Humanware Innovation

Humanware: The Third Ware which Creates Innovation in Information Technology

Information | Biology | Cognition

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Osaka University Humanware Innovation Program

Dramatic advancements in performance and cost of memory devices (1)

About the middle of 1980's: Development of high-capacity memory in workstations

In 1988
1 GB, approx
1 million yen
($10,000 USD)

(giga = 10^9 = 1 billion; memory sufficient for 1,000 books)

Dramatic advancements in performance and cost of memory devices (2)

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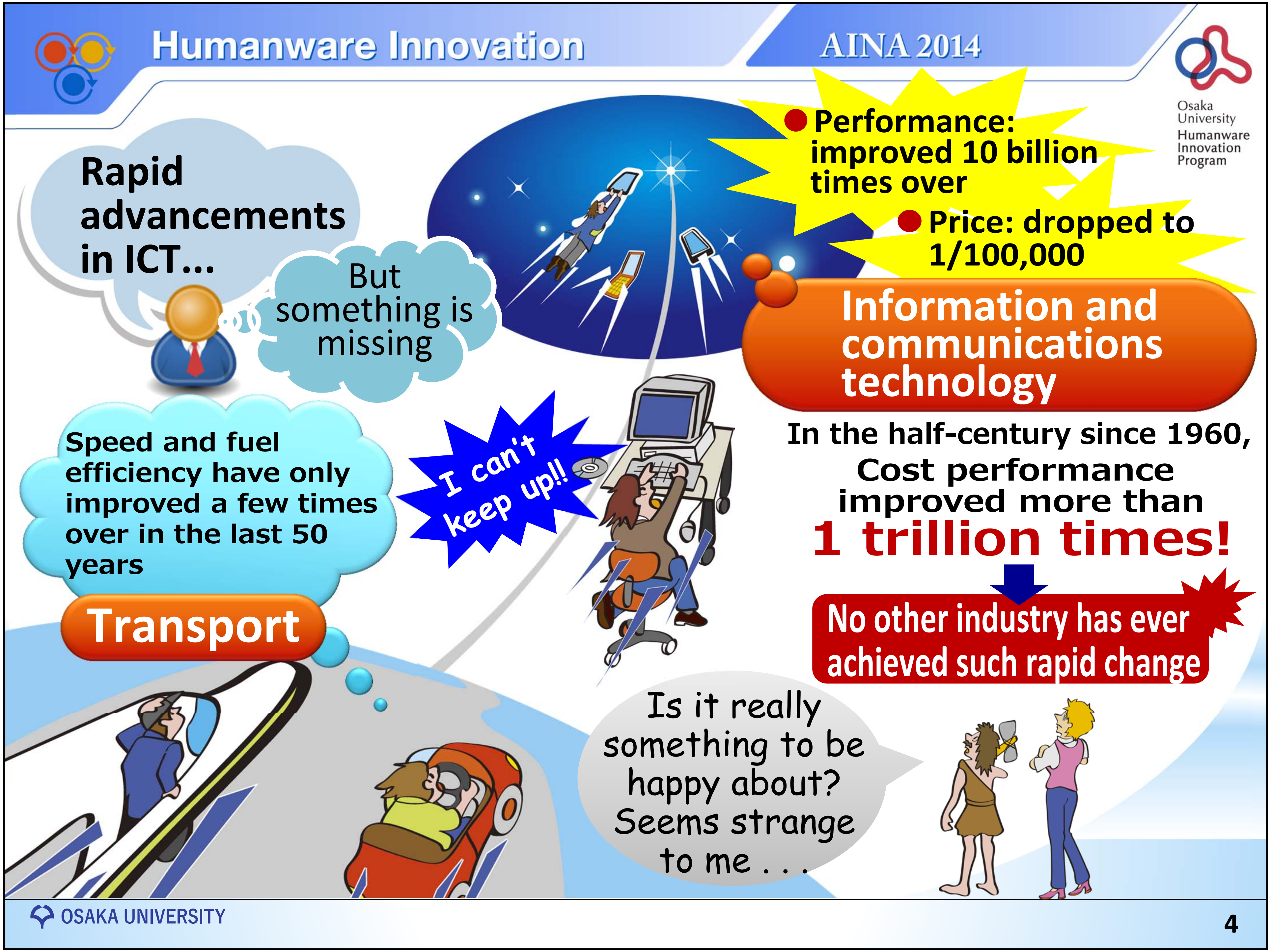
Rapid development of USB memory, DVD-R disks, etc.

A 128 GB USB memory device costs around 10,000 yen ($100 USD)

in 2014...

4.7 GB DVD-R disks cost around 50 yen ($0.50 USD) each


Humanware Innovation
AINA 2014
Osaka University Humanware Innovation Program
Rapid advancements in ICT...
But something is missing
● Performance: improved 10 billion times over
● Price: dropped to 1/100,000
Information and communications technology
I can't keep up!!
In the half-century since 1960,
Cost performance improved more than
1 trillion times!
No other industry has ever achieved such rapid change
Speed and fuel efficiency have only improved a few times over in the last 50 years
Transport
Is it really something to be happy about? Seems strange to me . . .
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The third ware: Humanware

Complex mega-networked society with people, transportation and economic behavior linked at unprecedented speeds and generating mutual impacts.

Increasing complexity of information systems ⇄ Individuals and human society unable to adapt

- Infrastructure destruction in unforeseen disasters
- Energy challenges posed by mass-scale information and communications

- Limitations on existing approaches to developing social environment
- Communication challenges in a hyper-aging society

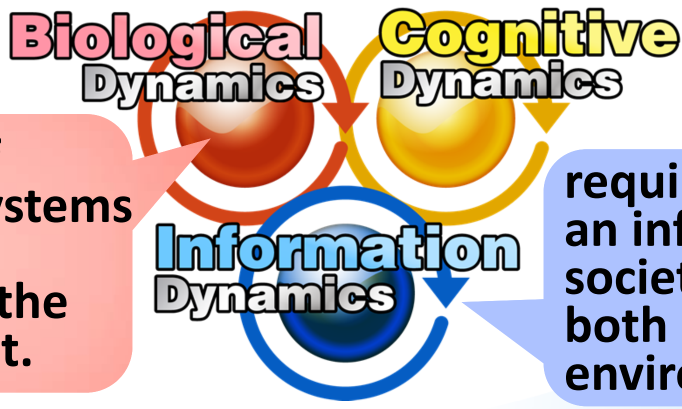
Emergence of many unforeseen challenges in the information society

Humanware

addresses the flows of information linking humans and the resulting transformation of human relationships.

dynamics of biological systems to adapt to people and the environment.

dynamics of higher brain functions for receiving, understanding, and generating information.



required to construct an information society attuned to both humans and the environment.

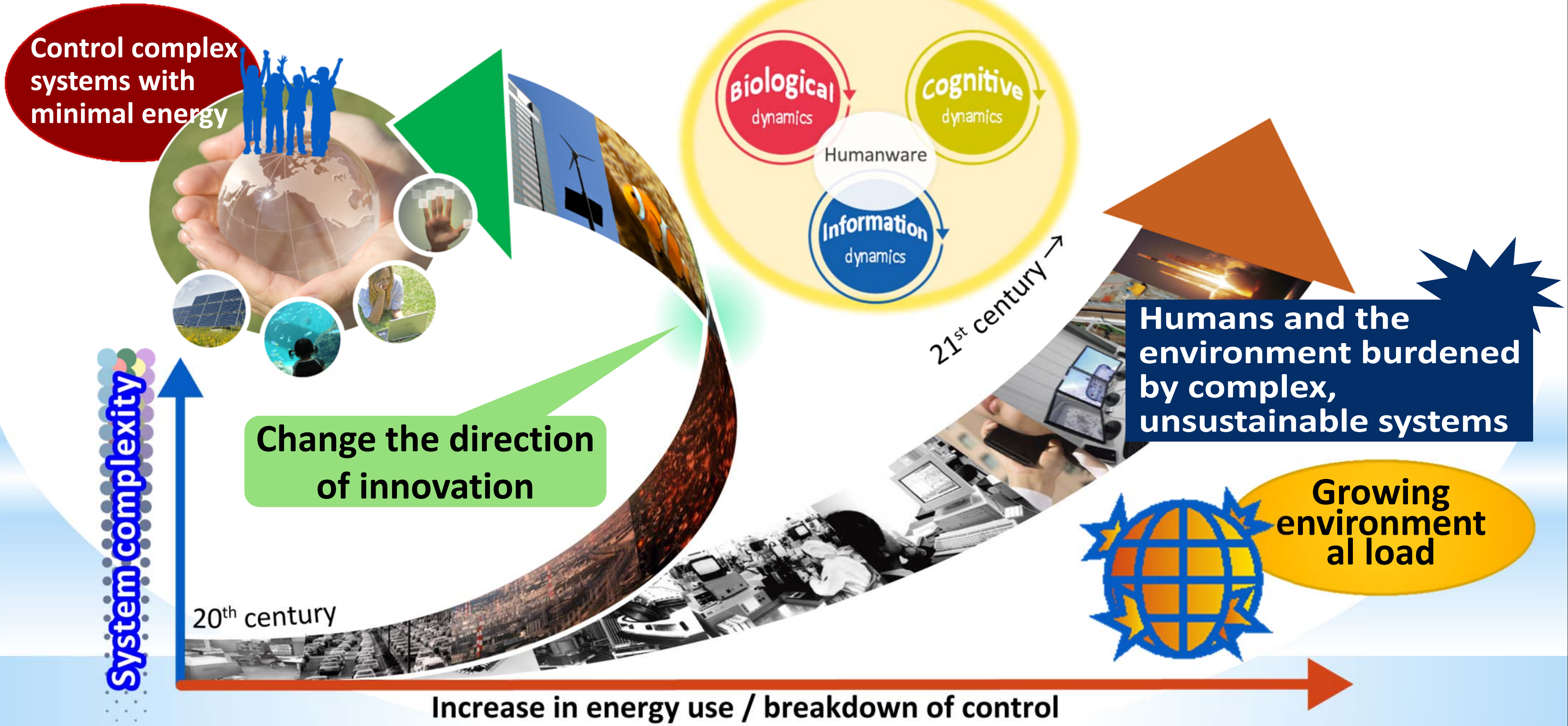
Humanware: Changing the direction of innovation

