd fig. 3.1 (p34)

The Form of the Neuron



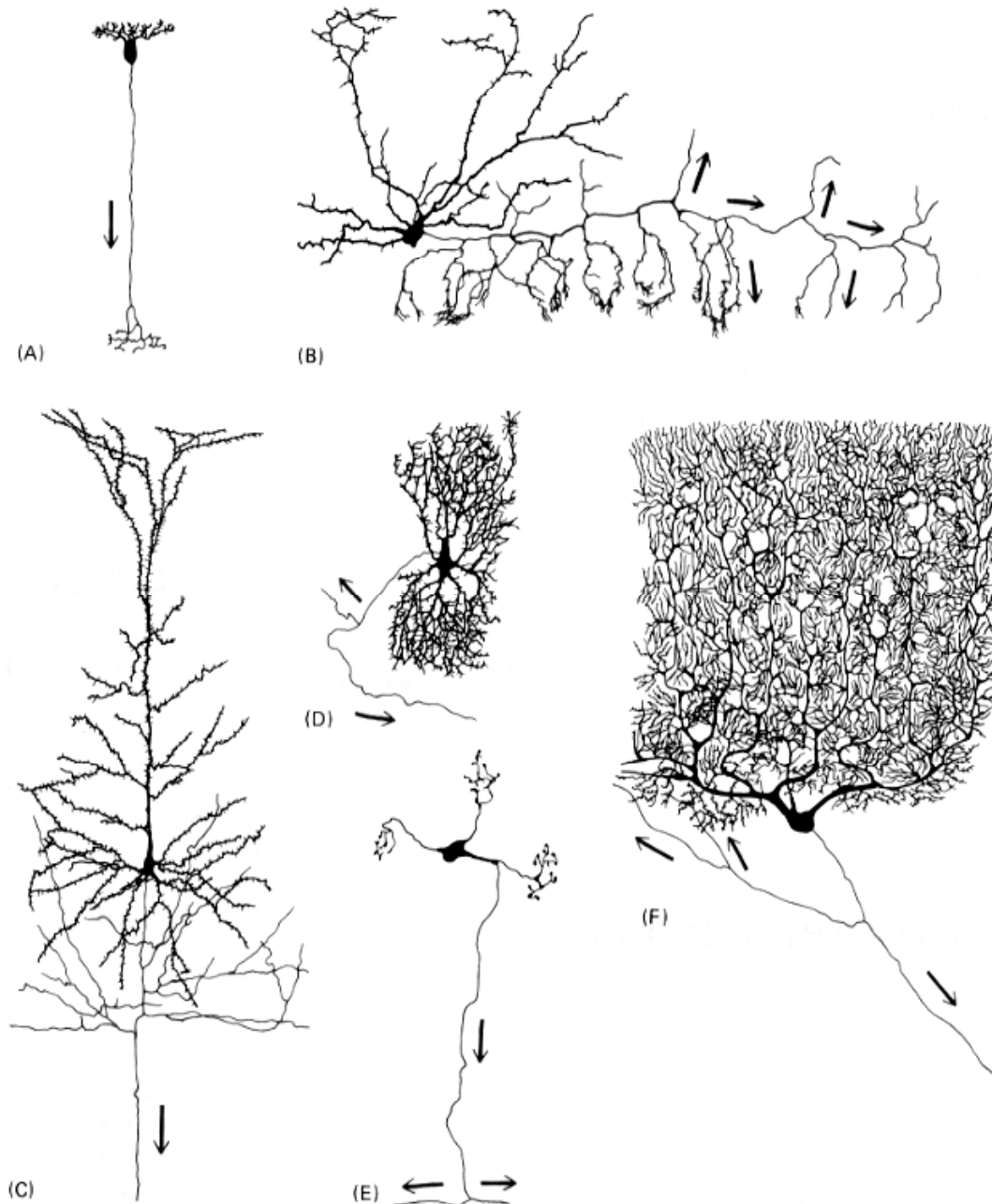
Santiago Ramon y Cajal

resource : wikipedia



Copyright: Iwanami Shoten "Brain, Nerve and Behavior", p2, fig. 1-1

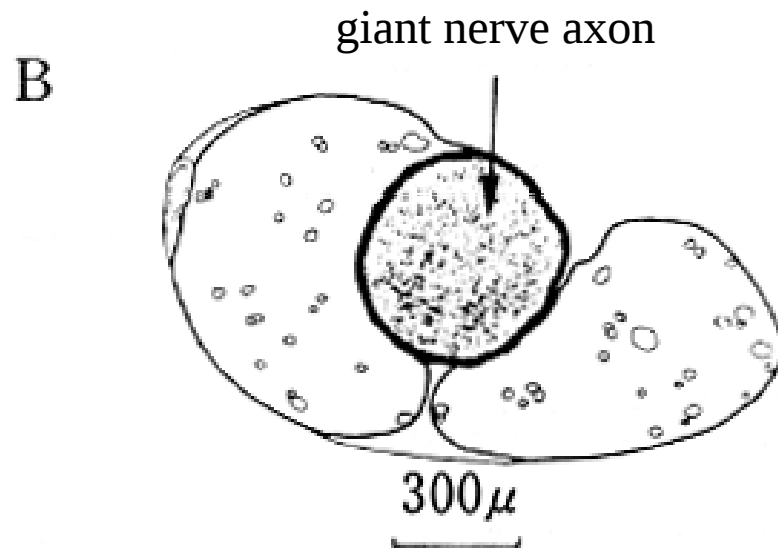
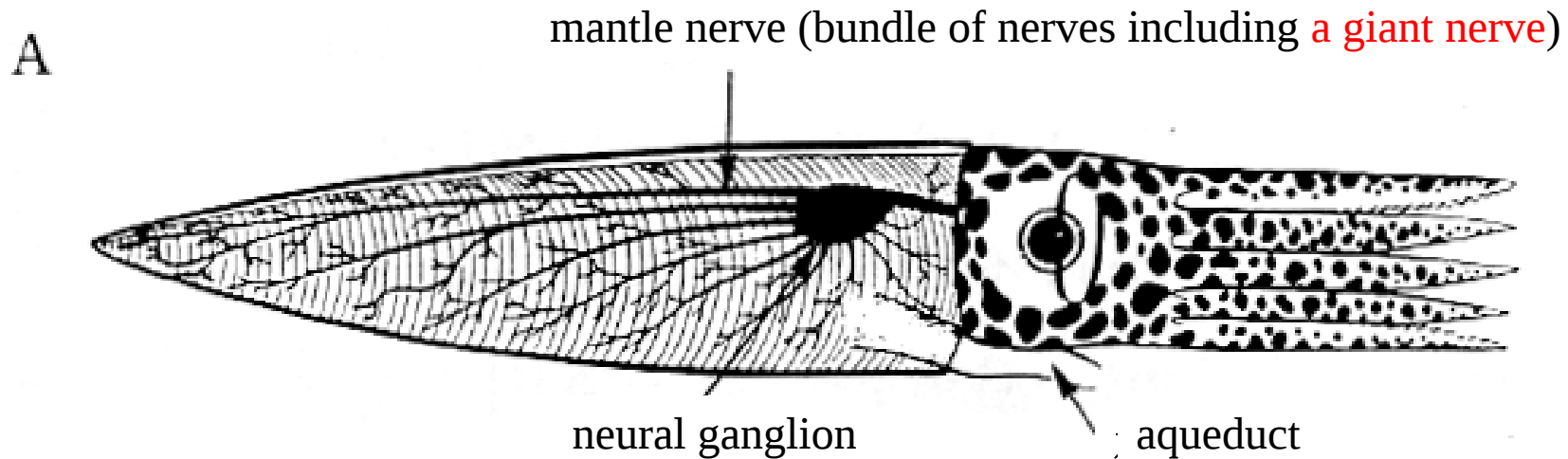
Different Forms of Neurons



- A) Lizard retina - bipolar cell
- B) Mouse - cerebellum basket cell
- C) Rabbit - cerebral cortex pyramidal cell
- D) Cells of a human brain stem
- E) Cat - cerebellar granular cell
- F) Human - cerebellar Purkinje cell

(S. Ramon y Cajal, 1909-1911)

Neural Information: Action Potential

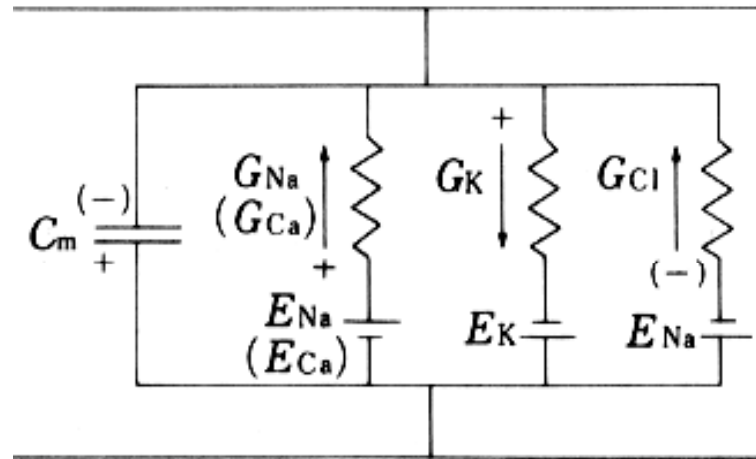


Spear squid's giant nerve axon
Eccles, J.C. 1977 2nd Ed.

Resource : nerve

A. L. Hodgkin and A. F. Huxley
 A Quantitative Description of
 Current and its Application to Conduction and
 Neural Excitation.
 Journal of Physiology, 117, 500-544, 1952.Fig.1
 (p501) , Fig.17 (p530)

inside the cell



current in a membrane outside the cell

- 1) ion current capacitive current
 - 2) ion current : Na, K, Cl
 - 3) ion current : Determined by drive force and membrane conductance
- Conductance change by membrane potential and time.

