

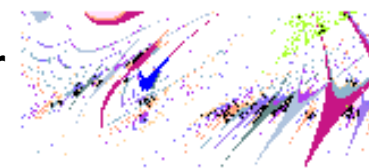
뇌의 복잡성 이해하기

"Boldly go where no one has gone before"

김승환

Nonlinear & Complex Systems Lab. (NCSL - NRL)
POSTECH

swan@postech.ac.kr
<http://www-ncsl.postech.ac.kr>

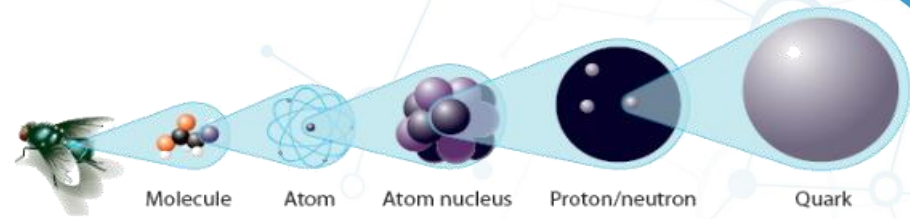


Nonlinear
and
Complex System
Laboratory

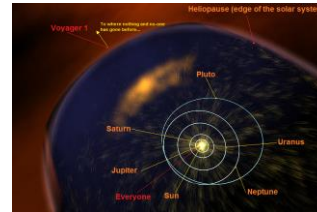
PHYSICS, POSTECH

과학이란 ...

과학 Science



세상은 무엇으로 이루지는가? (미시 세계)



우리는 어디에 속해있는가? (거시 세계)



인간이란 무엇인가? (생명 / 뇌)

HOMO SAPIENS
(CRO-MAGNON)