Humanware

Flexibility Robustness

Sustainability

Technologies dealing with "information dynamics" for the development of an information society harmonized with humans and the environment, equipped with the same mechanisms as biosystems. (flexible, robust, sustainable)



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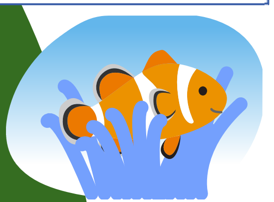
Biological systems and Information systems

LIFE / **INFORMATION**

	Life		Information	
Coexistence	**Ecology**	↔	**Social networks**	Society
Neuro-cognition	**Neuronal network**	↔	**Mass information networks**	Computer networks
Genes	**Genetic information expression control network**	↔	**Computer/ robot systems**	Source code

Coexistence — Ecology

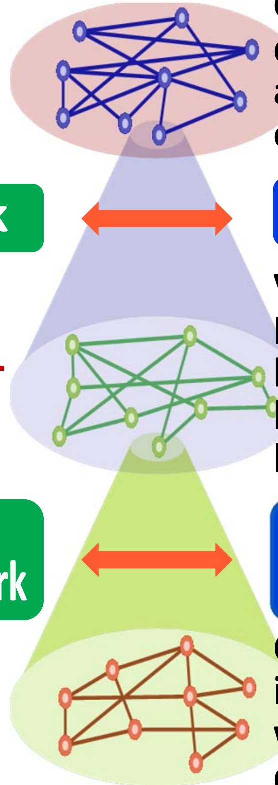


Symbiotic dynamics in harmony with environmental changes

Flexible

Society — Social networks

Growing complexity leading to disharmony among humans and between humans and the environment / hardware

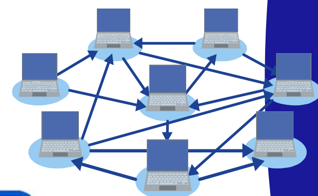


Neuro-cognition — Neuronal network

Trillions of synaptic connections controlled with just 1 watt of power in the human brain

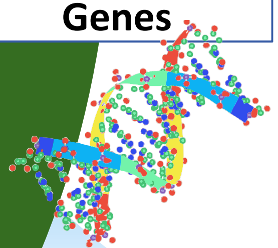
Sustainable

Computer networks — Mass information networks



Vast energy consumption
Information overload leading to disharmony between humans and hardware

Genes — Genetic information expression control network



30 thousand genetic combinations controlled with just 1 picowatt

Robust and flexible

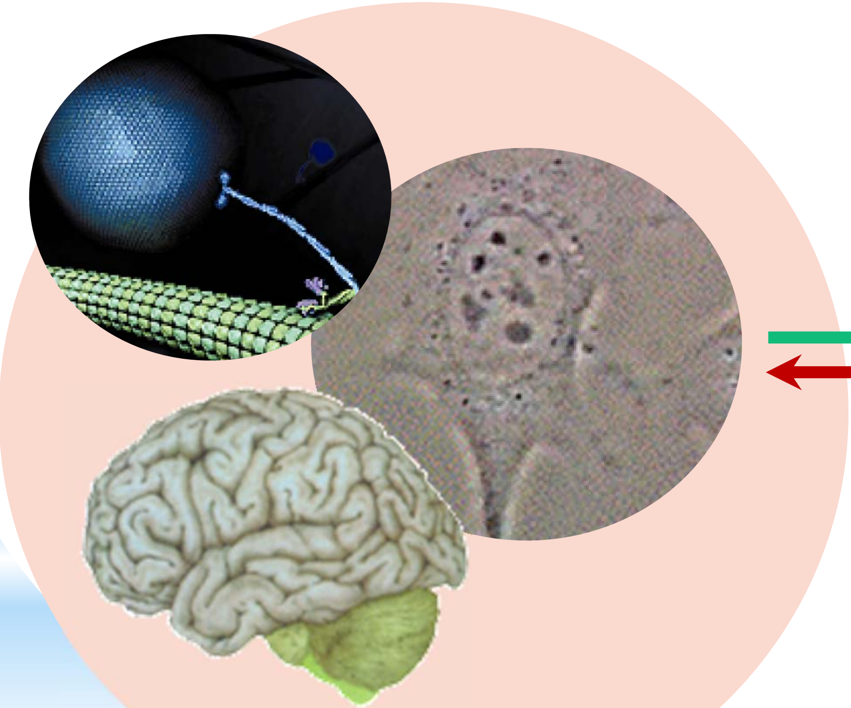
Source code — Computer/ robot systems

Control of hardware incapable of keeping pace with unforeseen social developments

Information dynamics to create a harmonized information society with the same flexibility, durability, and sustainability as living organisms = *HUMANWARE*

Biological and man-made machines

Is the performance of bio-components superior to that of man-made machines, or is it inferior?



Biological systems

One *kei* = 10 peta (1 peta=10^{16})

Man-made machines

Comparison 1: Operation rate and accuracy

	Biological	Man-made	(Ratio)
Operation time	~ msec (10^{-3})	~nsec (10^{-9})	$1/10^6$
Accuracy (Signal/Noise)	10^4	10^{80}	$1/10^{76}$

Brain

Slow
Erroneous

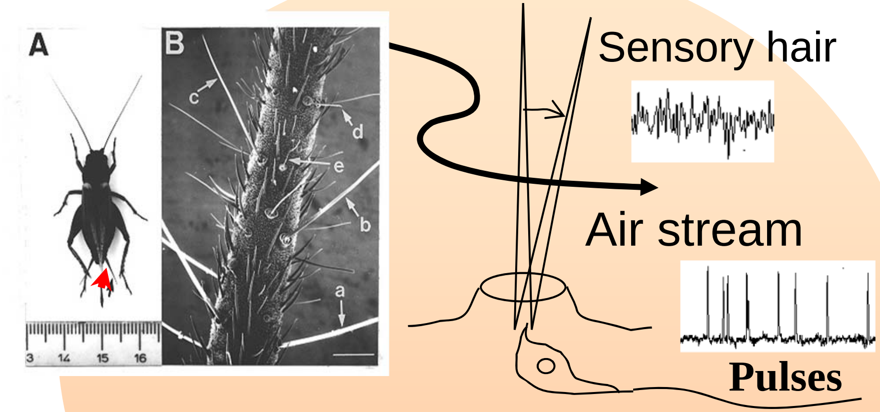
Rapid
Accurate

Computer

Neurons:
about $140X10^8$ elements

Super Computer
Semiconductor devices:
about $100x10^8$ IC elements

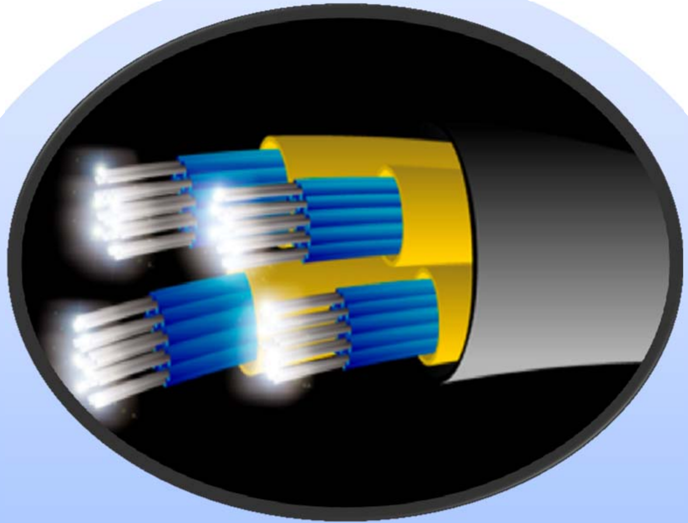
Comparison 2: Performance of nerve and optical guide



Data carrying rate by Shannon

$$I = \int_0^W \log_2 \left[1 + \frac{SS^*(f)}{NN^*(f)} \right] df \quad \text{[bits/sec]}$$

From T. Shimozawa



Optical fiber operated by electronic devices

Data transfer rate

400 bits/sec : **10^9 bits/sec**

Millions times slower !

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Comparison 3: Memory capacity

The maximum memory capacity of a human brain?

http://en.wikipedia.org/wiki/File:Kim_Peek_on_Jan_16,_2007.png#file

Laurence Kim Peek
He can memorize 7,600 books.

1 book=1MB
7,600 books=7.6GB

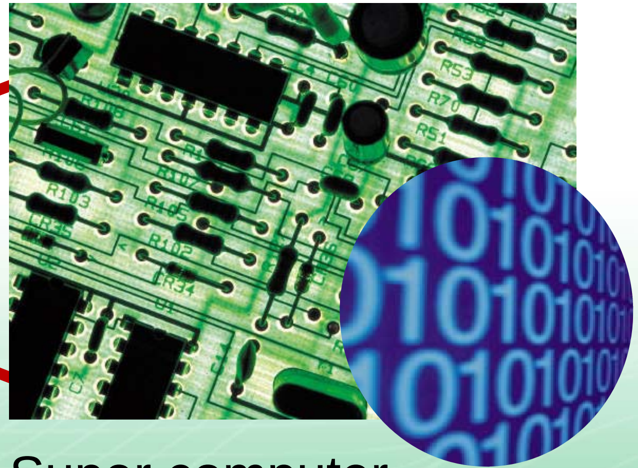
↑

Human brain memory size

DVD disc: 4.7GB (50yen)
50yen x 2 = 100 yen ($1.00 USD!!)