Quantitative Record of Neural Excitation Hodgkin & Huxley, 1952

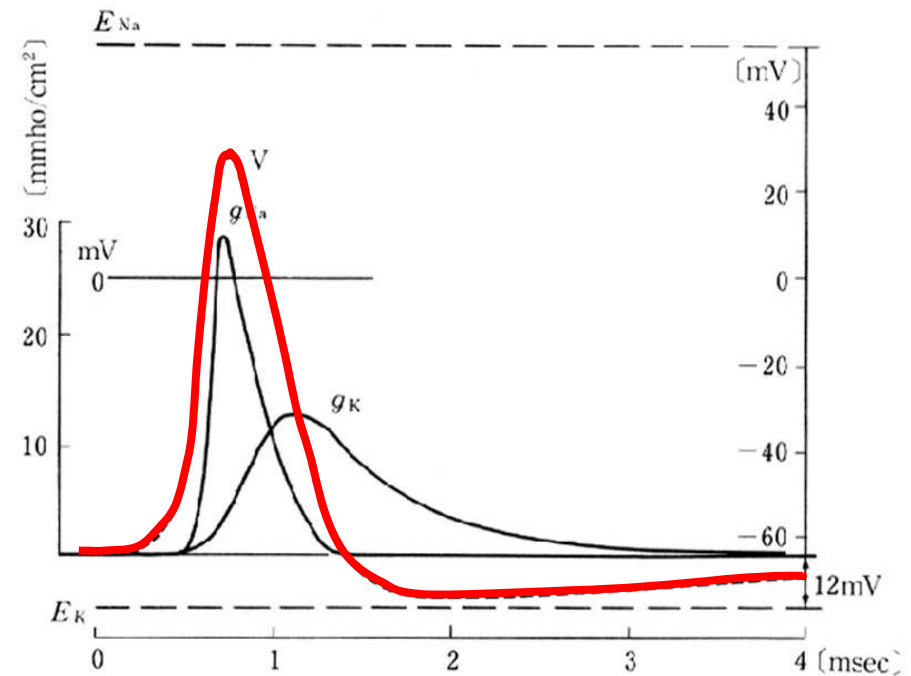


図 2・6 g_{Na} と g_K の変化と活動電位 [Hodgkin, A.L. and Huxley, A.F., 1952b]

$$I = C_m \frac{dV}{dt} + \bar{g}_{Na} \cdot m^3 h \cdot (V - V_{Na}) + \bar{g}_K \cdot n^4 \cdot (V - V_K) + \bar{g}_L \cdot (V - V_L) \quad (1.4)$$

$$\frac{dm}{dt} = \alpha_m(V) \cdot (1 - m) - \beta_m(V) \cdot m \quad (1.5)$$

$$\frac{dh}{dt} = \alpha_h(V) \cdot (1 - h) - \beta_h(V) \cdot h \quad (1.6)$$

$$\frac{dn}{dt} = \alpha_n(V) \cdot (1 - n) - \beta_n(V) \cdot n \quad (1.7)$$



The Neural Circuit: Data Processing by Nerves

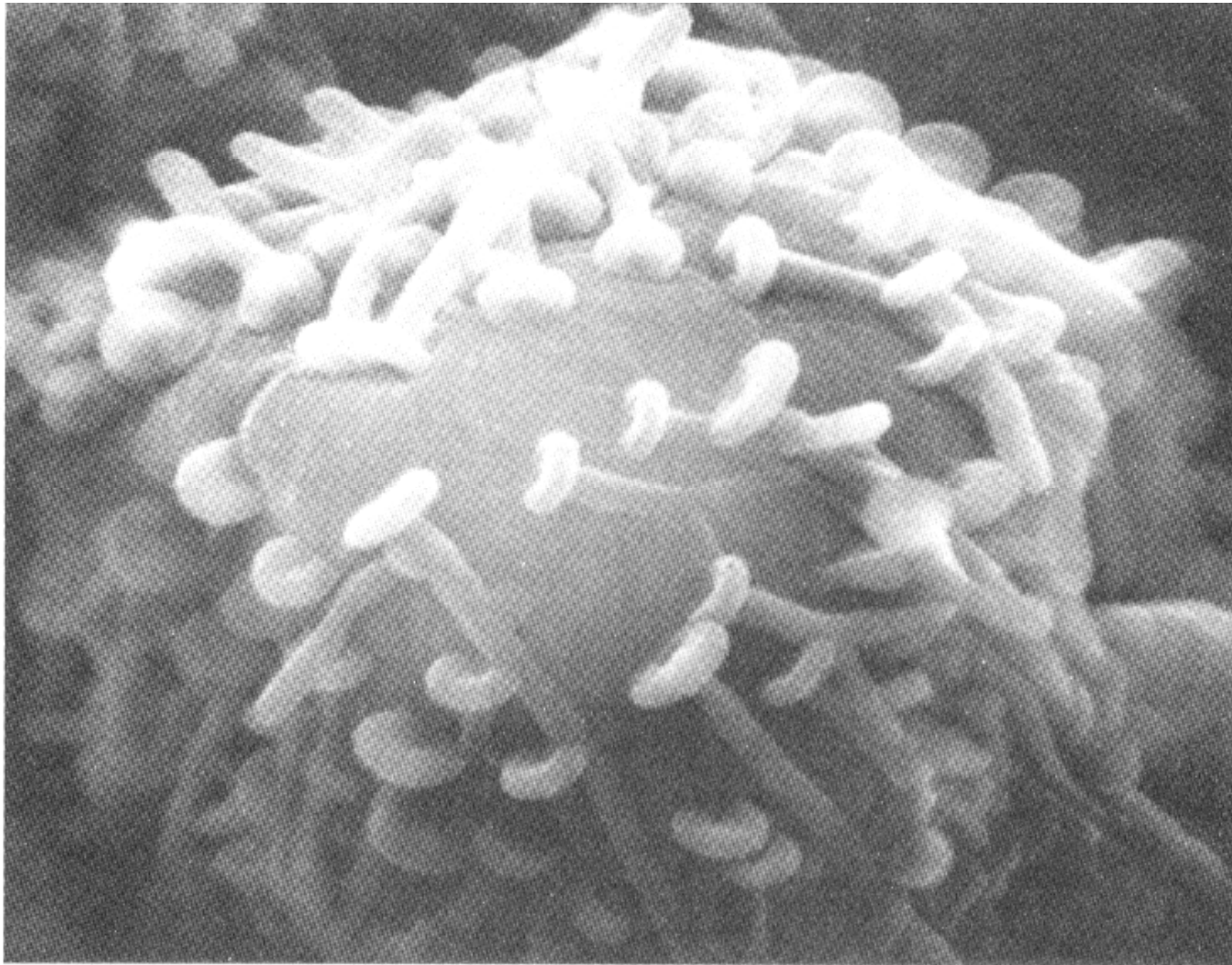
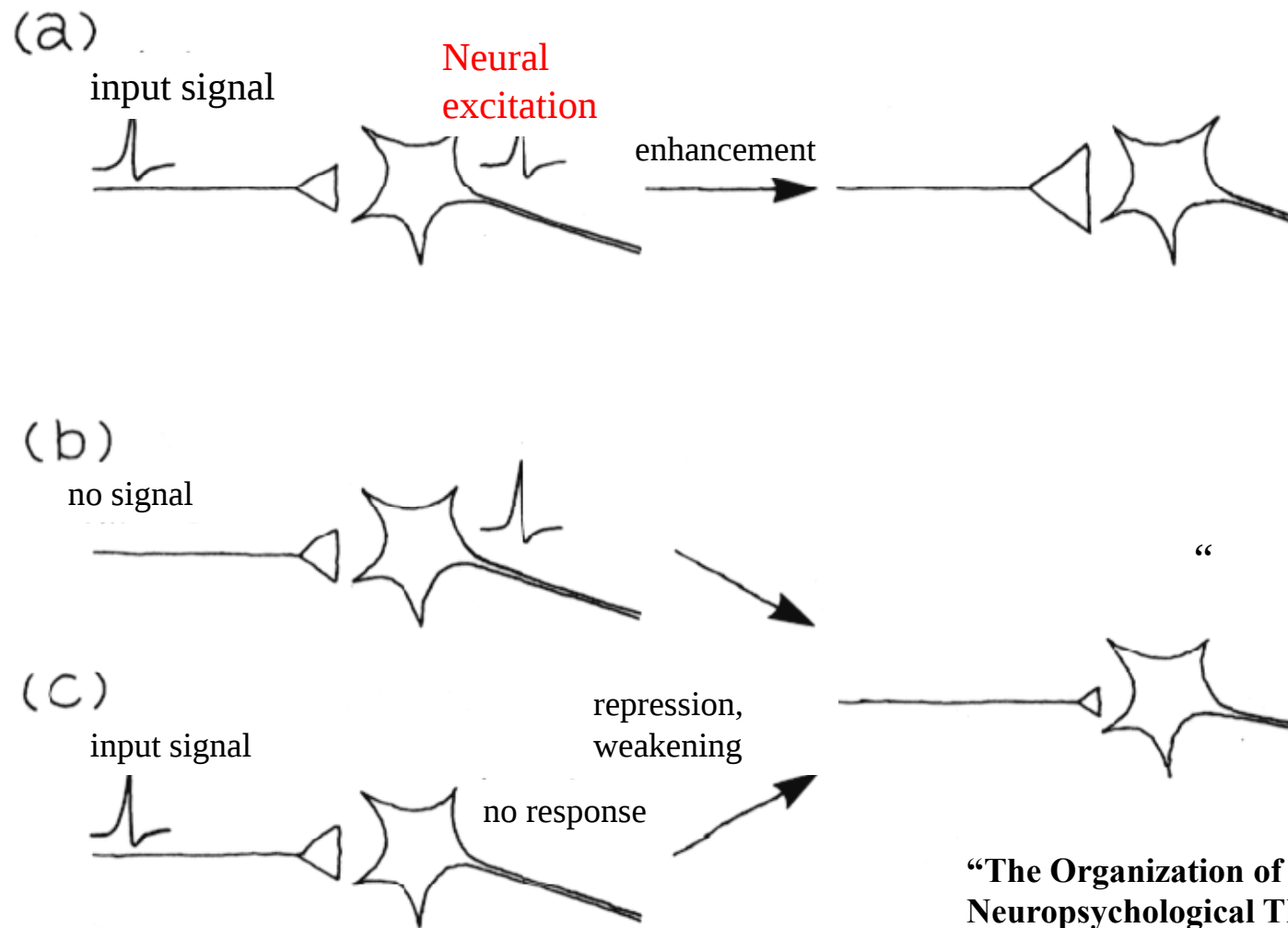


Fig 6-C. End of an axon-formulating synapse in another neuron. 3-dimensional interactions of micro structures are understood by an electron-scanning microscope

Hebb-Type Learning



Donald Hebb
(1904-1985)
from “**The** Thinking
Cellular Neuron” by
Yoshio Sakurai



“The Organization of Behavior : A
Neuropsychological Theory” (1949)

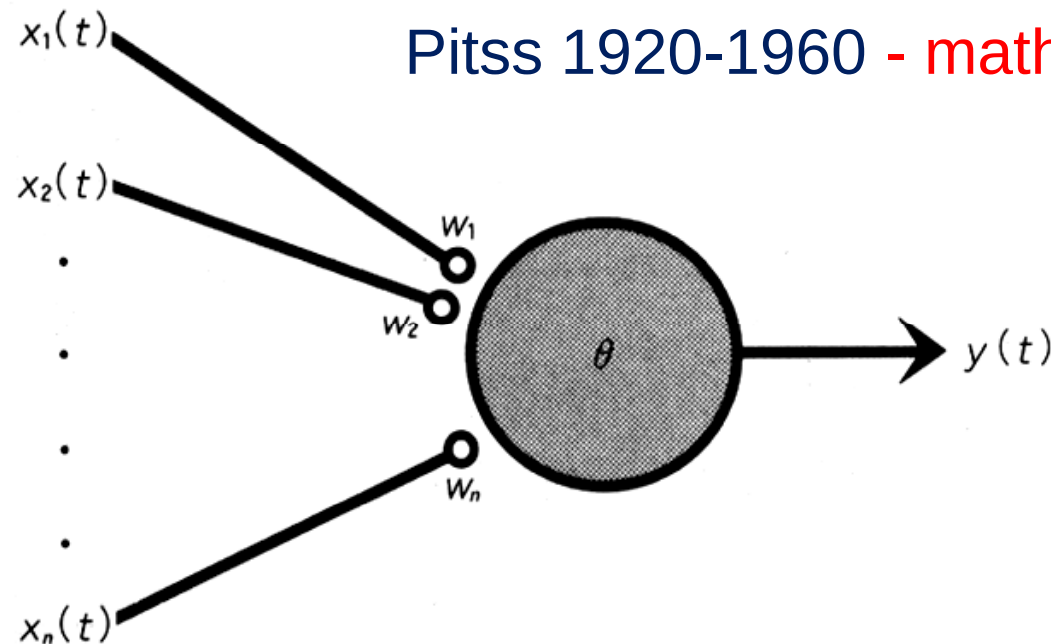
Fig 9-10. Hebb-type (a) or reverse Hebb-type (b, c) flexible synapses. Expansion of the end of **a** synapse means enhancement of **the** synapse connection. **Shrinking at the end of a** synapse means repression and weakening. From “**The Brain, Nerves** and Behavior”

Model of a Neural Circuit

McCulloch–Pitss Model (1943)

McCulloch 1898-1969 - biologist

Pitss 1920-1960 - mathematician



$$y(t+1) = 1[\sum w_i x_i(t) - \theta]$$

ただし,

$$1[u] = \begin{cases} 1 & (u \geq 0) \\ 0 & (u < 0) \end{cases}$$

A machinery-like brain can be made by bonding simple elements and hence abstracting the behavior of nerve cells.