Homo Sapiens

호기심



HUMAN

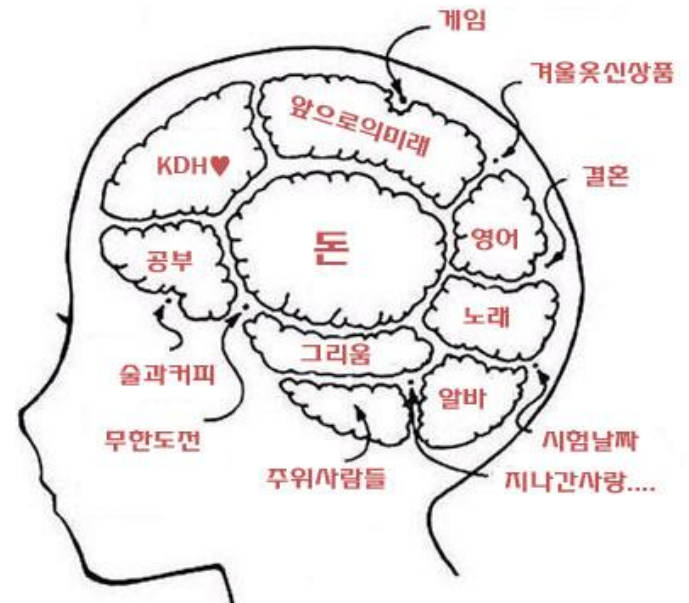
THE SCIENCE BEHIND WHAT MAKES US UNIQUE

MICHAEL S. GAZZANIGA

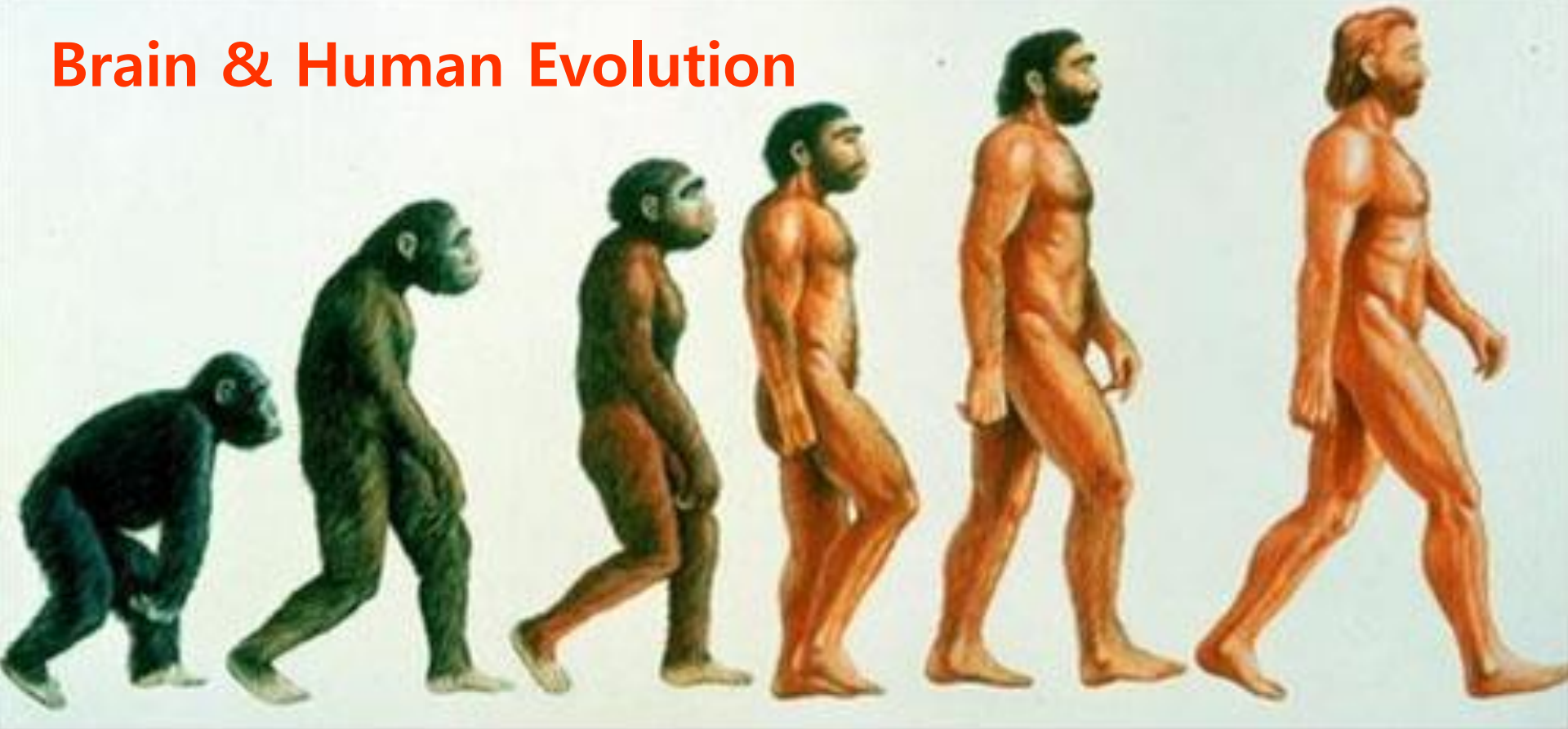
AUTHOR OF THE ETHICAL BRAIN



물질, 생명, 마음



Brain & Human Evolution



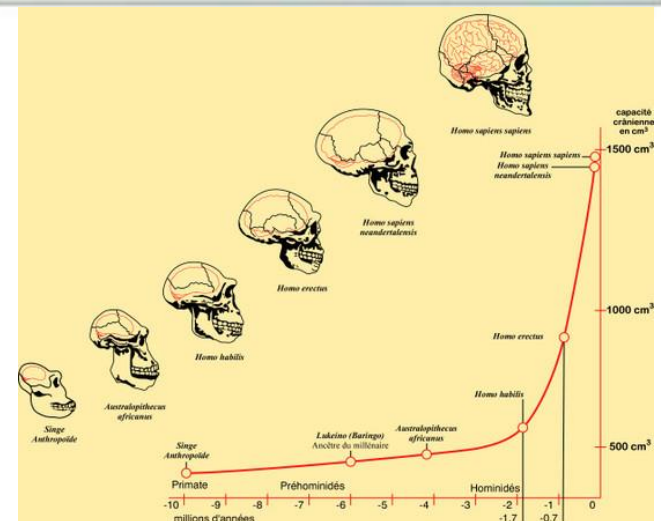
~96%



40%



74%



"The next great American project"



As humans we can identify galaxies light years away, we can study particles smaller than an atom; but we still haven't unlocked the mystery of three pounds of matter between our ears.

1986



"Whoa! That was a good one! Try it, Hobbs—just poke his brain right where my finger is."

**What
Cortical
Region of
the brain
would these
doctors be
stimulating?**

Brain is complex & hierarchical

1 m



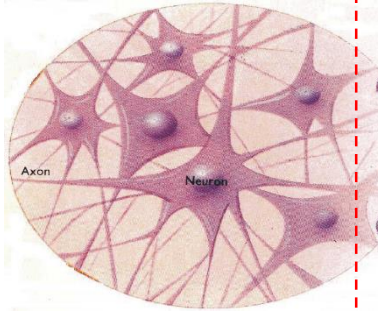
Cognitive neuroscience

Area

Functional column

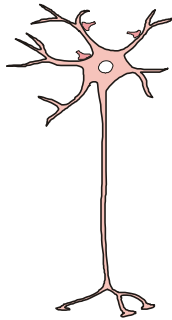
Computational neuroscience

Neural networks



Nonlinear dynamics/chaos

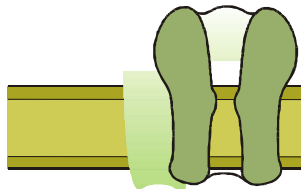
Neuron



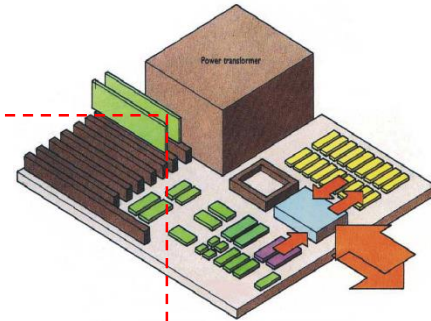
Biological physics

Membrane
Ion channel
Protein

10 nm
(10^{-9})

