東京大学 学術俯瞰講義

Information Changes the World
Informatics, Robots, and Life

Robotic Informatics Used to Understand Life

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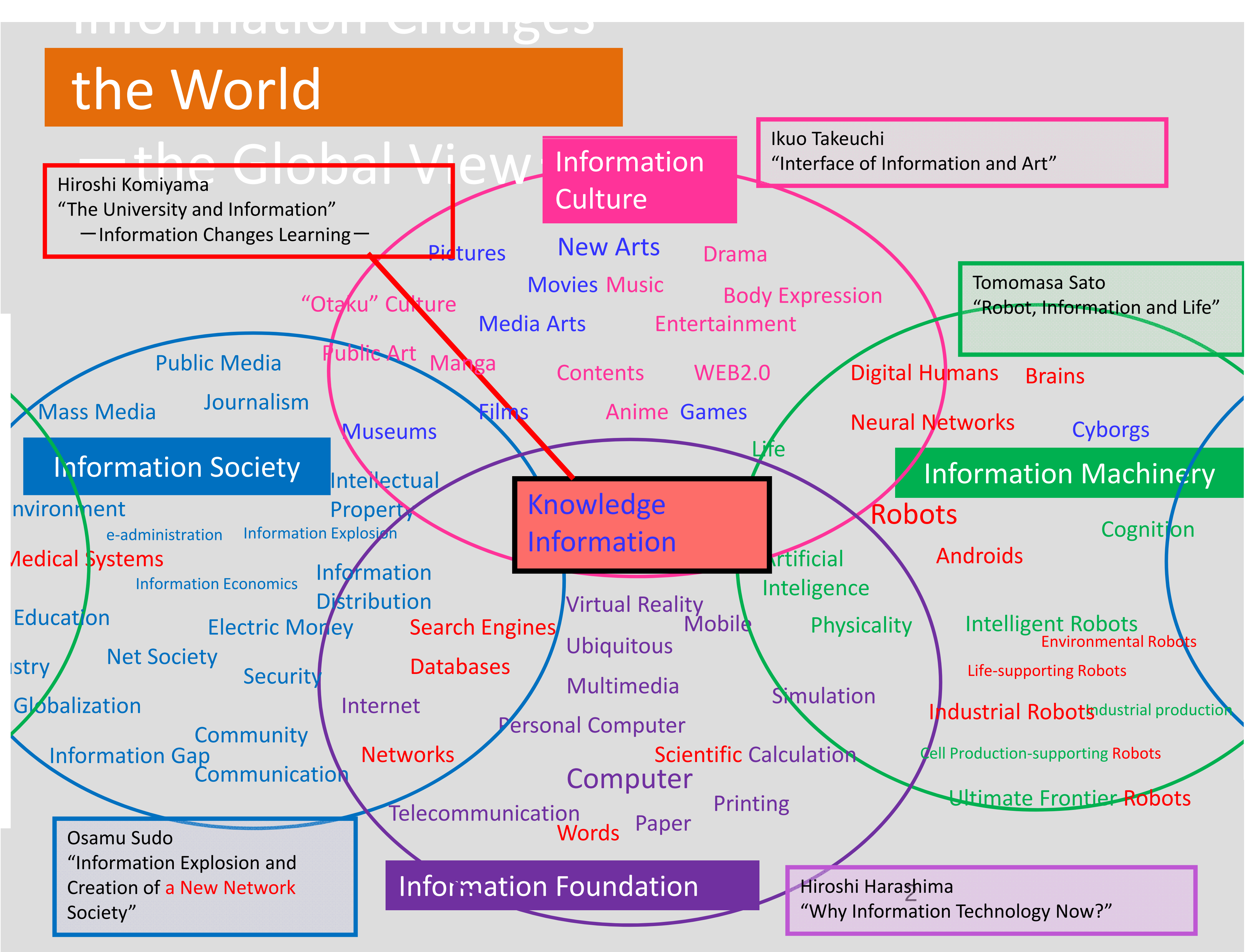
Information Changes
the World
—the Global View—
Hiroshi Komiyama
"The University and Information"
—Information Changes Learning—
Information Culture
Ikuo Takeuchi
"Interface of Information and Art"
Pictures
New Arts
Drama
Movies Music
Body Expression
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"Robot, Information and Life"
Public Media
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Information Society
Intellectual Property
Knowledge Information
Information Machinery
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nvironment
Cognition
e-administration
Information Explosion
Artificial Inteligence
Androids
Medical Systems
Information Economics
Information Distribution
Education
Virtual Reality
Electric Money
Search Engines
Mobile
Physicality
Intelligent Robots
Environmental Robots
Net Society
Ubiquitous
ustry
Databases
Life-supporting Robots
Security
Multimedia
Simulation
Globalization
Internet
Industrial Robots
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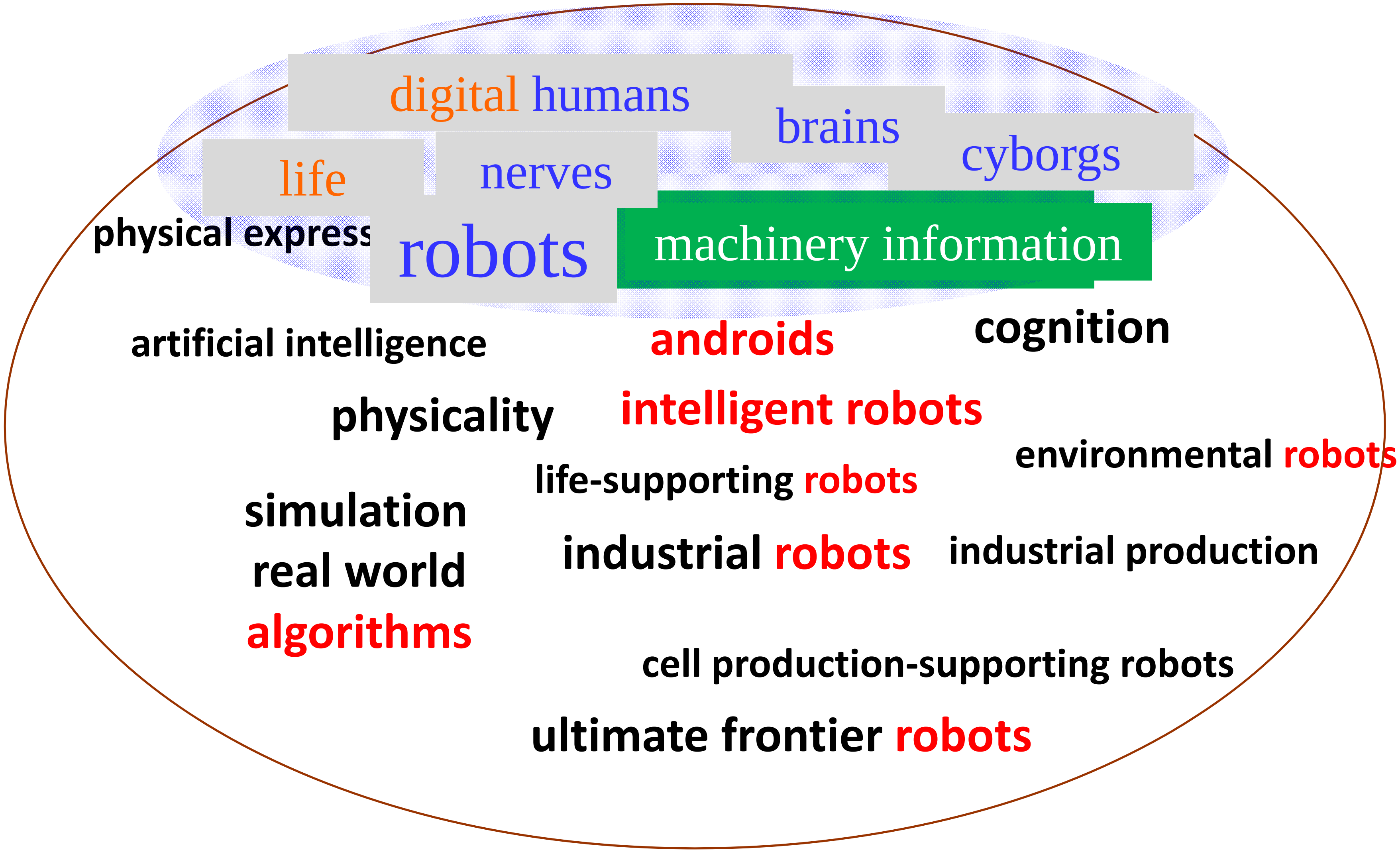
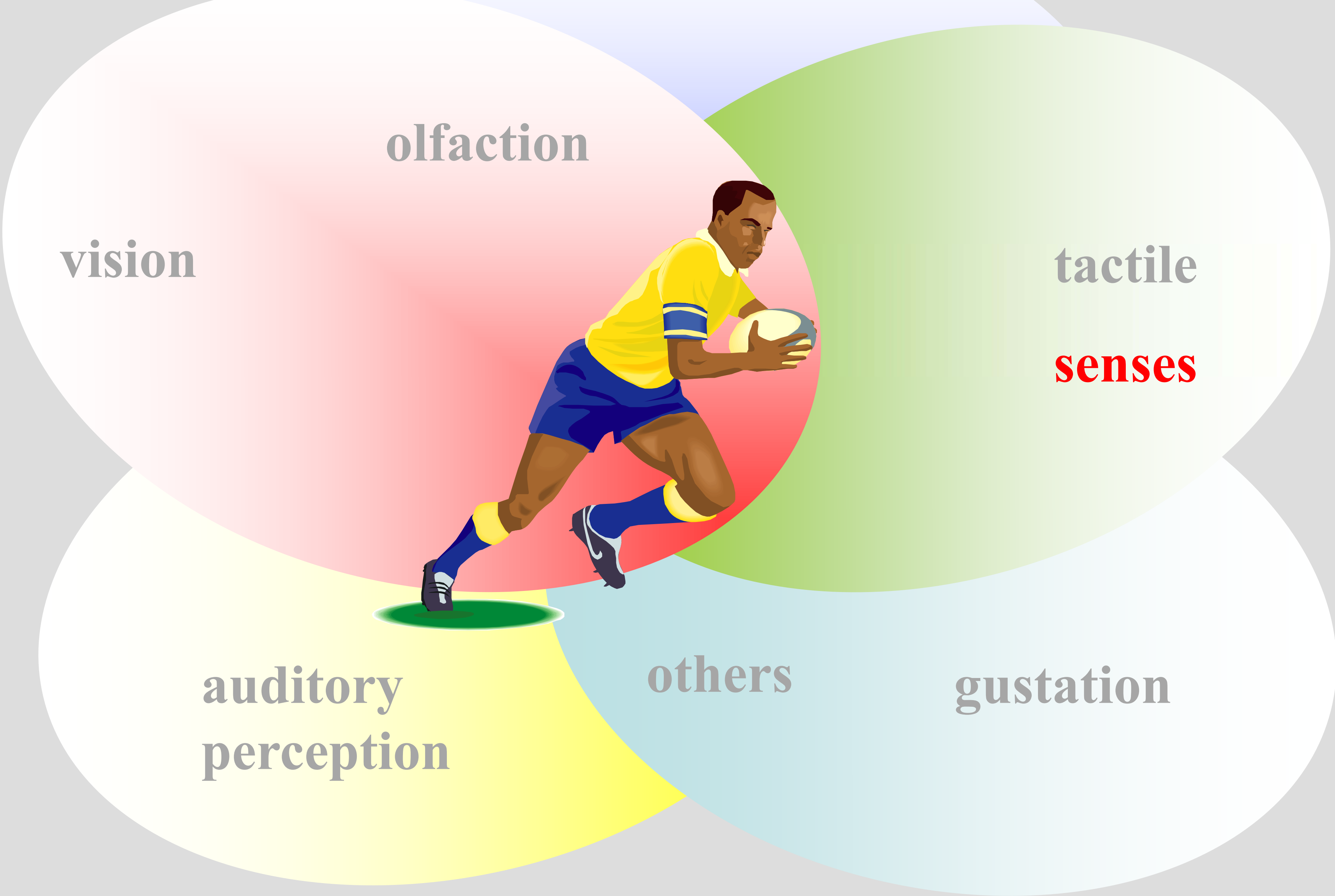
Community
Networks
Scientific Calculation
Cell Production-supporting Robots
Information Gap
Communication
Computer
Ultimate Frontier Robots
Printing
Telecommunication
Paper
Words
Osamu Sudo
"Information Explosion and Creation of a New Network Society"
Information Foundation
Hiroshi Harashima
"Why Information Technology Now?"

Covering the Range of Robotics (a close-up)

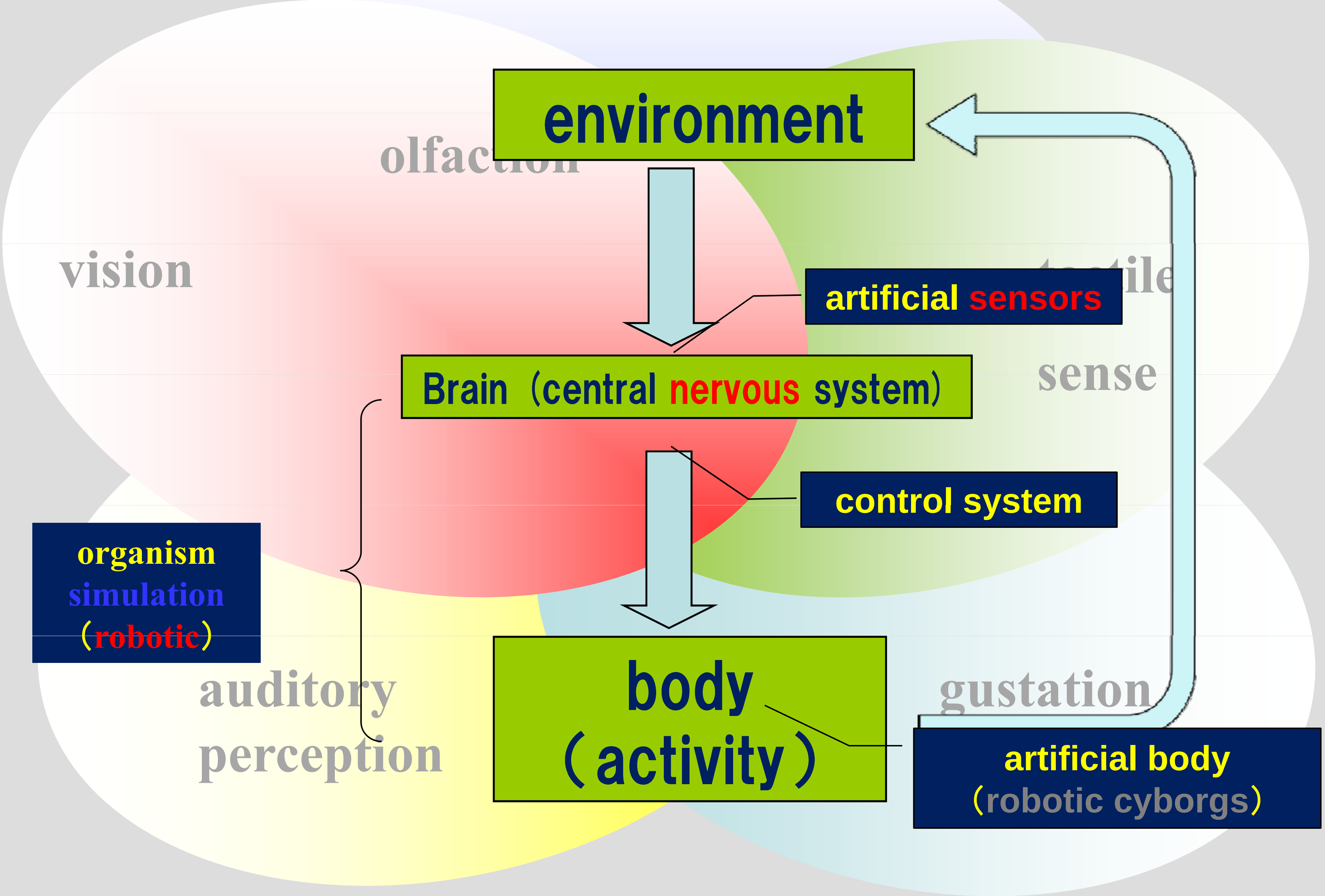


Informatics, Robots, and Life
Robotic Informatics to Understand Life



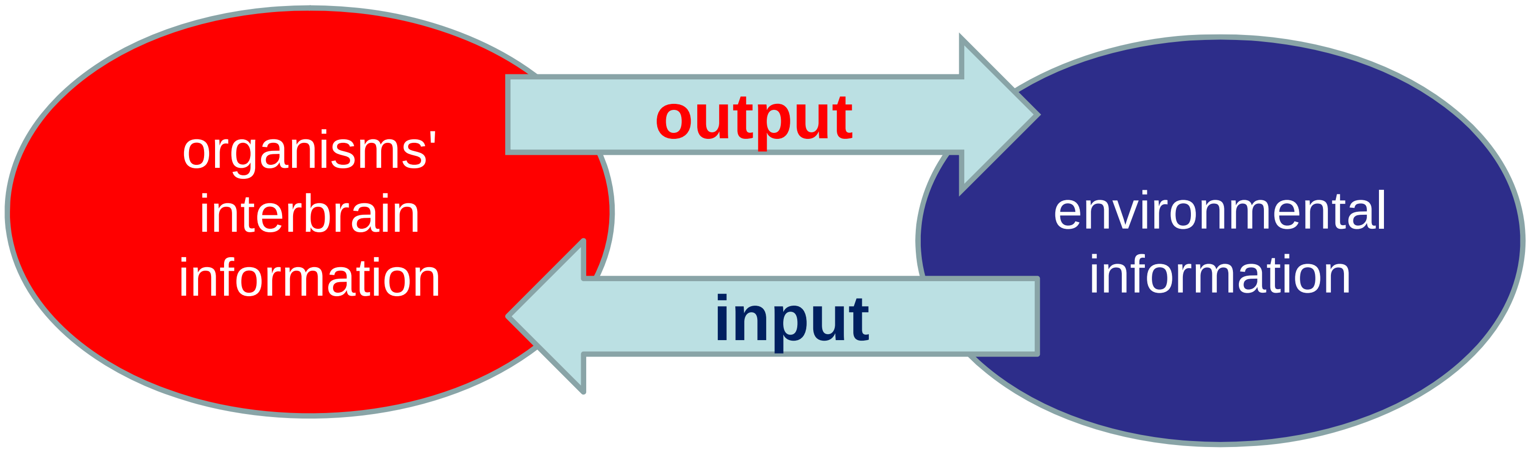
Informatics, Robotics, and Life

Robotic Informatics to Understand Life



Brain – Machine Interface
'hat 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.

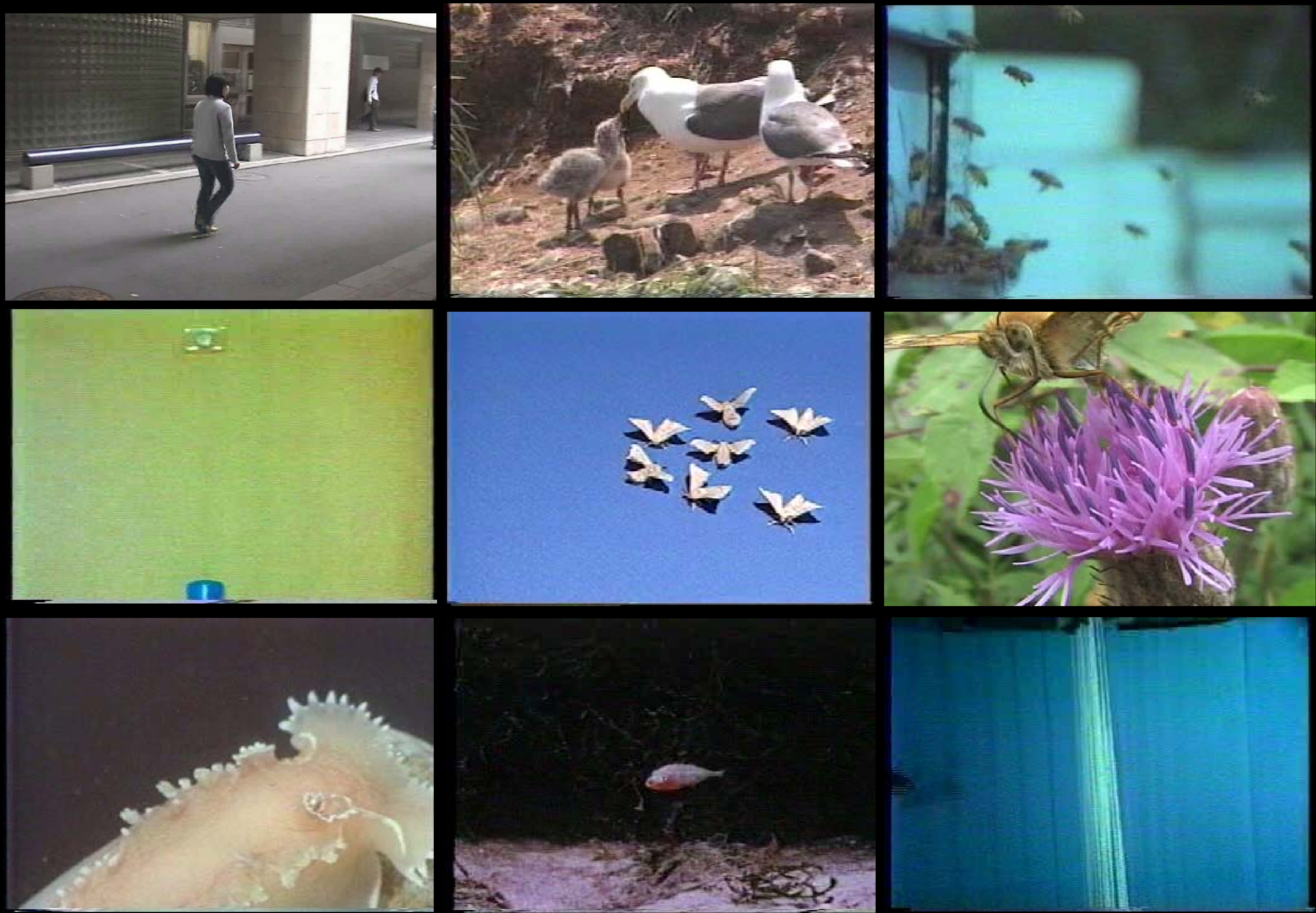


Global view of the information world brought about by the fusion of biology, informatics and engineering.

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.

