Brain-like Computer

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Acknowledgement

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1 Introduction

2 Cognitive Neuroscience

3 Mind Models

4 Architecture

5 Perspective

Human dream

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- **There are three revolutions with impact in the human history, the tool-making revolution, agricultural revolution and industrial revolution. Acompanying these revolutions, the situation of society, economy and civilization have transformed from one to another.**
- **What is the next revolution? It is the intelligence revolution with the goal of replacing work performed by human brain work with machine intelligence.**

Alan M. Turing

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Alan Turing
(1912-1954)

•*On computable numbers with an application to the Entscheidungsproblem* (1936)

230 A. M. TURING [Nov. 12,

ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. TURING.

[Received 28 May, 1936.—Read 12 November, 1936.]

The "computable" numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means. Although the subject of this paper is ostensibly the computable *numbers*, it is almost equally easy to define and investigate computable functions of an integral variable or a real or computable variable, computable predicates, and so forth. The fundamental problems involved are, however, the same in each case, and I have chosen the computable numbers for explicit treatment as involving the least cumbrous technique. I hope shortly to give an account of the relations of the computable numbers, functions, and so forth to one another. This will include a development of the theory of functions of a real variable expressed in terms of computable numbers. According to my definition, a number is computable if its decimal can be written down by a machine.

In §§ 9, 10 I give some arguments with the intention of showing that the computable numbers include all numbers which could naturally be regarded as computable. In particular, I show that certain large classes of numbers are computable. They include, for instance, the real parts of all algebraic numbers, the real parts of the zeros of the Bessel functions, the numbers π, e, etc. The computable numbers do not, however, include all definable numbers, and an example is given of a definable number which is not computable.

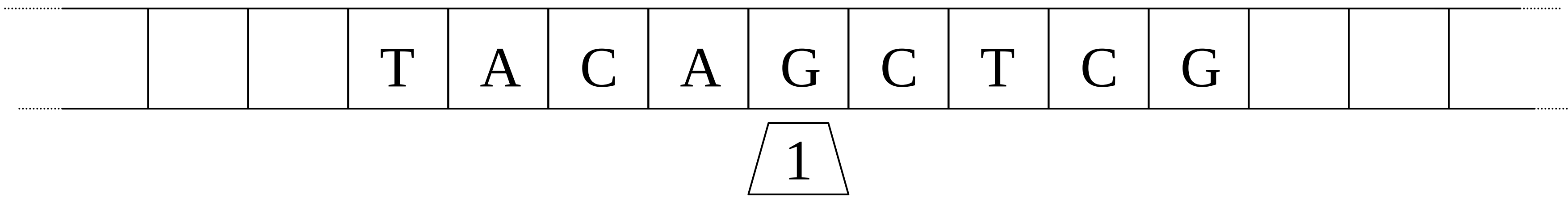
Although the class of computable numbers is so great, and in many ways similar to the class of real numbers, it is nevertheless enumerable. In § 8 I examine certain arguments which would seem to prove the contrary. By the correct application of one of these arguments, conclusions are reached which are superficially similar to those of Gödel†. These results

† Gödel, "Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme, I", *Monatshefte Math. Phys.*, 38 (1931), 173–198.

Turing Machines

- Turing machine introduced by Alan M. Turing in 1936 is conceptual device for studying the power of algorithmic processes.
- It consists of a control unit that can read and write symbols on a tape by a R/W head.
- The tape extends indefinitely at both ends.   Each cell on the tape can store any one of a finite set of symbols– alphabet.
- At any time, it must be in one of a finite number of states, including start/halt states.
- Its computation starts in the start state, and ceases in the halt state.

The Turing Machine



	-	A	C	G	T
0	HALT	HALT	HALT	HALT	HALT
1	-,<=,0	A,=>,1	C,=>,1	G,=>,2	T,=>,1
2	-,<=,0	A,=>,1	C,<=,3	G,=>,2	T,=>,1
3				T,=>,4	
4			A,=>,1		

Replaces GC with TA

Turing machine operation

- Inputs at each step
  - State
  - Value at current tape position
- Actions at each step
  - Write a value at current tape position
  - Move read/write head
  - Change state

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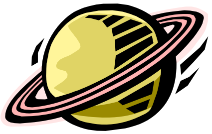
A Turing machine for incrementing a value

Current state	Current cell content	Value to write	Direction to move	New state to enter
START	*	*	Left	ADD
ADD	0	1	Right	RETURN
ADD	1	0	Left	CARRY
ADD	*	*	Right	HALT
CARRY	0	1	Right	RETURN
CARRY	1	0	Left	CARRY
CARRY	*	1	Left	OVERFLOW
OVERFLOW	*	*	Right	RETURN
RETURN	0	0	Right	RETURN
RETURN	1	1	Right	RETURN
RETURN	*	*	No move	HALT

John von Neumann

 = 

Mathematician: Game Theory, Quantum Mechanics, Theory of Computing...

Von Neumann Architecture

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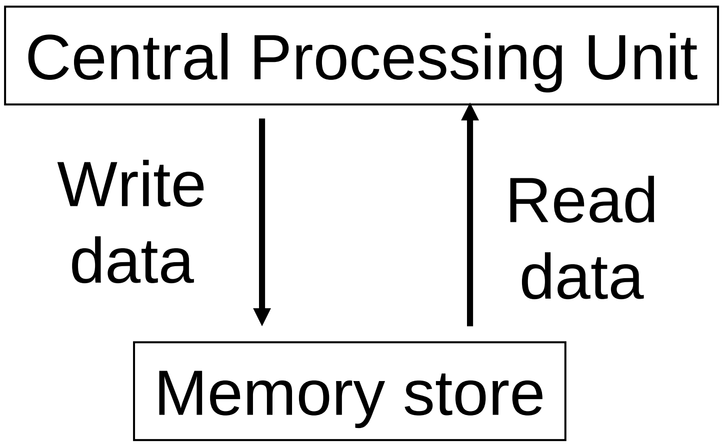
Practical Implementation of Turing Machine



‘fetch-execute-store’ cycle

Repeat

- **Fetch** an instruction and any associated data from memory
- **Execute** the instruction
- **Store** the results in memory

Until...