A linear threshold element model of a neuron was presented

Common Nerve **Signals** in Organisms

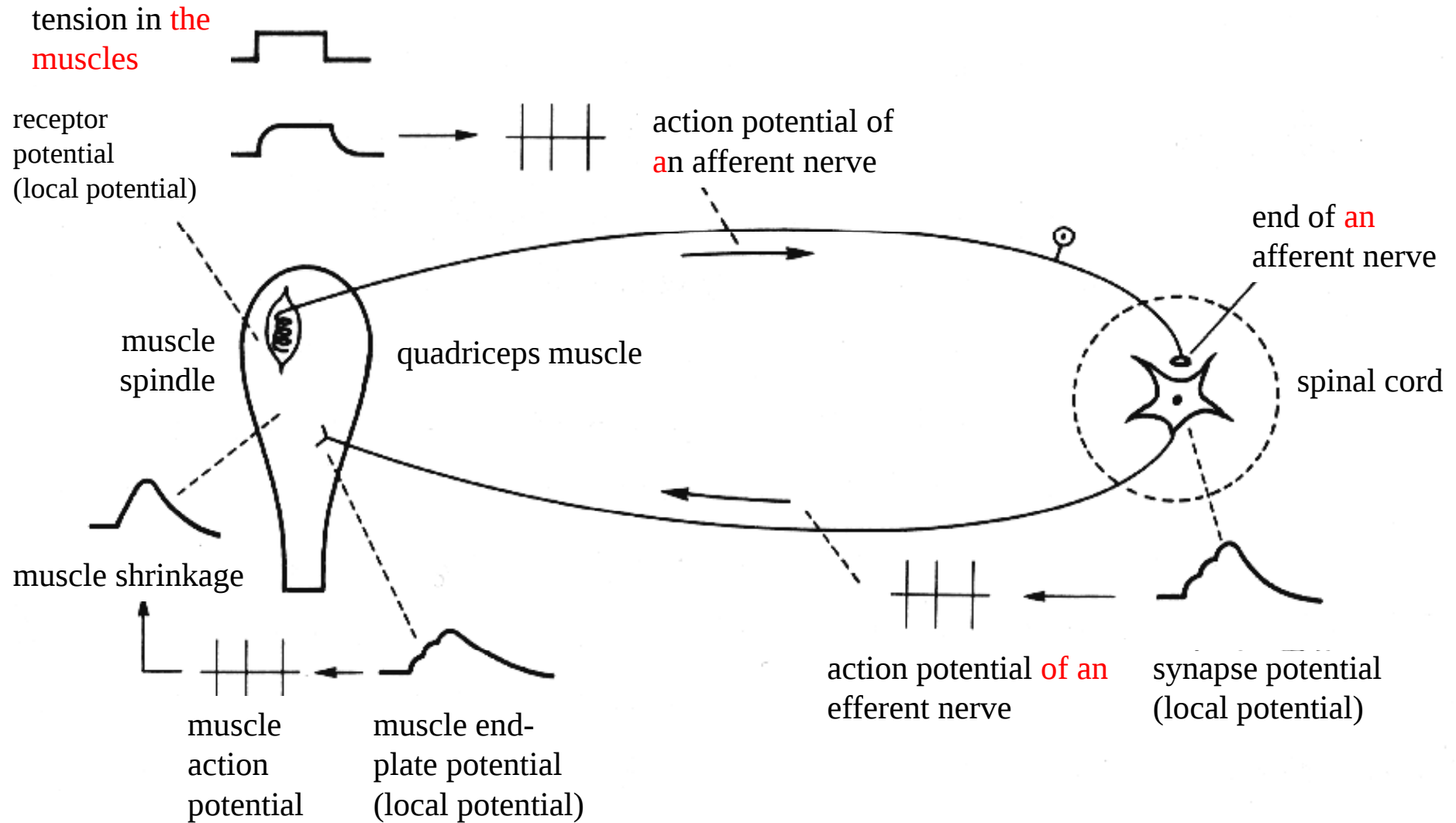


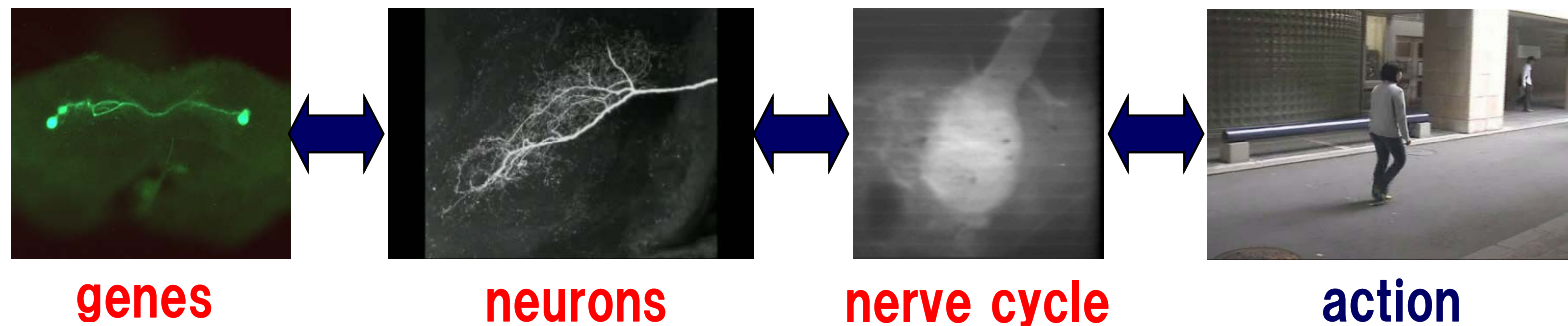
Fig 1.8 **Signals** used in patellar tendon **reflexes**

Technologies in **Sensors** and Brain Research

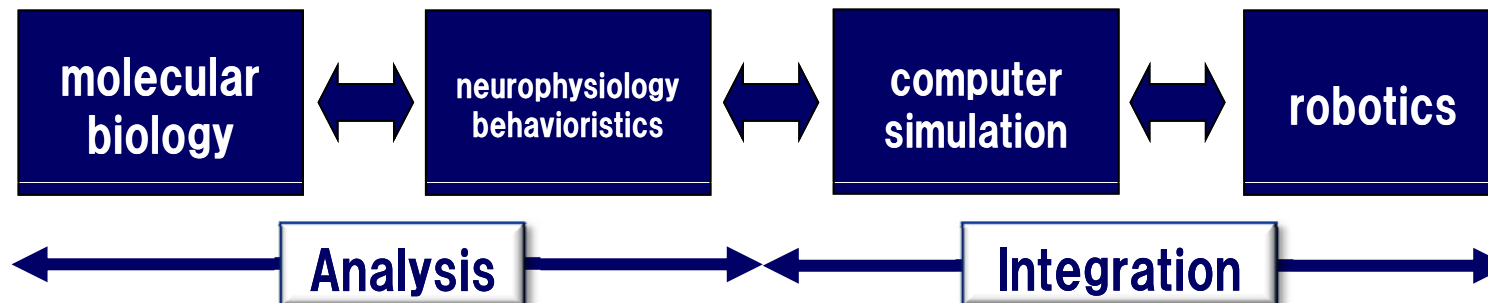
System from sensory input to action output



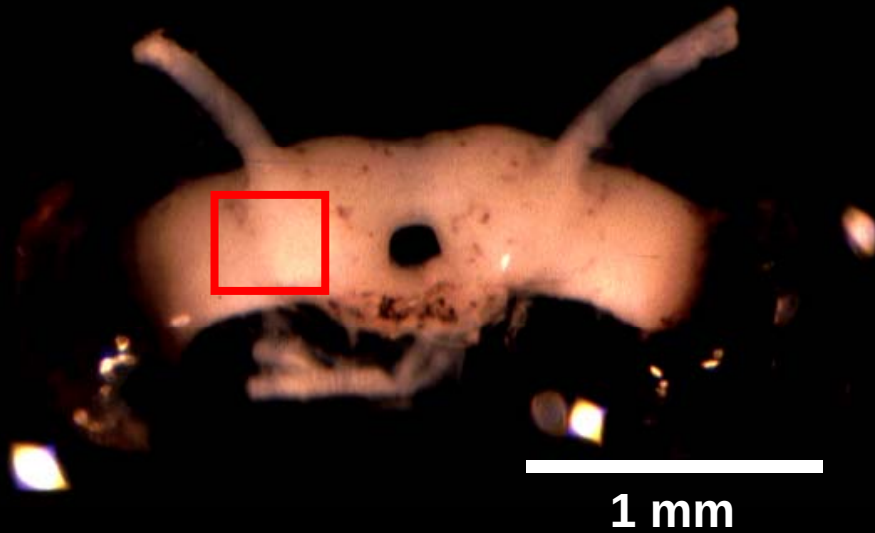
Approaches from Different Levels



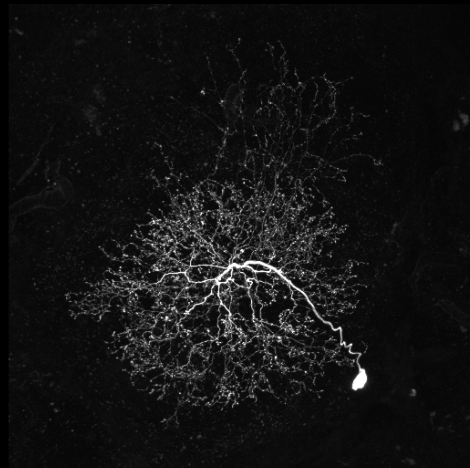
Approaches by Analysis and Integration



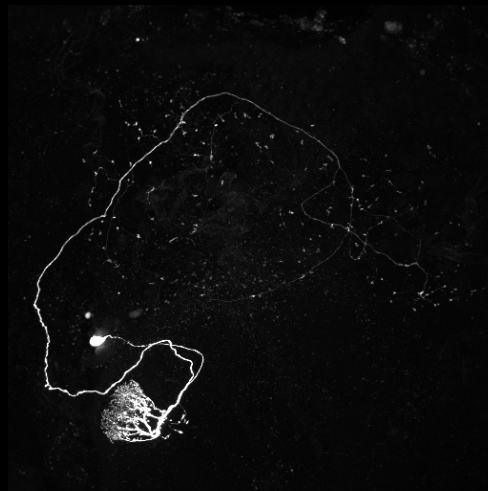
Model Brain and Visualization of a Single Nerve Cell