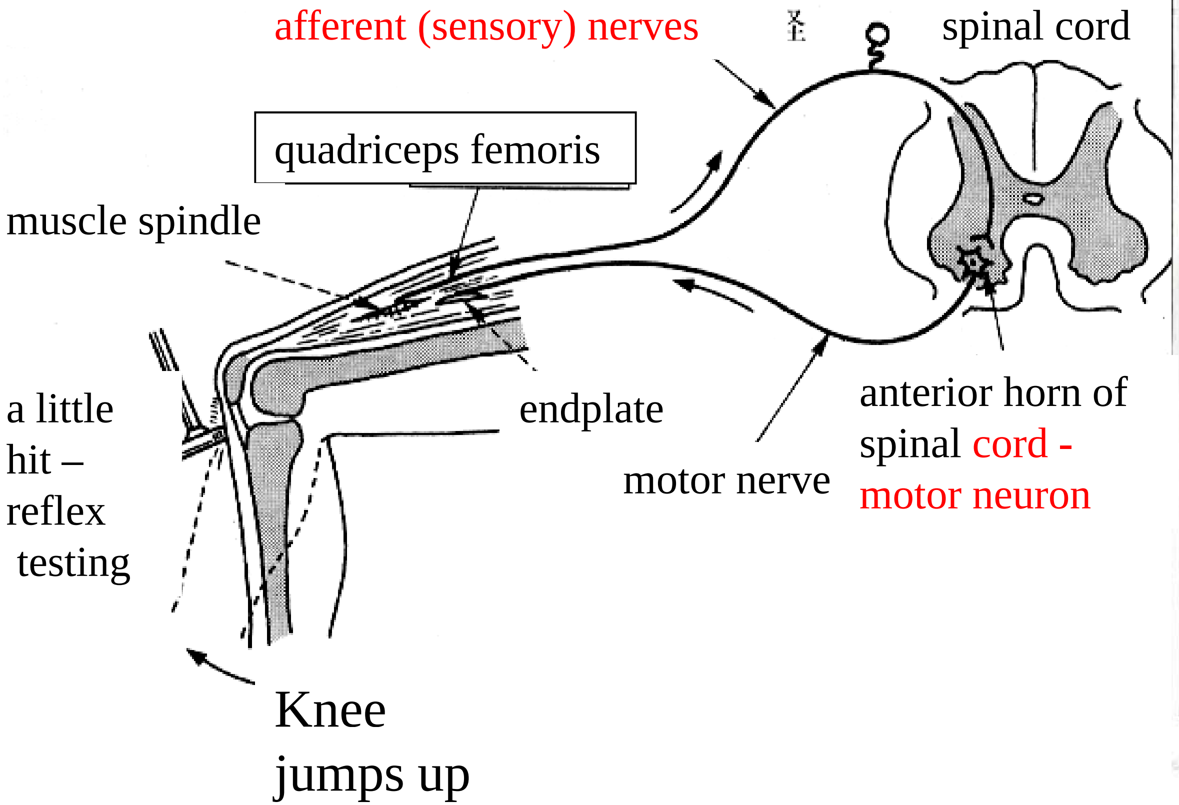
Animal Behavior

What is "behavior" ?

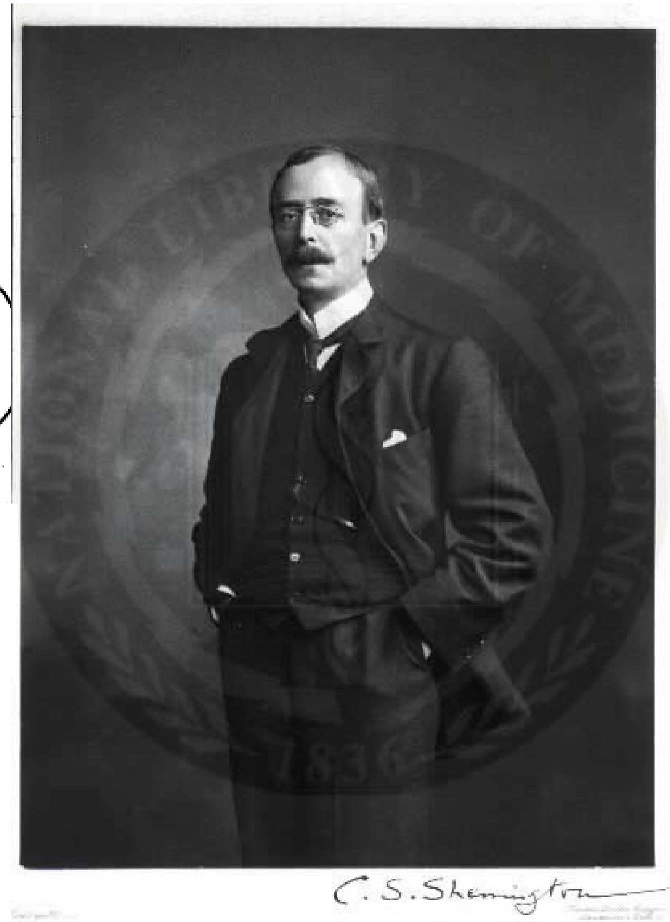
Motions that an individual animal performs actively in the environment (activities which play some role in the animal's adaptation to life.)

What is a unit of behavior?

Units of Behavior: Reflexes

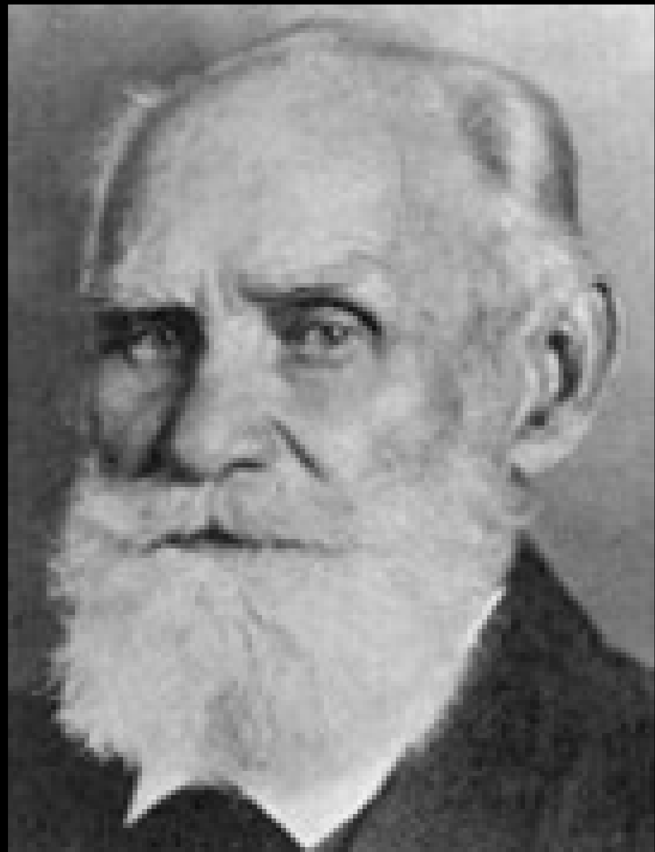


Reflex reaction



Charles Sherrington (1857～1952)

Ivan Pavlov
(1849～1936)

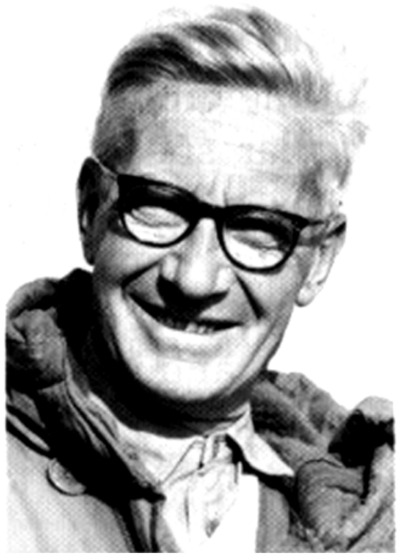


conditioned reflexes

A Behavior-Based Robot

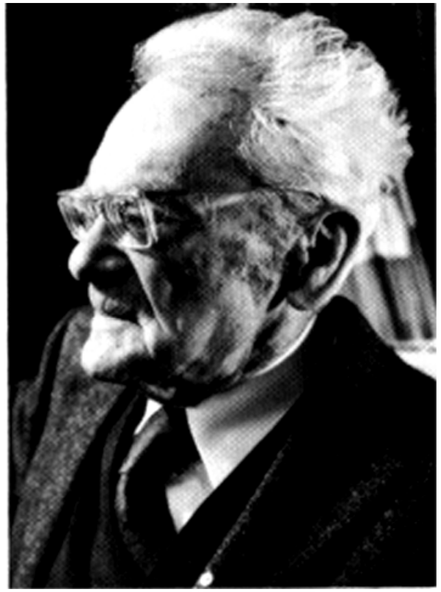
According to perceived sensor information , a module which outputs simple reflex behavior is executed paratacticly. By performing small paratactic processes, quick judgments and flexible behavior suited to a real environment are possible.
Complex behavior can be created by the interactions of simple 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

Resources : The Open University of Japan

Units of Behavior:Inherent Behavior Patterns

sensory organs — central nervous system — effector organs

releaser (key stimuli) → releasing system → Inherent behavior patterns

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

嗅覚 聴覚 その他 味覚

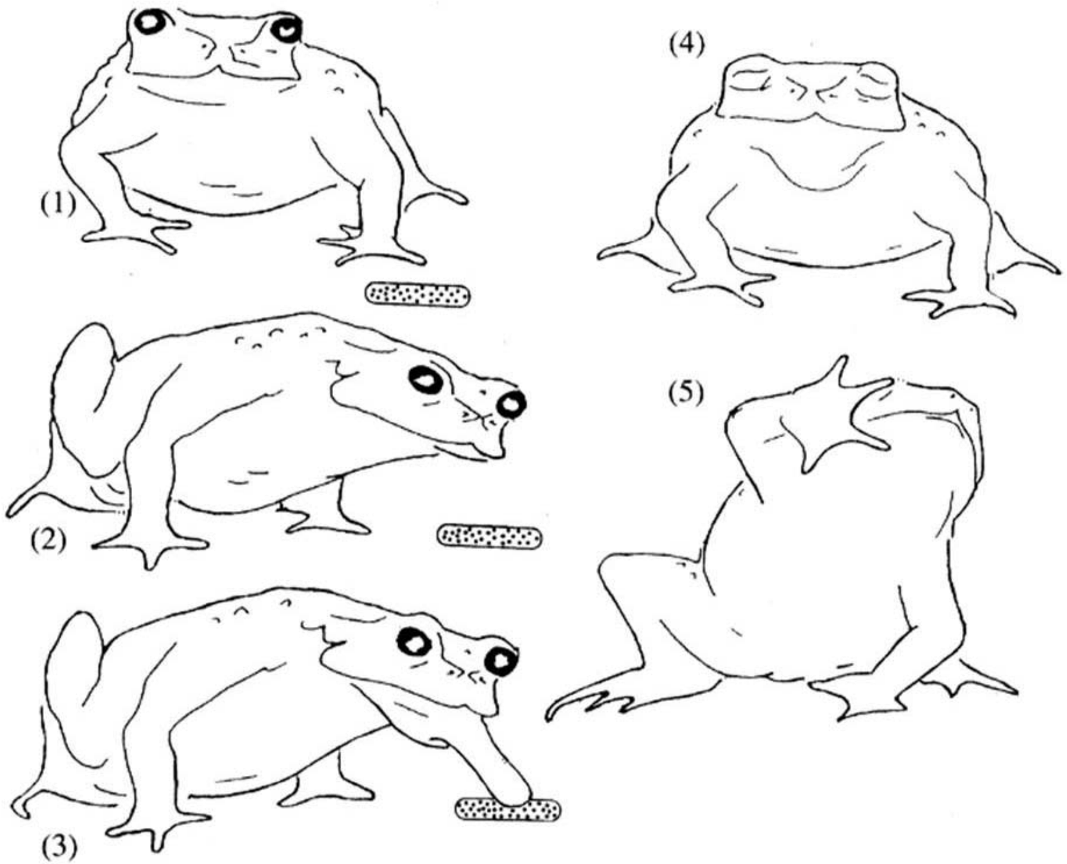
Supply information on how to move in the environment.

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

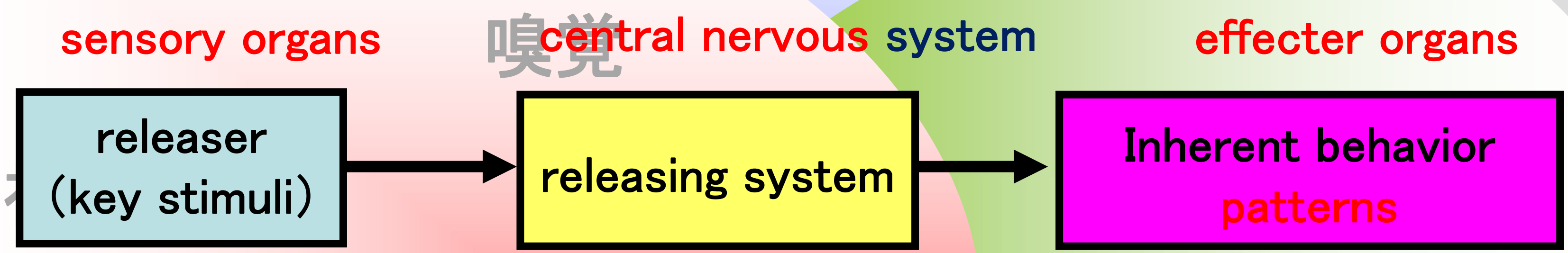
[J.-P.Ewert, *NEUROETHOLOGY*, Fig.41, Springer (1976)]

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)to5). 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. Effecter organs（inherent behavior patterns）

嗅覚

聴覚

その他

味覚

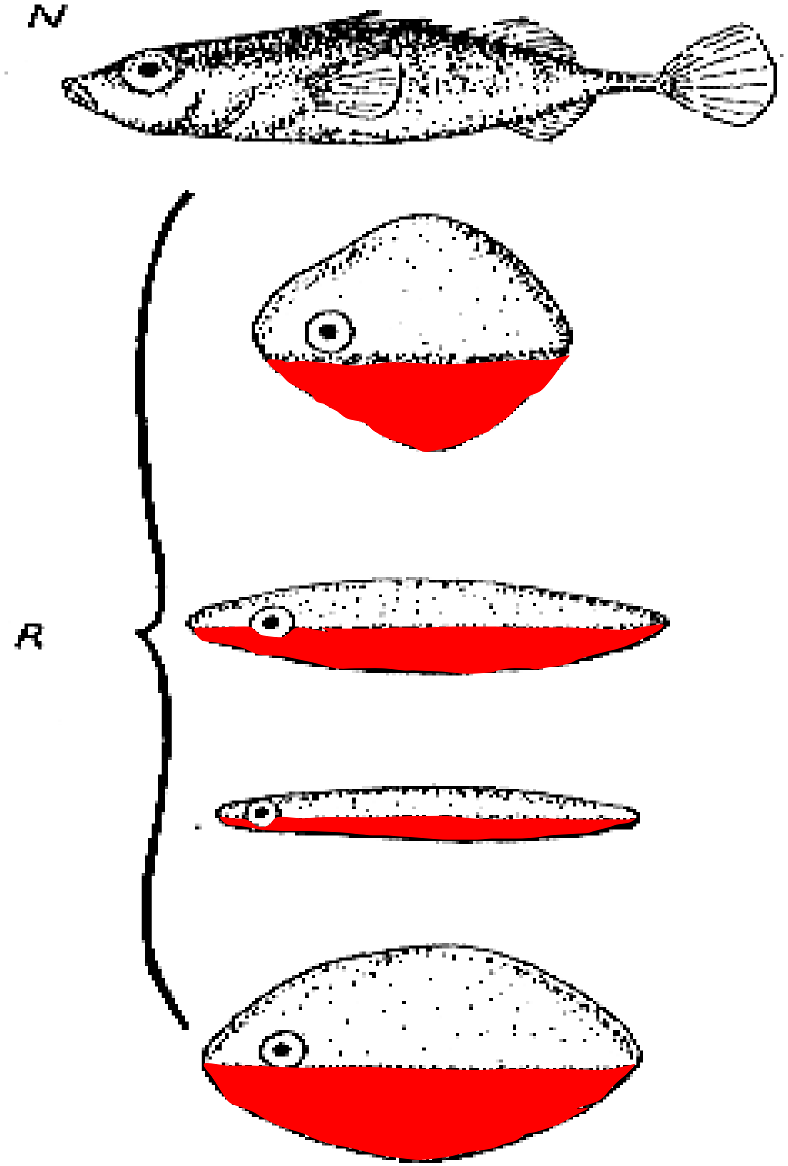
This is information on how to move in the environment.

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.

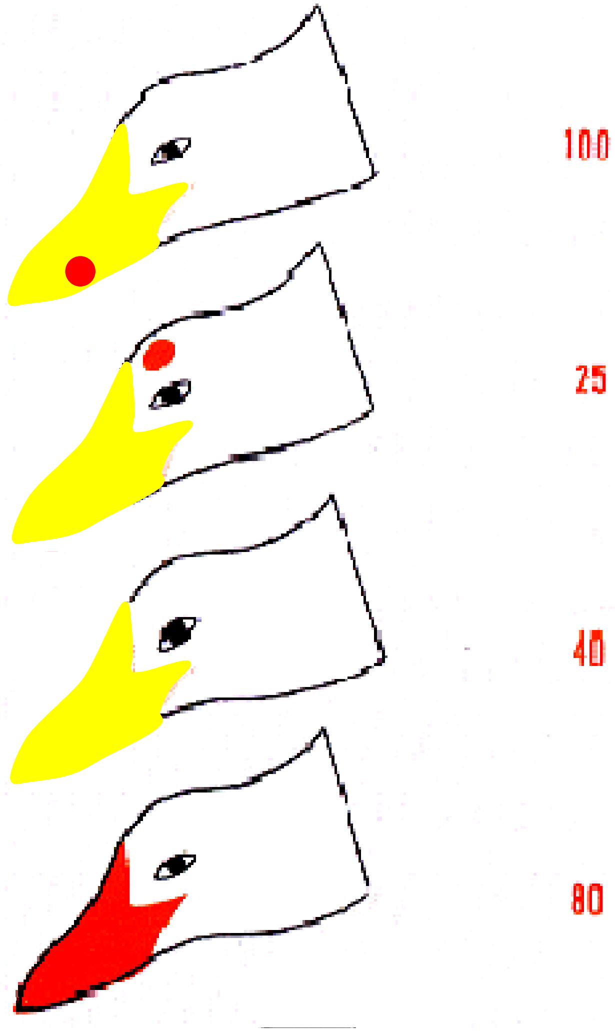
The study of Instinct, Oxford University Press, Fig.20, p28

Teasing Behavior of Feeding Herring Gulls

Tinbergen and Perdeck, 1950

Resources : The Open University of Japan

Key Stimuli

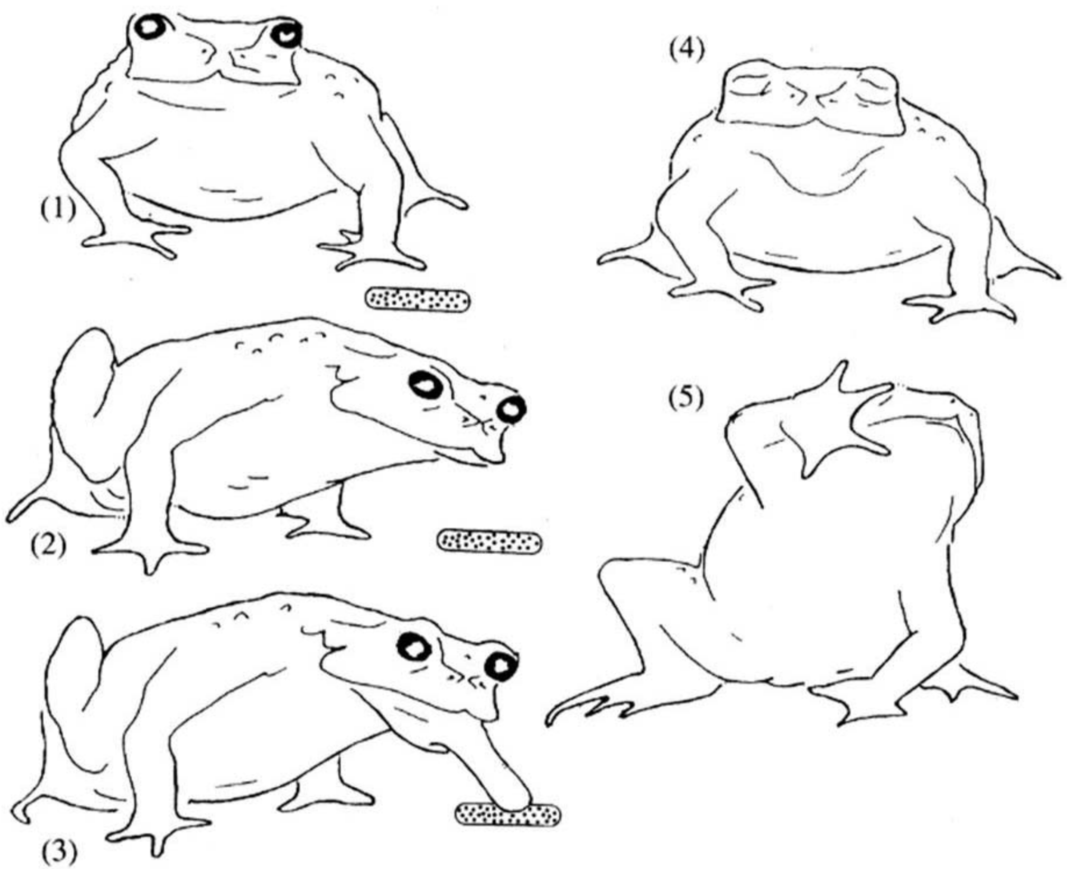


Gulls stuff their crops with food. They feed their mates and chicks from their crop.