Knowledge Information Processing

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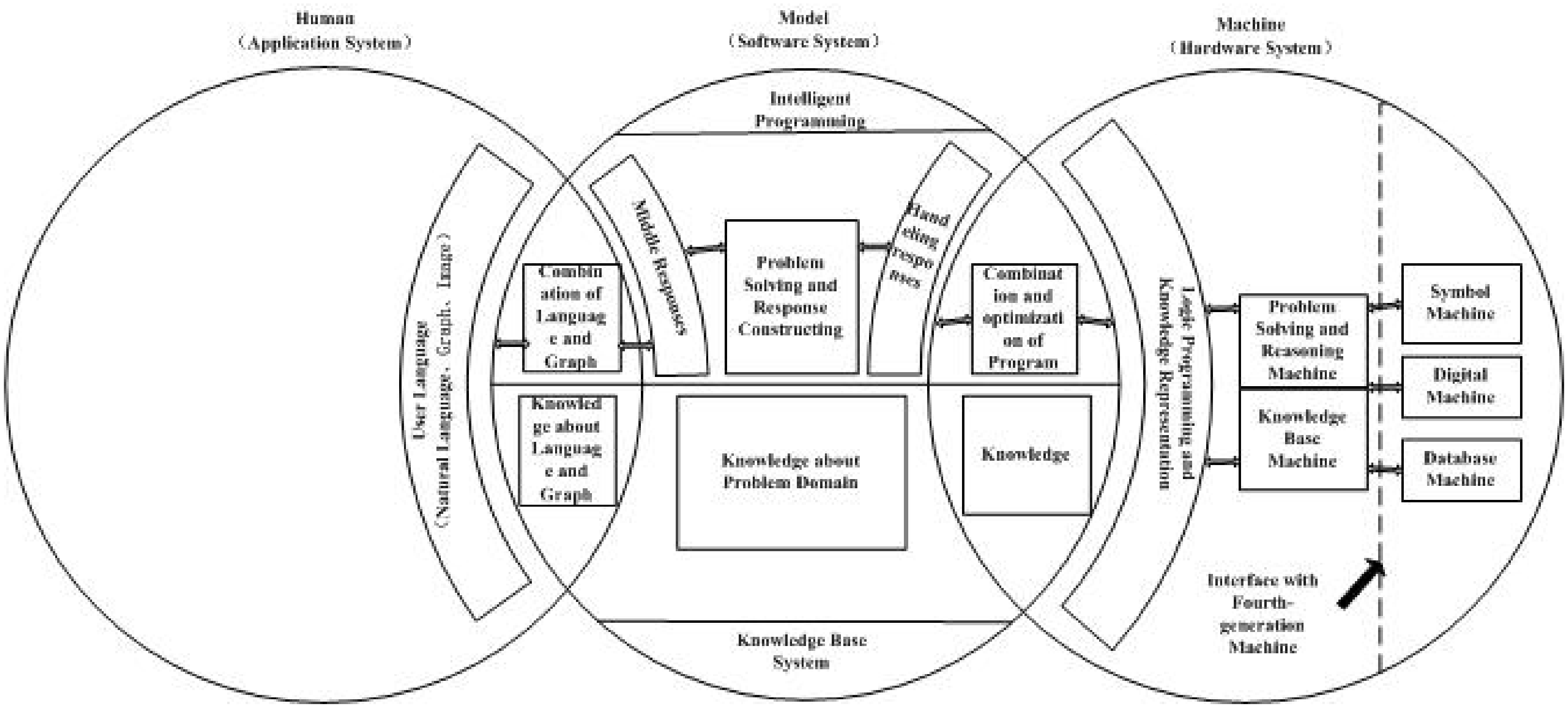
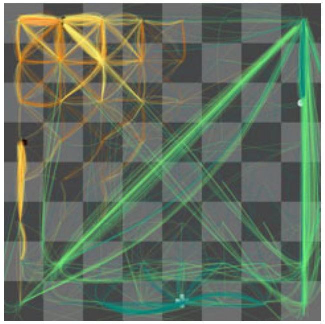
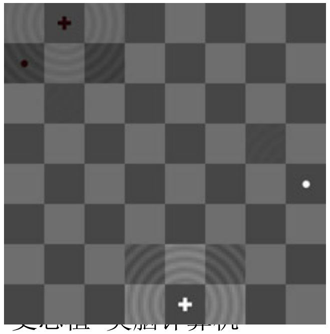
Japanese fifth generation computer



Thinking Machine

Connection Machines from Thinking Machines, Inc. (D. Hills, 1987)
Thinking Machine 4 explores the invisible, elusive nature of thought. Play chess against a transparent intelligence, its evolving thought process visible on the board before you.The artwork is an artificial intelligence program, ready to play chess with the viewer. If the viewer confronts the program, the computer's thought process is sketched on screen as it plays. A map is created from the traces of literally thousands of possible futures as the program tries to decide its best move. Those traces become a key to the invisible lines of force in the game as well as a window into the spirit of a thinking machine.

Visualizing Thinking

Martin Wattenberg
Thinking Machine 03-04

CAM Brain

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Cellar automation--CAM-Brain Machine (CBM) was a part of the artificial brain plan proposed by Hugo de Garis, Evolutionary Systems Department of Kyoto Advanced Telecommunications Research (ATR) in Japan in 1993.