Biological systems consume a small amount of energy for their functions (1)

? ↔ **50,000 watts**

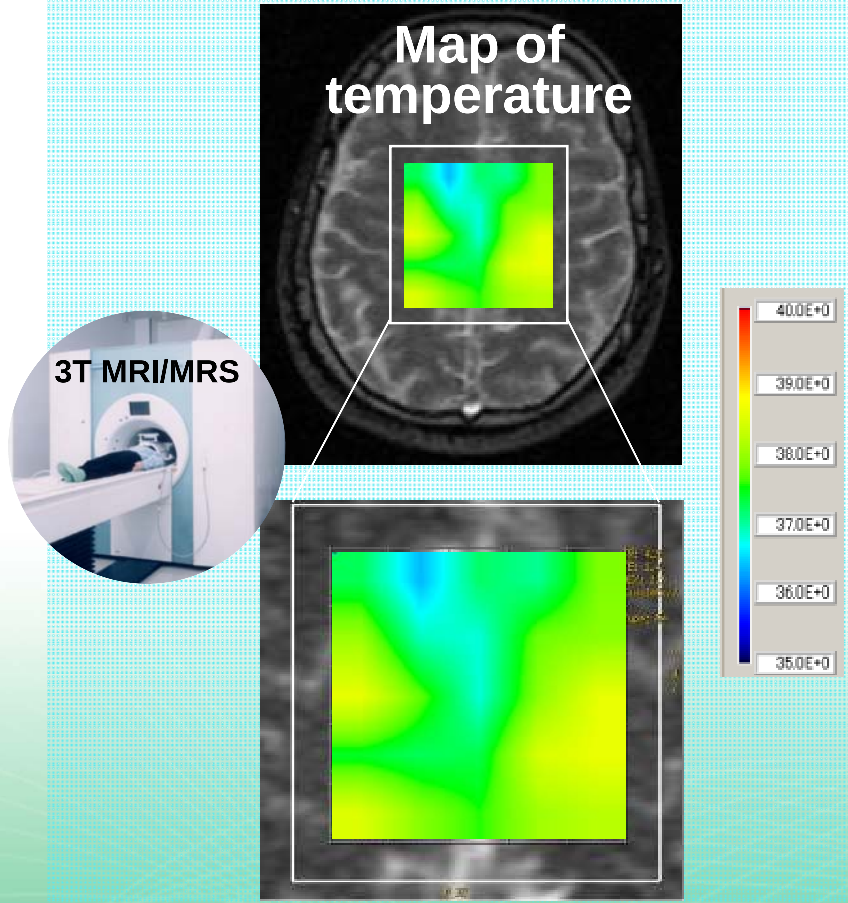


http://ja.wikipedia.org/wiki/file:Kasparov-29.jpg

Garry Kasparov
World champion of chess game

Super computer
Deep Blue (IBM)
4T FLOPS x 2

Brain temperatures of adult human

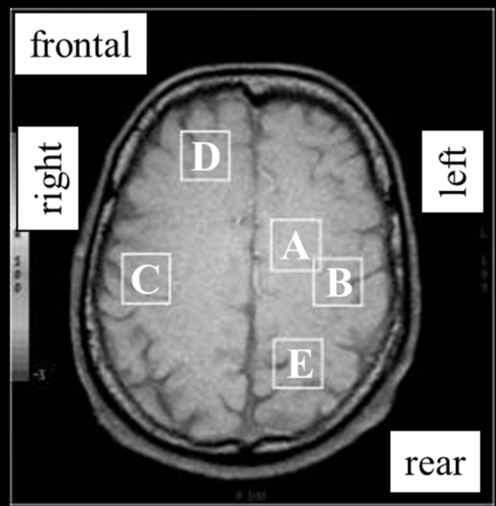


^{1}H-NMR spectrum shift in human brain

Temperatures at 5 regions (n=6)

A: 37.9±0.1 ºC (mean±SD)
B: 37.7±0.3 ºC
C: 37.8±0.3 ºC
D: 36.6±0.2 ºC
E: 38.1±0.3 ºC

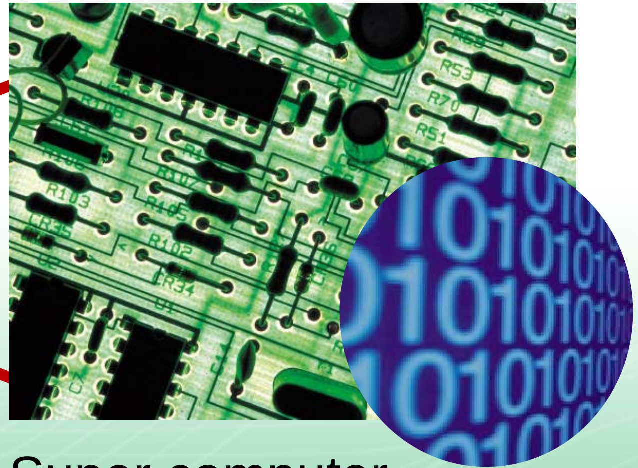
$2x2x2cm^3$, 3min



Biological systems consume a small amount of energy for their functions (2)

1watt
while thinking
20watts for basal metabolism
(relax, anesthesia)

50,000 watts



http://ja.wikipedia.org/wiki/file:Kasparov-29.jpg

Garry Kasparov
World champion of chess game

Super computer
Deep Blue (IBM)
4T FLOPS x 2

Human brain should process a huge amoun of information

Brain (cerebrum) contains 140×10^8 neurons, and the neuronetwork has about 10^{15} synaptic connections

Energy consumption

1 watt

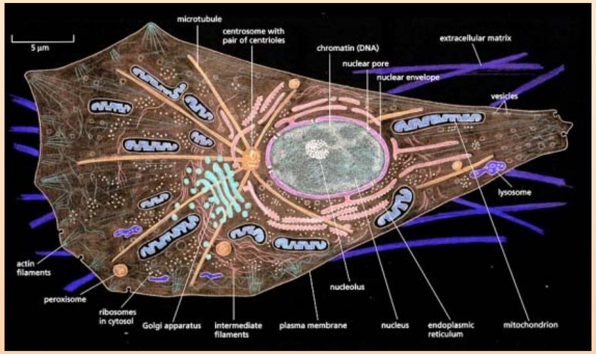
Please note that every on/off switch of connections is settled by each neuron.

Number of combinations = $2^{10^{10}}$

If this number of combinations is strictly calculated by computers, $10^{1000000000}$ watts is consumed, which is much larger than that of billions nuclear plants!!

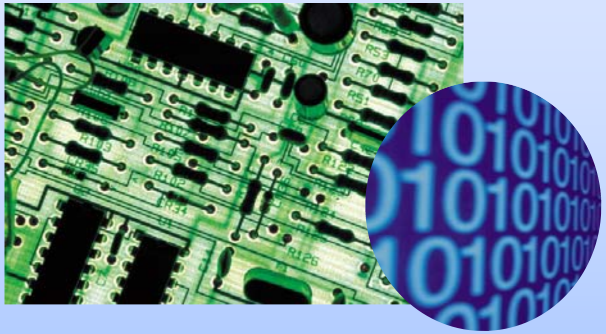
Difference between biological and man-made machines

Cell



?

Man-made machine

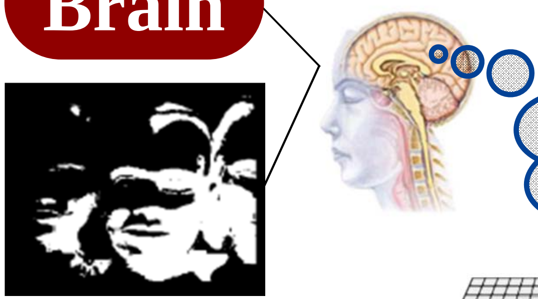


- Deterministic and digital
- Accurate

Principle of biological machine is essentially different from that of man-made machine?

We need a new concept to understand biological systems

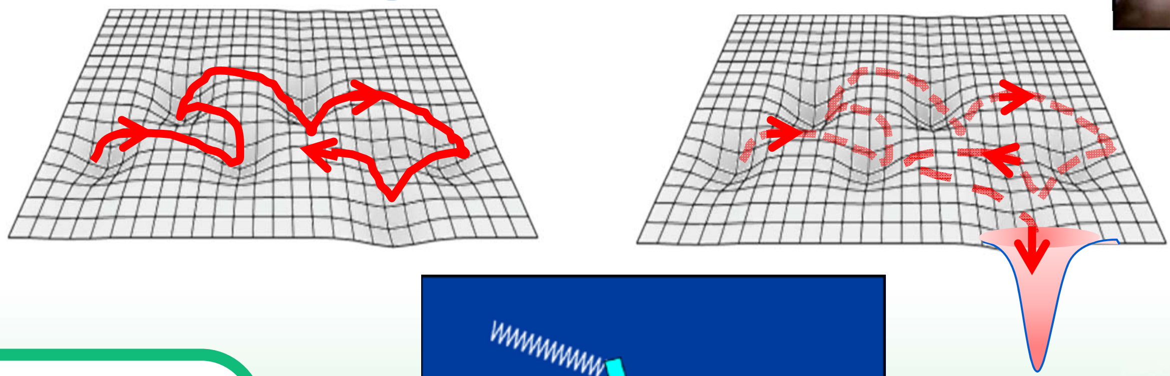
Brain



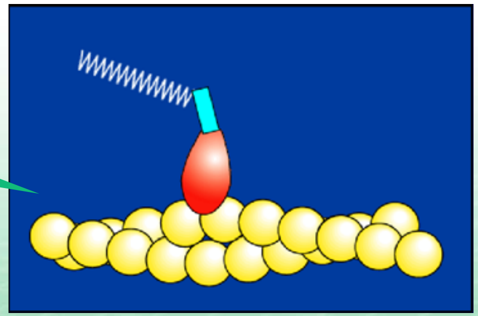
Fluctuation → **Decision**

ひらめき！

Flash



Molecular motor

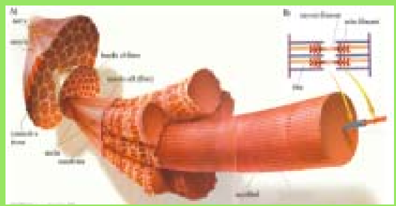


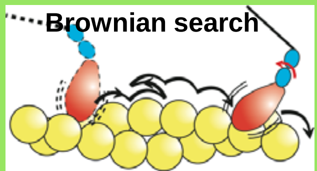
Common principle

Brownian search and catch "attractor selection" by spontaneous fluctuation

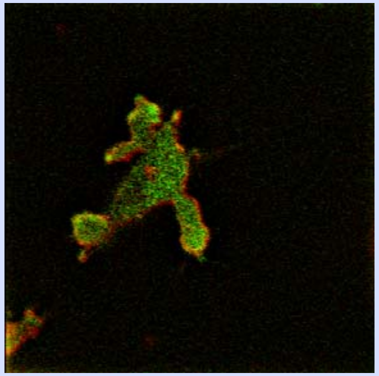
Common principle *(fluctuation search and catch mechanism)* operates from molecule to brain *"Yuragi equation"*