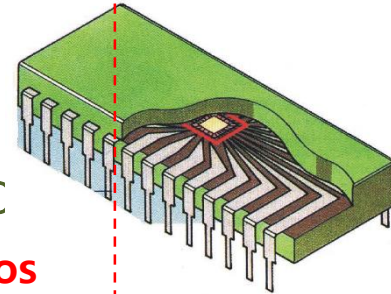


AI AC



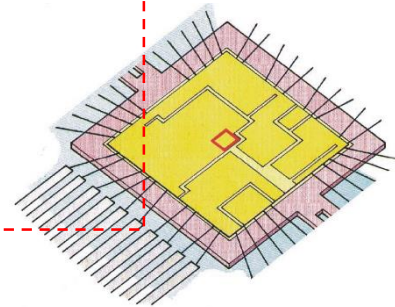
**Complex networks/
systems**

VLSI/SOC

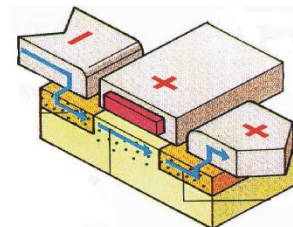


Statistical physics

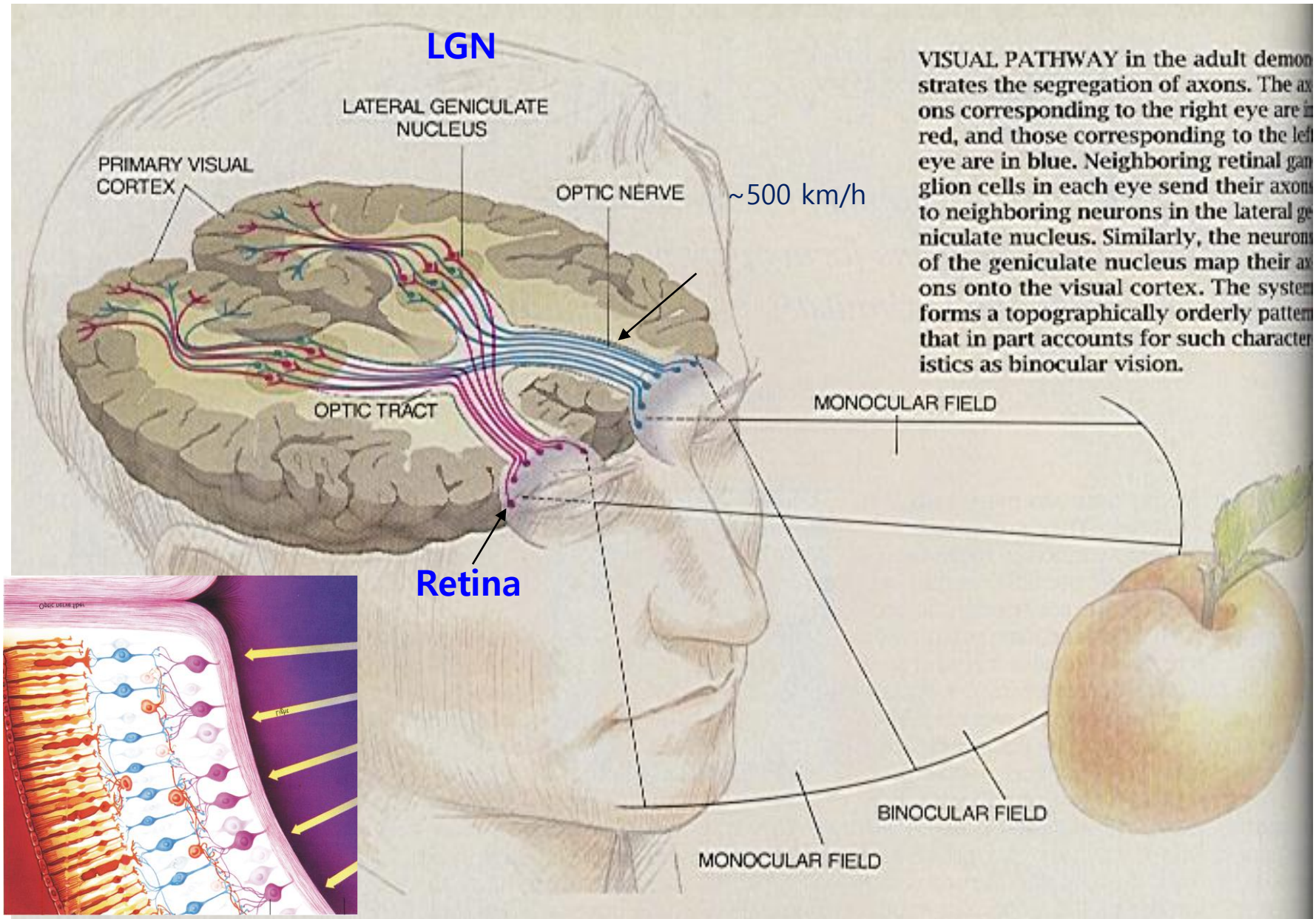
IC



Transistor



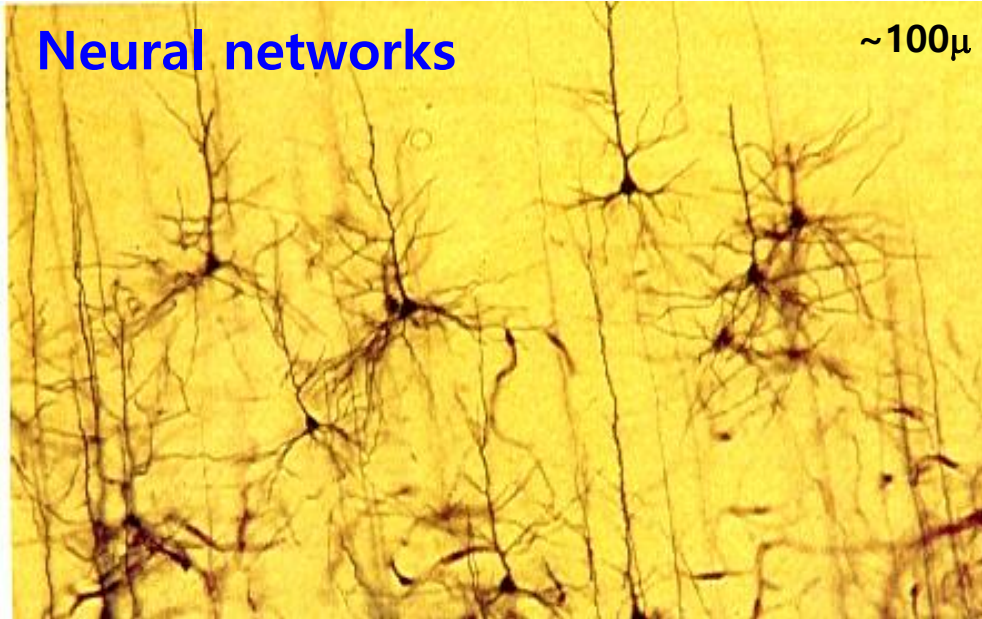
How does the brain work? Visual Information Processing