- Cellular Automata Module
- Genotype/Phenotype Memory
- Fitness Evaluation Unit
- Genetic Algorithm Unit
- Module Interconnection Memory
- External Interface

Human Brain vs. CAM-Brain

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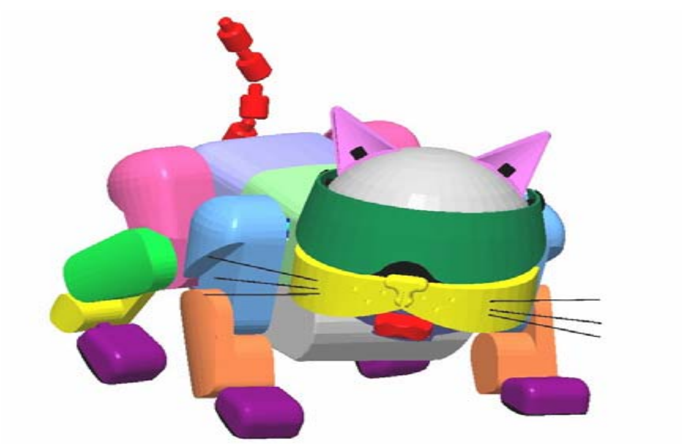
- 10^{14} Neurons
- Parallel Computing
- Speed: 100+ M./sec.
- Natural Evolution

- $4*10^{7}$ Neurons
- 1150 parallel neurons
- Approx. speed of light
- “Designable” Evolution

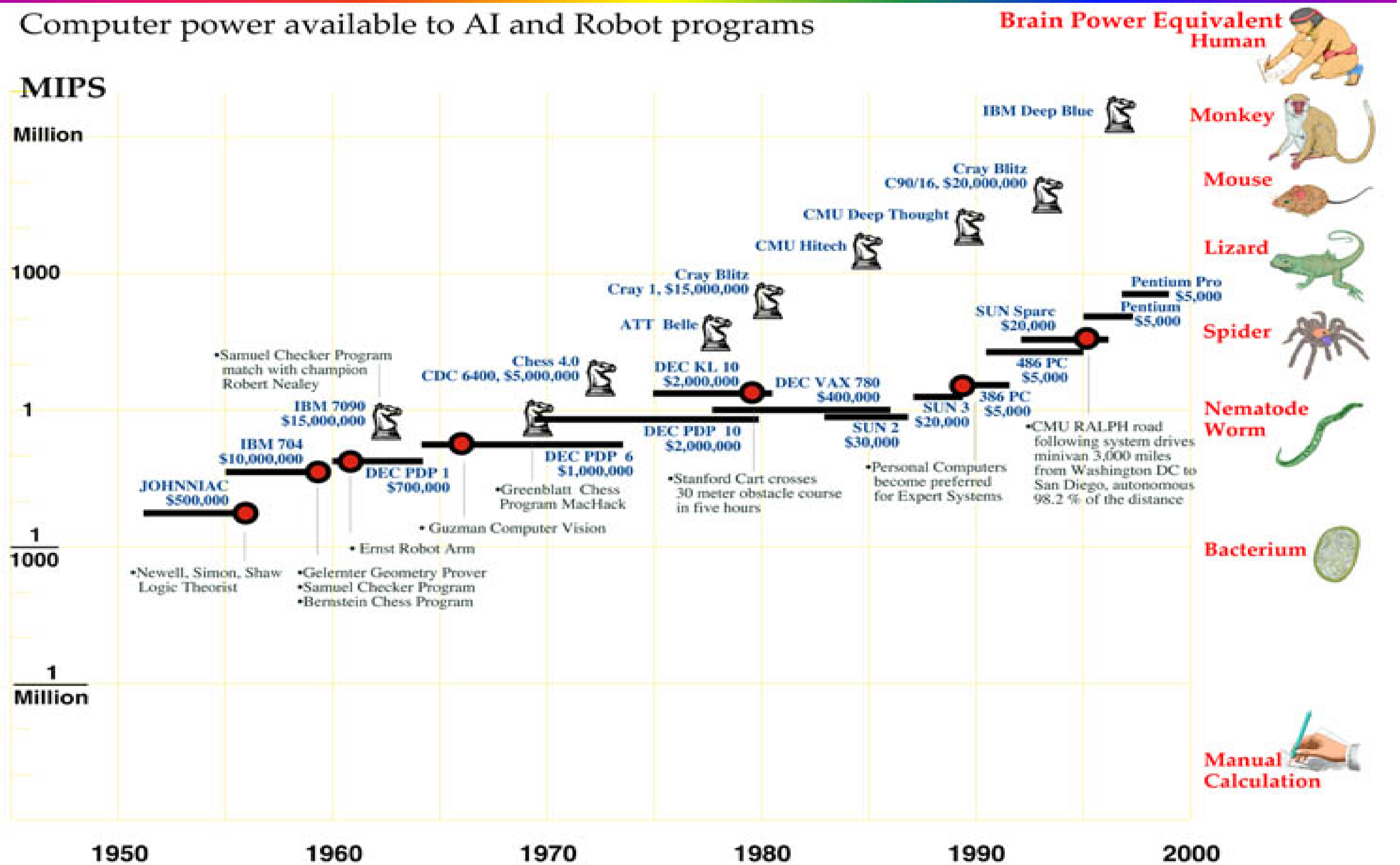


- ROBOKONEKO

CAM Brain

CAM Brain (ATR Kyoto) is impossible to repeat evolutionary process (lack of data about initial organisms and environment, almost infinite number of evolutionary pathways). Evolutionary algorithms require supervision (fitness function) but it is not clear how to create fitness functions for particular brain structures without knowing their functions first; but if we know the function we can program it without evolving.