Molecular motor





Cell signaling



Visual perception

Generalization

$$\frac{d}{dt}x = f(x)\cdot activity + \eta$$

Model — Consistency — Spontaneous fluctuation

Yuragi equation

Molecular motor

$$\frac{dx}{dt} = -\frac{1}{\rho}\frac{\partial U(x,t)}{\partial x} B + \sqrt{\frac{2kT}{\rho}}\eta(t)$$

Brownian force — Bias — Thermal noise

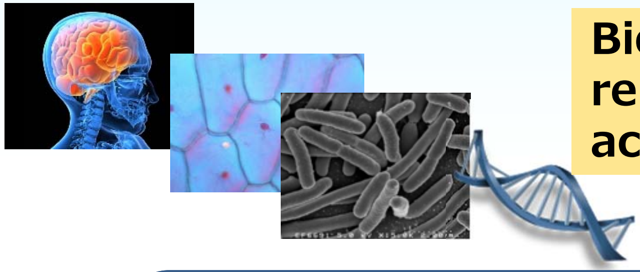
Yuragi – Key principle of biological adaptation

Conventional control (deterministic and optimized control)

- **Put assumption on fluctuation**
- **Design system to achieve optimal performance by filtering fluctuation or noise to conform with assumptions**

⬇

- **Considerable performance degradation against predictable changes**

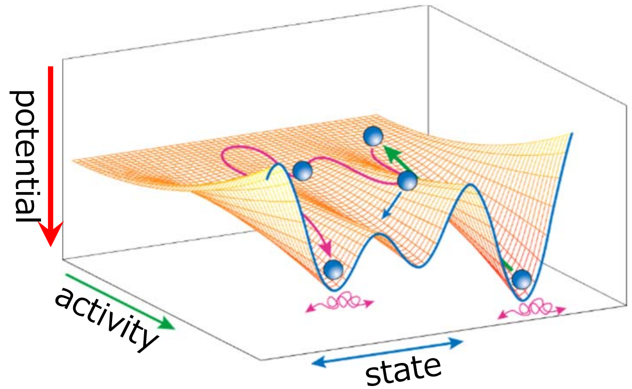


Biological systems, from genes to brain, do not remove noise, but they utilize noise or Yuragi and achieve highly energy-efficient and adaptive behavior

Yuragi equation

$$\frac{d}{dt}\boldsymbol{x} = f(\boldsymbol{x}) \cdot activity + \eta$$

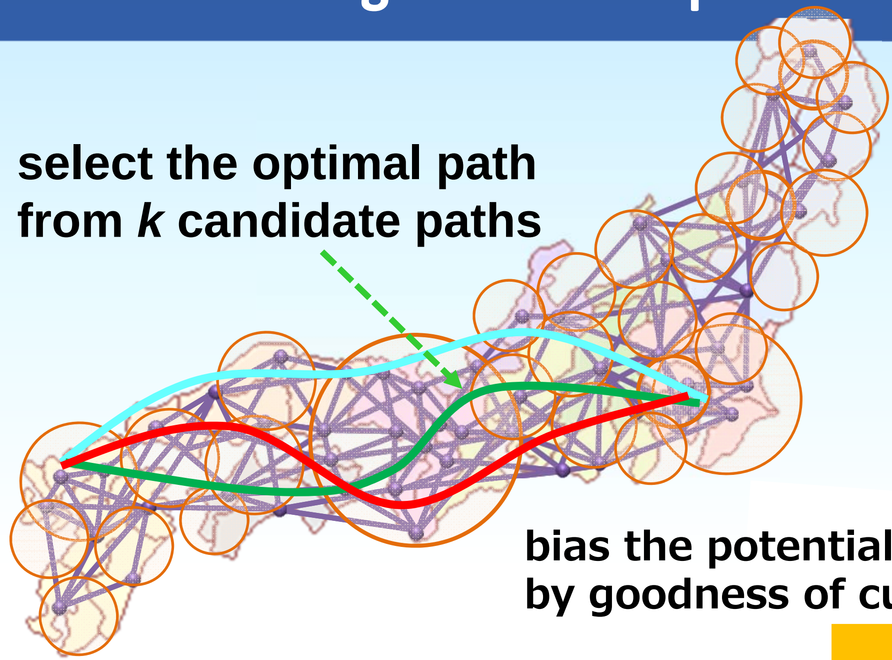
state, potential space, goodness of current state, noise



"Yuragi" enables information and communication technology which is highly adaptive, robust, and energy efficient

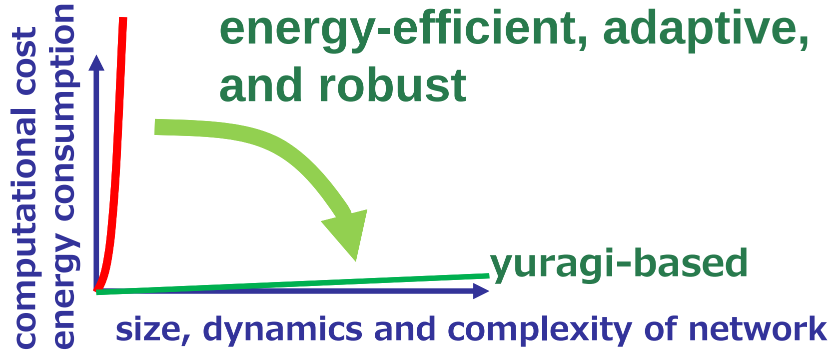
Yuragi-based adaptive routing – Multipath scenario

select the optimal path from *k* candidate paths



global optimization

Yuragi-based routing is energy-efficient, adaptive, and robust

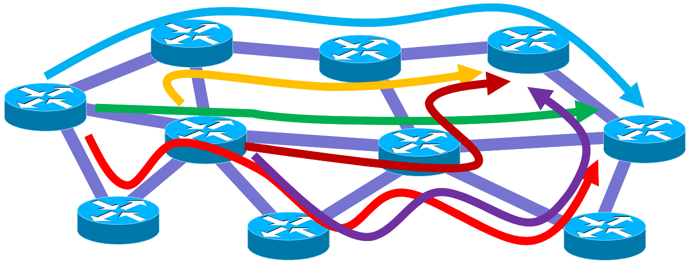


bias the potential (solution space) by goodness of current selection

Global optimization by exhaustive search

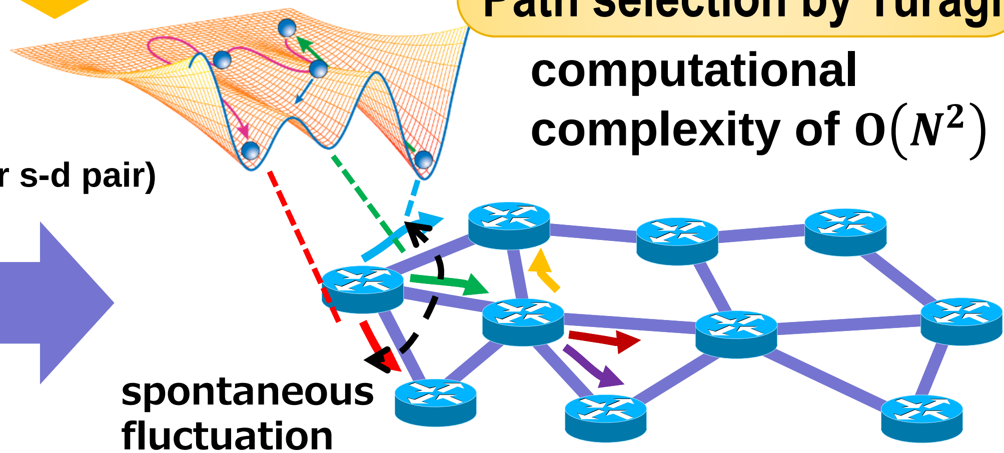
computational complexity of $O\left(k^{N^2}\right)$

(*N*: number of nodes, *k*: number of candidates per s-d pair)



Path selection by Yuragi

computational complexity of $O(N^2)$



spontaneous fluctuation

Yuragi-based adaptive routing – Algorithm

Routing information

- state value x_i of path i $(1 \le i \le k)$: select path with the largest state value
- activity α $(0 \le \alpha \le 1)$:goodness of current path, e.g. delay or throughput