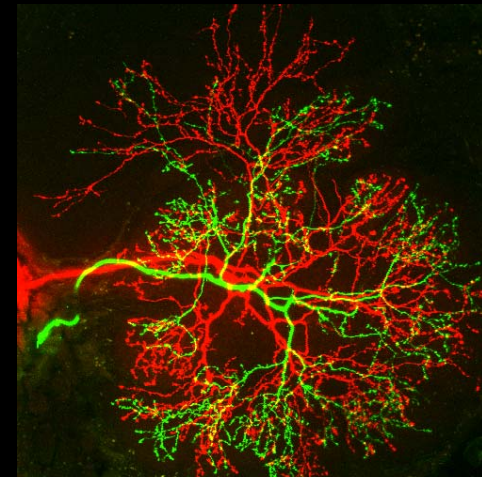
differential interference - **microscopic view**



local interneuron



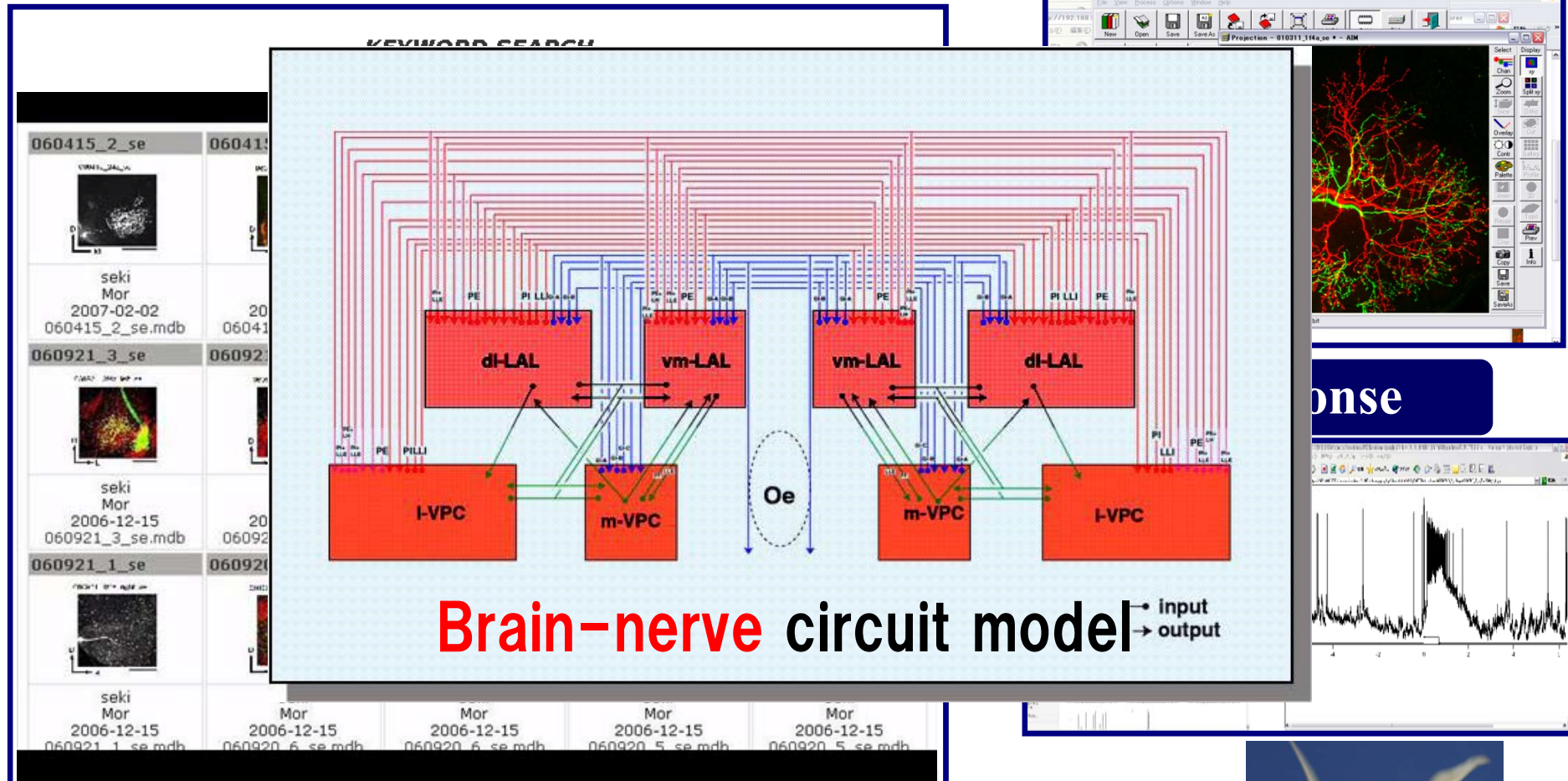
output nerve



Cyclopedic Database of a Model Brain-Structuring Neuron

neuron database

form of nerve



onse

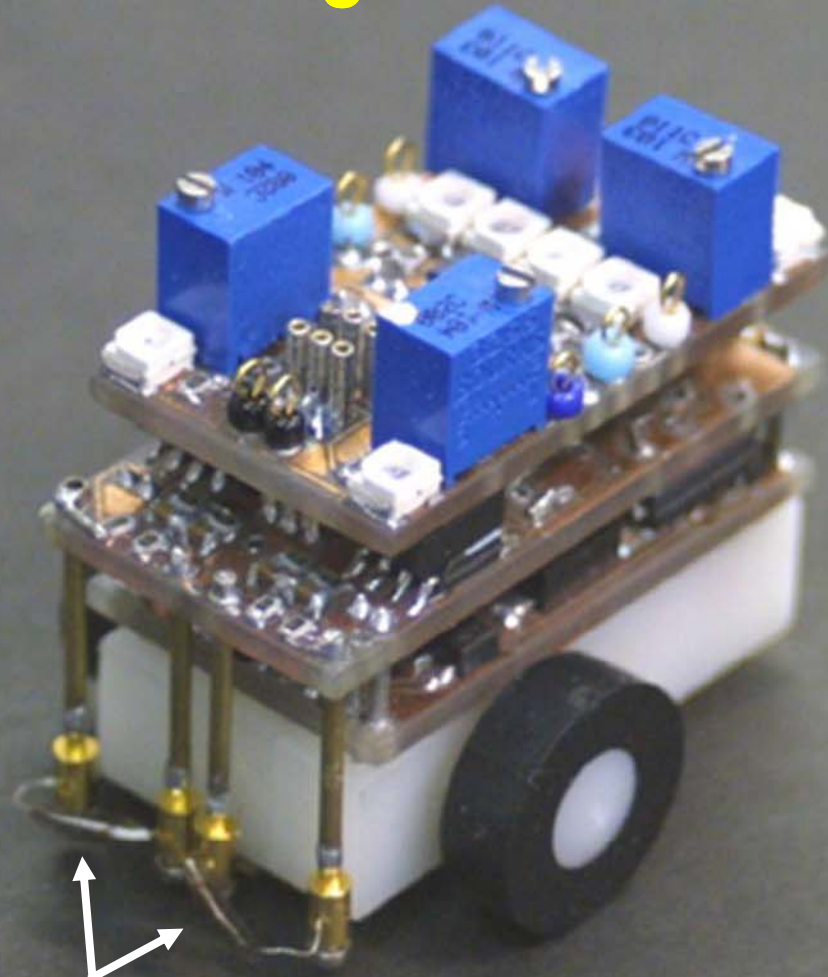
Brain-nerve circuit model → input → output

morphology : a single nerve cell, cell body groups
 physiology: olfactory, vision, machinery sensory responses
 imaging : membrane-potential receptive pigments, calcium receptive pigments
 immune tissue chemistry : GABA, 5HT, FMRFamide, tyramine, histamine

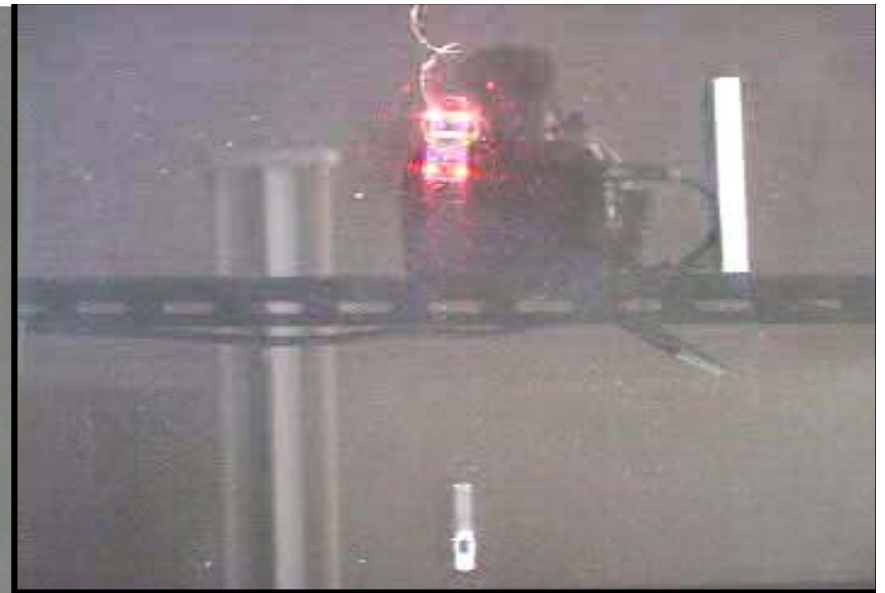


Bombyx mori

A Small moving robot tracking a scent



antennae



antennae

Informatics, Robotics, and Life

Robotic Informatics to Understand Life

1. Information That Links Organisms and the Environment

- senses and behavior

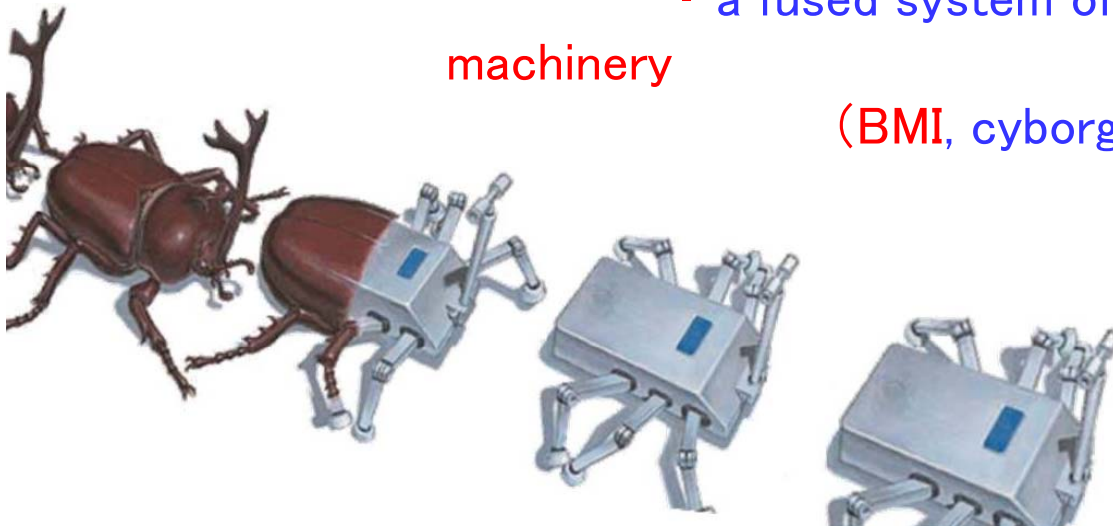
2. The World as Environment

- sense, time, size information

3. Information That Links the Environment, the Brain and the Body

- nerves and brain
- a fused system of organisms and machinery

(BMI, cyborgs)



Activating Brain

“Reading the Brain” “Brain Connections” “The Brain and Society”

When neurophysiologists, experts in computational theory, clinicians, engineers measuring the brain, computer scientists, robotic researchers, control scientists, medical/electronic engineers, economists, companies, writers and many other experts collaborate beyond the borders of their affiliations and disciplines, and then they have discussions, do research and develop technology, internationally competitive research will be born.