Challenge：Computing/inteligence



Intelligence Science

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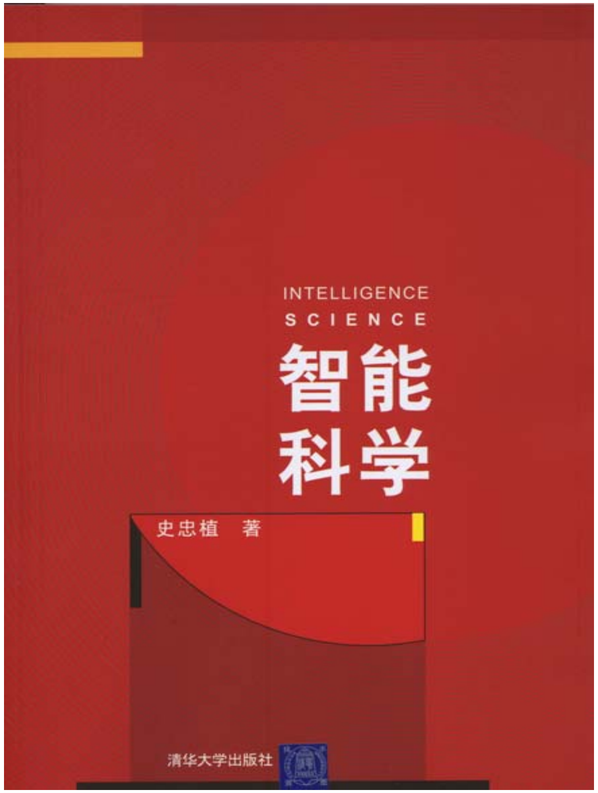
- **Intelligence science is an interdisciplinary subject on basic theory and technology of intelligence, mainly including brain science, cognitive science, artificial intelligence and others.**



Intelligence Science

Intelligence Science

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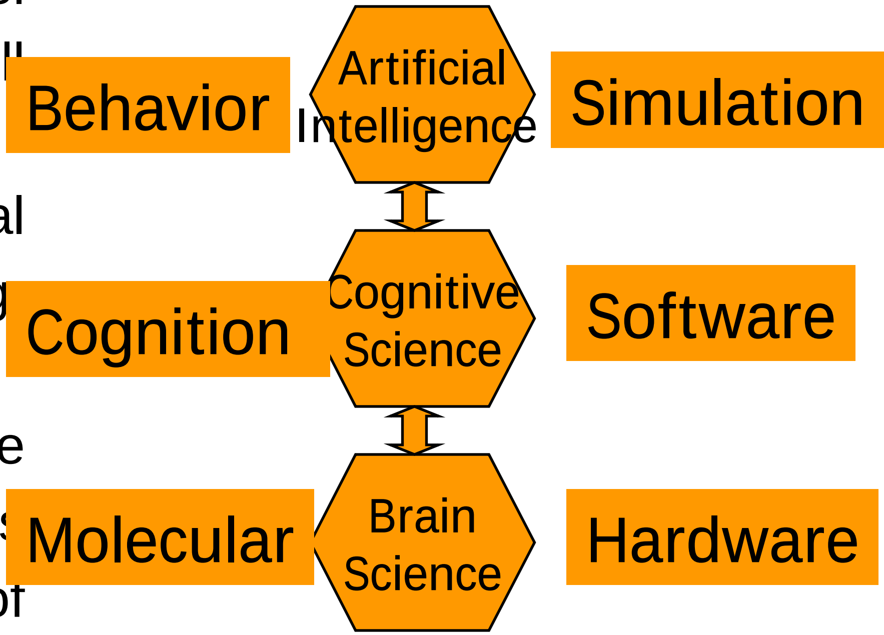
•Brain science explores the essence of brain, research on the principle and model of natural intelligence in molecular, cell and behavior level.

•Cognitive science studies human mental activity, such as perception, learning memory, thinking, consciousness etc.

• In order to implement machine intelligence, Artificial intelligence attempts simulation, extension and expansion of human intelligence using artificial methodology and technology



Series on Intelligence Science

Would Scientific Publishing will publish Series on Intelligence Science. Prof. Zhongzhi Shi is the Editor-in-Chief.

Special Advisors：

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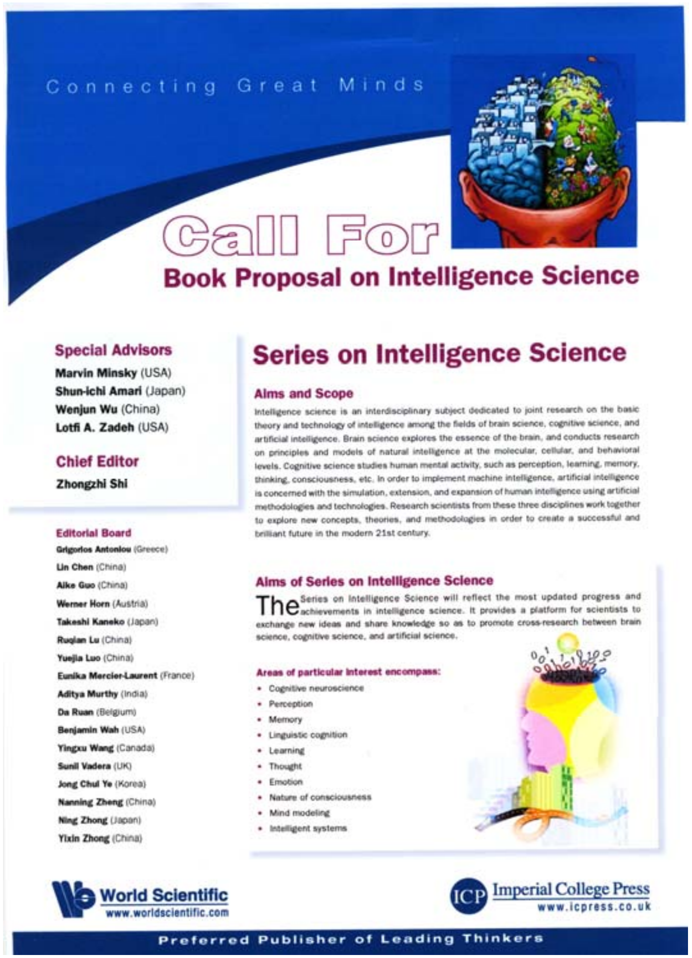
Shun-ichi Amari (Japan)

Wenjun Wu (China)

Lotfi A. Zadeh (USA)



Connecting Great Minds

Call For

Book Proposal on Intelligence Science

Special Advisors

Marvin Minsky (USA)
Shun-ichi Amari (Japan)
Wenjun Wu (China)
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Series on Intelligence Science

Aims and Scope

Intelligence science is an interdisciplinary subject dedicated to joint research on the basic theory and technology of intelligence among the fields of brain science, cognitive science, and artificial intelligence. Brain science explores the essence of the brain, and conducts research on principles and models of natural intelligence at the molecular, cellular, and behavioral levels. Cognitive science studies human mental activity, such as perception, learning, memory, thinking, consciousness, etc. In order to implement machine intelligence, artificial intelligence is concerned with the simulation, extension, and expansion of human intelligence using artificial methodologies and technologies. Research scientists from these three disciplines work together to explore new concepts, theories, and methodologies in order to create a successful and brilliant future in the modern 21st century.