Complex Information Pathways of the Brain

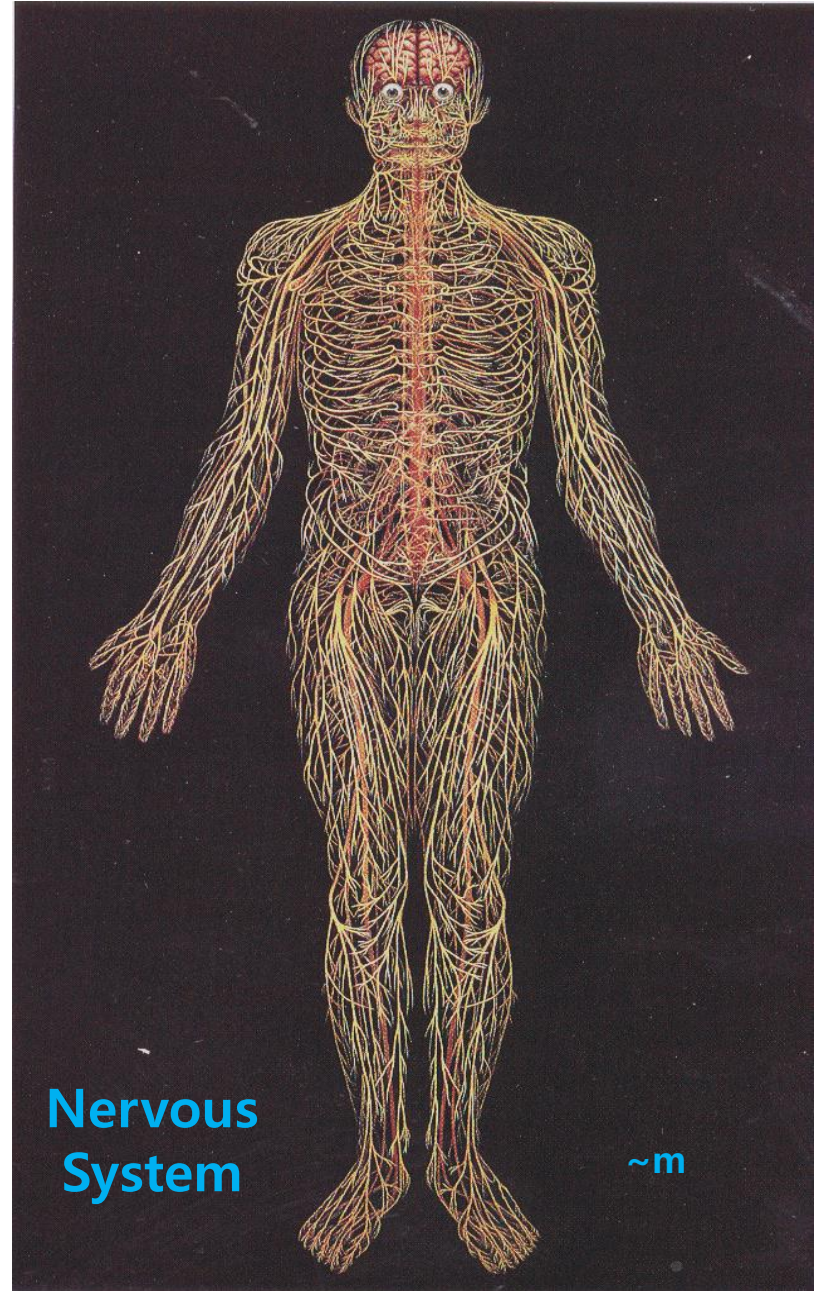
Neural networks

~100 μ



Connectome

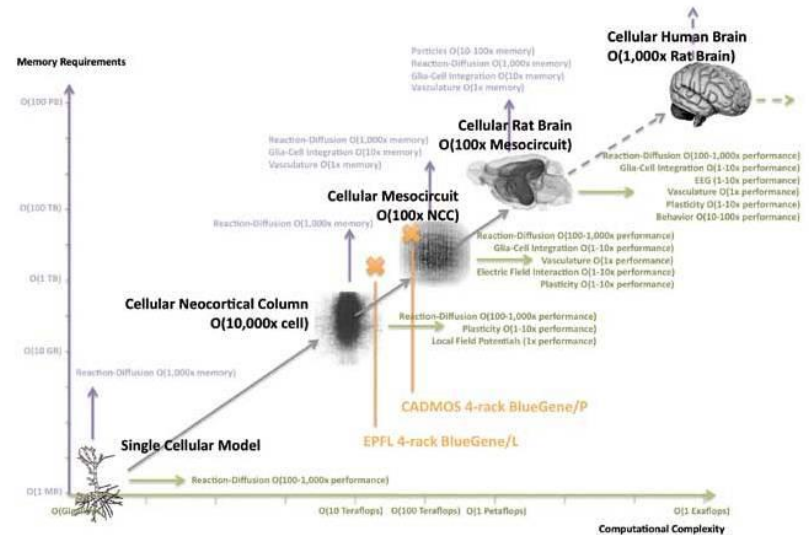
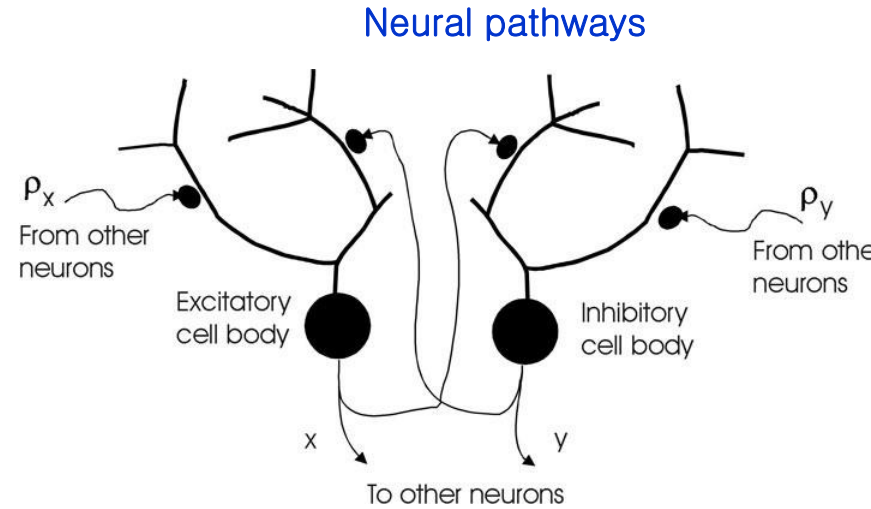
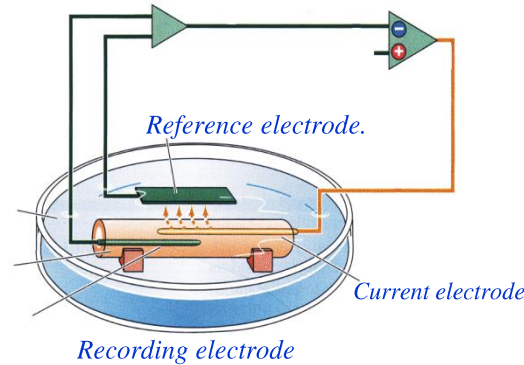
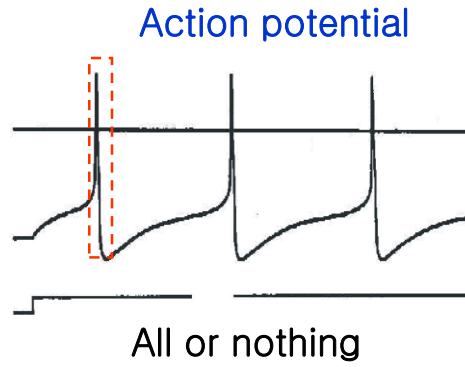
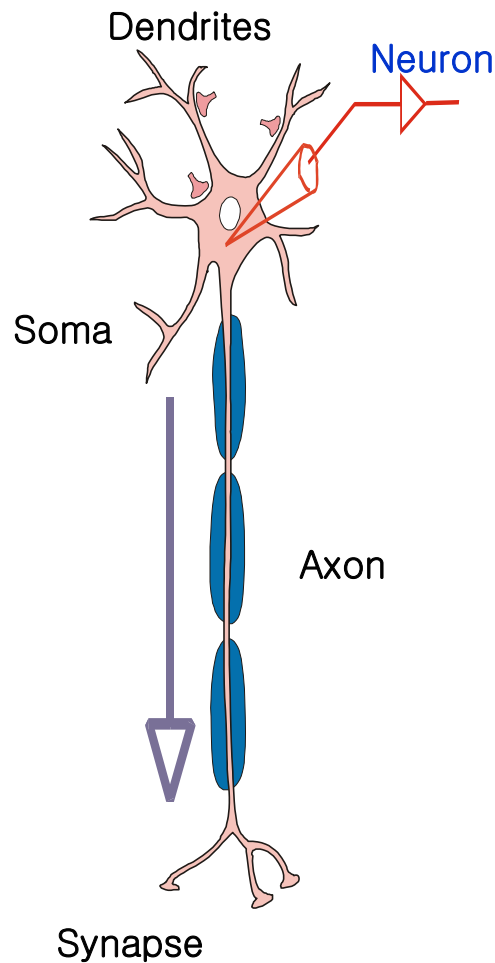
~mm/cm



Nervous System

~m

Simulating Neural Dynamics: Bottom-up



- Dynamical neurons** e.g. Hodgkin-Huxley
- + Synaptic coupling** e.g. chemical, electrical
- + Complex networking geometry**

Simulations \Downarrow Nonlinear dynamics

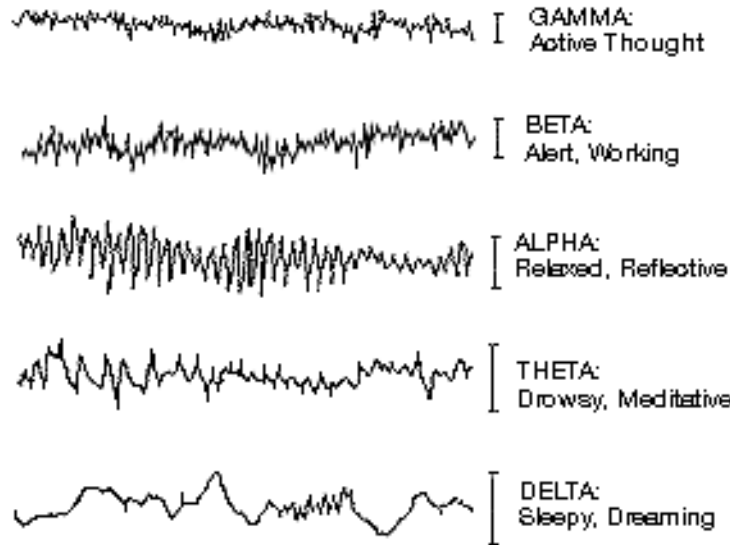
Synchronization, clustering, bifurcations, self-organization, pattern formation



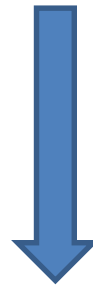
Neural correlates for cognitive functions?