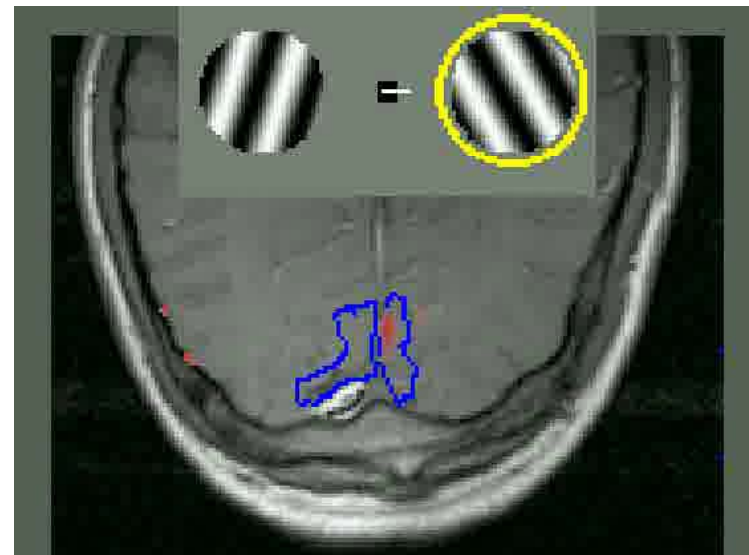
<http://www.cns.atr.jp/nou-ikasu/index.html>

“Reading the Brain”

Extracting and decoding essential information from brain signals.

Application

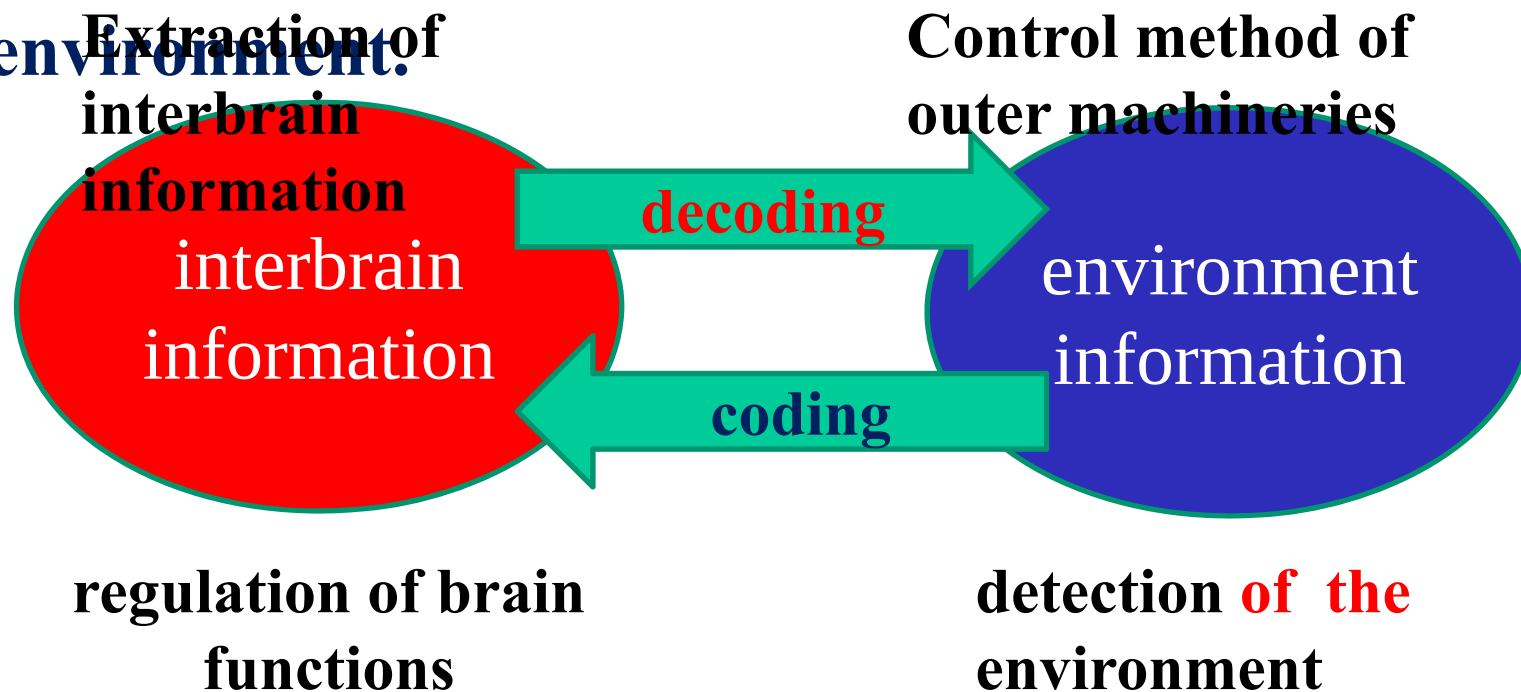
- ① Read subjective notions and opinions and information in the subconscious from the human brain.
- ② Neuroeconomics, neuro-marketing, and similar product development, advertising, and recruitment.



<http://viperlib.york.ac.uk/index.asp>

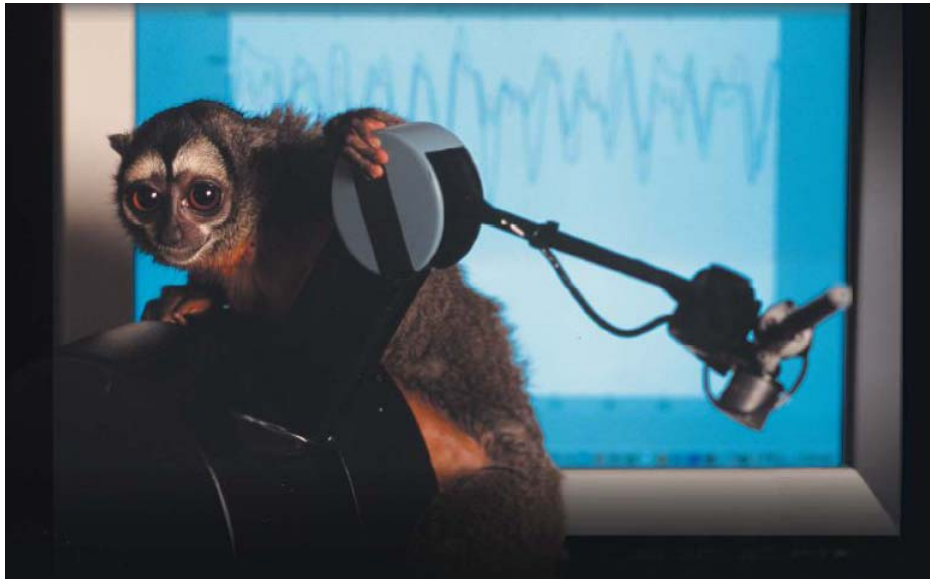
CONNECTING THE BRAIN (Brain-Machine Interface – BMI)

Brain Machine Interface (BMI technology) is a technology facilitates direct input and output of information between the brain and the environment.

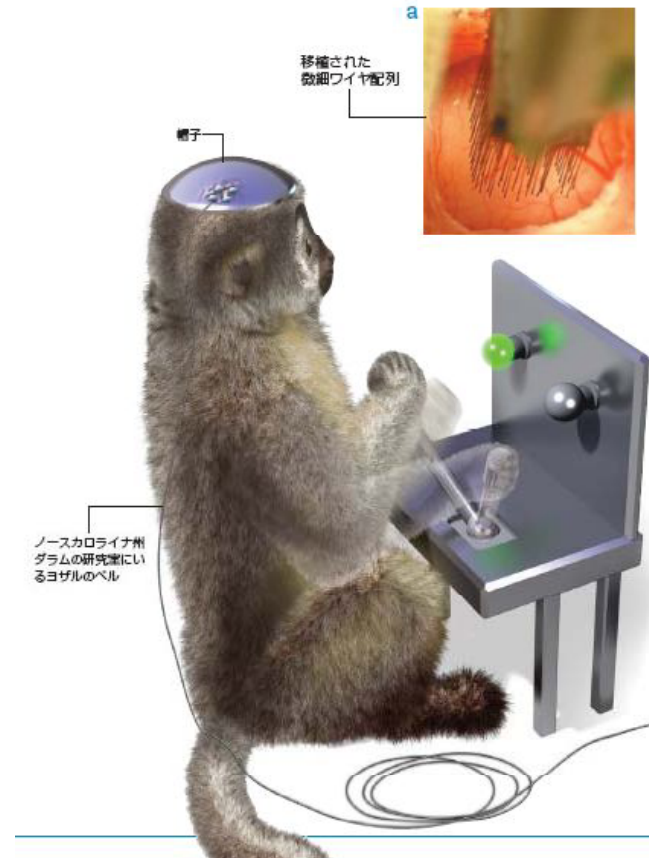


The Brain/Machine Interface

1. Sends the output of a brain directly to a machine.
2. Send signals from a machine directly to the brain and manipulates brain activity.



Bell, a night monkey who can **control an arm set in another room just** by thinking.



Classification of **the** BMI

■ sense input type (artificial sense)

Sends signals to the brain and generates or reinforces some senses.

- Artificial Sensory **Organs**
- Cochlear **Implants**
- Visual Prosthesis
- Artificial **Sensations**