Aims of Series on Intelligence Science

The Series on Intelligence Science will reflect the most updated progress and achievements in intelligence science. It provides a platform for scientists to exchange new ideas and share knowledge so as to promote cross-research between brain science, cognitive science, and artificial science.

Areas of particular interest encompass:

- Cognitive neuroscience
- Perception
- Memory
- Linguistic cognition
- Learning
- Thought
- Emotion
- Nature of consciousness
- Mind modeling
- Intelligent systems

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Basic Scientific Issues

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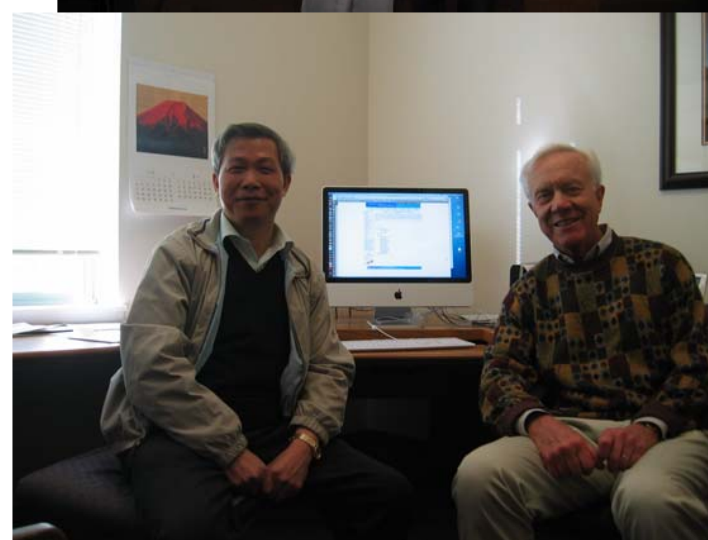
- Signaling in the Nervous System
- Synaptic Plasticity
- Perceptual Representation and Learning
- Learning Mechanisms
- Coding and Retrieval of Various Memory
- Linguistic Cognition
- Thought and Reasoning
- Mind Models
- Nature of Consciousness
- Brain-like Computer



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The History of Neuroscience

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1982 Renaissance of connectionism from the papers by Hopfield, and popularizing the back-propagation algorithm for multiplayer feed-forward networks

1969 End of Perceptron era:
Work "Perceptron" by Minsky and Papert

1957 Frank Rosenblatt invented the modern "perceptron" style of NN, composed of trainable threshold units

1952 Ashby puts the idea that intelligence could be created by the use of "homeostatic" devices which learn through a kind of exhaustive search

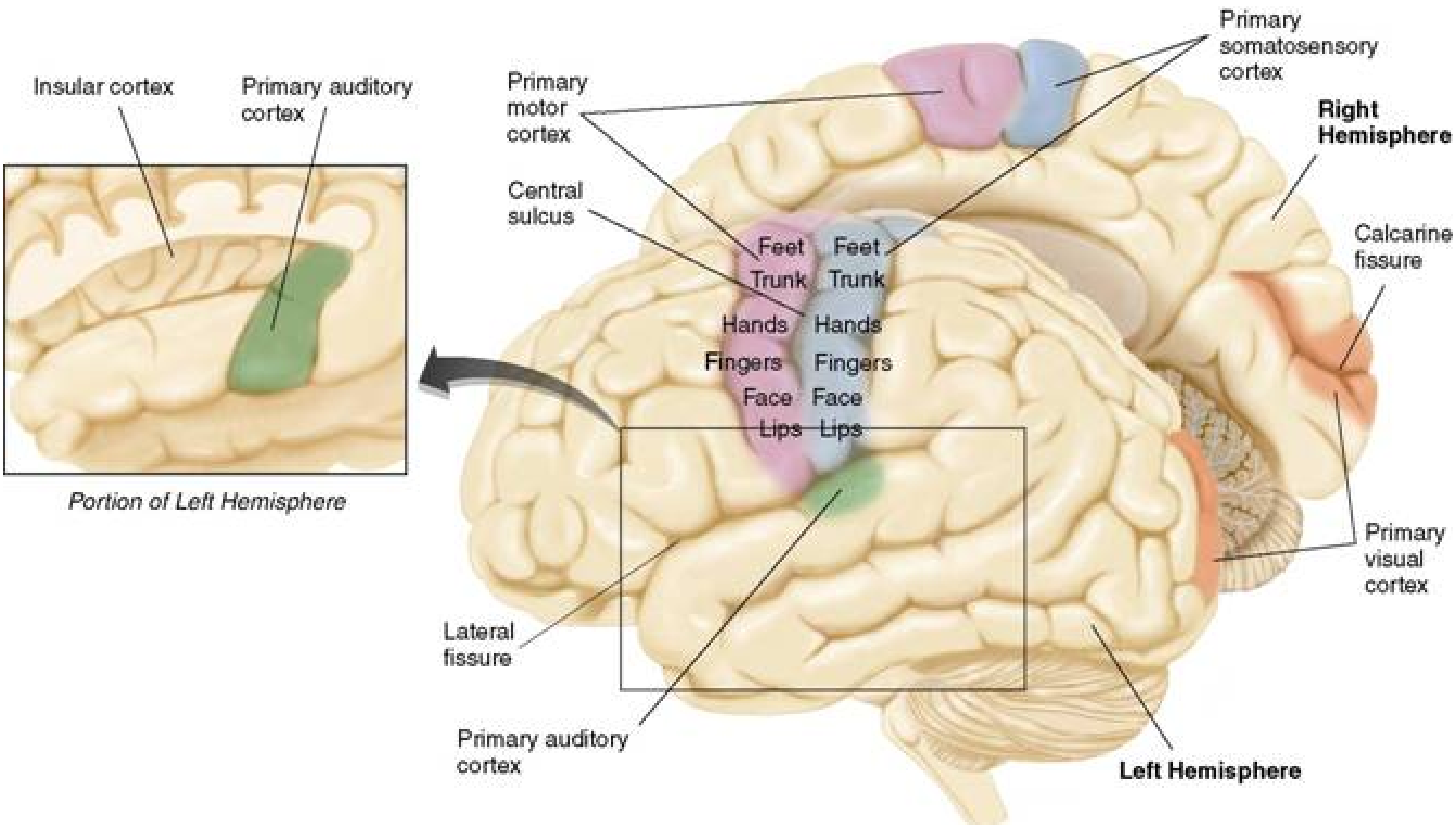
1951 Minsky's builts the first actual neural network learning system