Router performs the following steps per control interval

1. calculate activity based on feedback information from destination
2. update state values

$$\frac{dx_i}{dt} = \frac{s(\alpha)}{1 + \max_j x_j{}^2 - x_i^2} - d(\alpha) \times x_i + \eta$$

$$s(\alpha) = \alpha\left(\beta \times \alpha^\gamma + 1/\sqrt{2}\right), \ \ d(\alpha) = \alpha, \ \ \eta = \text{WGN}$$

computational complexity per router $O(k \times N) = O(N)$
computational complexity in network $O(N^2)$

Shortest path routing (Dijkstra algorithm)

computational complexity per router $O(N^2)$
computational complexity in network $O(N^3)$

Global optimization (exhaustive search)

computational complexity in network $O\left(k^{N^2}\right)$

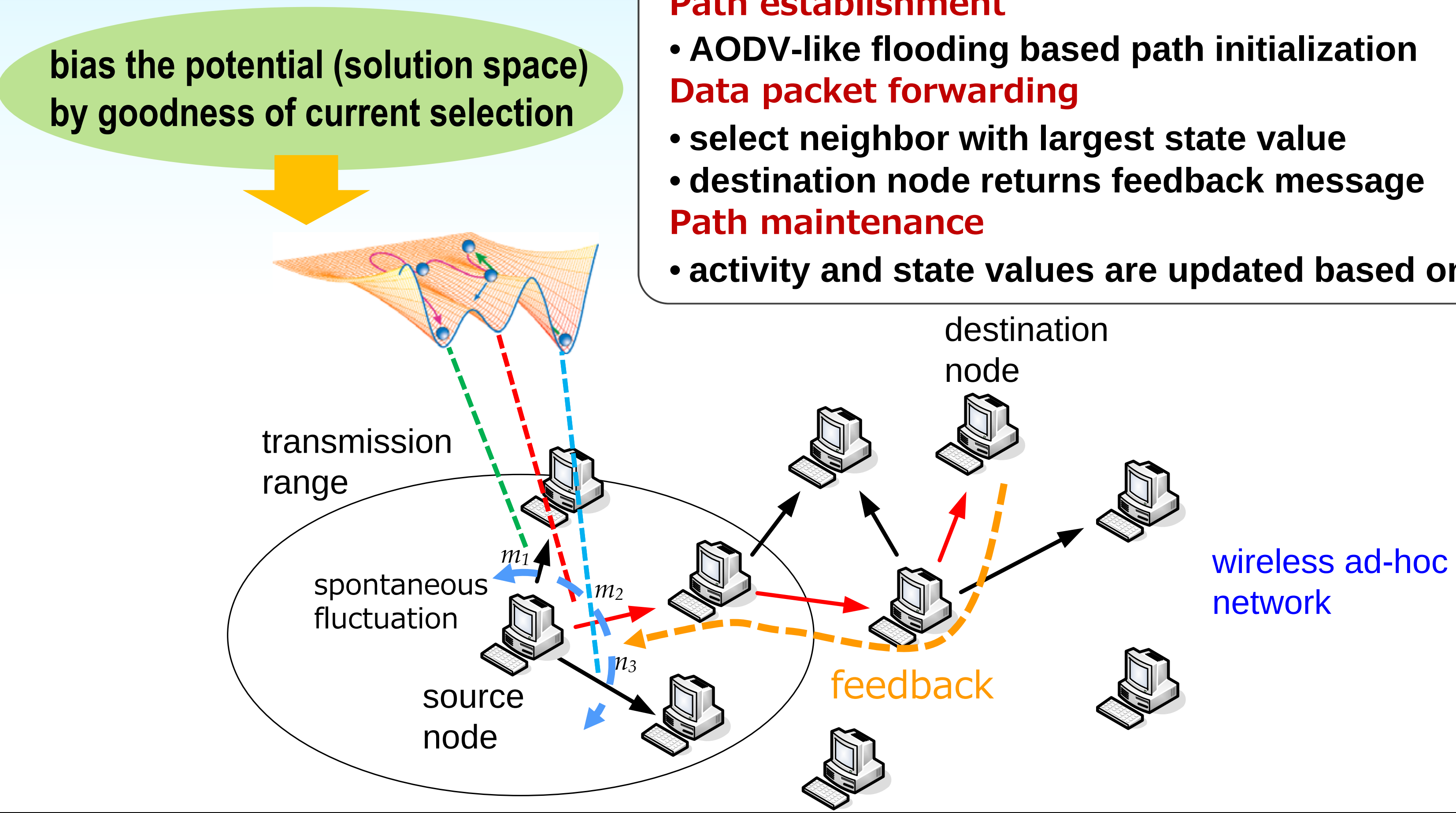
Yuragi-based adaptive routing – MANET scenario (1)

Each node selects the optimal next-hop node for destination by using Yuragi (hop-by-hop routing)

Path establishment
- AODV-like flooding based path initialization

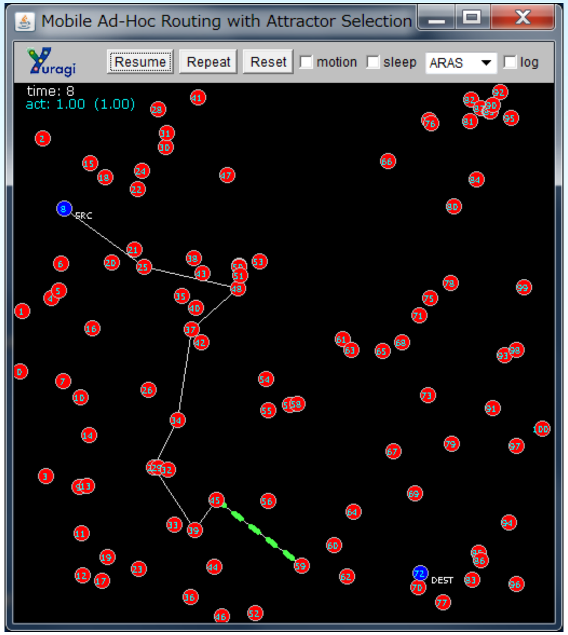
Data packet forwarding
- select neighbor with largest state value
- destination node returns feedback message

Path maintenance
- activity and state values are updated based on feedback



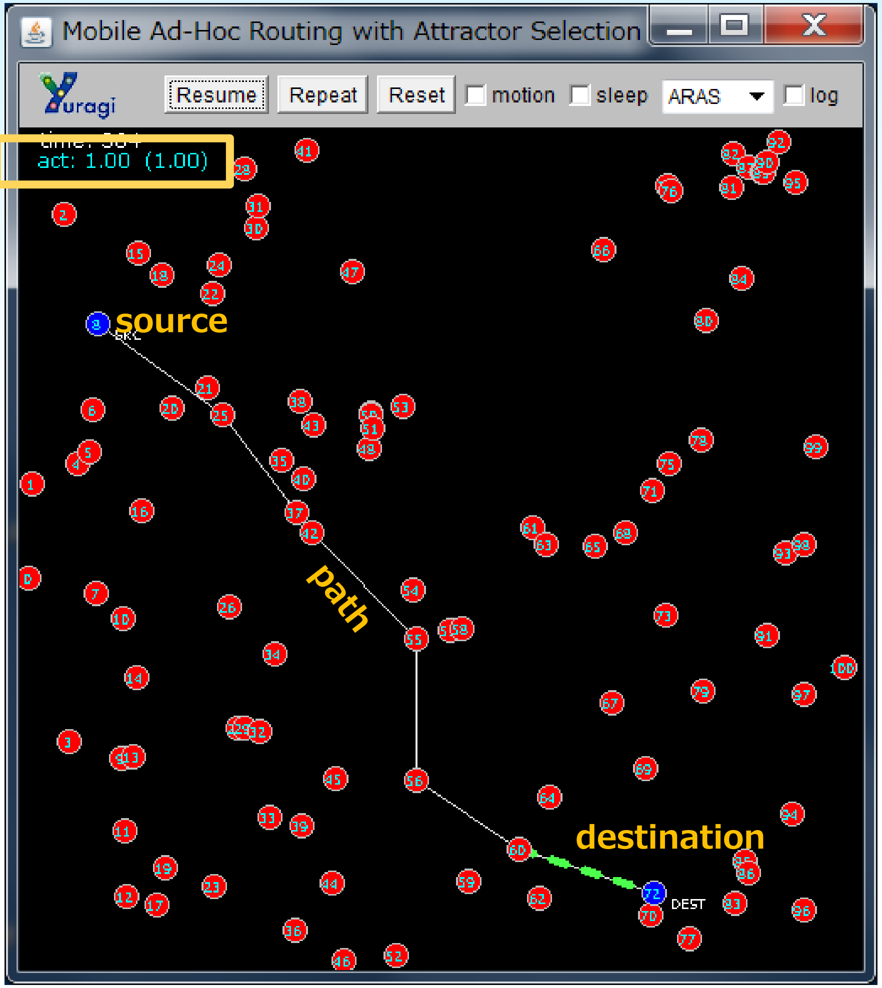
Yuragi-based adaptive routing – MANET scenario (2)

Initial random search



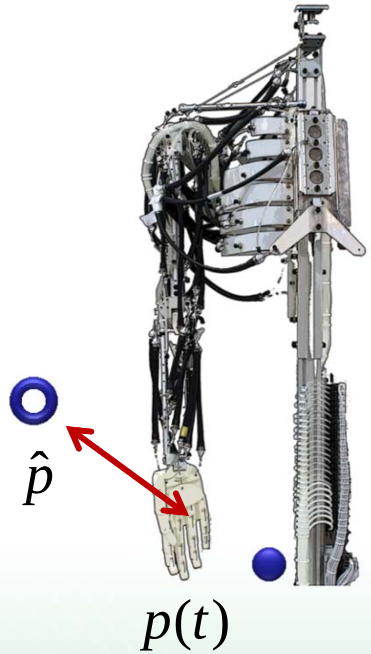
Converged path

activity



Each node autonomously and adaptively selects next hop to maximize activity, i.e., goodness of path