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

The study of Lnstinct, Oxford University Press, Fig.24, p31

Meaning of the Environment (Stimuli)



The Hunting behavior of a toad

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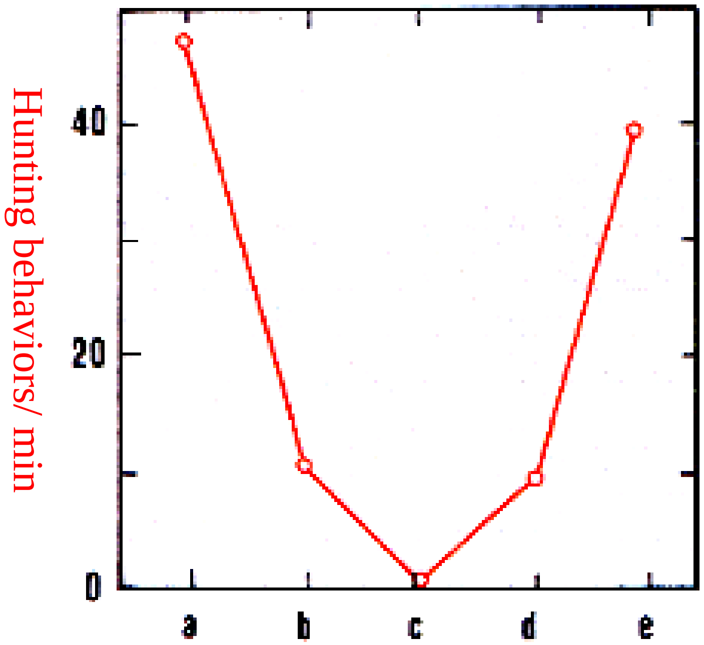
The Meaning of the Environment (Stimuli)

Moving direction of a model



Direction of a model

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

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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 iss 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

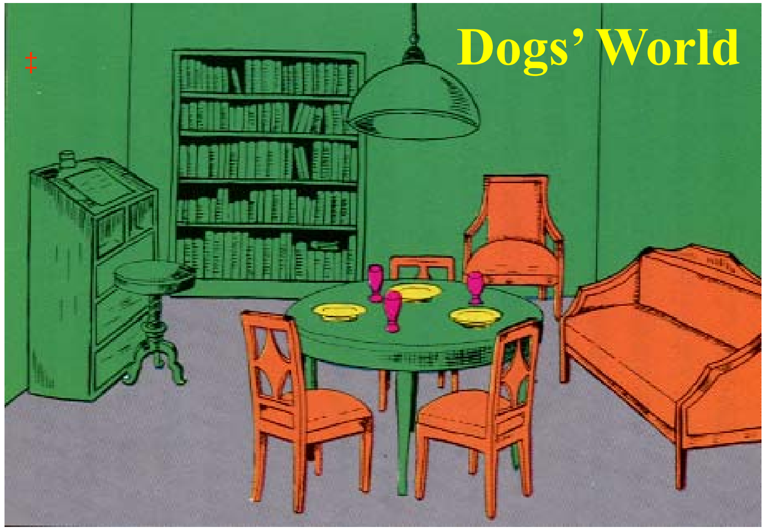
The Different Sensing Ability of Animals

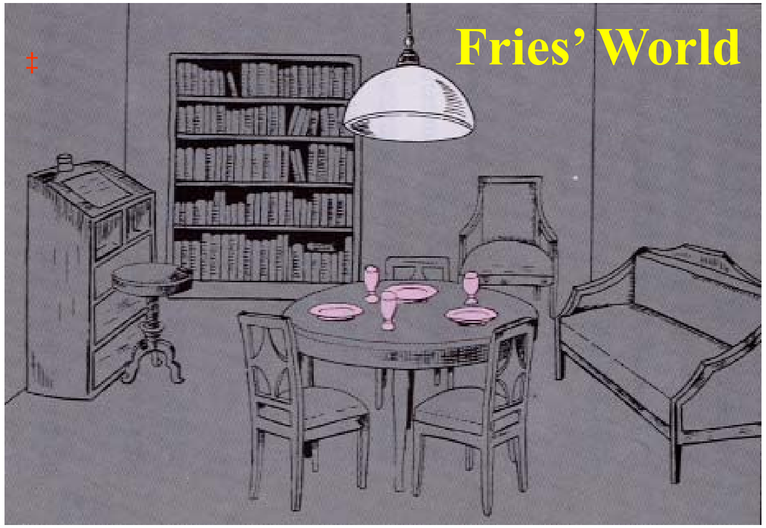
1. Honey bees sense ultraviolet rays and polarization using their compound eyes.
2. Elephants sense sounds of 1Hz.
3. Rats sense sounds of 80 thousand Hz.
4. Dogs sense of smell is a million times stronger than humans (acidum tartaricum contained in their sweat).
5. A scallop has 100 eyes.
6. Woodcocks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

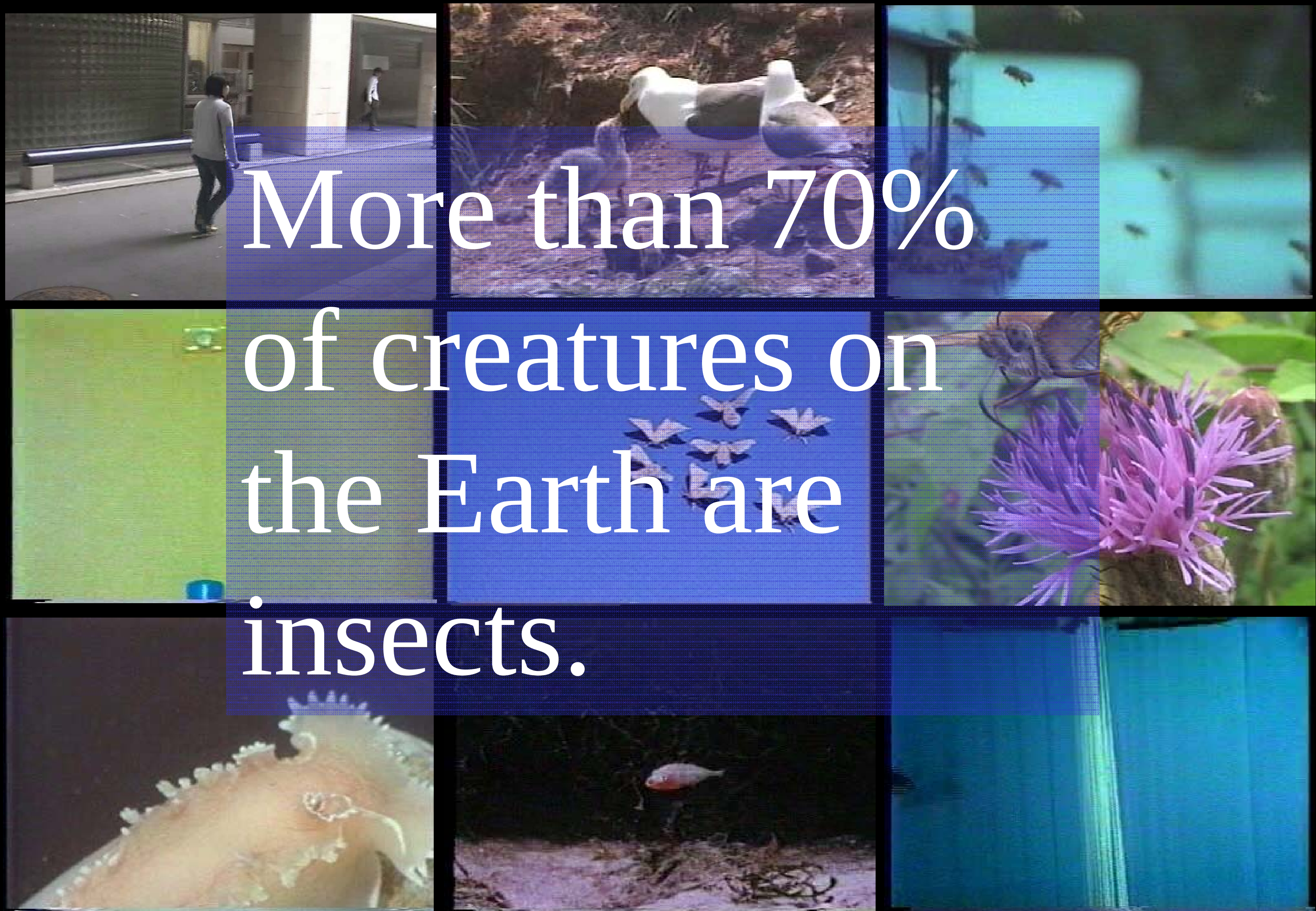
World of Senses





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

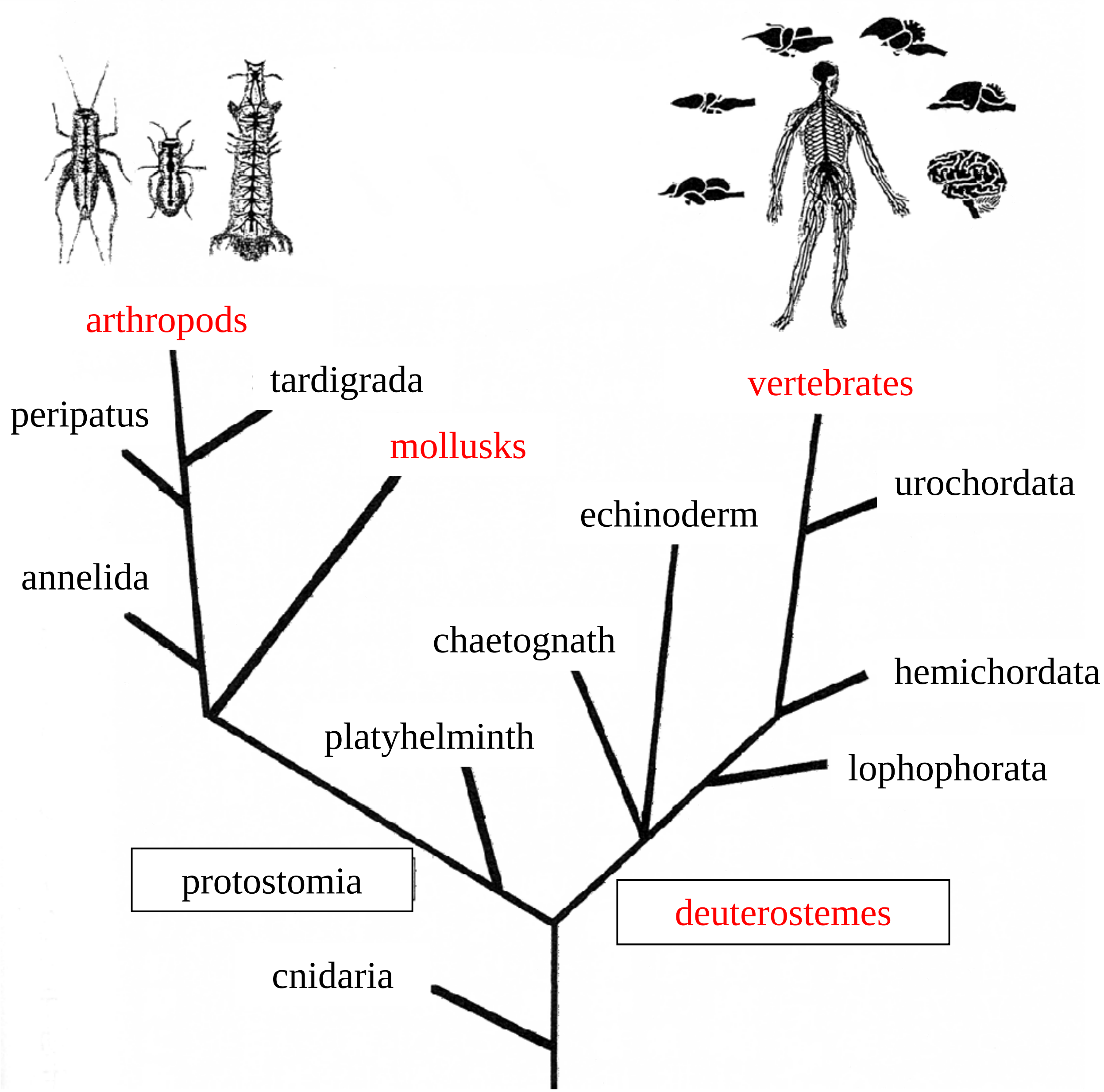
Various Animals Living on the Earth



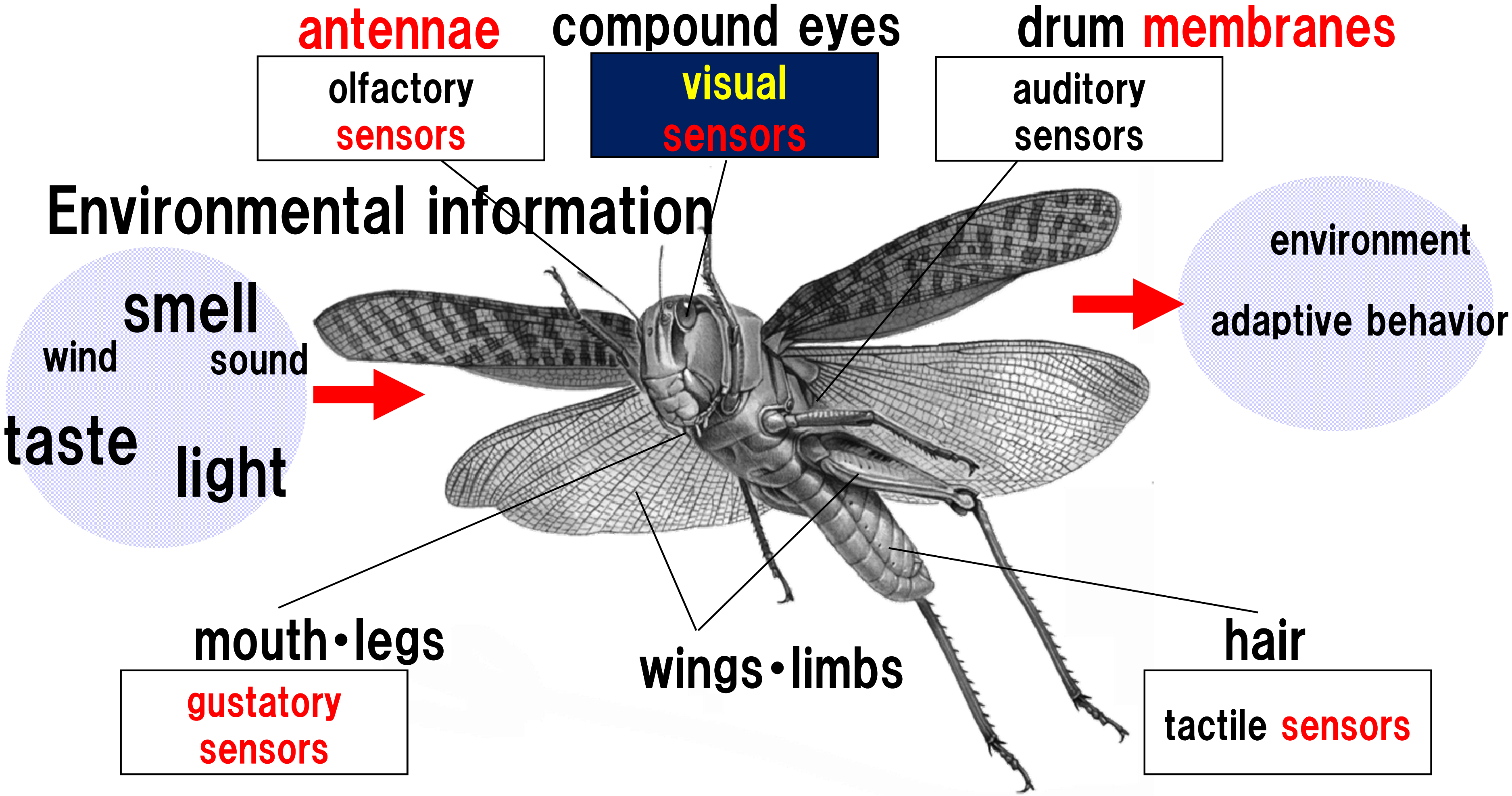
More than 70% of creatures on the Earth are insects.

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

Insects have experienced an utterly different phyletic evolution than humans.



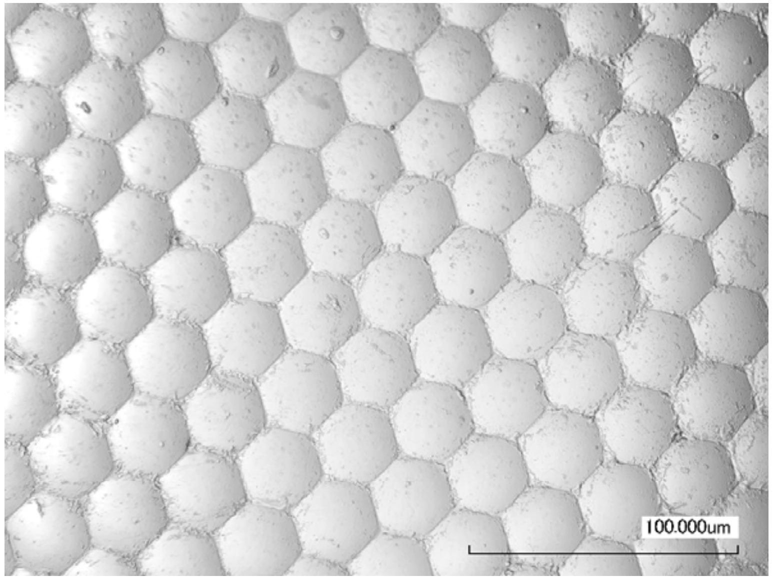
Insects' Sensory World (visual sensors)

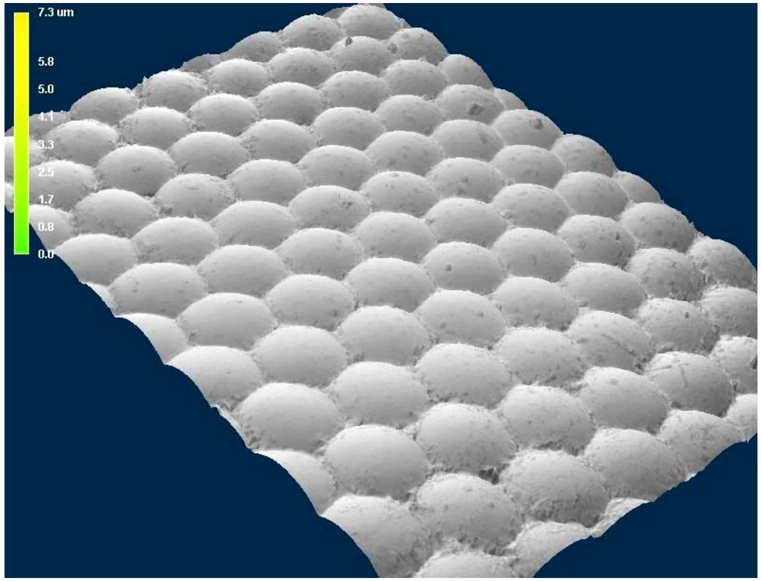


Insects’ Visual Sensors（Compound Eyes）

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）

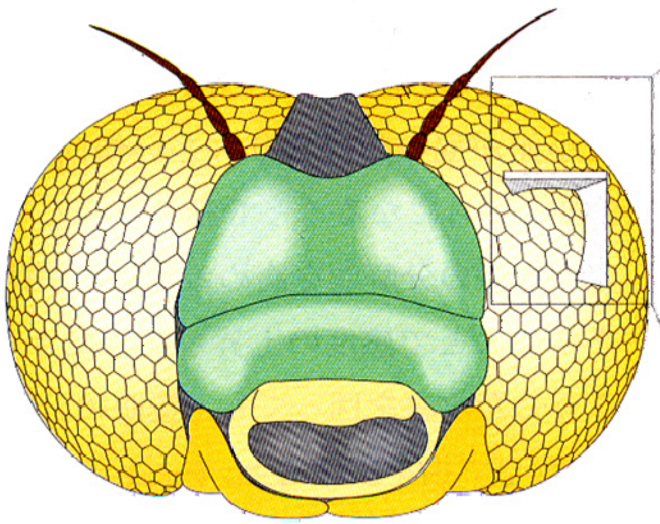
1） Optical flow
2） Subject detection
3） Visual action reflexes

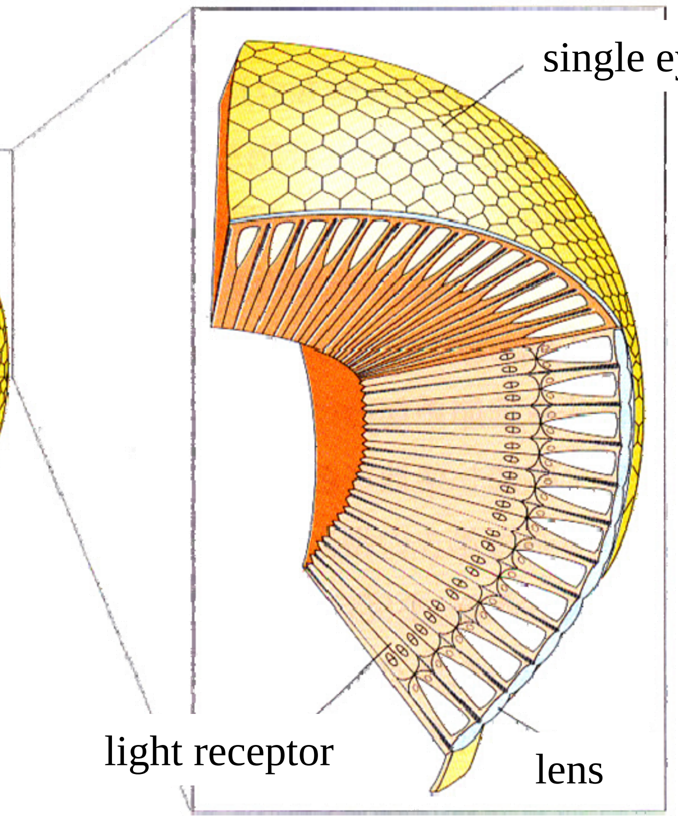
Low-space resolution

Distance information：Stereovision cannot be used structurally

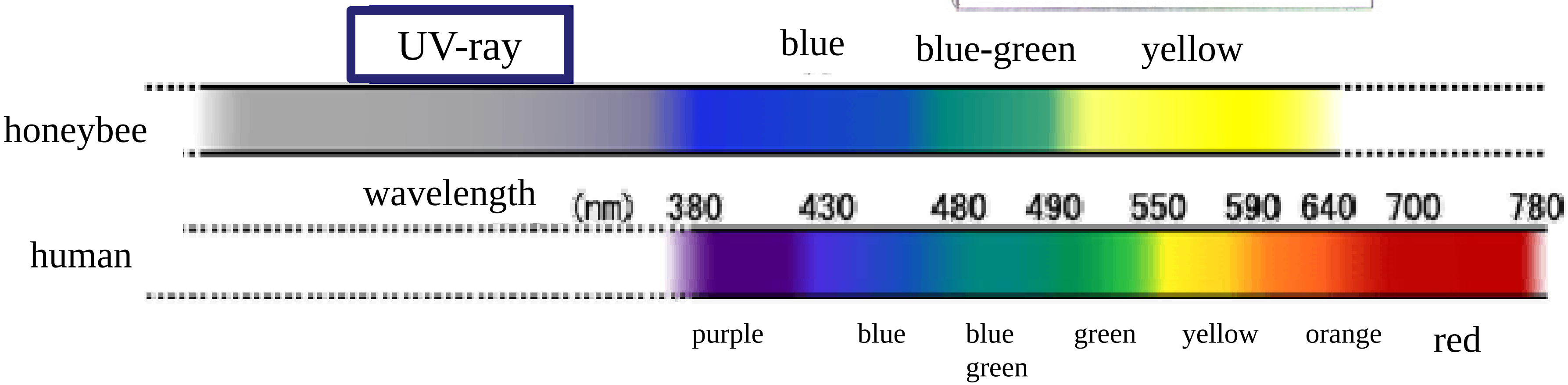
Dragonflies have a different optical structure than humans