Measuring & Analyzing Brain EEGs: Top-down

Measure EEG activities in various brain states



Multi-channel data



Multi-variate signal analysis

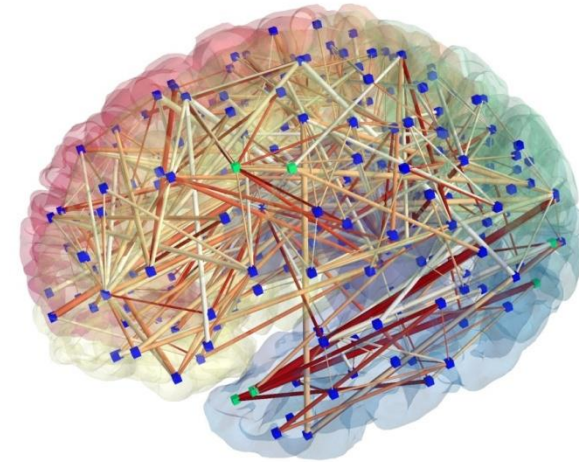
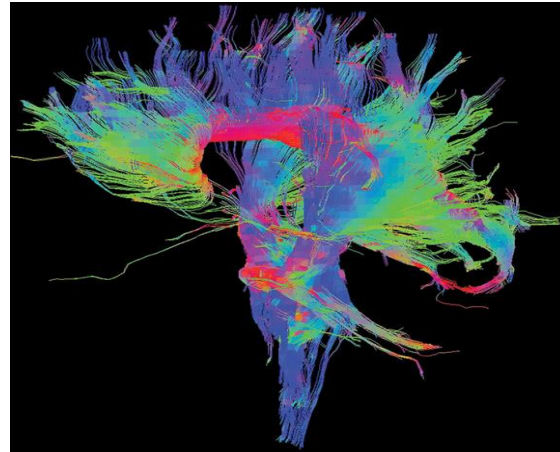
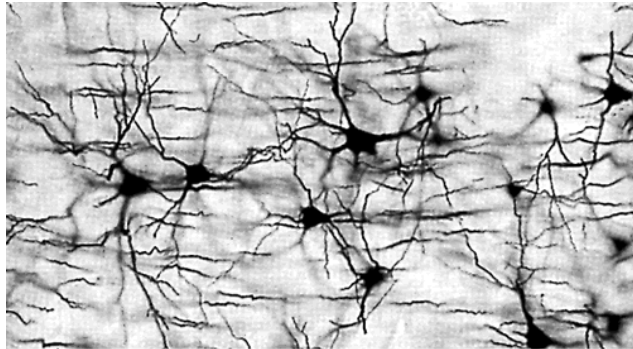
Nonlinear quantifiers

Information flow

Functional networks

Q. spatiotemporal organization of patterns & segregated functions?

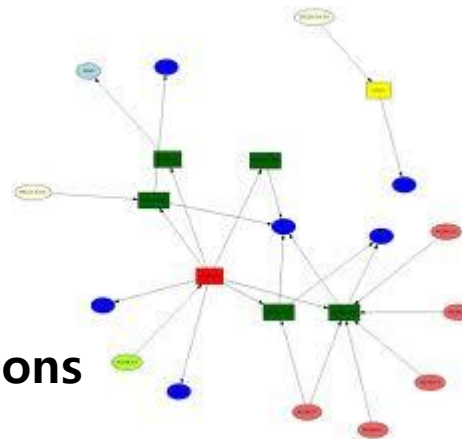
Complex Brain



- One of the most complex systems
- Massively interconnected structure “networks of networks”

Node:

biomolecules/genes
individual neurons
neuronal populations
cortical minicolumns
anatomically segregated regions
EEG channels



Link:

signal transduction pathways
structural links
- synapses/fiber pathways
statistical/causal relationships

Science of Complex Systems 1999

Complexity, System, Dynamics



Beyond Reductionism

- Exploring the Systems of Life, Robert F. Service
Building Working Cells 'in Silico', Dennis Normile
Unraveling Bacteria's Dependable Homing System,
Elizabeth Pennisi
Life After Chaos, Carl Zimmer
Simple Lessons from Complexity, Nigel Goldenfeld
and Leo P. Kadanoff
Complexity in Chemistry, George M. Whitesides and
Rustem F. Ismagilov
Complexity in Biological Signaling Systems, Gezhi
Weng, Upinder S. Bhalla, and Ravi Iyengar
Complexity and the Nervous System, Christof Koch
and Gilles Laurent
Complexity, Pattern, and Evolutionary Trade-Offs in
Animal Aggregation, Julia K. Parrish and Leah
Edelstein-Keshet
Complexity in Natural Landform Patterns, B. T.
Werner
Complexity and Climate, D. Rind
Complexity and the Economy, W. Brian Arthur

Complexity in Nonlinear, Complex Systems



Q: Why is the nature so complex?

Q: How such complexity can emerge from fundamental origins spontaneously?

=> Nonlinear dynamics, chaos theory, complex systems

Synchronization in Complex Systems



slow (~60Hz)