Application of Yuragi equation to arm robot with 50 actuators (1)



Yurgi equation

$$\frac{d}{dt}x = f(x)\cdot activity + \eta$$

Number of combinations to be calculated is huge = 2^{50} = 10^{15}

Modeling is almost impossible.
Even if possible, a huge amount of calculations are necessary if we use a conventional algorism.

$$\frac{d}{dt}x = \frac{d}{dx}\sum_i G_i(x)\cdot activity + \eta$$

$$G_i(x) = \exp\left(-\frac{1}{2\sigma^2}(x-\bar{x}_i)^2\right)$$

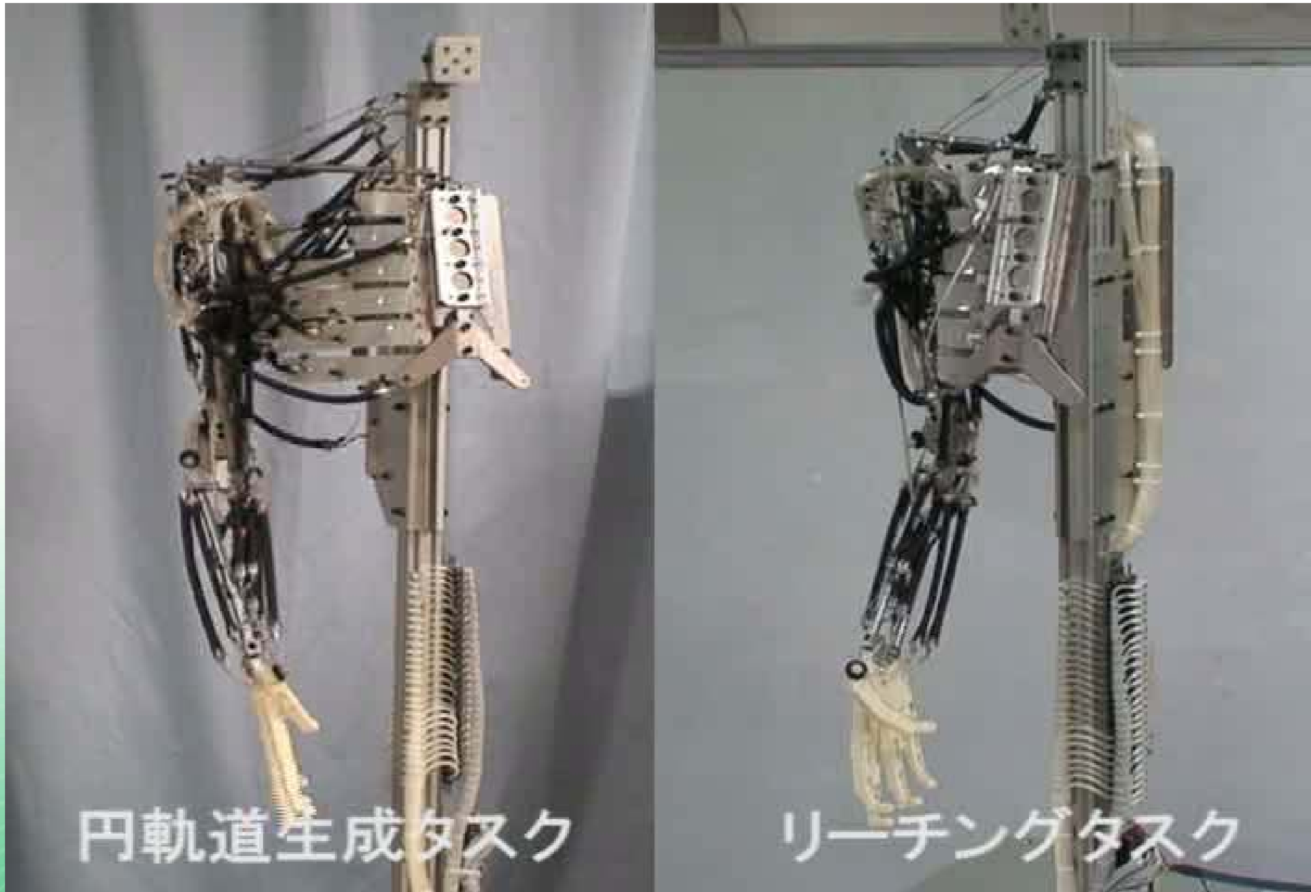
$$activity := \alpha(t) - \overline{\alpha}(t)$$

$$\alpha(t) = \left|\hat{p} - p(t)\right|^{-1}$$

$$\overline{\alpha}(t) = \sum_\tau \gamma^\tau \alpha(t-\tau) \Big/ \sum_\tau \gamma^\tau$$

Application of Yuragi equation to arm robot with 50 actuators (2)

Brownian search and catch mechanism is useful to control complex biological system with simple control



Task of circular motion　　Task of extending motion

This process can be observed when baby learns to capture a thing by hands

by H. Ishiguro Lab. (Osaka Univ.) and Mitsubishi Heavy Industries, Ltd.

MEXT Program for Leading Graduate Schools

Intention:

To become a driving force behind drastic reform in applicable areas of graduate school education at leading educational centers.

Aims:

To promote the efforts of graduate schools to create and develop world-class degree programs, programs transcending field borders, with the aim of producing graduates capable of serving as international leaders in academia, business, and government.

The maximum duration of programs: 7 years.

Applications for three types of programs:

1 All-round programs:
programs to produce leaders with a wide range of expertise.

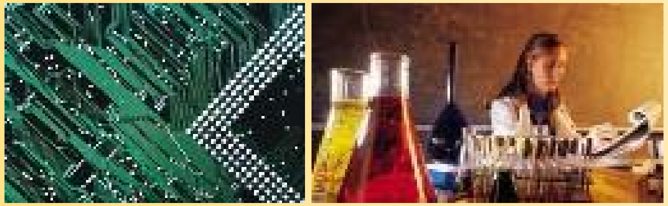
2 Multidisciplinary programs:
programs to produce leaders with expertise in overlapping fields.

3 Only-one programs:
programs to produce leaders with a clearly defined specialty.

MEXT: Ministry of Education, Culture, Sports, Science and Technology

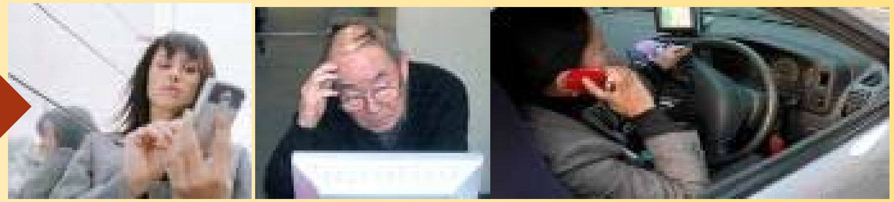
Paradigm shift toward human- (user-)oriented products and systems

Science & technology



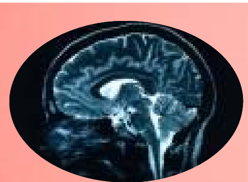
Misconception that innovation arises from revolutionary science and technology alone

Users



Japan's global competitiveness in info./comm. Technology (ICT): 20th worldwide because innovation is not pursued from the user's perspective

Surveys
Ascertain users' preferences



Scientific methods
Understand users

Importance of Cognitive Science

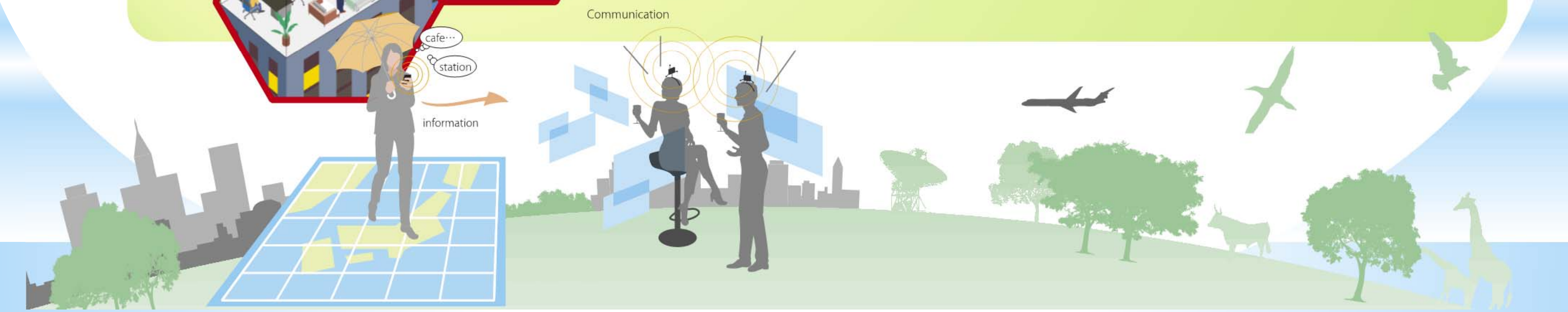
Goal of "Information" filed of the program