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

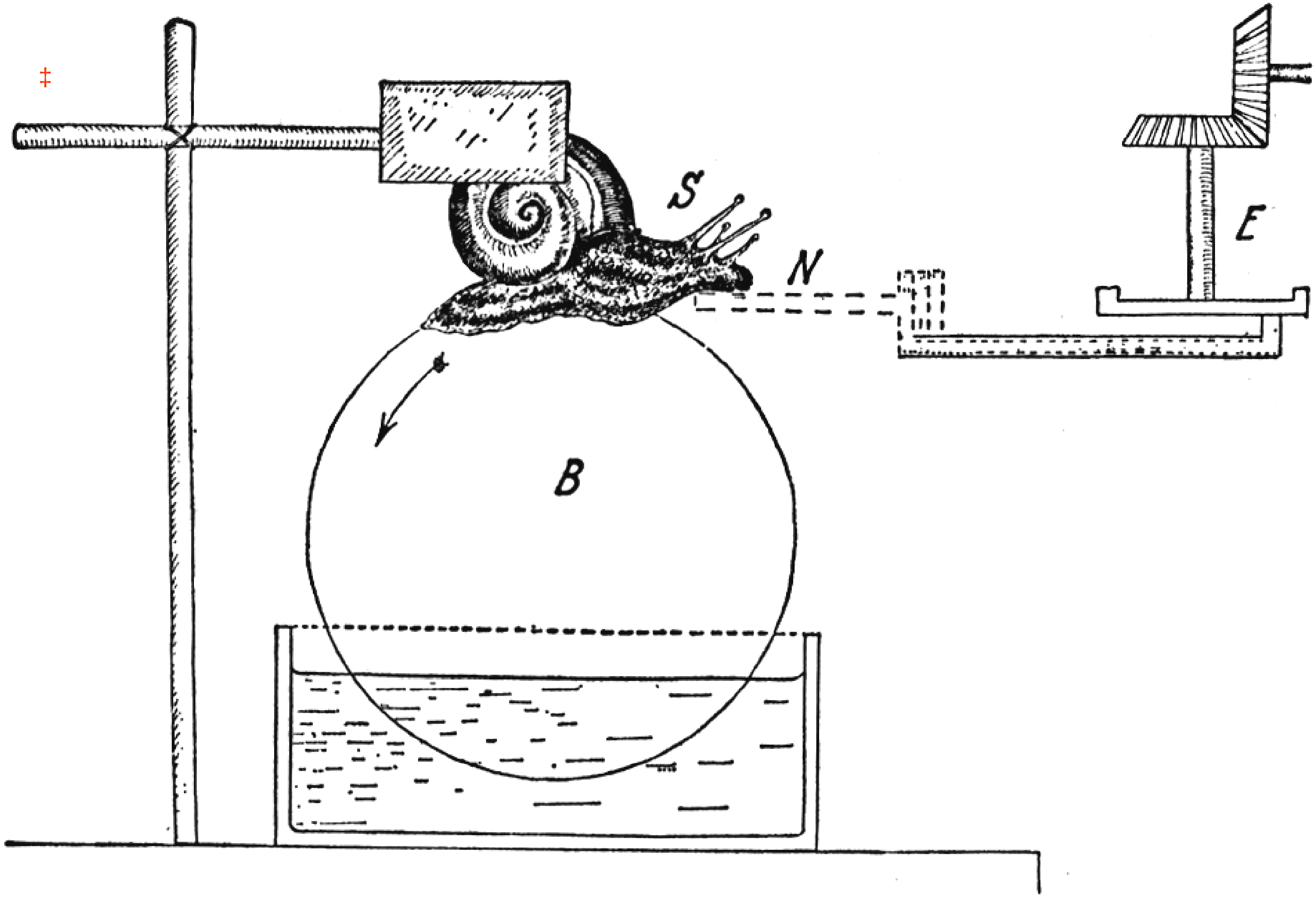


Fig.16 At a Snail's Pace B: rubber ball E: eccentric wheel N: stick S: snail

"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：

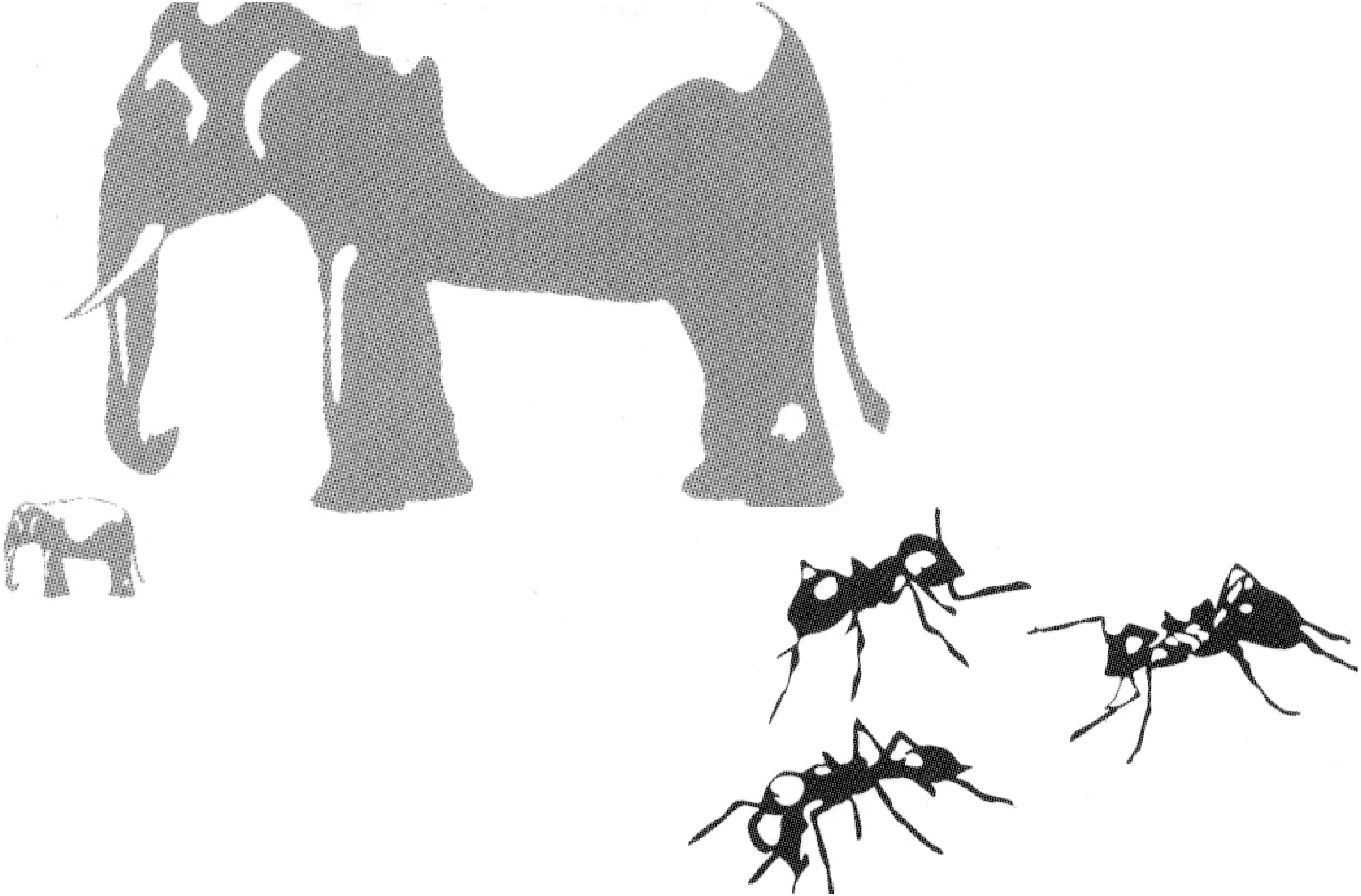
time resolution of vision

The CFF of Various Animals

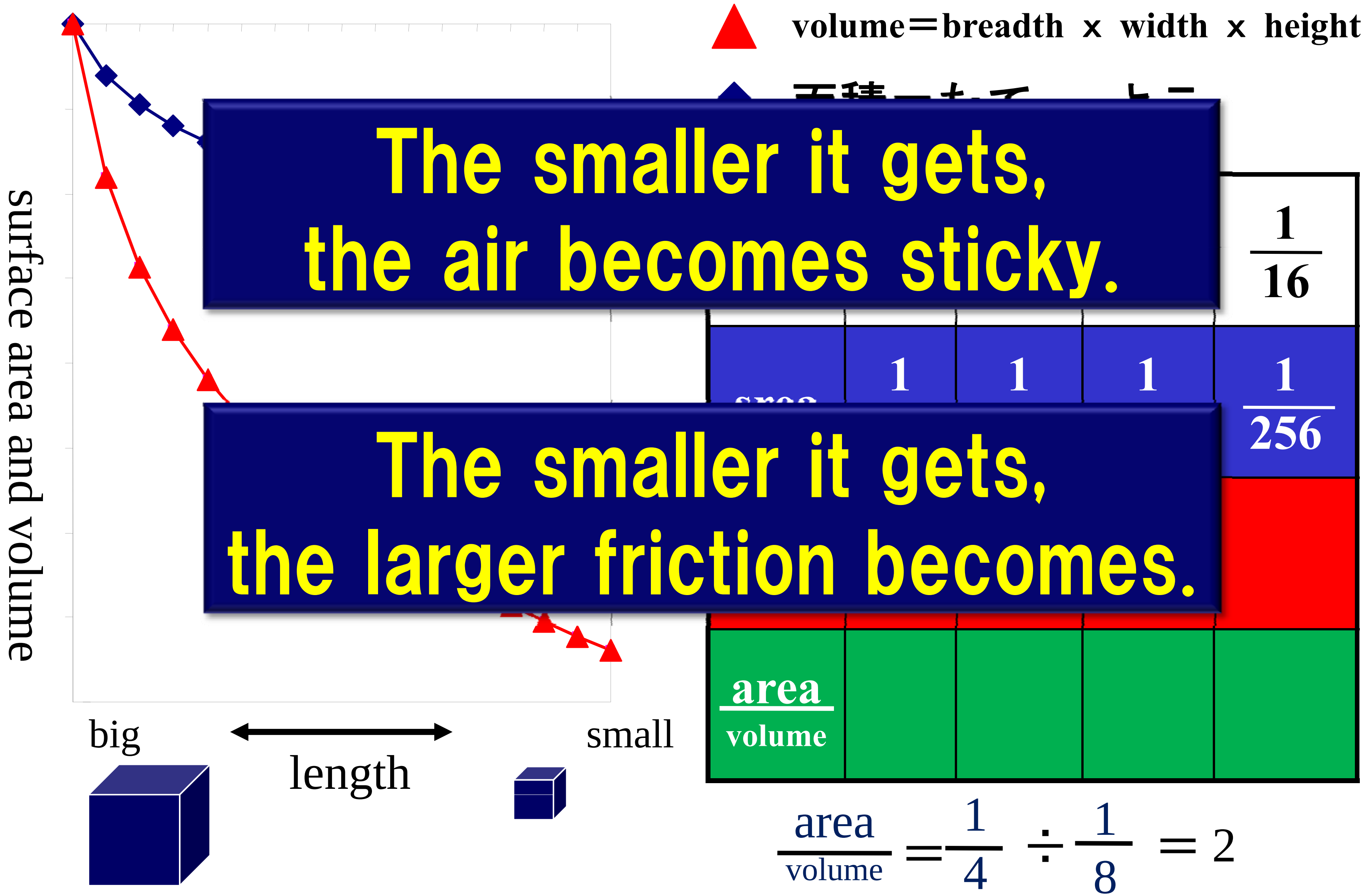
(weak light ー strong light. Animals with only one value were exposed to strong light.)

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

The World of Size



Scale **Effects**



The smaller it gets, the air becomes sticky.

The smaller it gets, the larger friction becomes.

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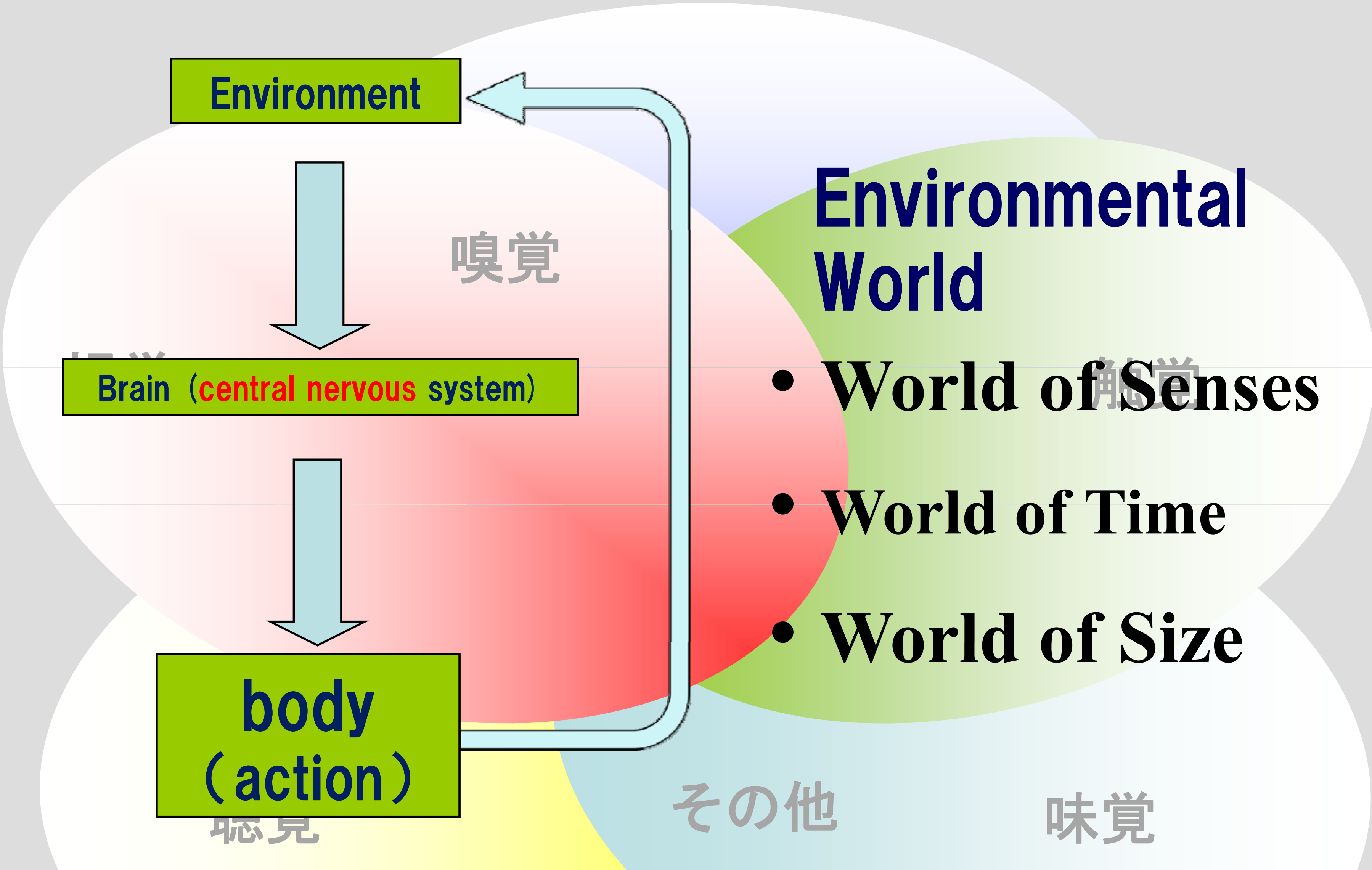


Environmental World

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

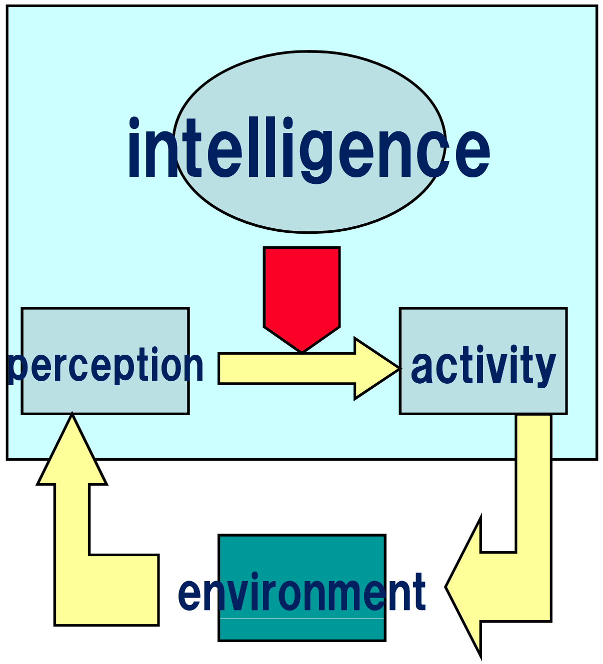
Information about how to move in an environment.

Some environmental information（its key stimuli）determines movement.

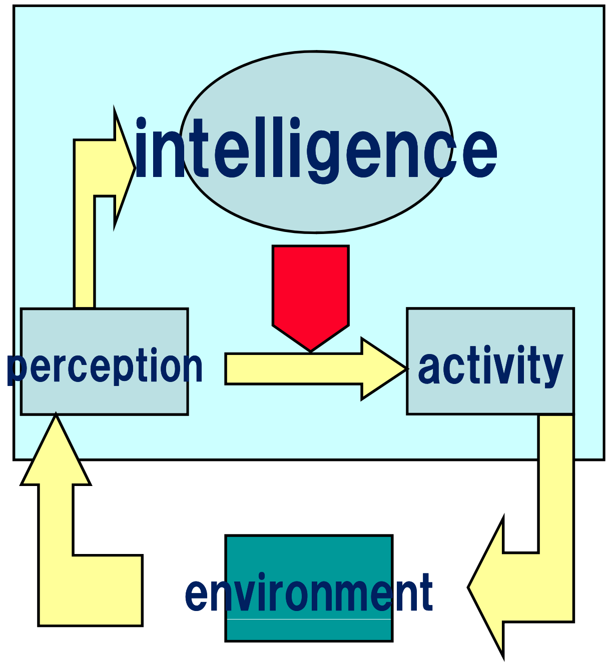
The Concept of Intelligence

robotics and mobiligence

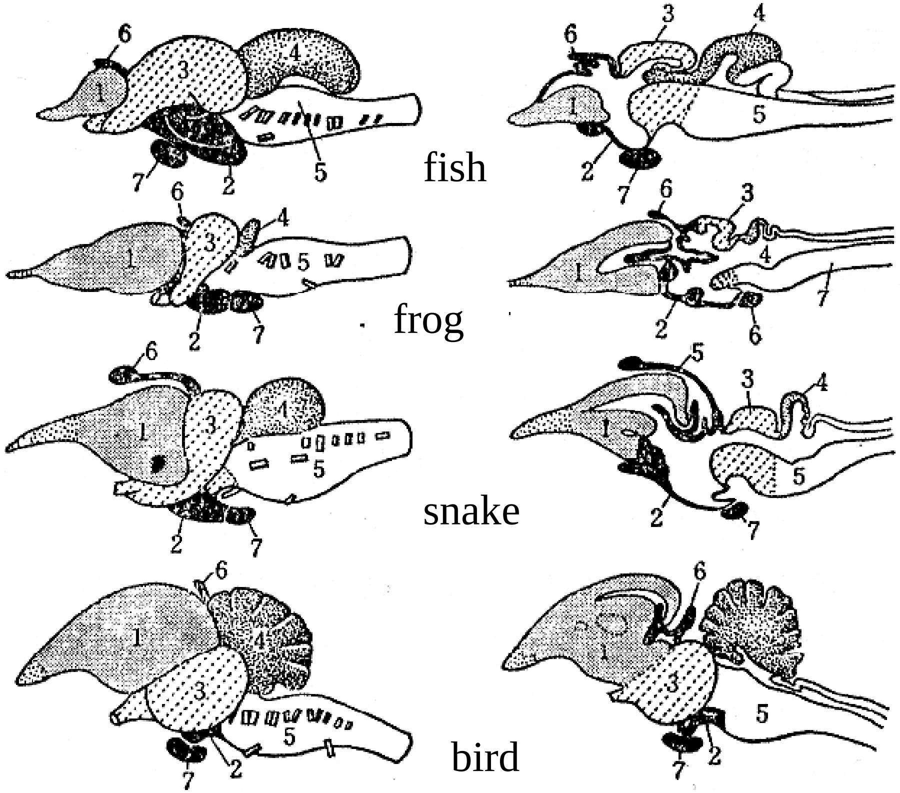
past robotics



mobiligence



The Brains of Various Animals



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

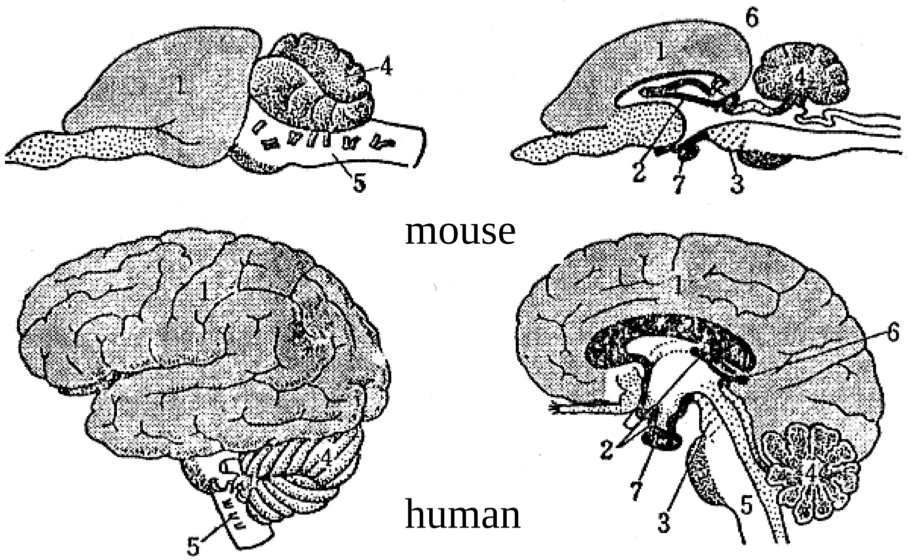
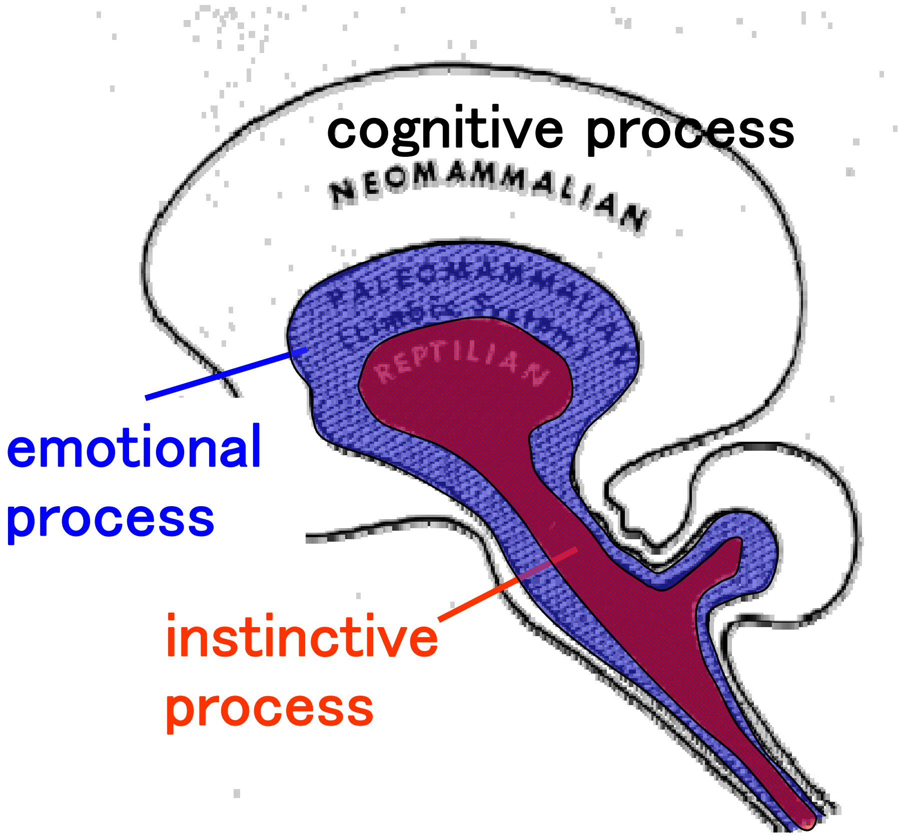


fig. 1-1 systematic evolution of vertebrates 1. cerebral hemisphere 2. interbrain 3. midbrain 4. cerebellum 5. medulla 6. pineal apparatus 7. hypophysis