massively parallel

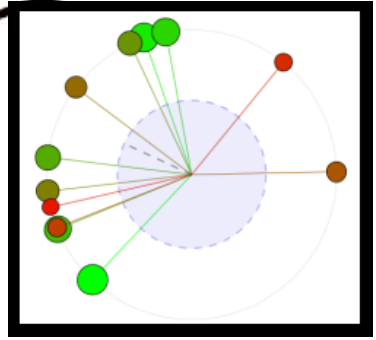
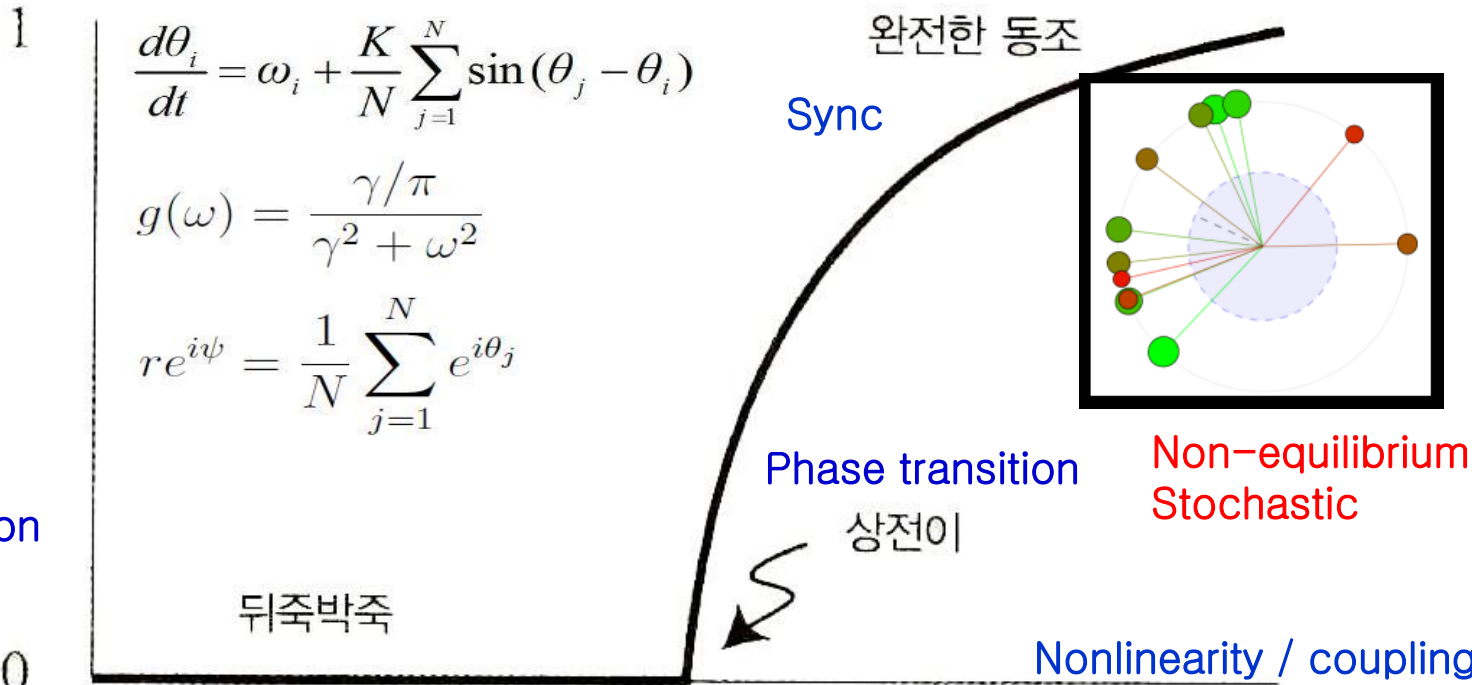


Modeling Collective Rhythms in Nature

Winfree, 1965
Kuramoto, 1975

동조의 양:
같은 속도로
달리는 집단의
주각

Degree of
synchronization



Non-equilibrium
Stochastic

No sync

집합 내 동질성의 양

Heterogeneity

Nonlinearity / coupling



Dispersed

Sync

Twins

Central Questions in Brain Studies

- **Central questions** **Complex Structure vs complex function**
 - Q. How functional networks interact with their structural substrates?
 - Q. Which parameters of complex brain networks are relevant to cognitive and behavior functions?
- **Focus on dynamics of brain networks**
 - Q. spatiotemporal organization of patterns & brain functions?
 - Searching for Neural Correlates: Complex dynamics <-> function**
 - **Quantify & measure brain states & their transitions**
 - **Study effects of modulation of functional connectivity/parameters**

Science

1 July 2005

Vol. 309 No. 5731
Pages 1-204 3-10

125



Questions:

WHAT DON'T WE KNOW?

AAAS

Top 25 questions

What is the biological basis of consciousness?

“Consciousness”

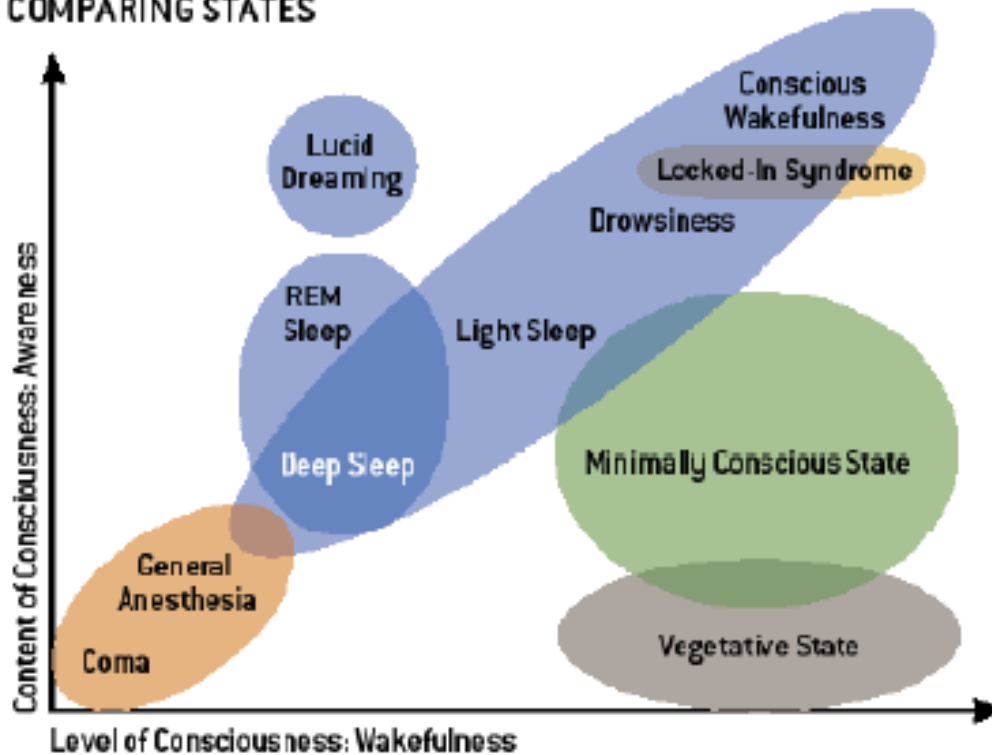
10 unsolved problems in physics, IOP, 1999

“Holy grail of neuroscience”



Complex Issues in Consciousness

COMPARING STATES



Laureys, Scientific American, 2006

Wakefulness vs consciousness

sleep-walking, vegetative state

- Behavioral definition in trouble
 - subconscious voluntary acts
 - cortices alone are not enough
- Subjective experience:
 - sensory + emotion + volition...