Aspiring to an affluent, convenient society connected by **networks** transcending national, regional and temporal boundaries; advancing

cognitive/brain science and simulation science

to achieve paradigm shifts which will

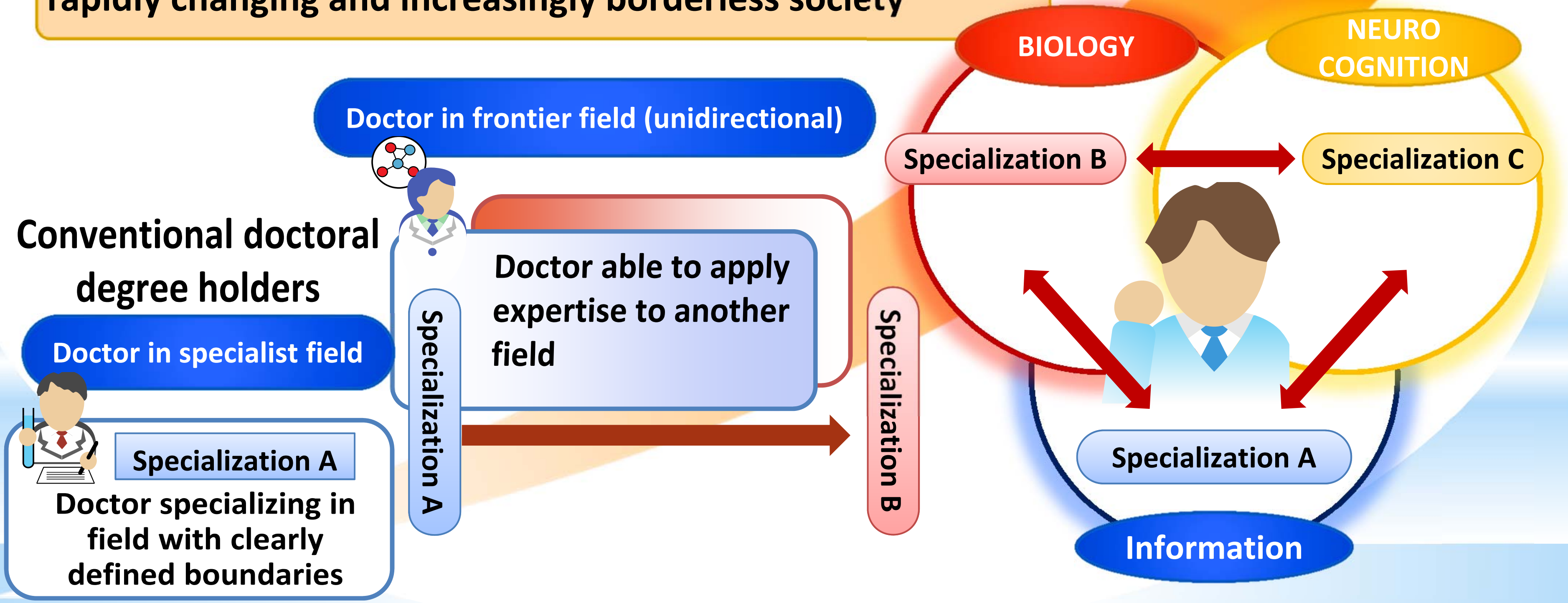
advance lifestyles, cultures and societies and lead to the creation of new industries and services



Human resource paradigm for the degree program

"Networking Doctors" (multidirectional)

Experts with an integrated understanding of the dynamics of information, biological, and cognitive/brain sciences and the capacity to use "humanware" to address the needs of a rapidly changing and increasingly borderless society



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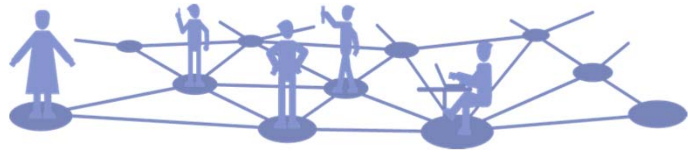
Innovations driven by Networking Doctors

Transforming the direction of innovation



1. Build human-oriented information and communications technology in line with diverse, globalizing social demand
2. Create a low-energy information society
3. Develop information networks capable of self-repairing in times of disaster
4. Develop information technologies which promote communication and community-building across different generations and standpoints
5. Realize an advanced welfare society in which humans and robots work together

Osaka University Humanware Innovation Program

Structure and features of the degree program (1)

Features **1** **Joint initiative of three Graduate Schools with three main backgrounds**

Graduate School	Background
Grad. School of Information Science and Technology	Information Science
Grad. School of Frontier Biosciences	Molecular biology, neuroscience
Grad. School of Engineering Science	Robotics, cognitive Science

Humanware Innovation Program

- Fostering humanware researchers and engineers
- Well-versed in information, biological and cognitive dynamics
- Capable of creating highly human-friendly systems

Structure and features of the degree program (2)

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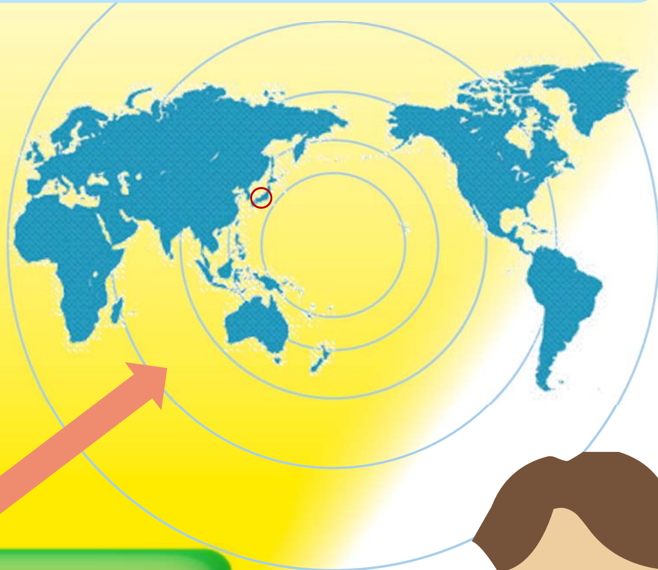
Features 2 Sharing insights into mechanisms for innovation generation with industry

Features 3 Collaborating with research institutions outside Japan; welcoming talented international students

Corporate partners

NEC	Panasonic	OMRON
NTT	HITACHI	HORIBA
TOSHIBA	Microsoft	

Utilizing collaborative relationships through IT academia industry partnership forum OACIS, etc.

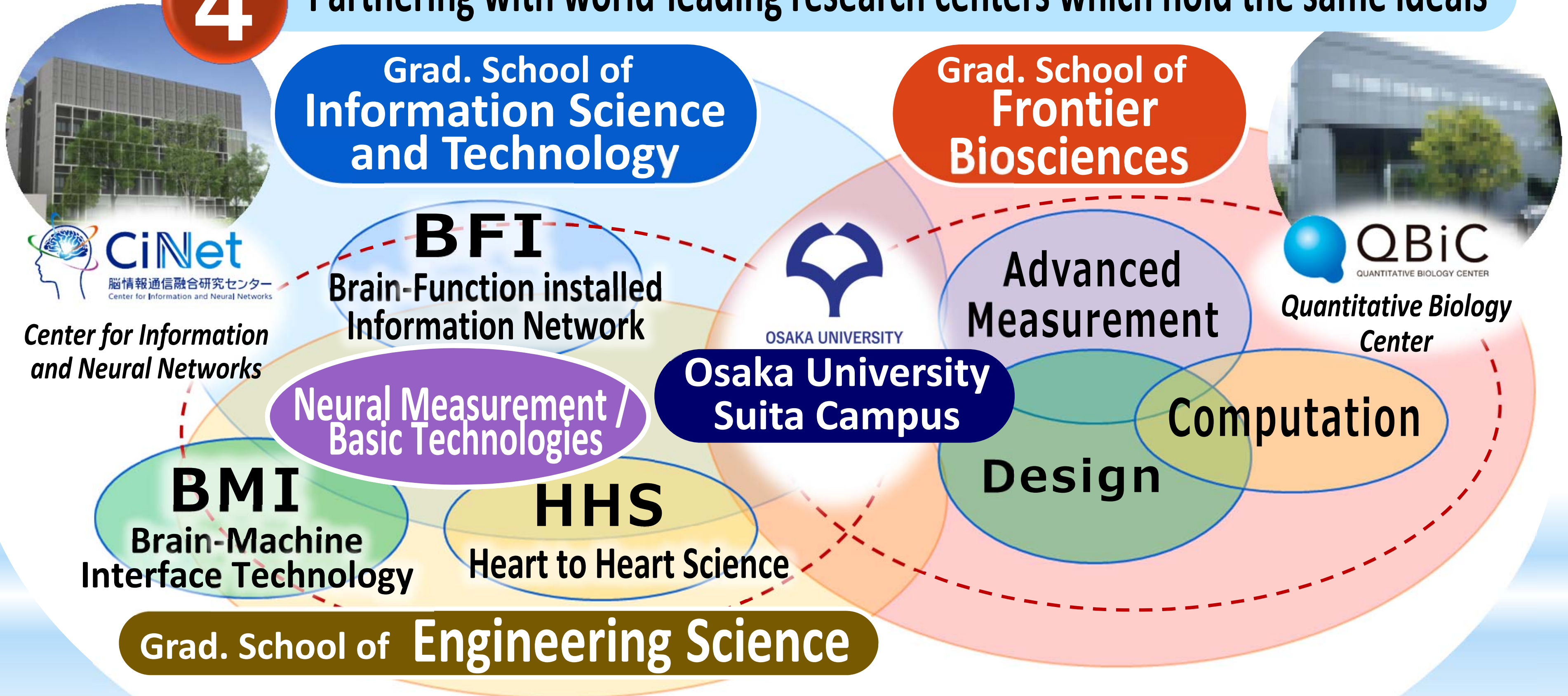


Humanware Innovation Program

- Fostering humanware researchers and engineers
- Well-versed in information, biological and cognitive dynamics
- Capable of creating highly human-friendly systems

Working closely with world-leading research partners

Features 4 Partnering with world-leading research centers which hold the same ideals



- Two new centers, CiNet and QBiC (both with around 150 personnel) have already been launched on campus; all 3 Grad. Schools are pursuing interdisciplinary and project research on complex networks
- Both centers augment our world-class environment for the training of doctoral experts

Osaka University Humanware Innovation Program

Admission policy and selection of participants

Admission Policy

- To cultivate individuals capable of developing “humanware” as a form of information technology to address a wide range of problems emerging in our ever-changing information society
- To produce doctoral leaders capable of setting their own goals and leading groups to formulate solutions to problems