The Layered Structure of the Brain



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

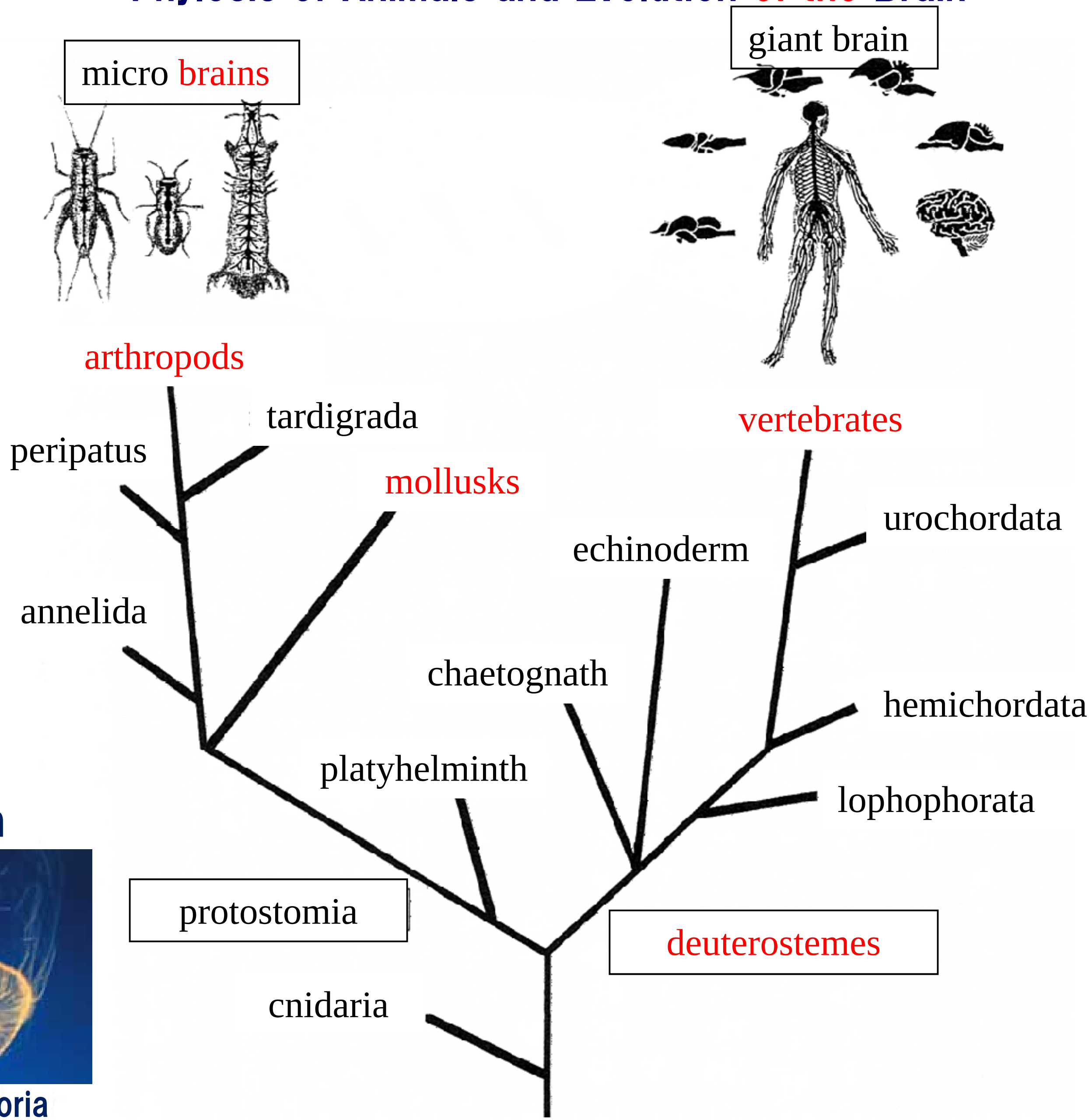
neomammalian brain : neocortex
cognitive process

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

Phylesis of Animals and Evolution of the Brain



cnidarian

Aequorea victoria

Discovery of the Neuron

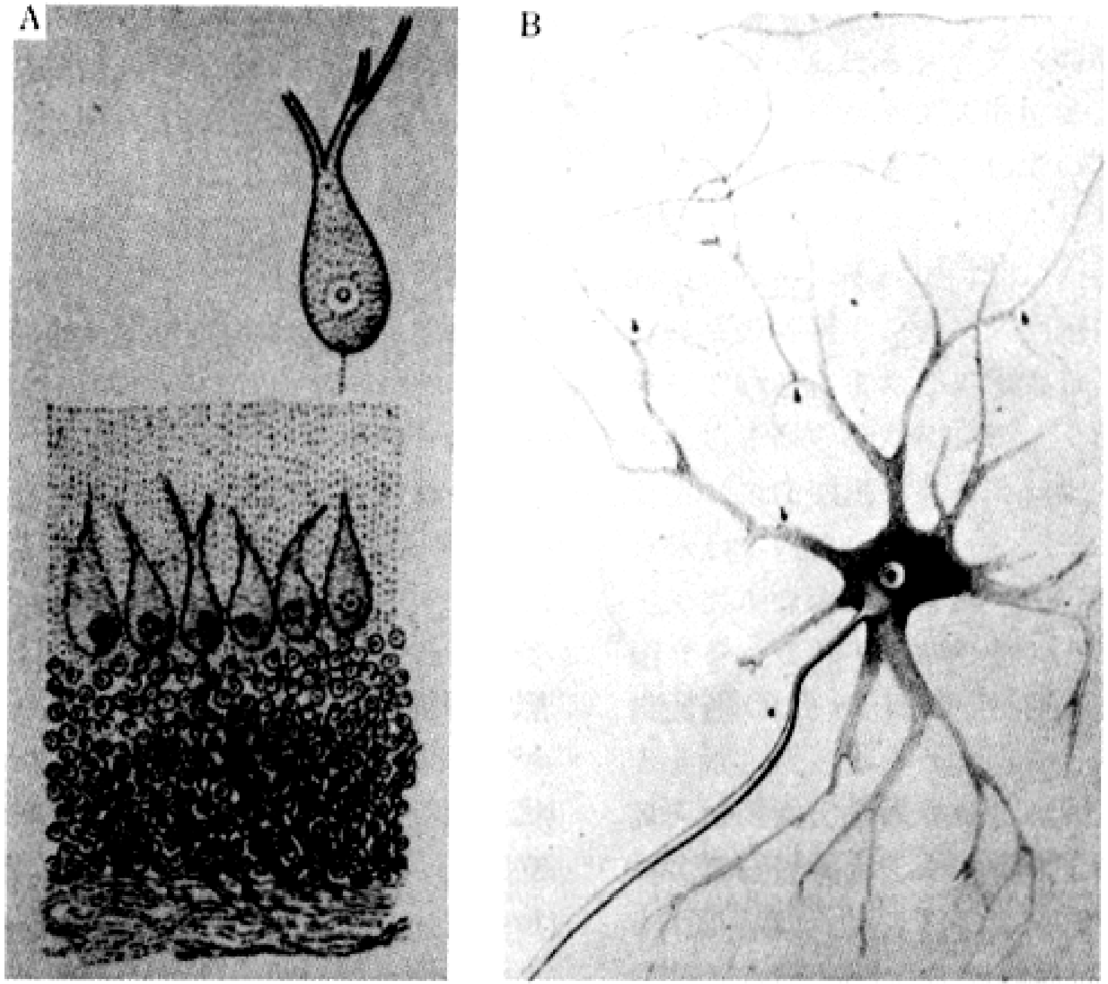


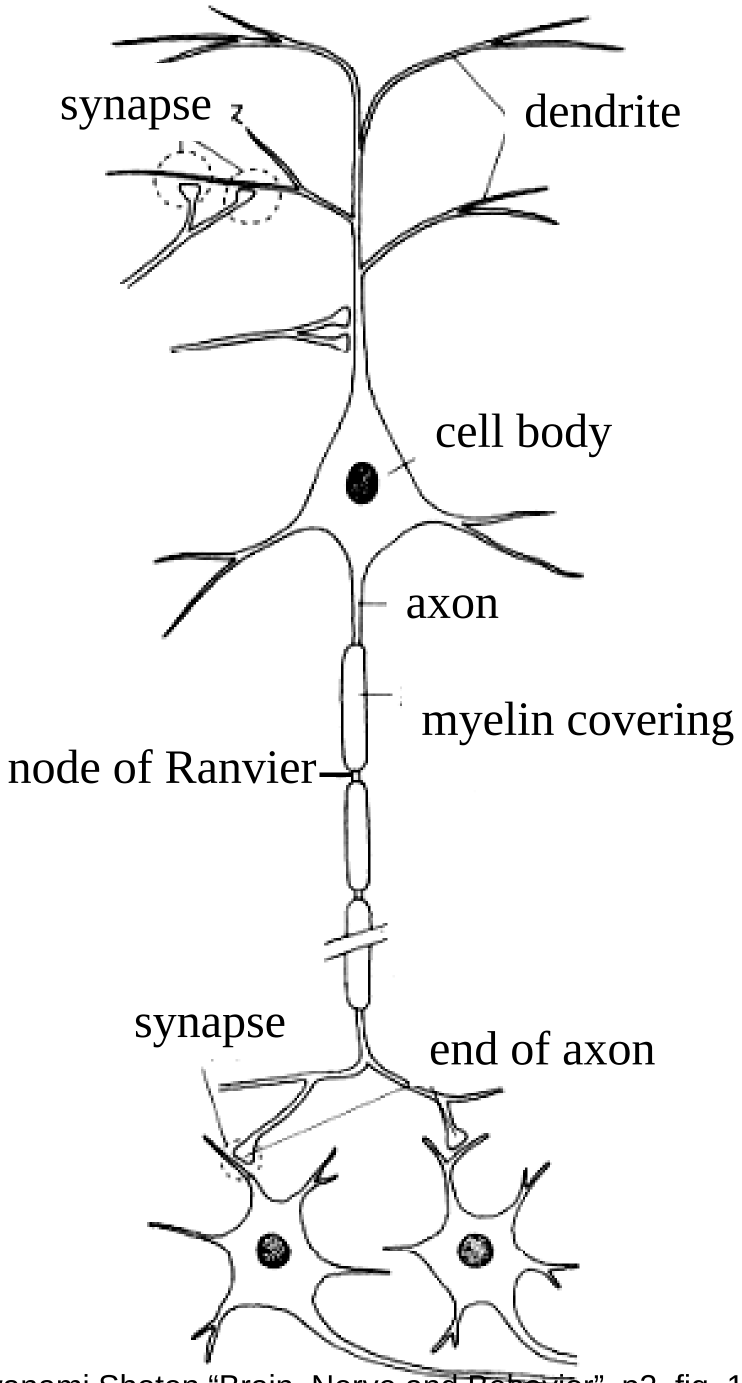
Fig 3.1 A. Neural cell in the cerebellum observed by Purkinje in 1837. Cells stuffed at the bottom are granule cells. The cerebellum will be discussed in Chapter 21. B. A large-size motor neuron in the spinal cord observed by Deiters in 1865. Focus on a long, smooth axon. This is clearly different from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

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

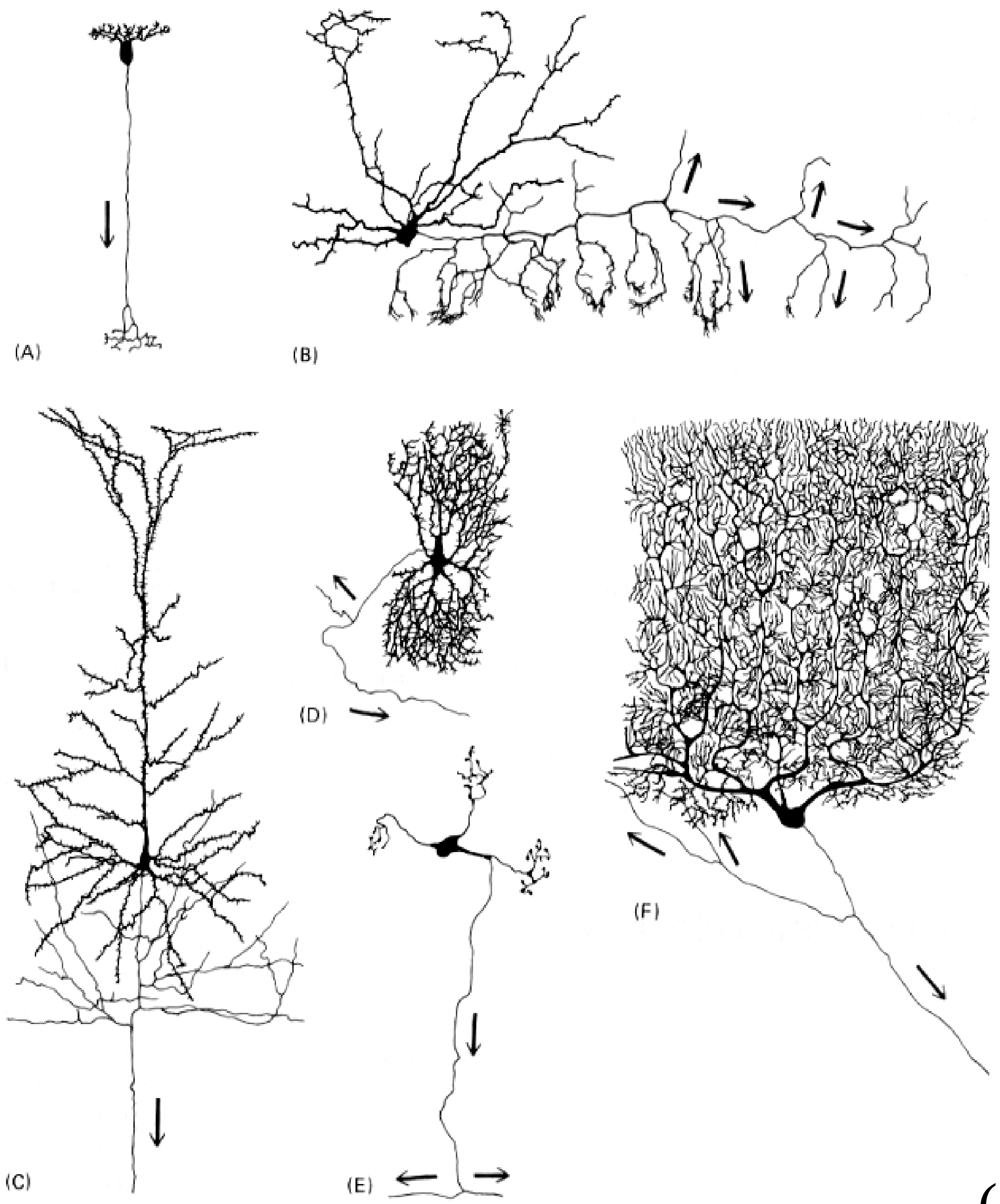
The Form of the Neuron

Santiago Ramon y Cajal

resource : wikipedia



Different Forms of Neurons

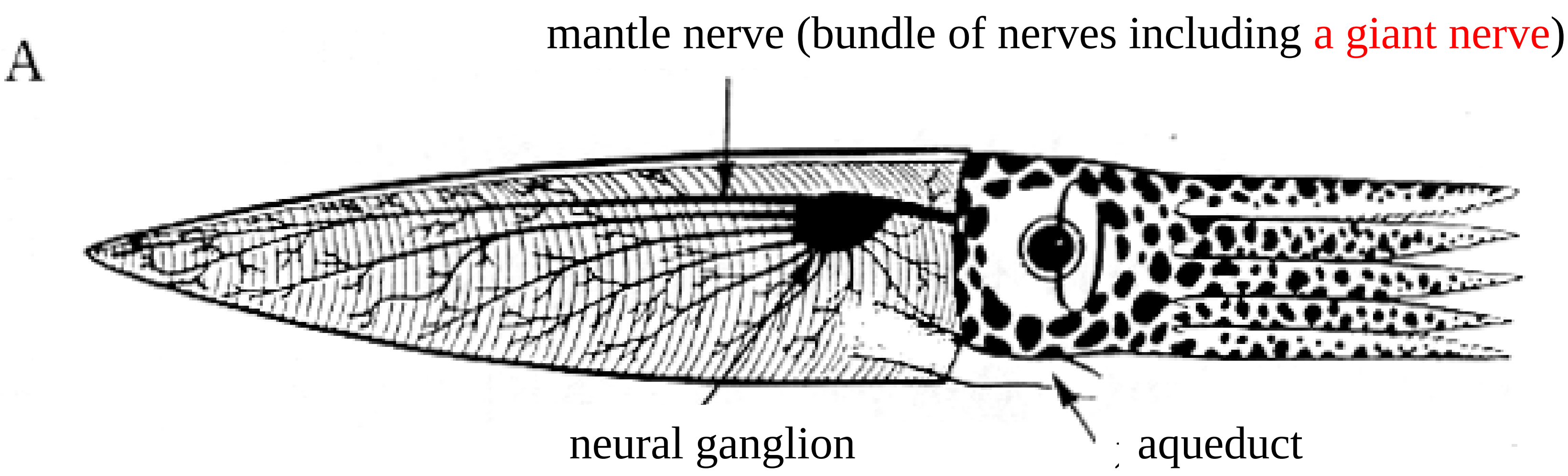


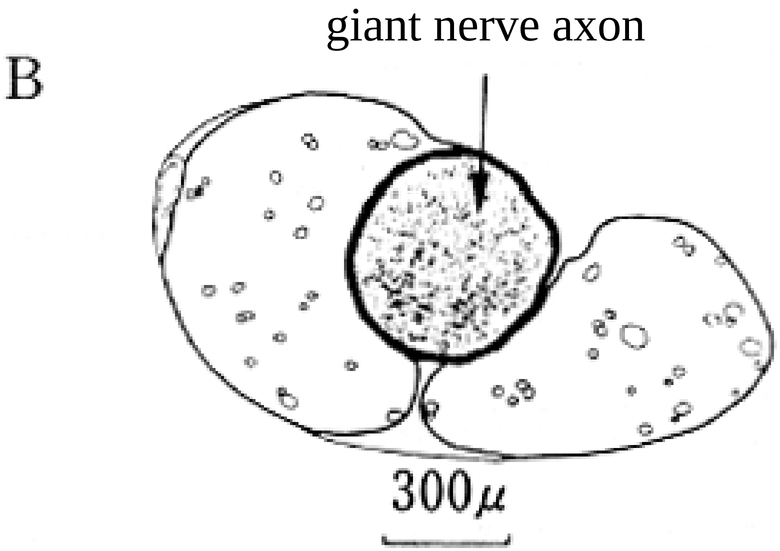
A)Lizard retina - bipolar cell
B)Mouse - cerebellum basket cell
C)Rabbit - cerebral cortex pyramidal cell
D)Cells of a human brain stem

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

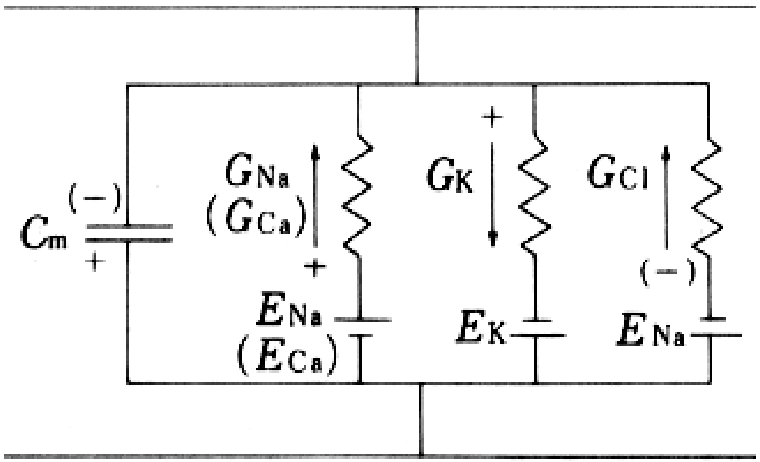
Eccles, J.C. 1977 2nd Ed.

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)

Quantitative Record of Neural Excitation
Hodgkin & Huxley, 1952

inside the cell



outside the cell

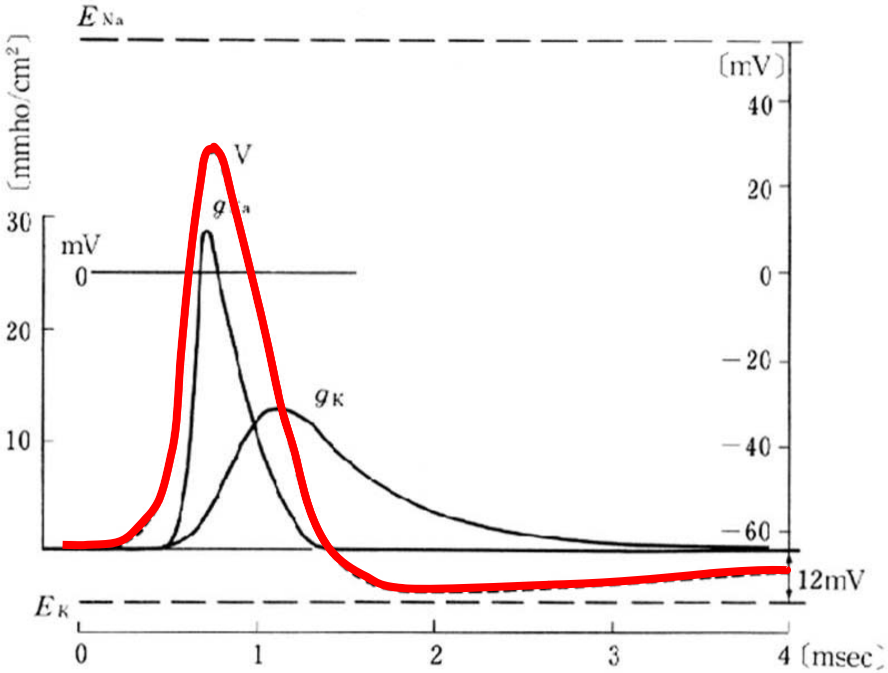


図 2・6 g_{Na} と g_K の変化と活動電位〔Hodgkin, A.L. and Huxley, A.F., 1952b〕

current in a membrane
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.