1949 Hebb hypothesis that human and animal long-term memory is mediated by permanent alterations in the synapses.

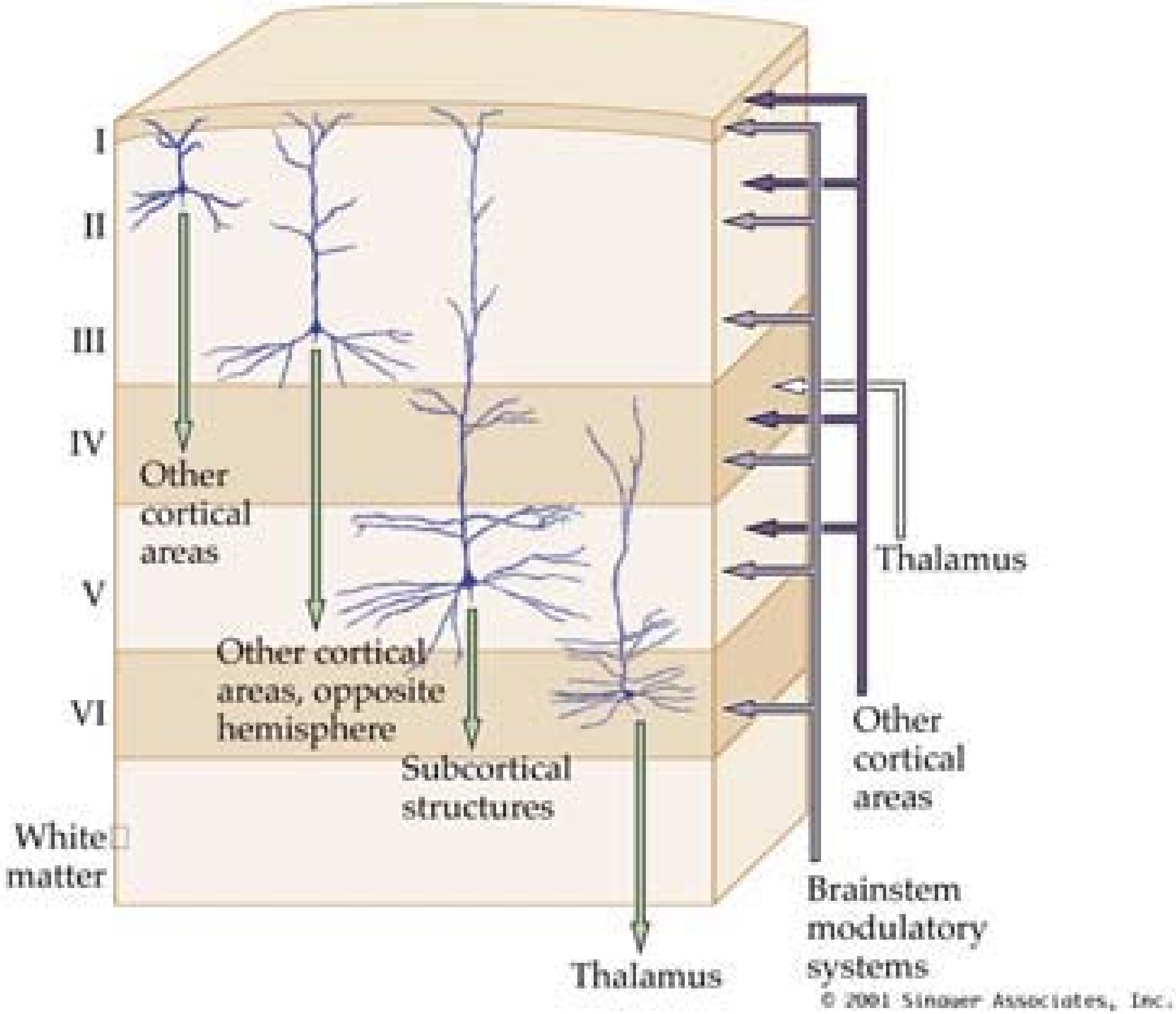
1948 Notion of Wiener about key role of connectionism and feedback loops as a model for learning in neural networks