Scientific Approach to Consciousness

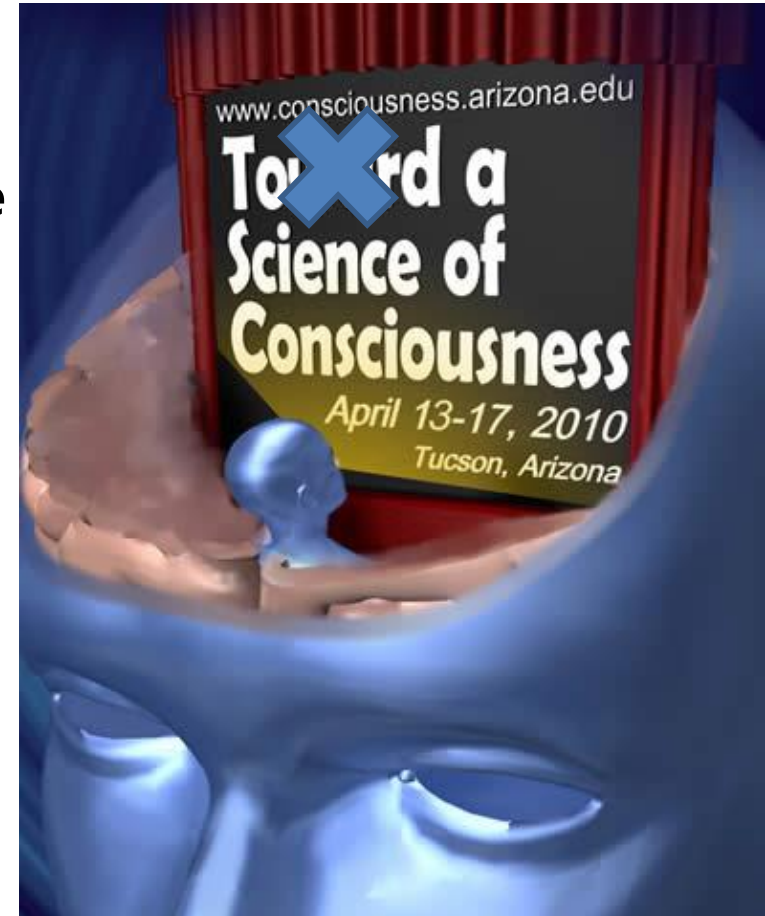
- Only in 20c a legitimate subject of scientific studies: First interdisciplinary conference in 1994.
- Now active research in philosophy of minds, psychology, neuroscience, cognitive science, artificial intelligence

Central Question: How to specify and measure consciousness?

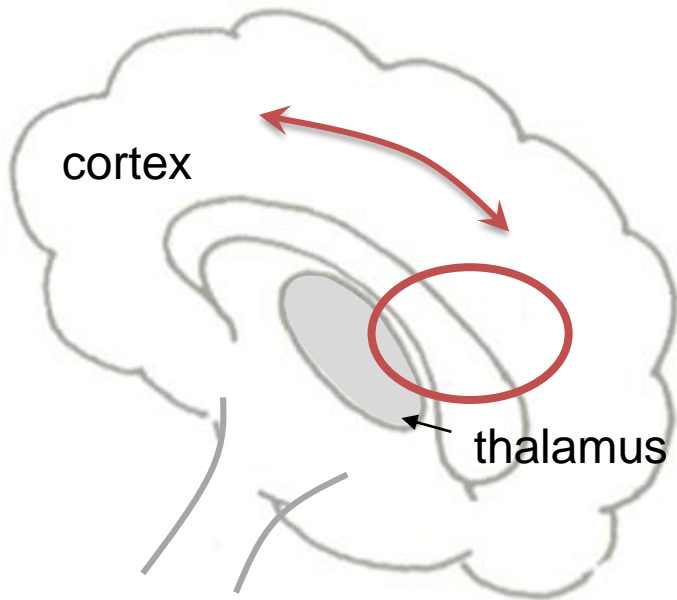
⇒ Neural correlates of consciousness (NCC)

General Anesthesia

Visual Attention



Hypotheses for neural correlates of consciousness



- Crick & Koch
Frontal homunculus watching back
Nat Neurosci (2003)
- Edelman & Tononi
Information integration
Science (1998)
- Llinas
Cortico-thalamic Synchronization
Phil Trans R Soc Lond B (1998)

“Consciousness is a product of high-level integration of information as processed by multiple functional brain regions.”

Consciousness & General Anesthesia



Mechanism of anesthetics in the brain not well known yet, not quantified.

EEG – nonlinear/statistical complex system analysis

Information integration pathways

Neural Correlates of Consciousness



QUESTIONS

1. Is it possible to quantify states of consciousness during general anesthesia? (*Clinically important*)
2. What is the mechanism for the loss and emergence of consciousness ? (*Neuroscientifically important*)

PLEM: Consciousness 기반 마취심도 진단 시스템

포스텍, 서울 아산병원, 인바디 콘솔시움
2013-2017, PLEM개발, 현재 임상중

Complexity of functional connectivity patterns

- Diversity of information flow/communications
- Phase synchronization diversity: Phase Lag Entropy

H. Lee et al, Diversity of functional connectivity patterns is reduced in propofol-induced unconsciousness, HBM, 2017







KH Seo et al, J Korean Med Sci. 2019 May;34(20):e151

Comparative Analysis of Phase Lag Entropy and Bispectral Index as Anesthetic Depth Indicators in Patients Undergoing Thyroid Surgery with Nerve Integrity Monitoring

“PLE is a reasonable alternative to BIS for evaluating consciousness and DOA during general anesthesia and during NIM”