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

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

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

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

The Neural Circuit: Data Processing by Nerves

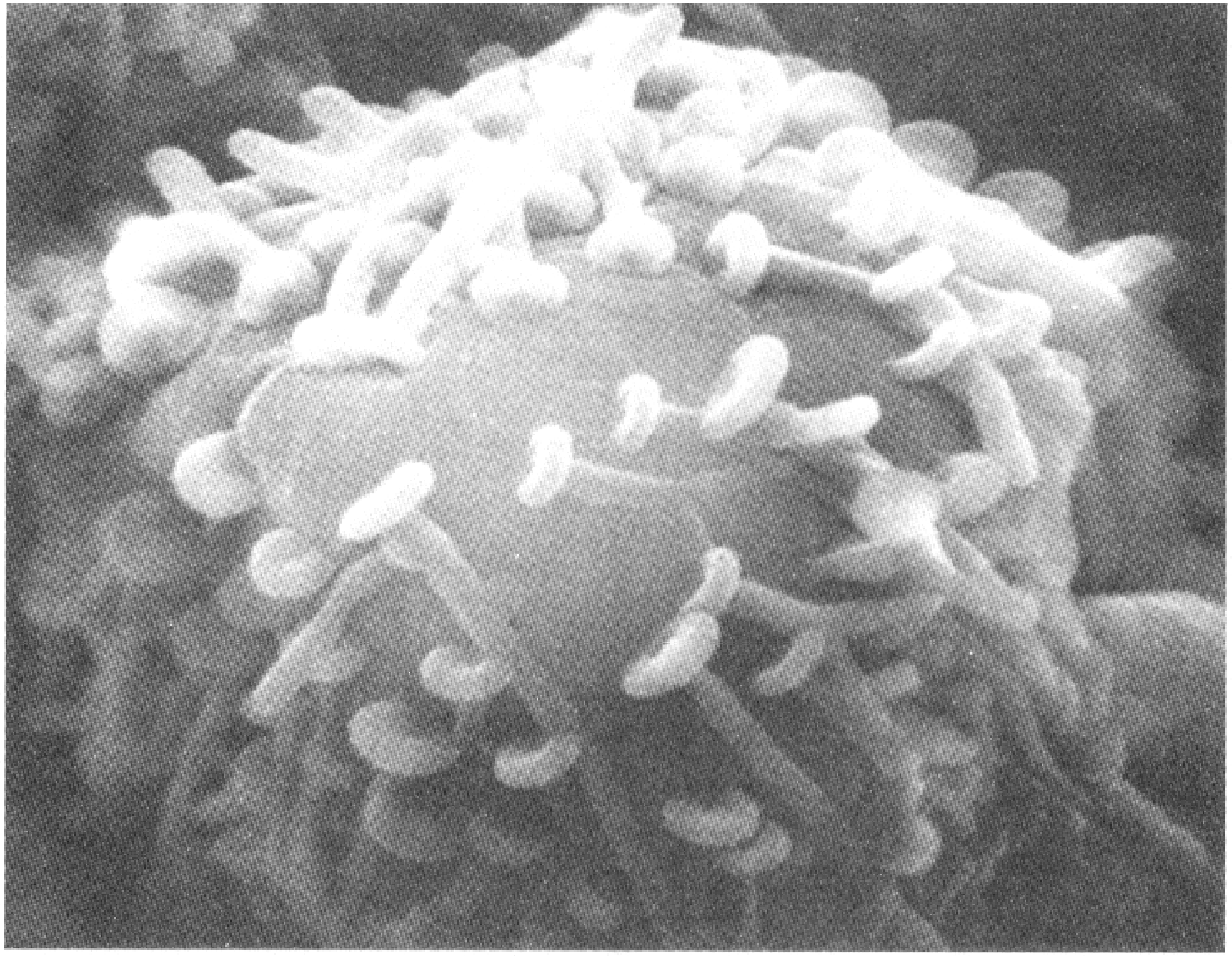
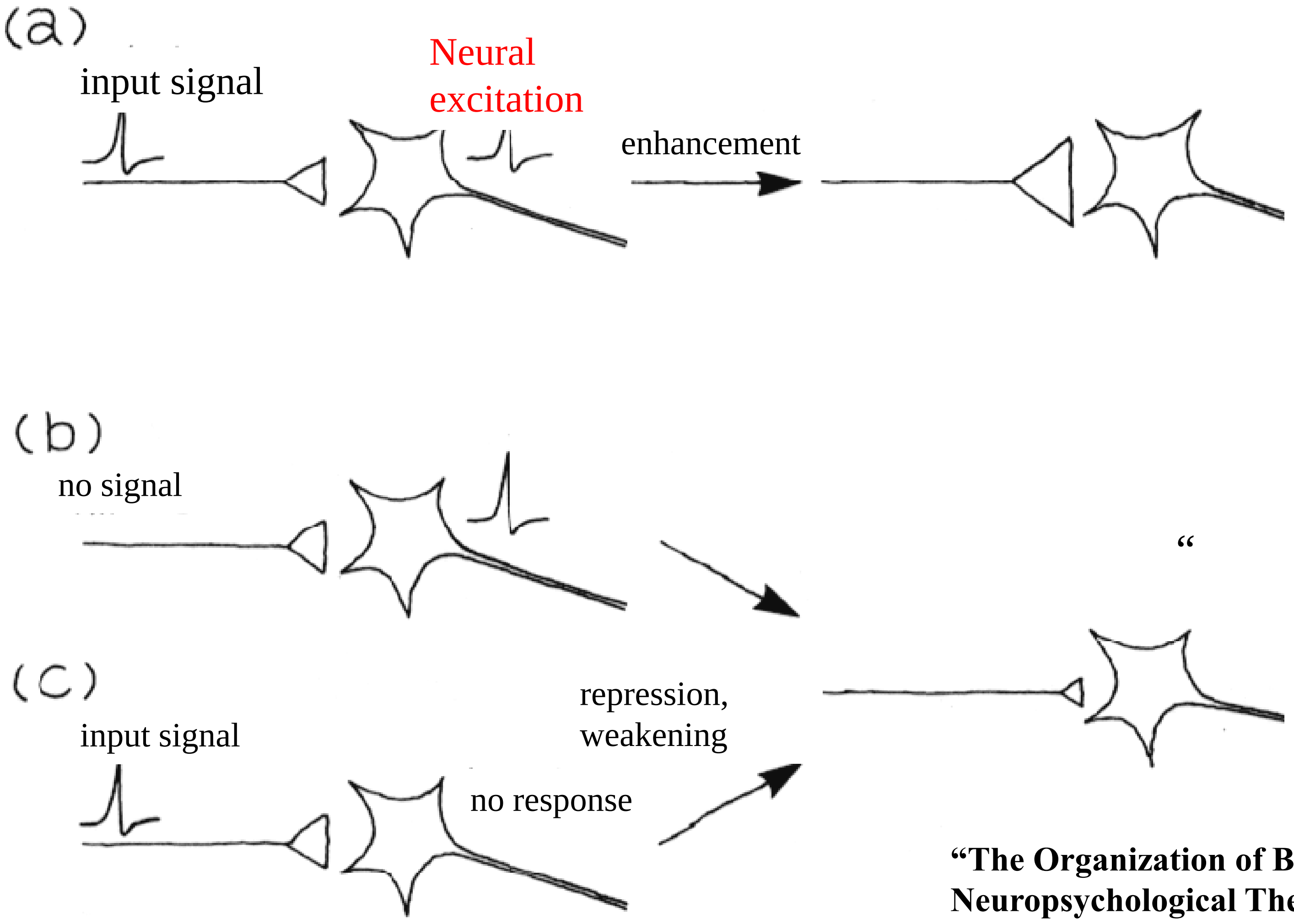
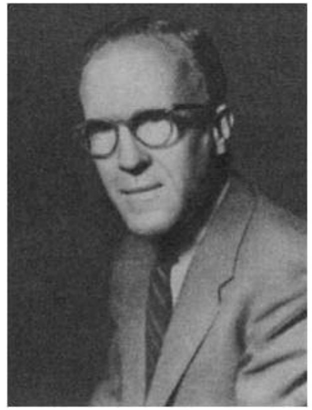


Fig 6-C. End of an axon-formulating synapse in another neuron. 3-dimensional interactions of micro structures are understood by an electron-scanning microscope

Hebb-Type Learning





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

“

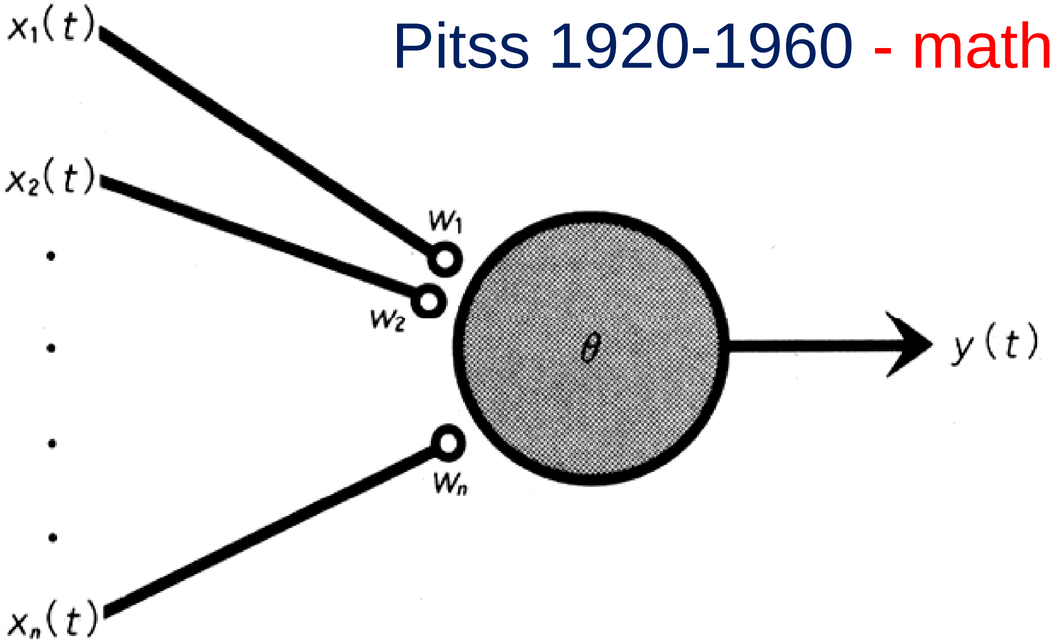
“The Organization of Behavior : A Neuropsychological Theory” (1949)

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



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

ただし,

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

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

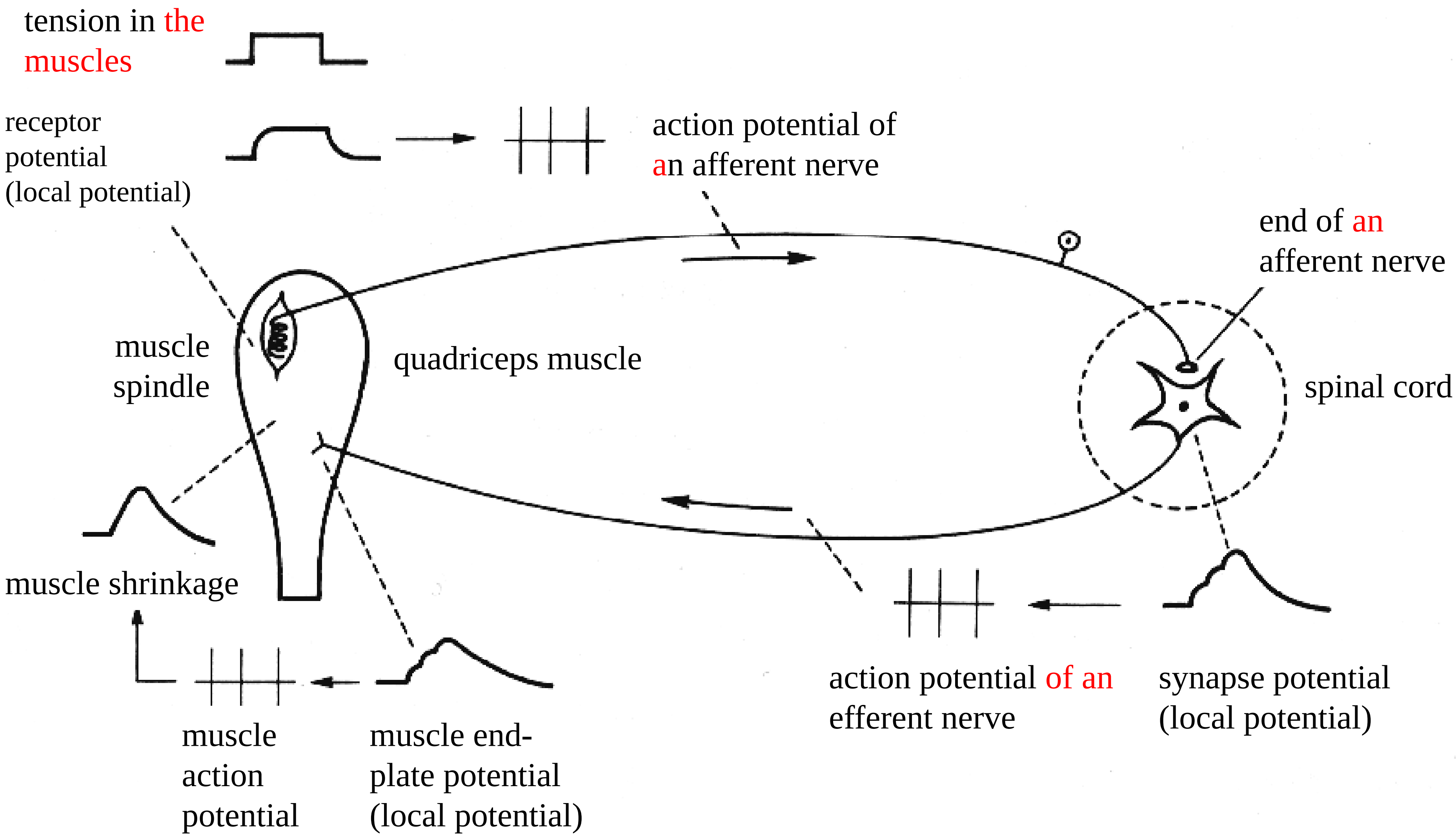


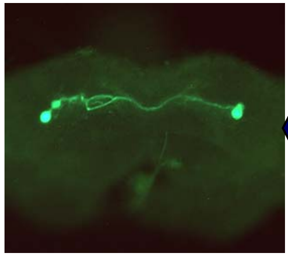
Fig 1.8 Signals used in patellar tendon reflexes

Technologies in Sensors and Brain Research

System from sensory input to action output

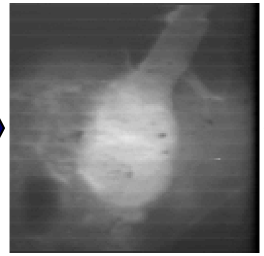
sense ⟷ brain ⟷ action

Approaches from Different Levels



genes

neurons



nerve cycle

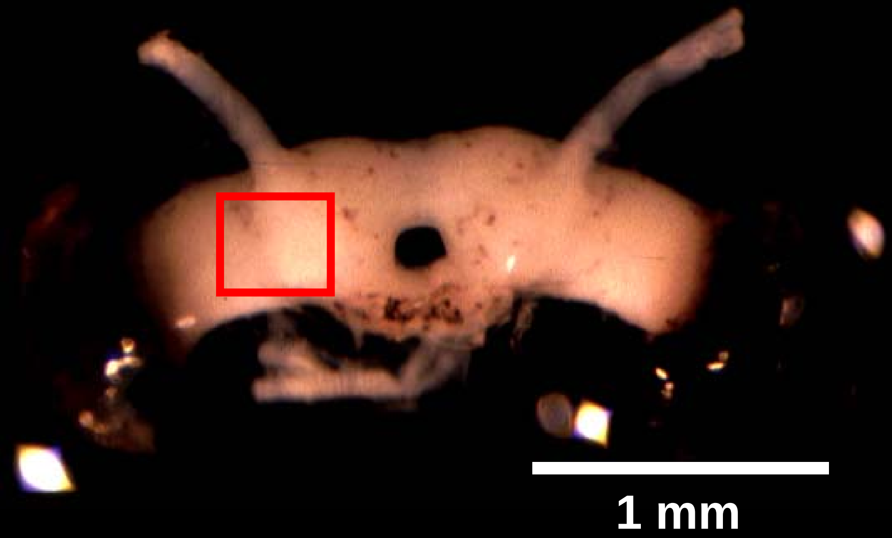
action

Approaches by Analysis and Integration

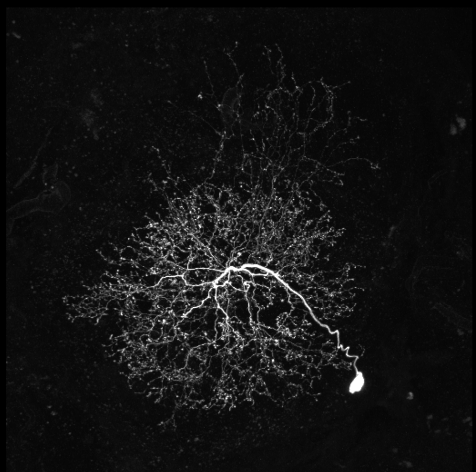
molecular biology ⟷ neurophysiology behavioristics ⟷ computer simulation ⟷ robotics

⟵ Analysis ⟶ ⟵ Integration ⟶

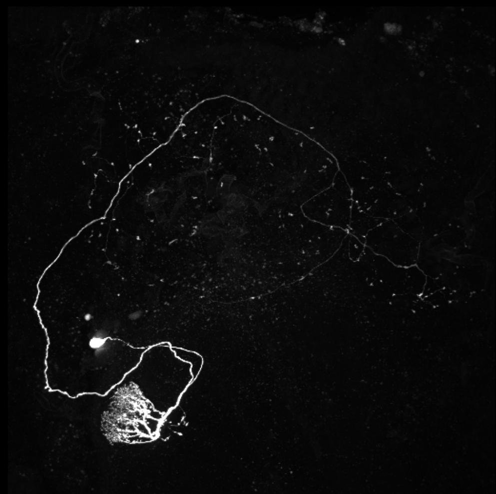
Model Brain and Visualization of a Single Nerve Cell



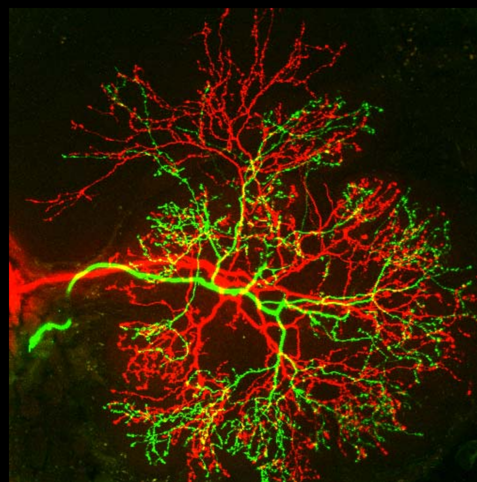
differential interference - microscopic view