1943 McCulloch and Pitts introduced the fundamental ideas of analyzing neural activity via thresholds and weighted sums

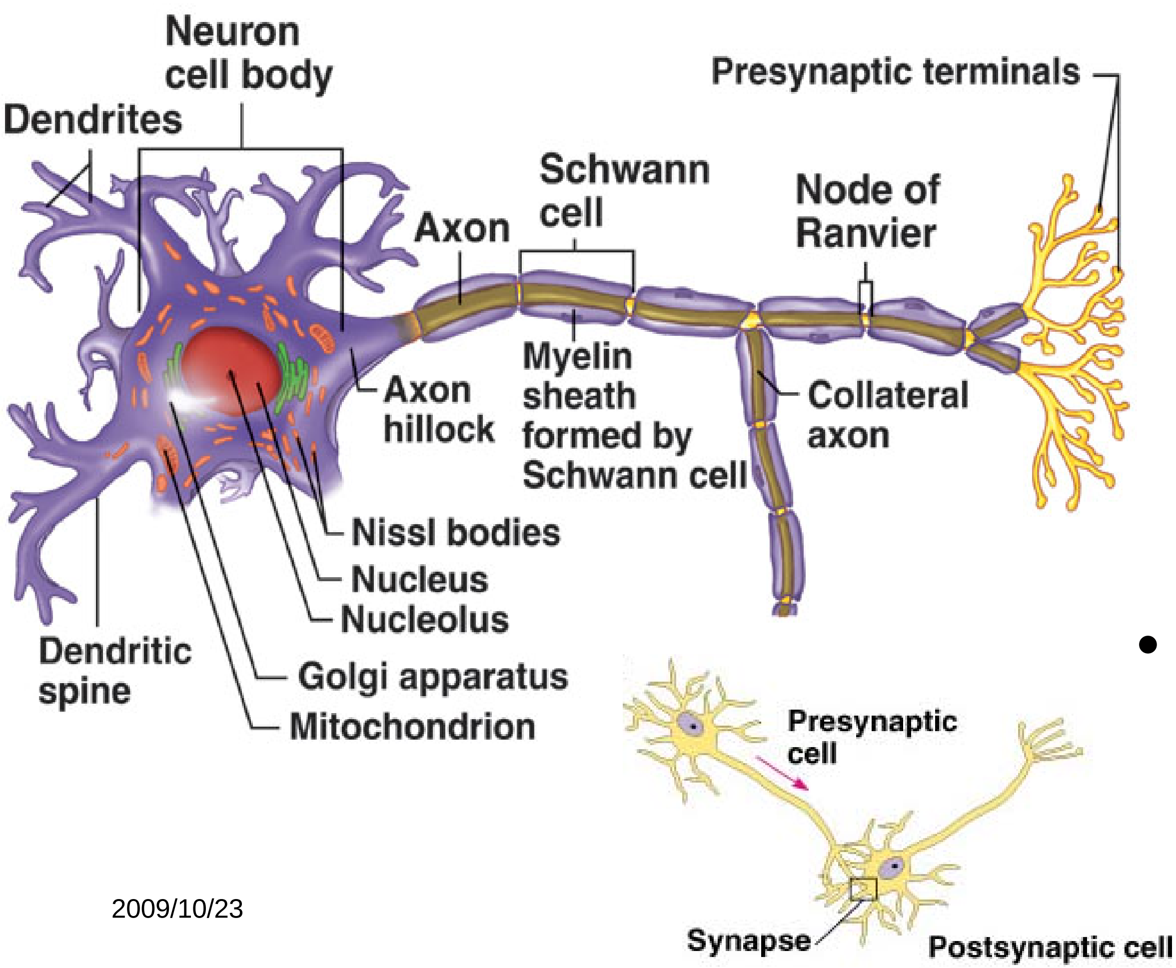
Brain


Insular cortex
Primary auditory cortex
Portion of Left Hemisphere
Primary motor cortex
Central sulcus
Primary somatosensory cortex
Right Hemisphere
Calcarine fissure
Feet
Trunk
Hands
Fingers
Face
Lips
Feet
Trunk
Hands
Fingers
Face
Lips
Lateral fissure
Primary auditory cortex
Primary visual cortex
Left Hemisphere

Brain Canonical Neocortical Circuitry – 6 layers

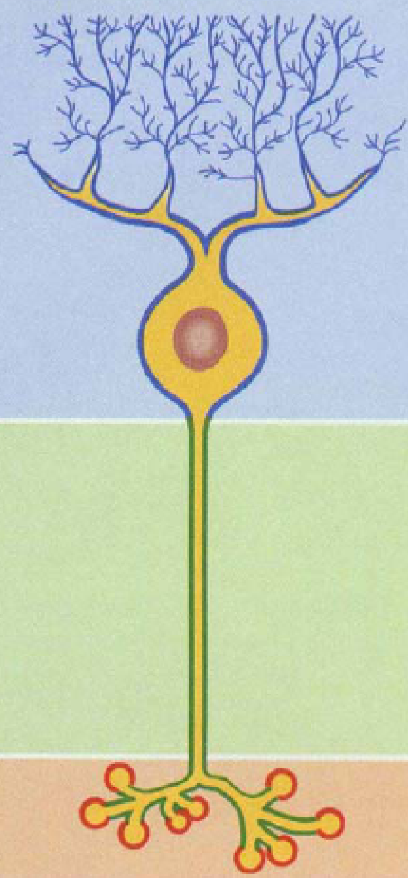


Cells of Nervous System



- Neurons or nerve cells
  - Receive stimuli and transmit action potentials
  - Organization
    - Cell body or soma
    - Dendrites: Input
    - Axons: Output
- Neuroglia or glial cells
  - Support and protect neurons

Neuronal Structure & Function

Diagram	Structure	Functions
	**Dendrites**	Receive stimuli through activation of chemically or mechanically gated ion channels; in sensory neurons, produce generator or receptor potentials; in motor neurons and association neurons, produce excitatory and inhibitory postsynaptic potentials (EPSPs and IPSPs).
	Cell body	Receives stimuli and produces EPSPs and IPSPs through activation of chemically or mechanically gated ion channels.
	Junction of axon hillock and initial segment of axon	Trigger zone; integrates EPSPs and IPSPs and, if sum is a depolarization that reaches threshold, initiates action potential (nerve impulse).
	Axon	Propagates (conducts) nerve impulses from initial segment (or from dendrites of sensory neurons) to axon terminals in a self-reinforcing manner; impulse amplitude does not change as it propagates along the axon.
	Axon terminals and synaptic end bulbs (or varicosities)	Inflow of Ca^{2+} caused by depolarizing phase of nerve impulse triggers neurotransmitter release by exocytosis of synaptic vesicles.