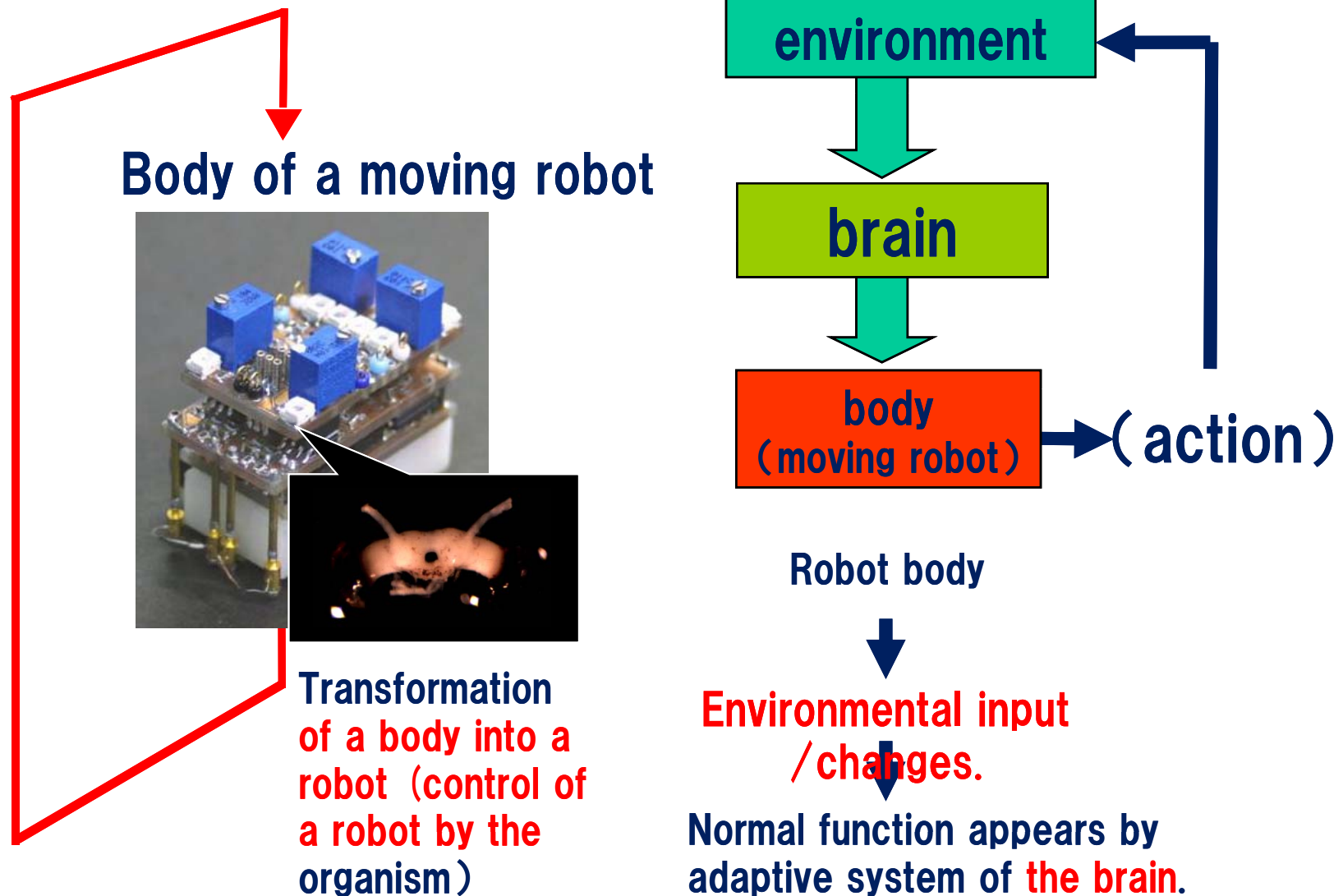
attack ▪ no attack

■ action output type

Detects an activity to express action output from nerve cell activities, and **to control** outer machineries .

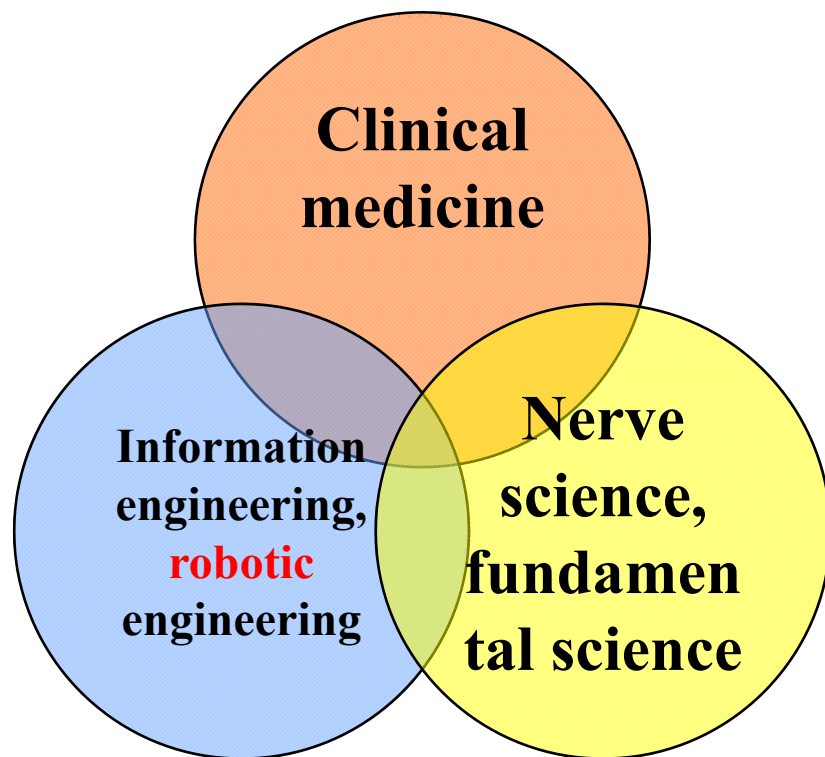
■ Deep Brain Stimulation (DBS)

Principles of **the** BMI



Purpose of the BMI

Realize “an enlargement of human abilities restricted by the body” using BMI.



Clinical medicine

- overcoming **physical disorders**
- walking **assistance** for patients **with spinal cord injuries**
- rehabilitation
- vision recovery **using artificial retinæ**

Information engineering, robot engineering

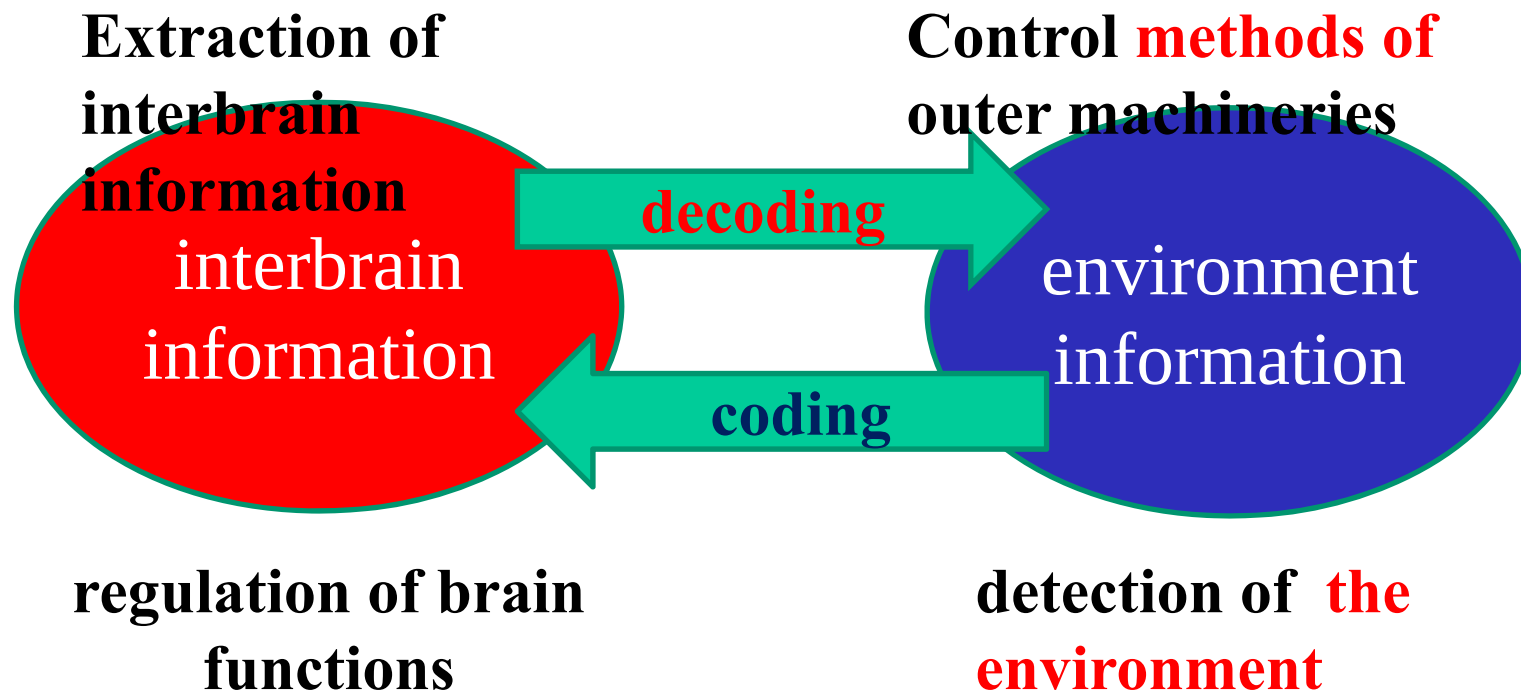
- **Manipulation of a super-free** robot
- Communication by sending and receiving interbrain information

Nerve science, fundamental science

- Elucidation of brain functions

Sensory-Input BMI

Sends signals to the brain and generates or enhances various senses (**using artificial sensor**) Cochlear implants, visual prosthesis, artificial touch



Cochlear Implants

transmission deafness

Disorders developed between the outer and middle ear.

perceptive deafness

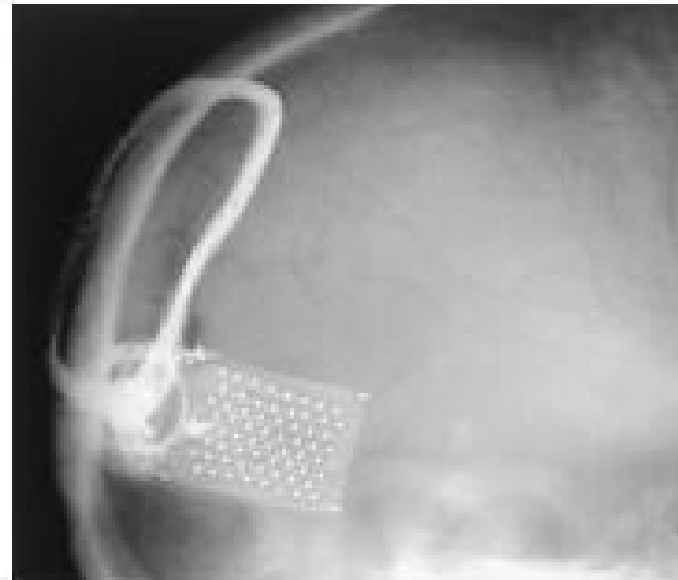
Disorders developed between inner ear and nerve center.



Visual Prosthesis



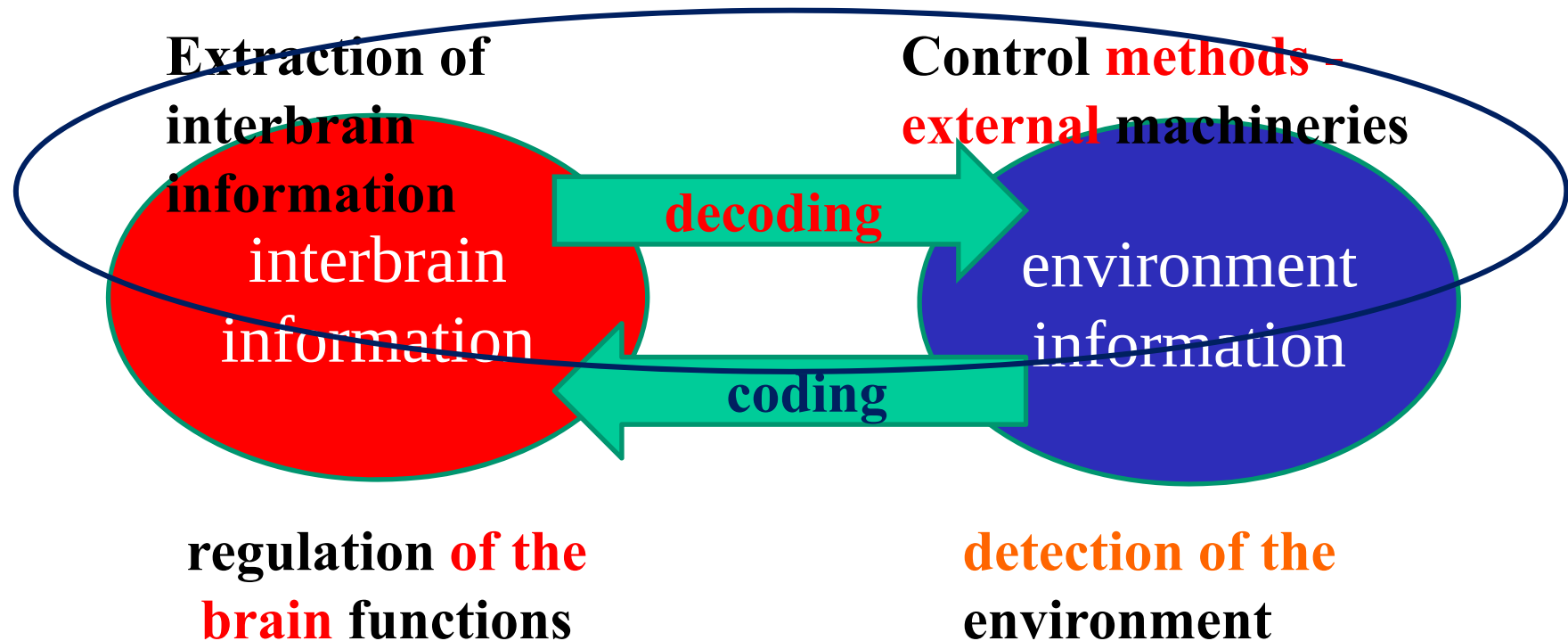
(b)