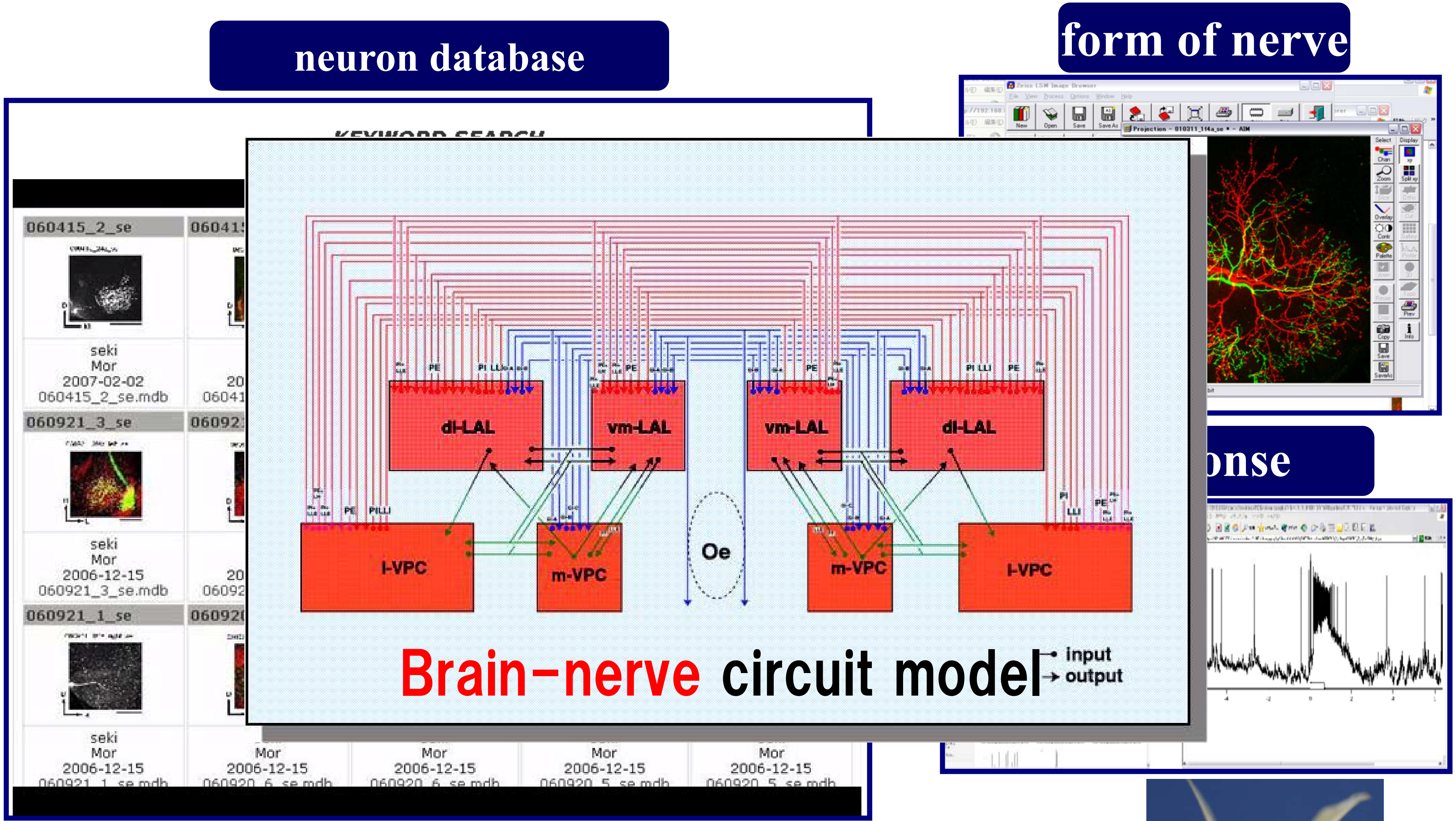
local interneuron



output nerve

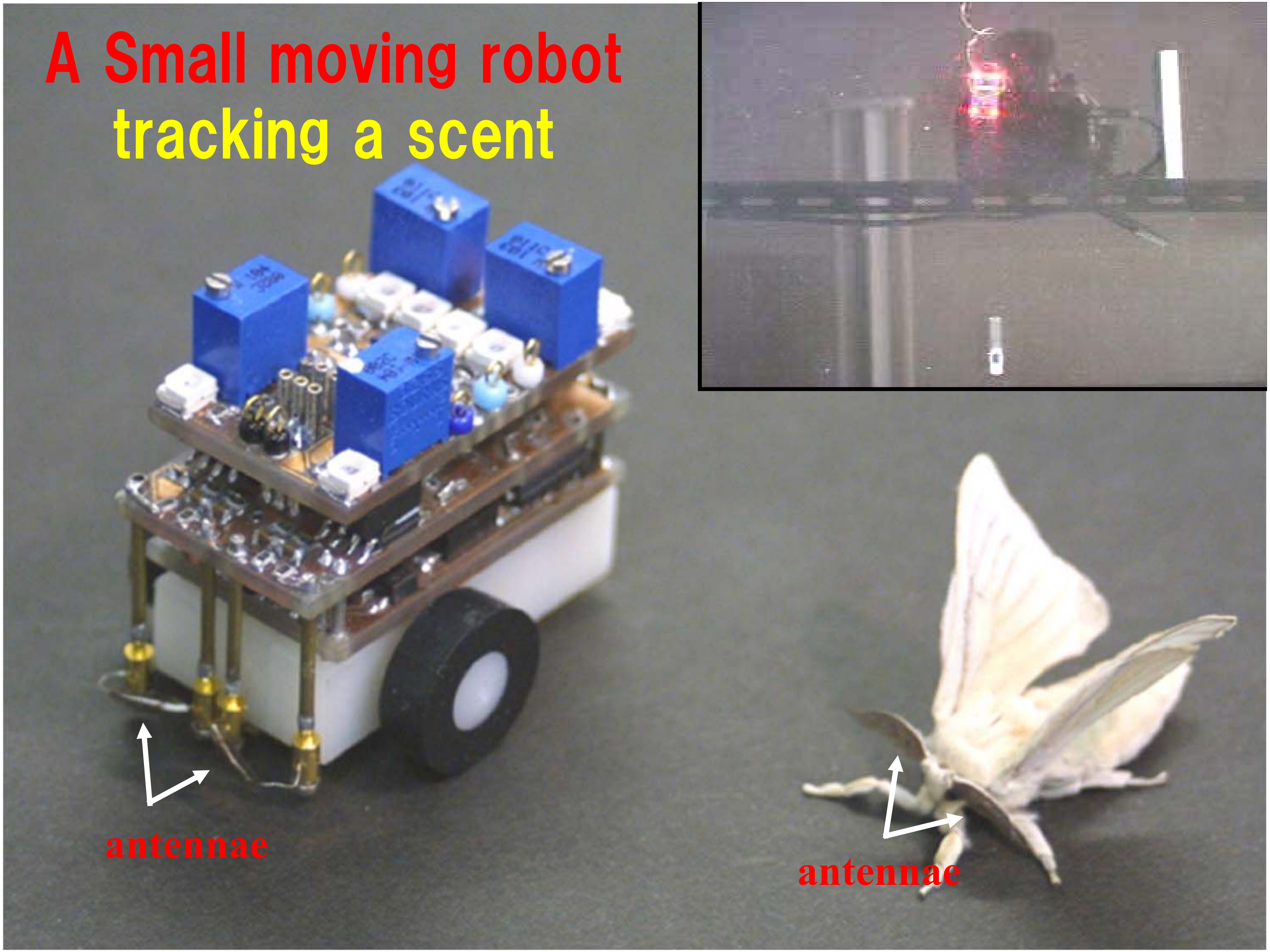


Cyclopedic Database of a Model Brain-Structuring Neuron



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

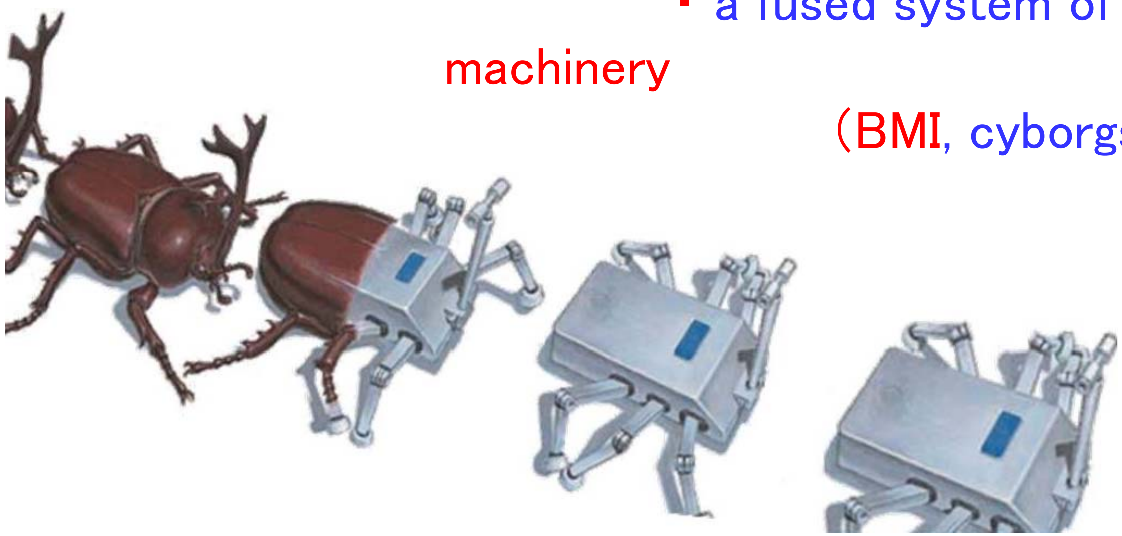
Bombyx mori


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 hen they have discussions, do research and develop technology, internationally competitive research will be born.

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

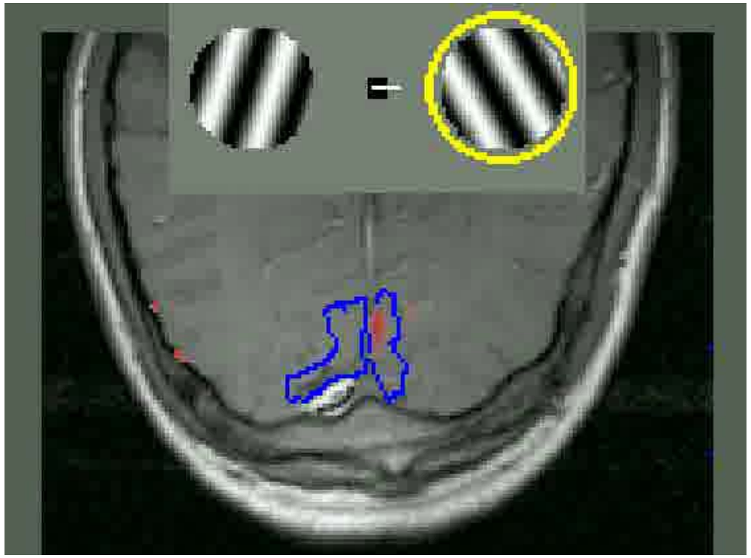
"Reading the Brain"

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.



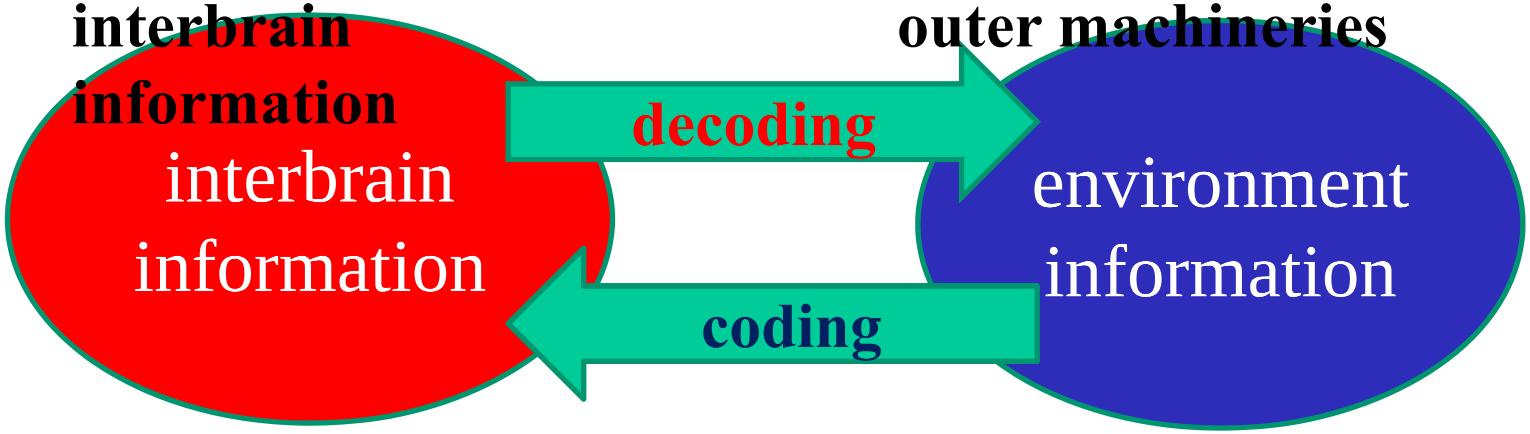
http://viperlib.york.ac.uk/index.asp

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.

Extraction of interbrain information

Control method of outer machineries

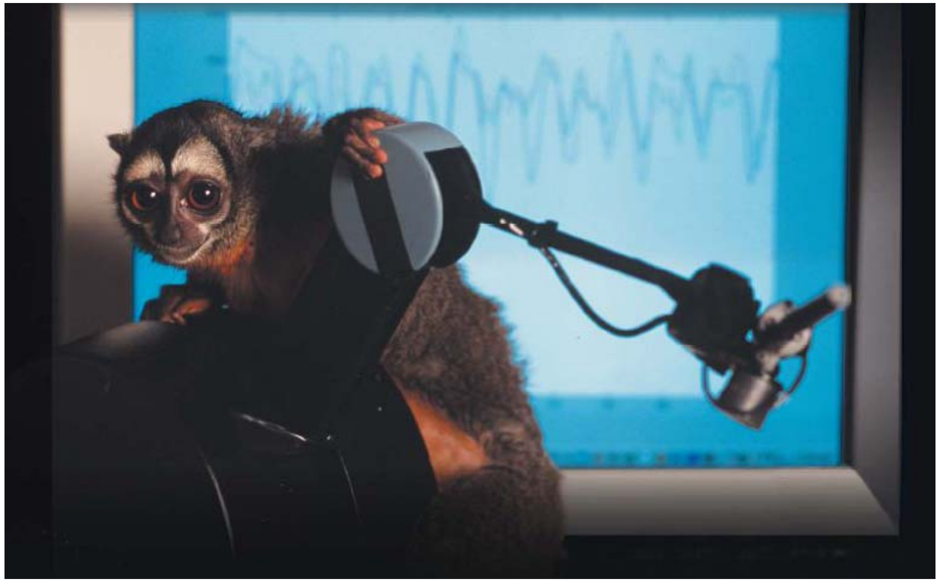


regulation of brain functions

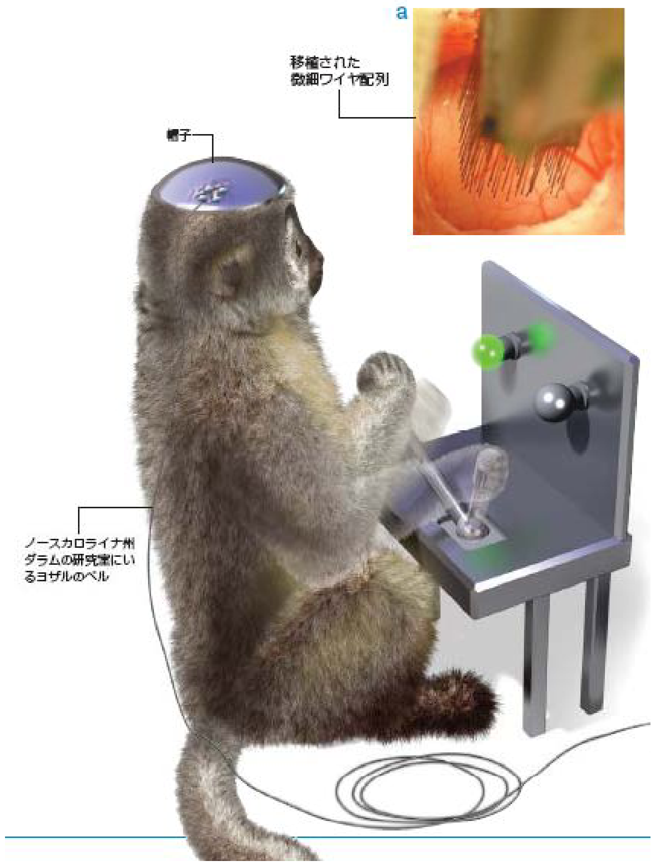
detection of the environment

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.



M.A.L. Nicolelis, 、J.K. Chapin：Nikkei Science , Jan 2003

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

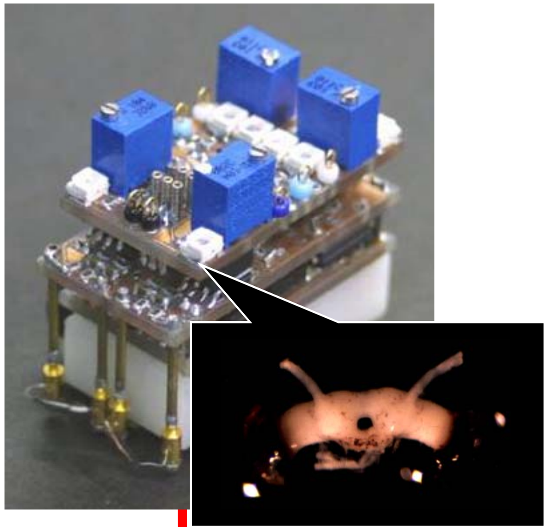
■action output type

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

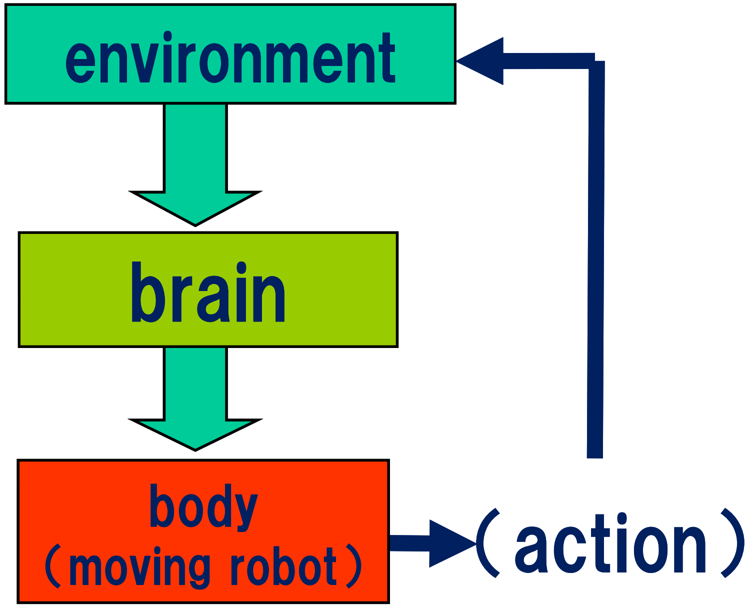
■Deep Brain Stimulation (DBS)

Principles of the BMI

Body of a moving robot



Transformation of a body into a robot (control of a robot by the organism)



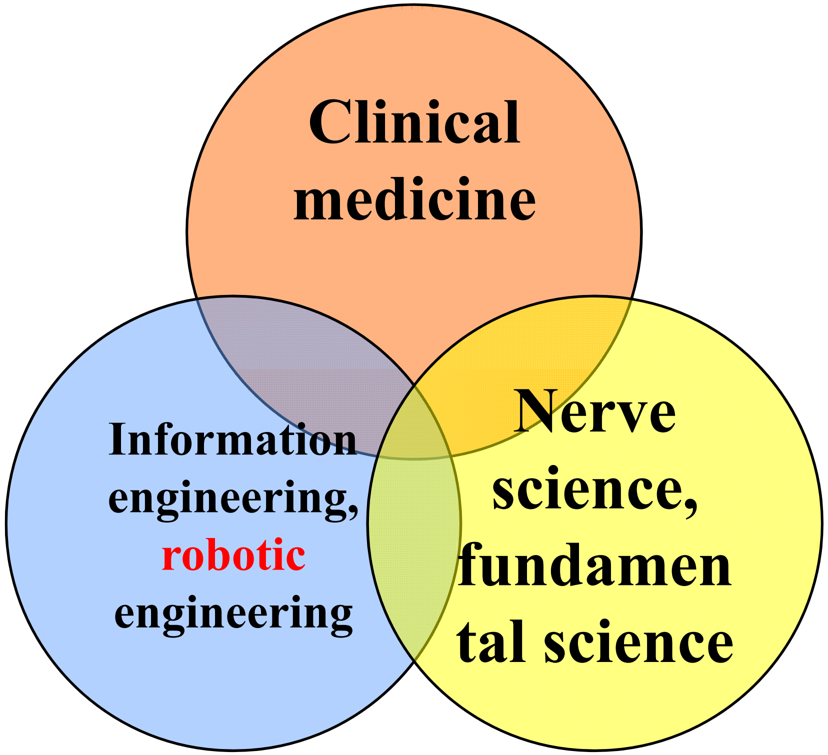
Robot body

Environmental input /changes.

Normal function appears by adaptive system of the brain.

Purpose of the BMI

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



<u>Clinical medicine</u>

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

<u>Information engineering, robot engineering</u>

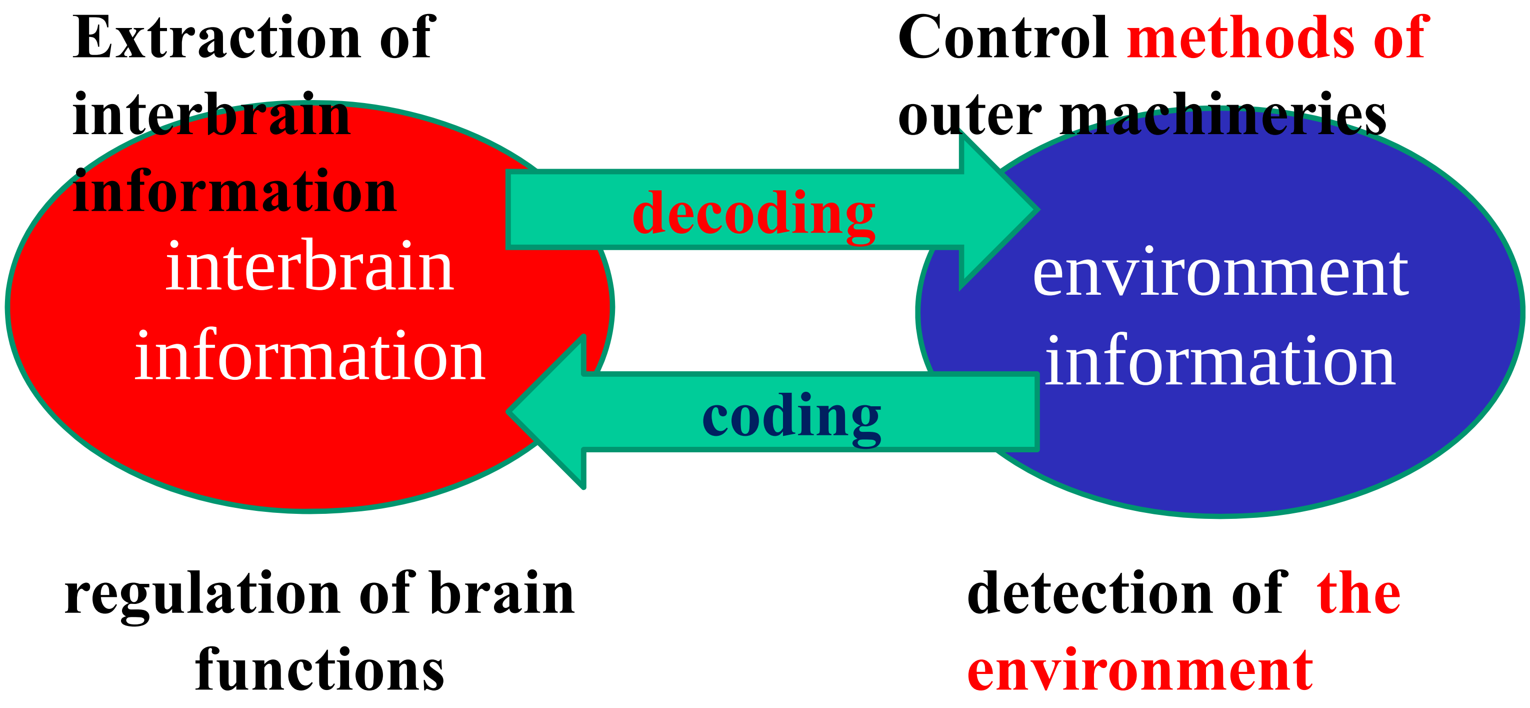
- **Manipulation of a super-free robot**
- **Communication by sending and receiving interbrain information**

<u>Nerve science, fundamental science</u>

- **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



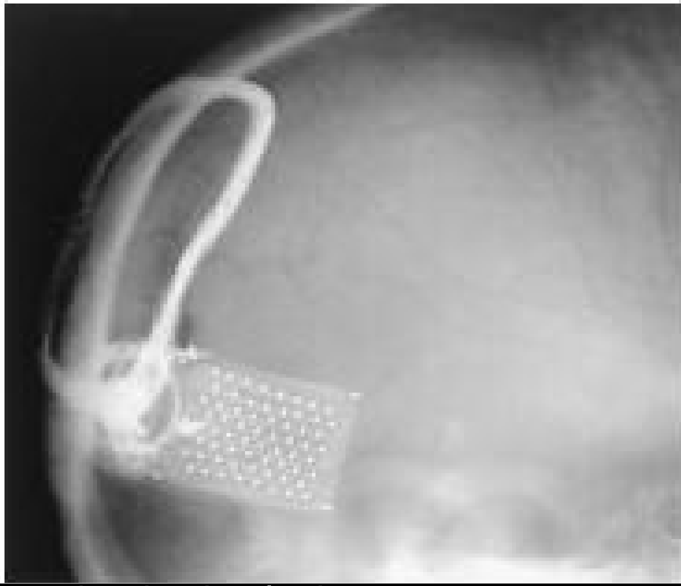
Cochlear Implants

<u>transmission deafness</u>
Disorders developed between the outer and middle ear.