Student profile

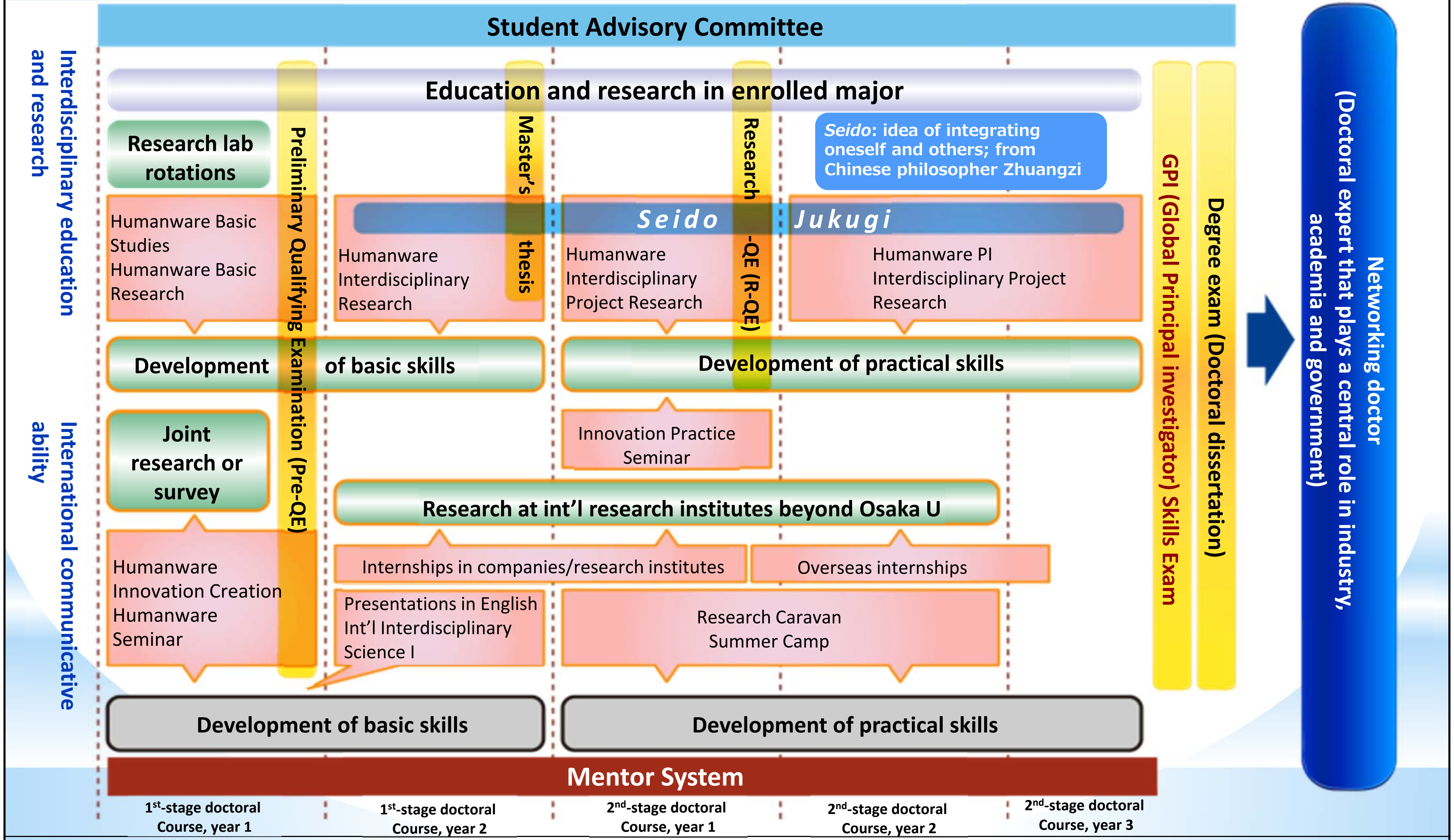
Students motivated to deepen their understanding of information science, biological science and cognitive/brain science, and take active roles in work to integrate these fields

Selection

Selection is based on an integrated evaluation of basic academic ability, capacity to formulate and address problems as established in screening of written documents, and communicative proficiency as demonstrated in interviews.

Osaka University Humanware Innovation Program

Course work overview



Academic and physical infrastructure

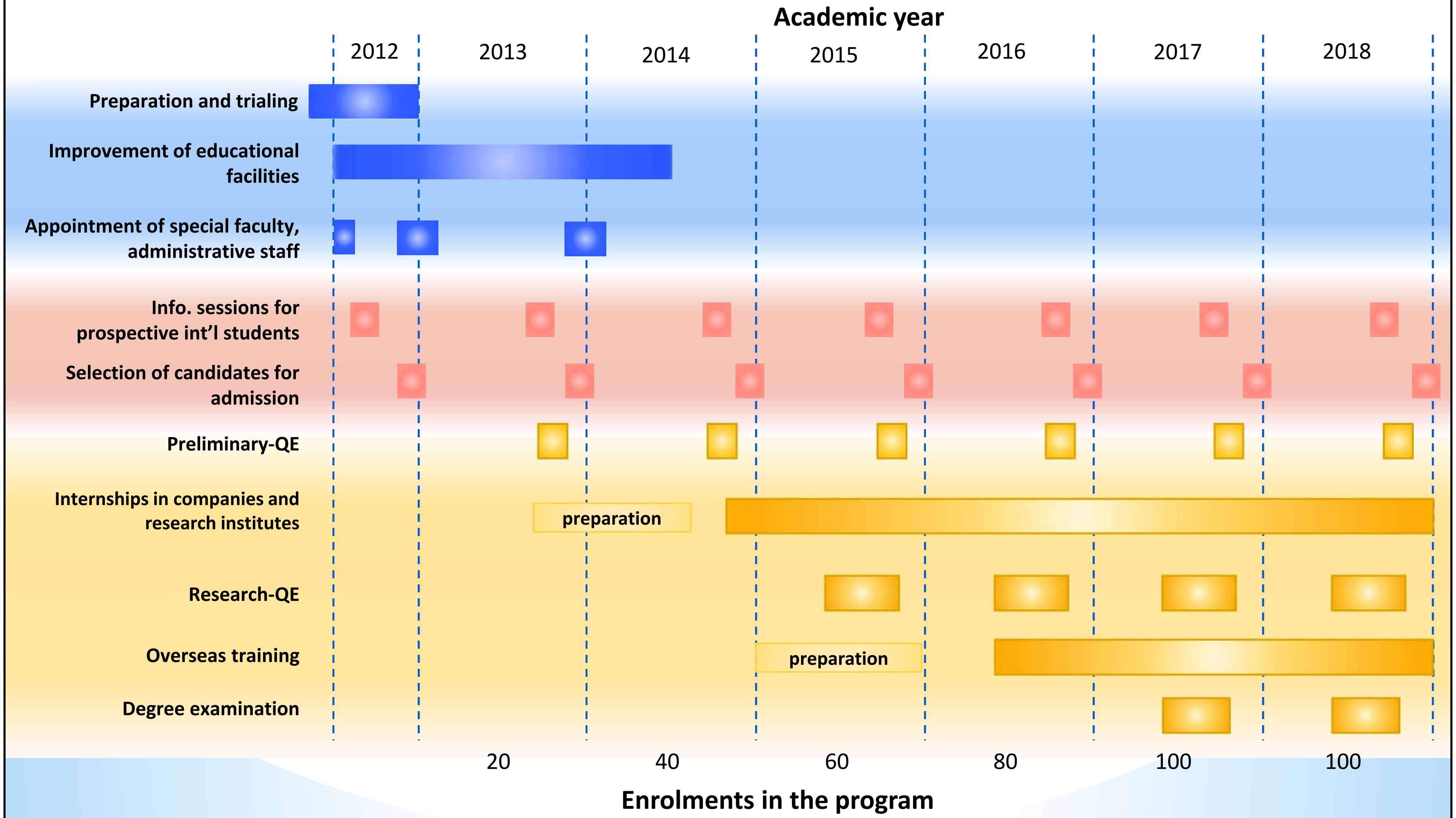
Core space for "seido jyukugi" interdisciplinary interaction

Hub Space (Information Science Building A and B)

Fostering lively discussion beyond disciplinary boundaries

Osaka University Humanware Innovation Program

Yearly plans



Budget outline

	FY2012	FY2013	FY2014
Materials expenses	79,930	62,175	37,771
Facilities and maintenance	21,900	35,000	0
Consumables for seminars and research subjects	58,030	27,175	37,771
Wages and honoraria	59,092	146,748	102,656
Specially-appointed faculty members	12,000	55,000	44,200
Administrative personnel	6,440	25,332	27,672
Student mentor program trialing and operation	39,424	64,680	27,300
Honoraria for lecturers, program and student advisories	1,228	1,736	3,484
Travel expenses	30,584	72,360	33,155
Domestic travel	2,884	11,110	7,805
Trialing and operation of overseas internships	6,550	15,200	10,800
International travel for program publicity and discussion	18,000	23,900	7,950
International travel for professors/researchers invitation	3,150	22,150	6,600
Scholarships	0	42,000	87,600
Scholarships	0	42,000	87,600
Other	58,244	86,847	64,319
Hosting symposia and workshops	5,002	5,800	8,400
Advisory Committee	232	232	390
Printing expenses	8,200	3,575	2,950
Public relations expenses (incl. website expenses)	9,800	11,800	7,280
Student research project trialing and operation	24,000	53,000	30,800
Business consignment expenses for program support	9,700	9,000	5,120
Miscellaneous expenses	1,310	3,440	9,379
TOTAL	227,850	410,130	325,501

21% CUT!!

Amounts are shown in units of 1,000 yen