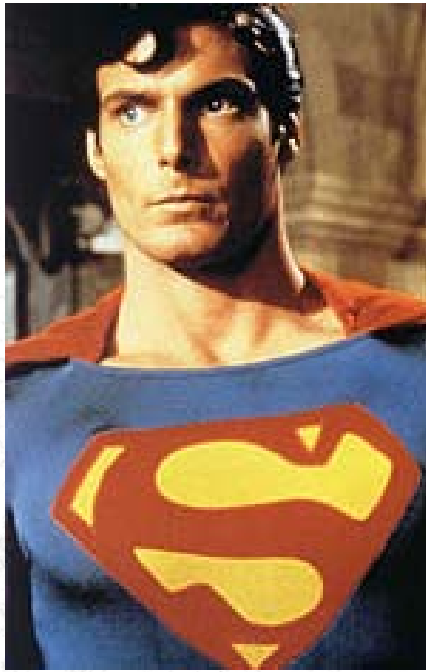


<http://web.archive.org/web/20041010113607/artificialvision.com/asaio1.html> Figure 1,2,4

Action Output BMI

Detects activities expressed by action output from the brain and neural activities, and manipulates robots or other external machineries.





Recovery Brain Function

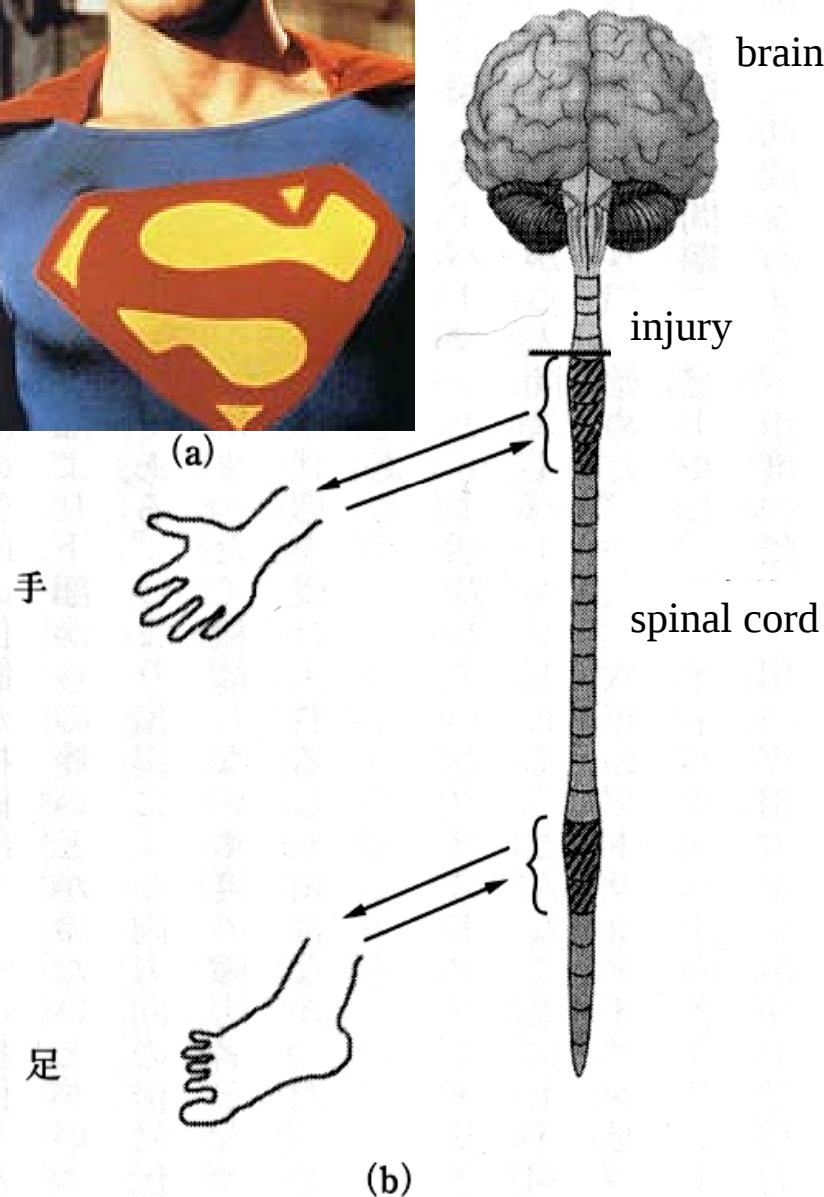


Fig.4.1 Superman (Christopher Reeves) and his spinal cord injury

The central nervous system is made up of the brain and the spinal cord. Orders from the central nervous system are sent to the hands and feet, and inversely, signals such as coldness or pain from perceptive organs in the skin are transmitted to the spinal cord and the brain. Christopher Reeve injured part of his neck indicated in the left figure by falling off his horse, and became unable to move his hands and feet.



©Japan Spinal Cord Committee

September 25, 1952 - October 10, 2004

Cursor Control by Electrodes Implanted in the Brain



The U. S., Cyber Kinetics Co. started **a clinical** experiment **using** "Brain Gate" System study participant : Mr. Nagle, who suffers from tetraplegia caused by **a spinal** cord injury

He is wearing **a 96 micro-electrode** apparatus (BrainGate) in his motor cortex.

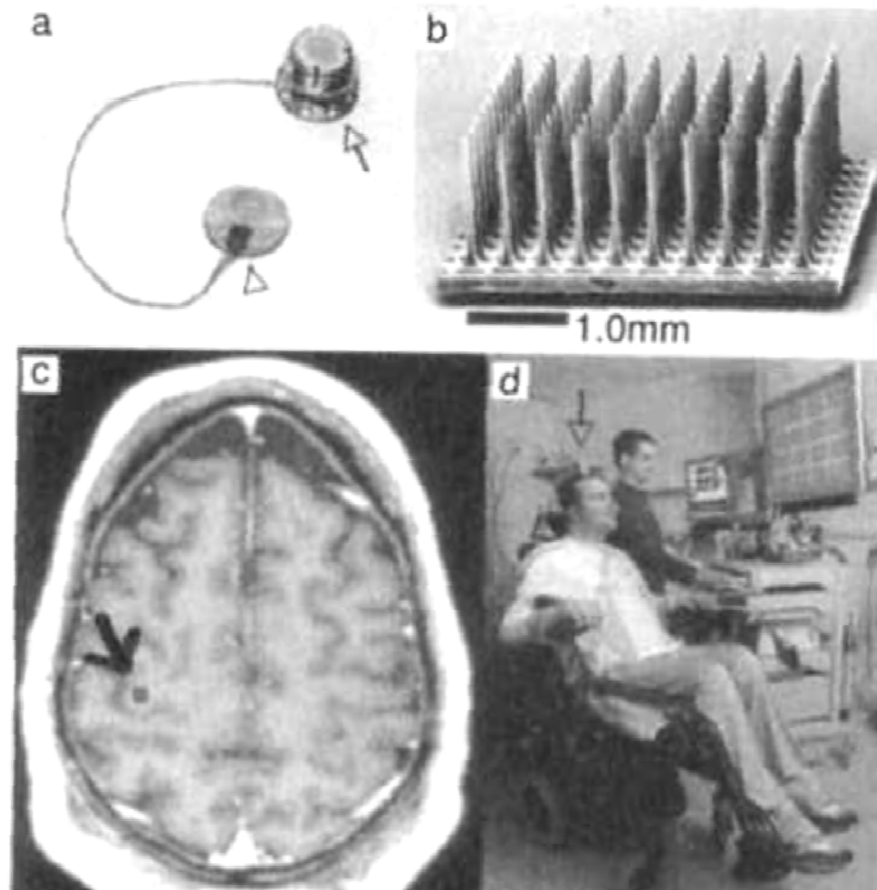
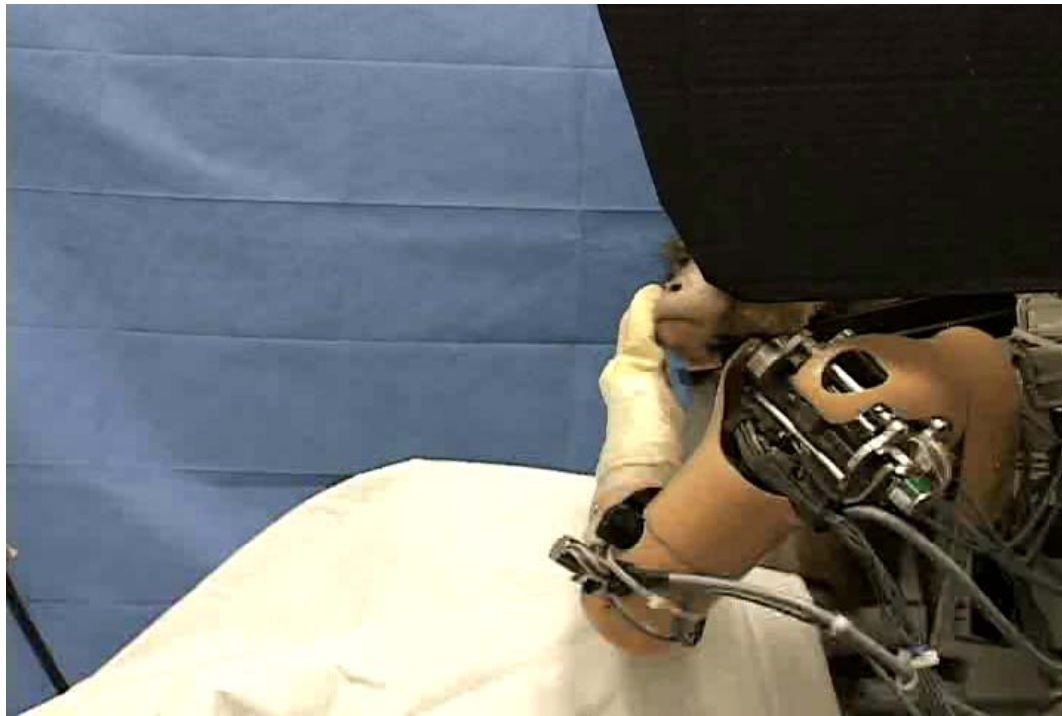


Fig. 2.11 **A BMI system used in a human** clinical experiment (Hochberg et al. (2006))
a,b: The Brain Gate and the electrodes c: electrode implanting **points** d:**a picture of the experiment**

図2.11 人の臨床試験で用いられているBMIシステム (Hochberg et al. (2006)より)