<u>perceptive deafness</u>
Disorders developed between inner ear and nerve center.

Visual Prosthesis

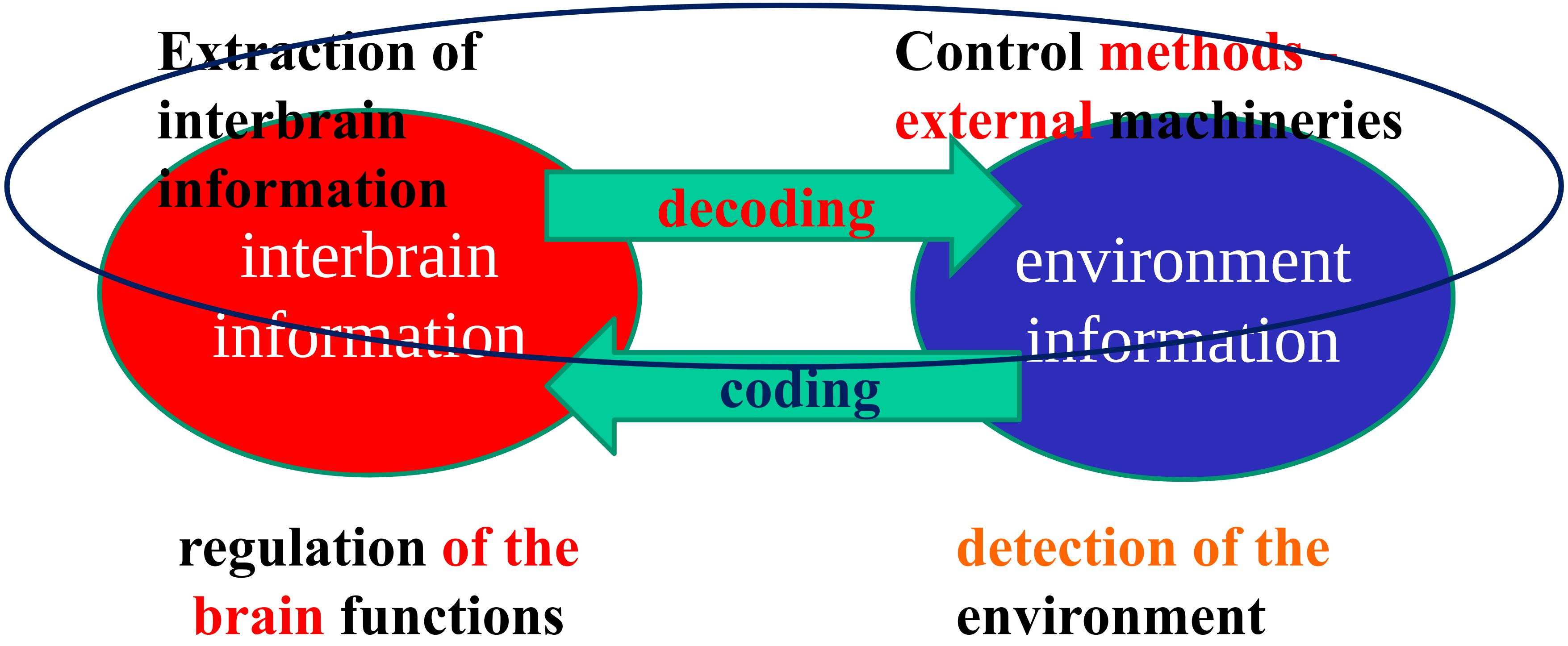
(b)



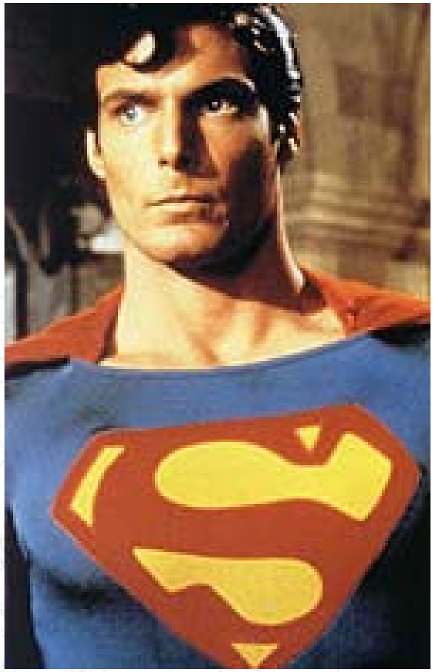
http://web.archive.org/web/20041010113607/artificialvision.com/asaio1.html Figure 1,2,4

Action Output BMI

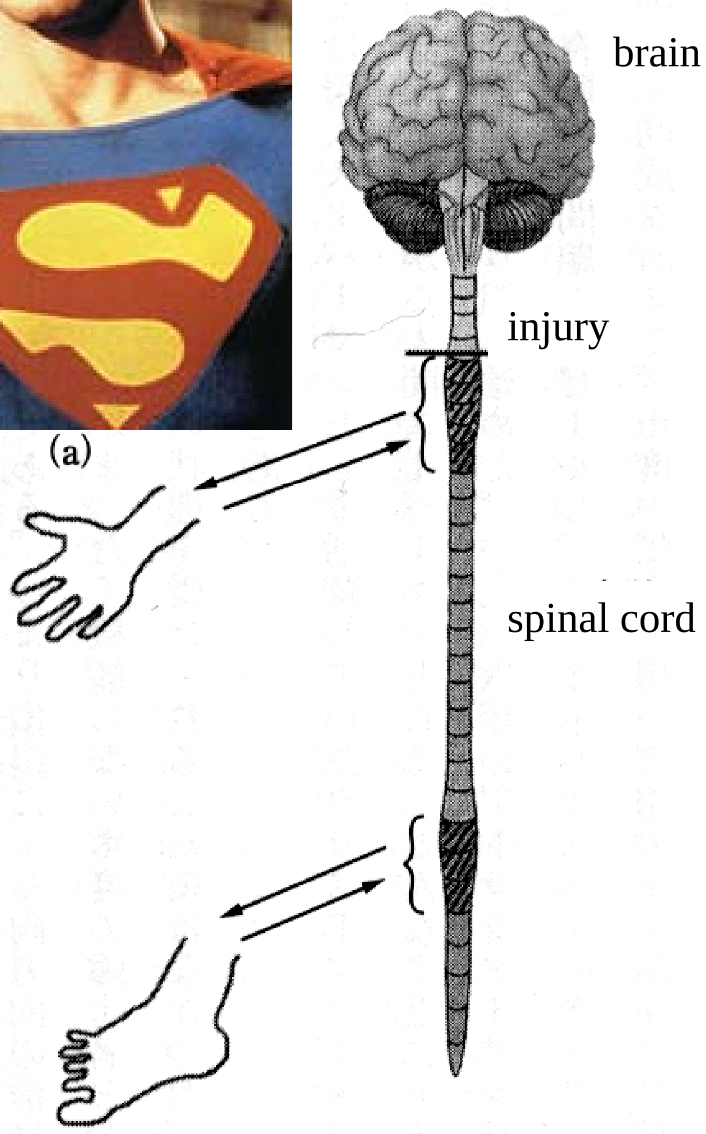
Detects activities expressed by action output from the brain and nerural activities, and manipulates robots or other external machineries.



Recovery Brain Function



(a)



(b)

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.

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.

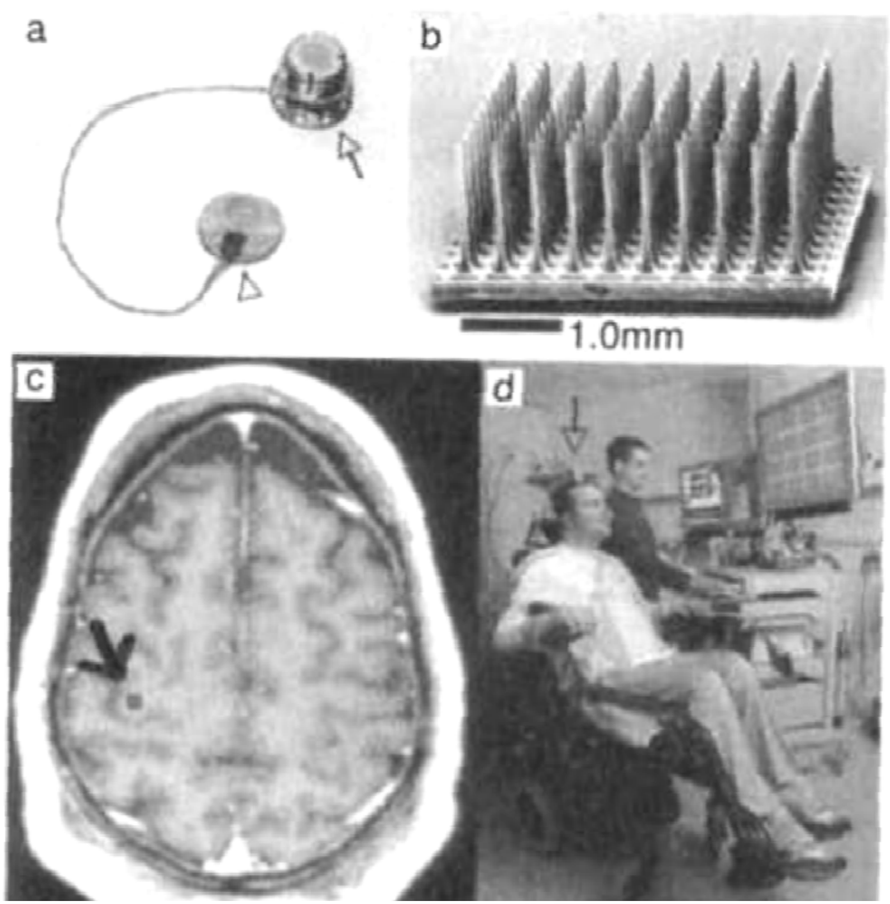
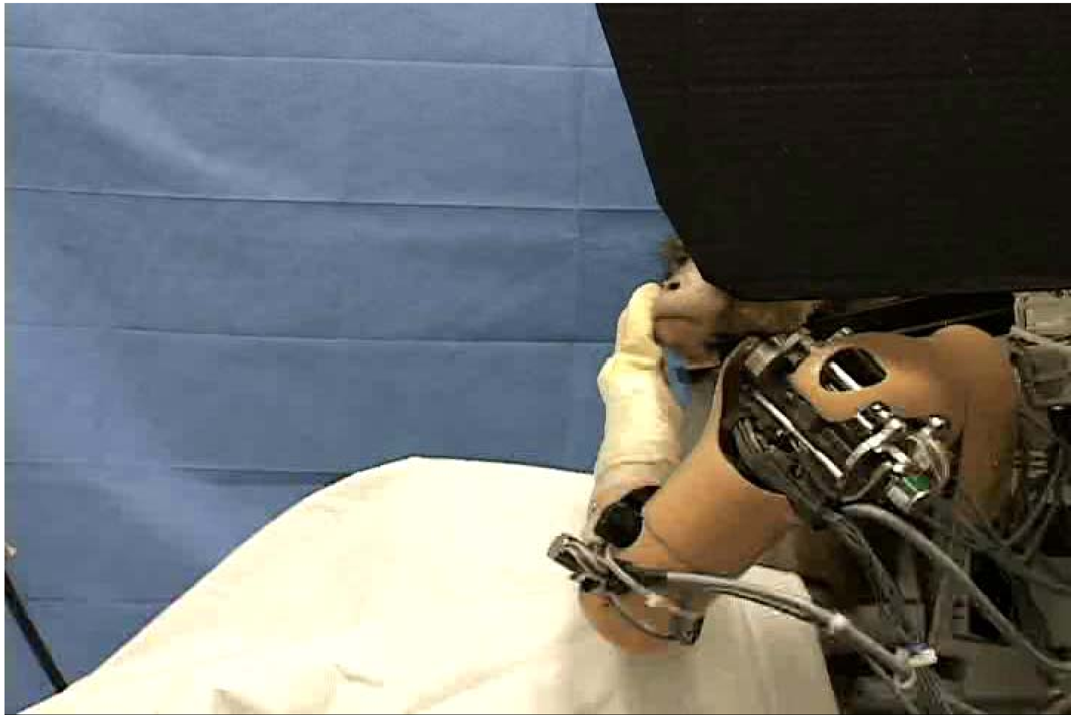


Fig. 2.11 A BMI system used in a human clinical experiment (Hochberg et al. (2006))
a,b: The Brain Gate and the electrodes c: electrode implanting points d:a picture of the experiment

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：ブレイン・ゲイトと電極，c：電極埋め込み部位，d：実験場面

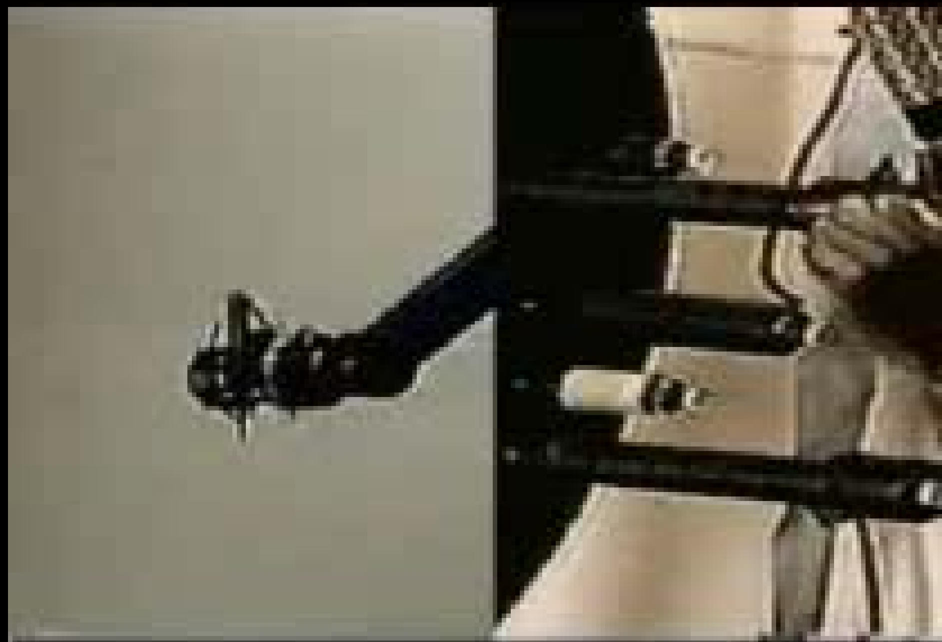
The study participant Mr. Nagle suffers from tetraplegia caused by a spinal cord injury

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



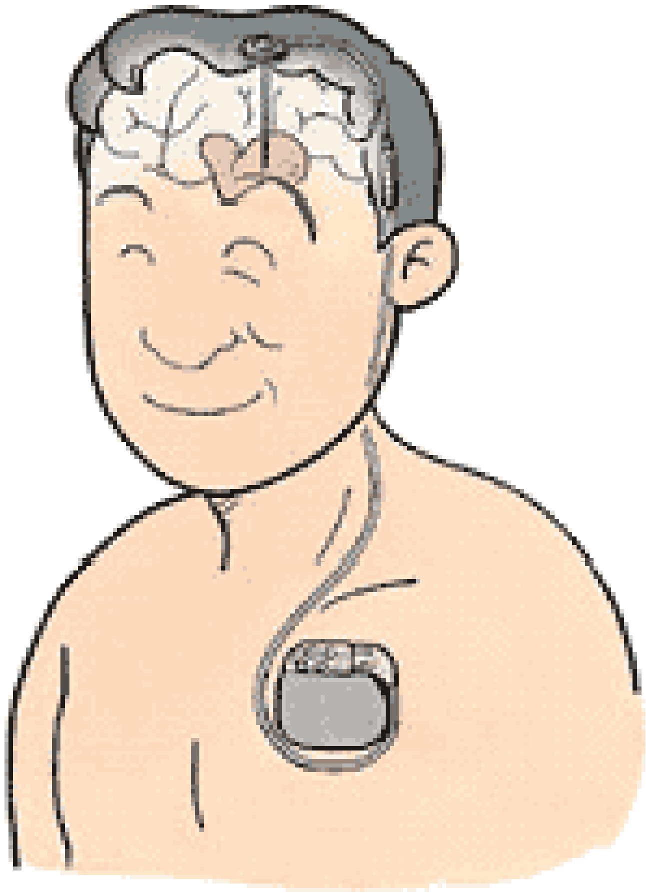
Controlling an artificial arm using signals from a monkey’s brain

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.



http://www.medtronic.co.jp/nro/tremor_deep-brain-stimulation.html

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）

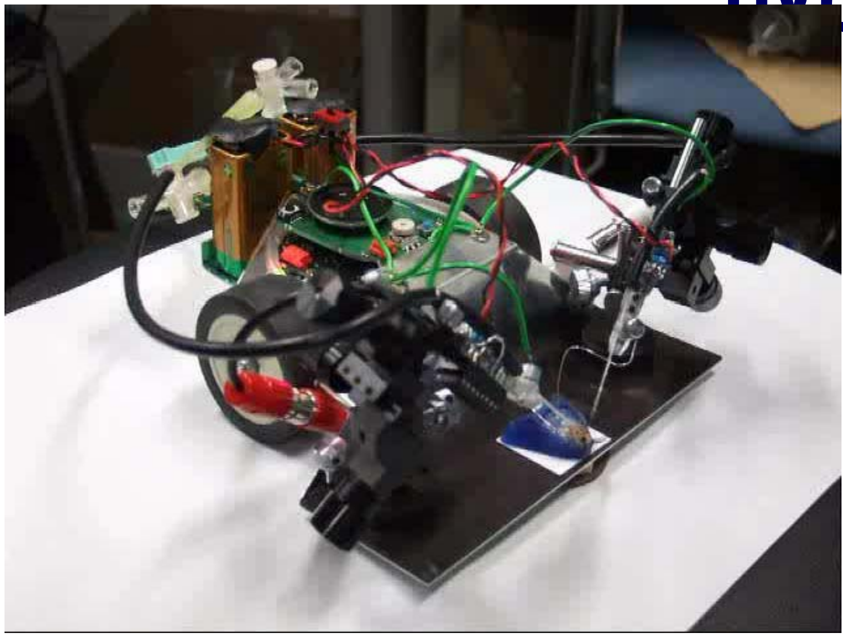
“Brain and Science”

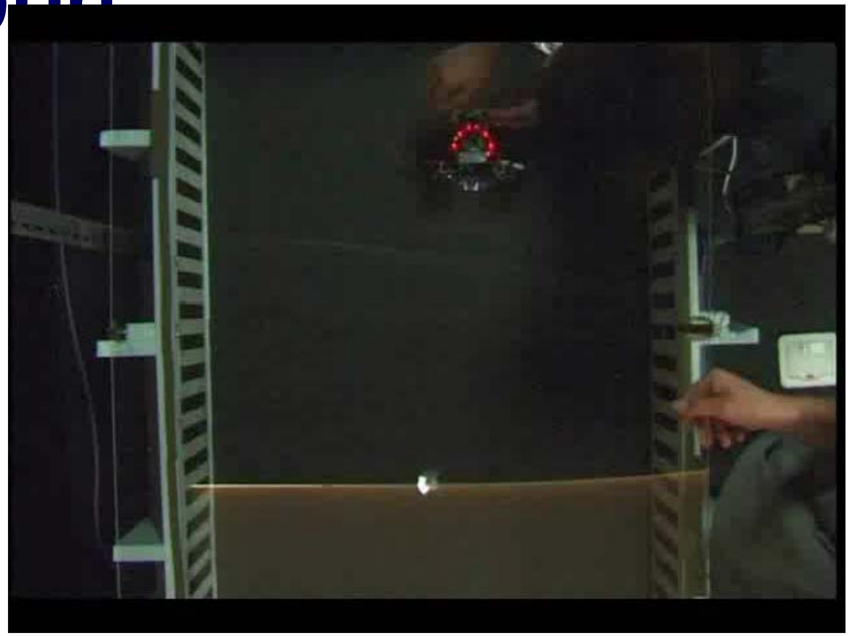
Neuroethics

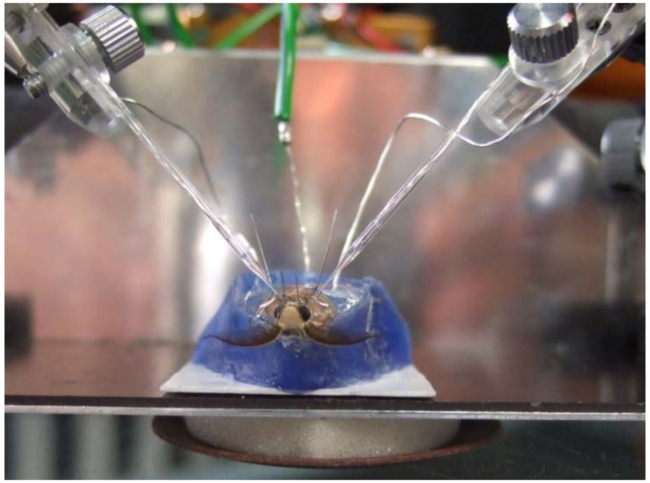
To change the input and output for the brain→ethical problem

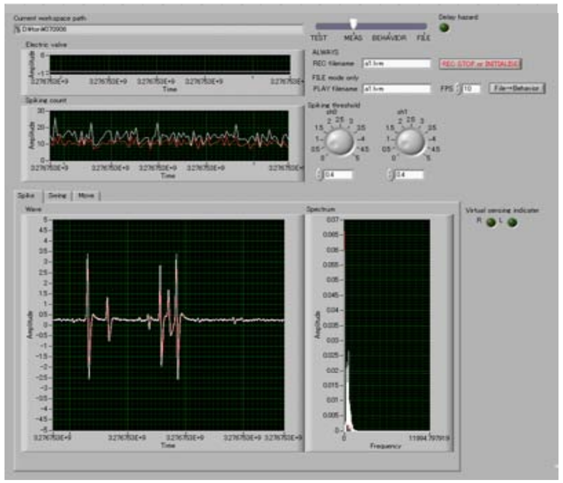
The material and neuro-scientific infrastructures of the mind are now better understood. In technologies to connect the brain and a computer or robot, the brain and the internet, or one human brain with another human brain being developed now, we surely need to consider the ethical

Controlling Robots by Insect's Brains – construction of an insect-machinery hybrid









Collaborating with Prof. Kurabayashi (Tokyo Inst.Teck)

Minegishi & Toriihara