Navigating the next industrial revolution

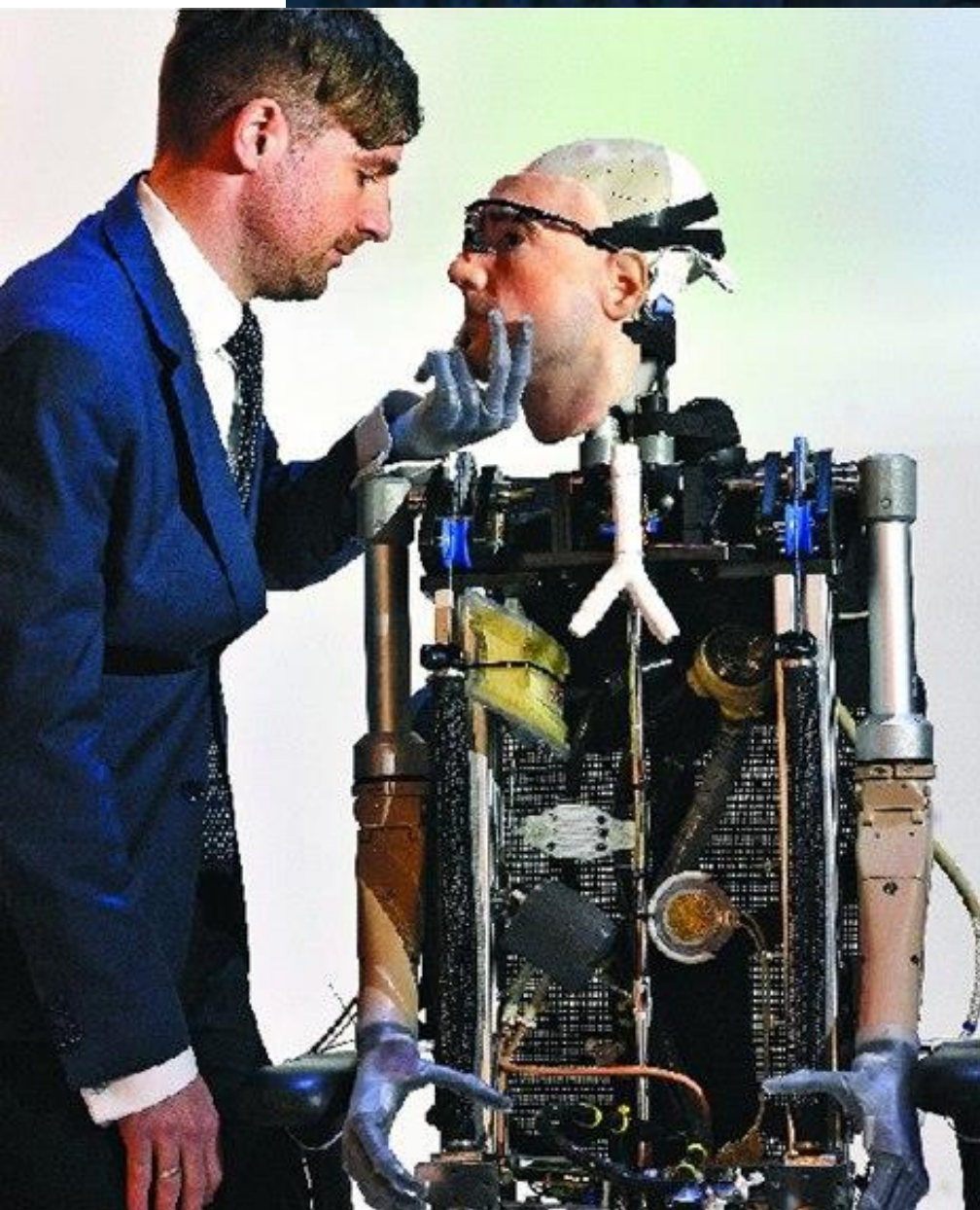
Revolution	Year	Information
	1 1784	Steam, water, mechanical production equipment
	2 1870	Division of labour, electricity, mass production
	3 1969	Electronics, IT, automated production
	4 ?	Cyber-physical systems

The Future of Jobs

Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution

January 2016





C2013 렉스



C2017 공각기동대

Intricate issues of consciousness

Hard problem of consciousness

Experience

Non-human consciousness

Emergence of consciousness

Computer & consciousness



=> What make a human? Artificial Consciousness

- Psychological philosophy, neuroscience, cognitive science, artificial intelligence

Arguably one of the biggest challenges in science!

Potential impact for science, medicine, and society

Brain is complex & hierarchical

1 m



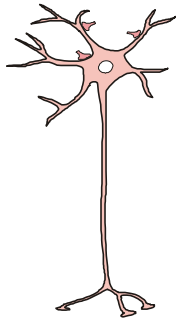
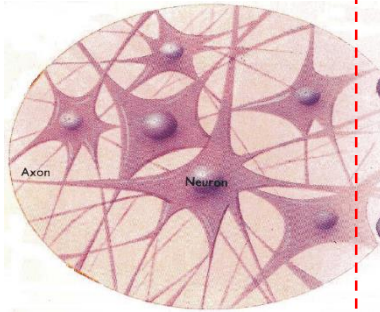
Cognitive neuroscience

Area

Functional column

Computational neuroscience

Neural networks

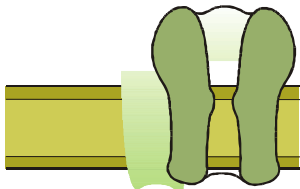


Neuron

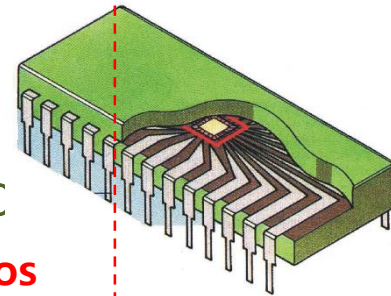
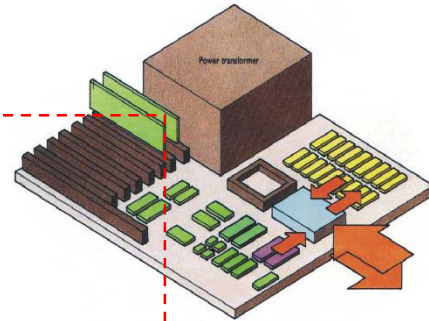
Biological physics

Membrane
Ion channel
Protein

10 nm
(10^{-9})



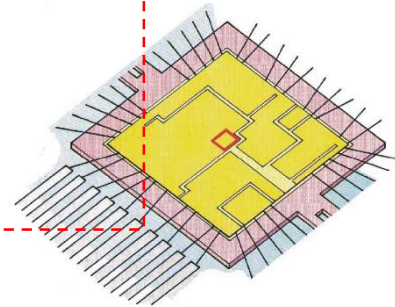
AI AC



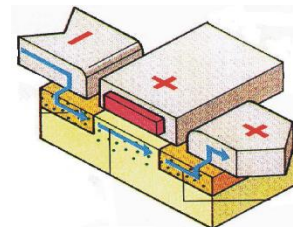
VLSI/SOC

Nonlinear dynamics/chaos

IC



Transistor



**Complex networks/
systems**

Statistical physics

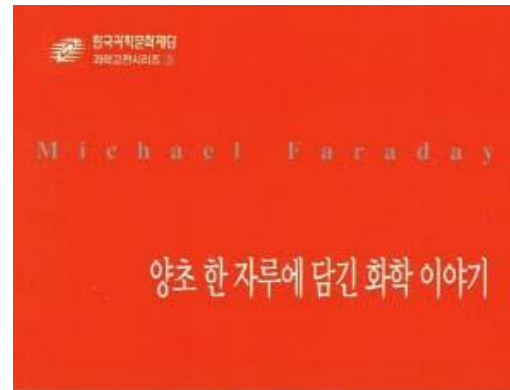
과학과 문화...



촛불의 과학



Thank you!



마이클 패러데이 자화 / 박태규 옮김

흔히 쓰는 양초 한 자루의
 어떠한 화학을 이해할 수 있을까?
 패러데이는 단 한 자루의 양초가 만들어져
 필요한 화학적 과정을
 세심한 관리하에 눈으로 관찰하고 실험한다.
 그는 양초의 연소 현상과, 산소 및
 각종 물질의 실험과 상관관계를
 화학이 기초 지식을 실험과 함께
 구체적이고 쉽게 설명함으로써,
 후기를 맞이하는 화학의 세계로 이끌어 간다.

서해문집