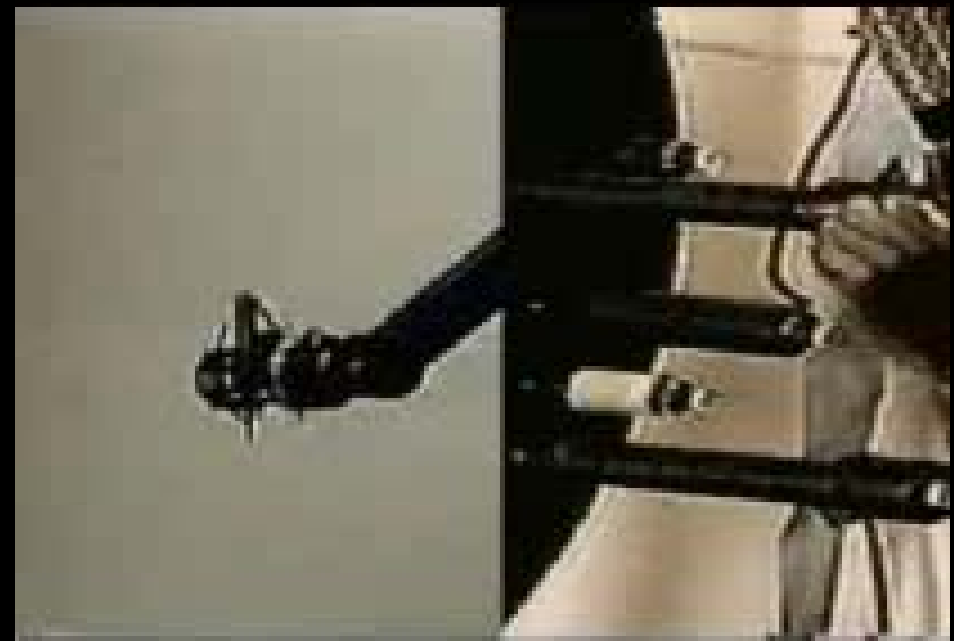
a,b: ブ레인・ゲイトと電極, c: 電極埋め込み部位, d: 実験場面

The study participant Mr. Nagle suffers from tetraplegia caused by a spinal cord injury
He is wearing a 96 micro-electrode apparatus (BrainGate) in his motor cortex.



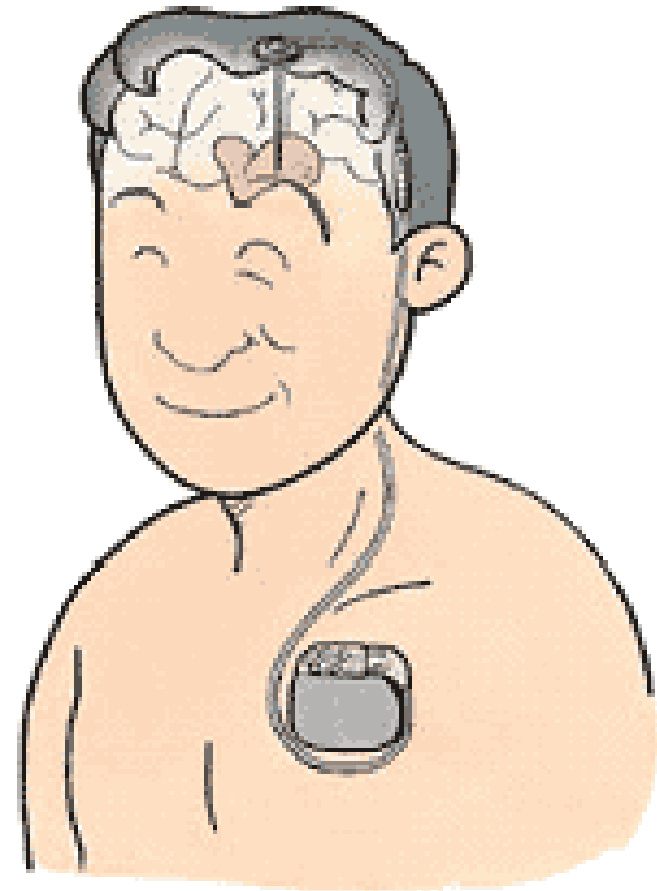
**Controlling an artificial
arm using signals from a
monkey's brain**

**Dr. Andrew Schwartz
Univ. of Pittsburgh**



Deep Brain Stimulation (DBS)

Involuntary actions such as shakes in the hands and legs have a close connection to brain function. Deep Brain Stimulation (DBS) treats such involuntary actions, controlling them by implanting thin electrodes into the brain that regulate physical movements.



Deep Brain Stimulation

Medical Renaissance

What is happening to **Parkinson's** disease now?

Surgery **and** rehabilitation

Electric stimuli to **the** brain

...they could walk again !

Procedures of Deep Brain Stimulation 〈 1 〉 Fix a metal frame to immobilize **the head**, and identify where to implant electrodes **using an MRI** image 〈 2 〉

Apply a local anesthetic to the surface of **the** head, drill a hole in the skull, and implant electrodes using X-rays **to localize problem areas** 3 〉 Check improvements in **motion by testing the brain waves and actual**

movements of the patient's own fingers 〈 4 〉 Implant a pulse (electric signal) generation **apparatus** in the shoulder on another day. This is to be **changed** once **every** 5 years. (Sept. 1, 2005 Yomiuri Shimbun)

**Due to copyright issues,
“Image of surgery”
inserted here was deleted.**

Surgery for Deep Brain Stimulation is conducted with the patient **remaining consciousness to check the** movements of hands and fingers **during surgery**. (At Nihon Oitabashi Hospital, Tokyo)

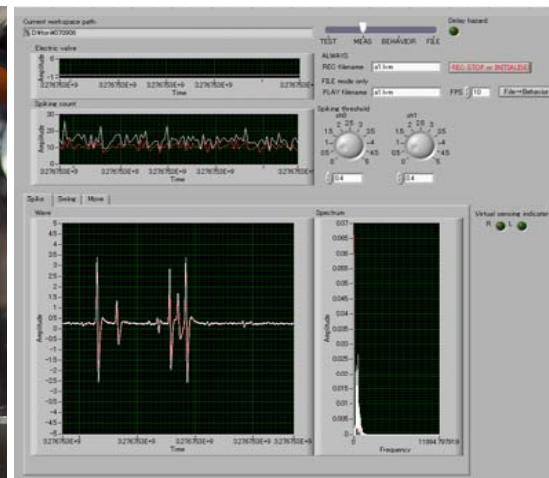
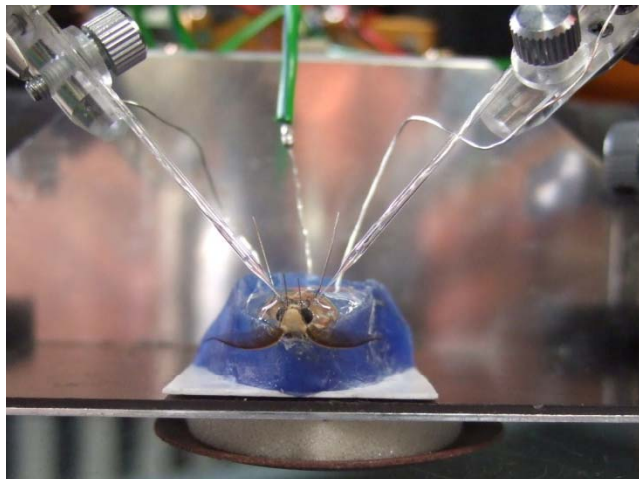
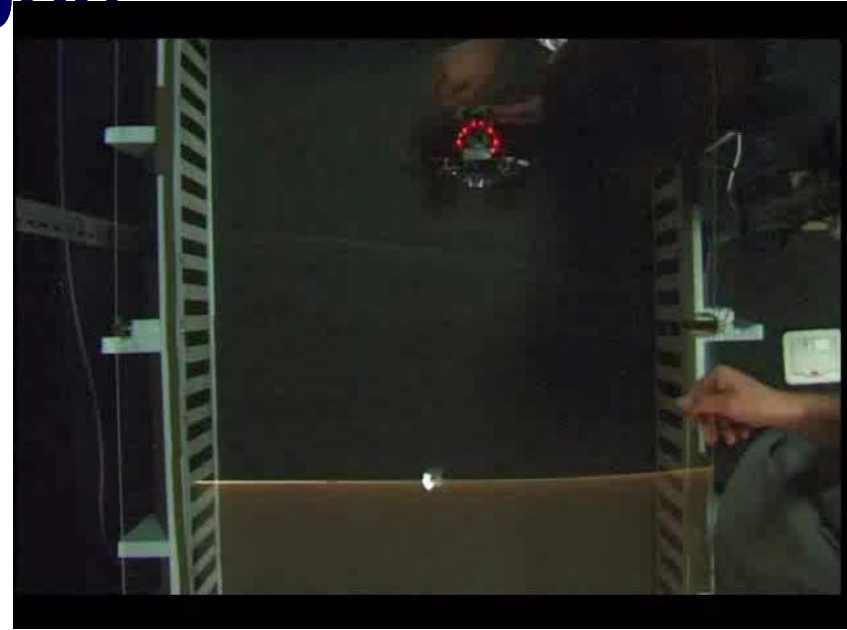
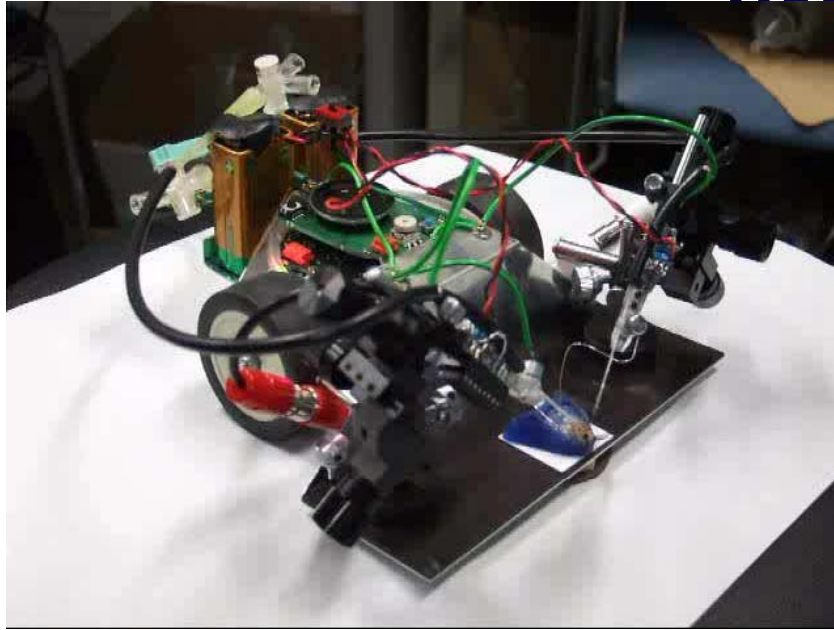
“Brain and Science”

Neuroethics

To change **the** input and output **for** the brain→ethical problem

The material and neuro-scientific infrastructures **of the mind are** now **better** understood. **In** technologies to connect **the** brain and **a** computer or robot, **the** brain and **the** internet, or **one human brain with** another human brain being developed now, we surely need to **consider the ethical**

CONTROLLING ROBOTS BY INSECT'S DETAILS – construction of **an** insect-machinery hybrid



Collaborating with Prof. Kurabayashi (Tokyo Inst.Teck)

Minegishi
& Torihara