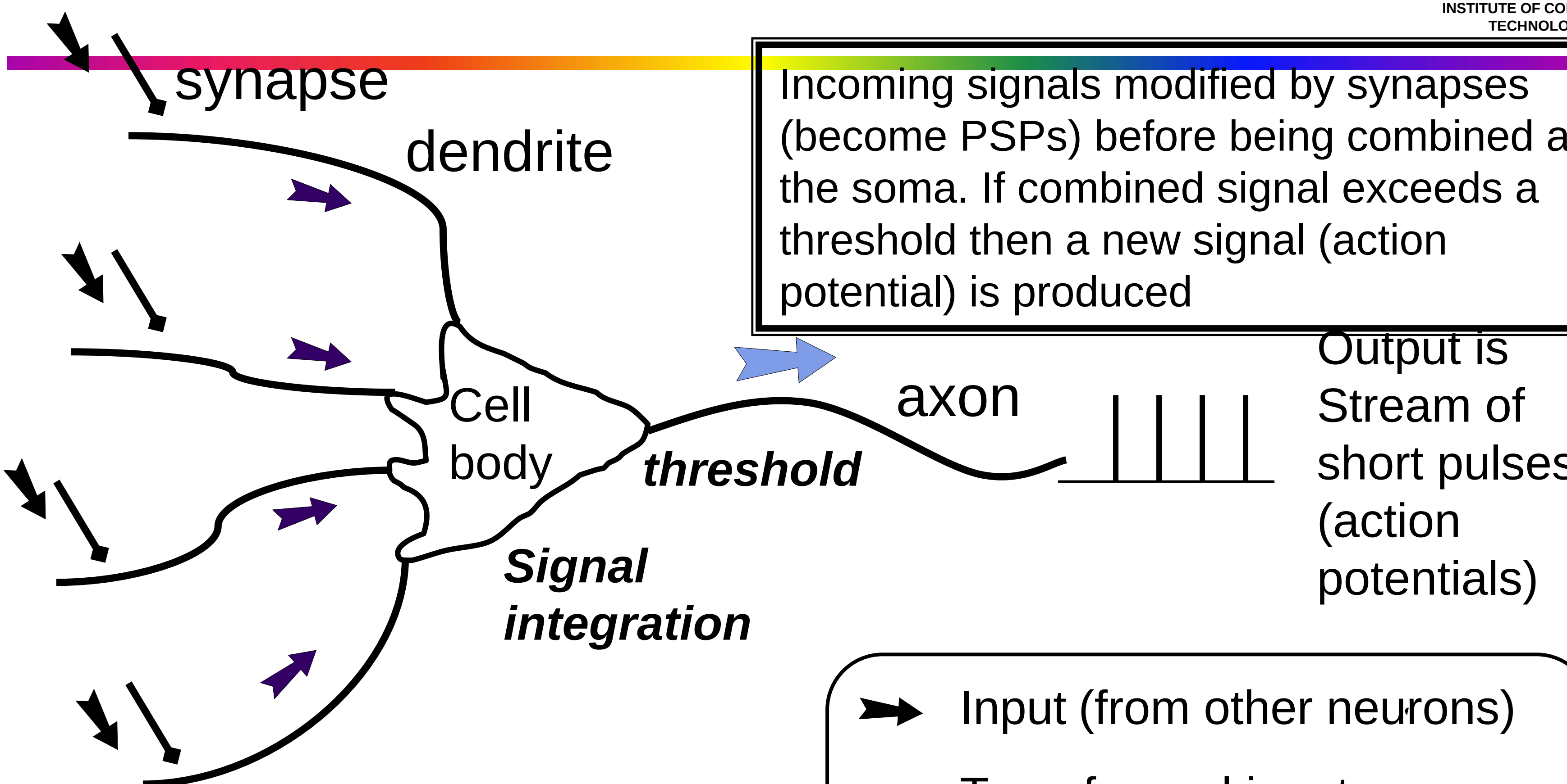
Plasma membrane includes chemically gated channels

Plasma membrane includes voltage-gated Na^+ and K^+ channels

Plasma membrane includes voltage-gated Ca^{2+} channels

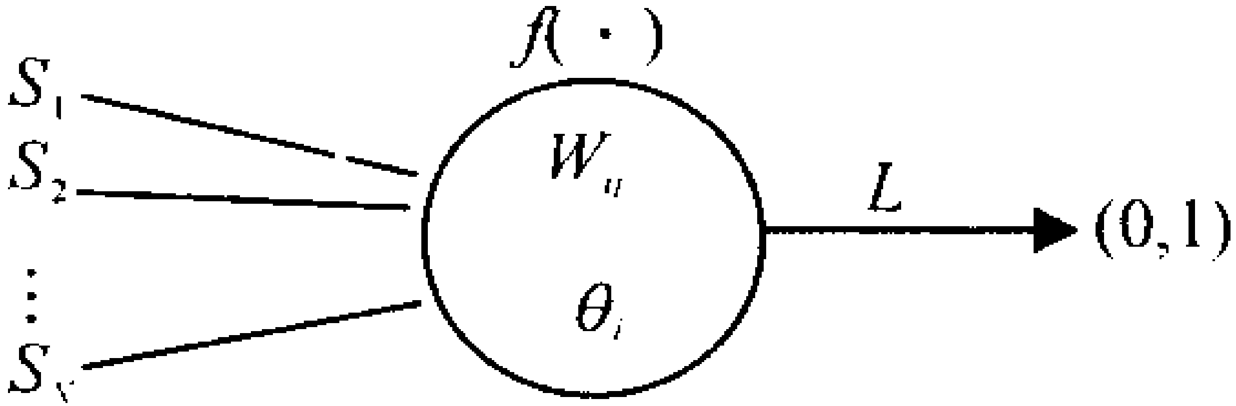
Basic biological neural operation

Incoming signals modified by synapses (become PSPs) before being combined at the soma. If combined signal exceeds a threshold then a new signal (action potential) is produced



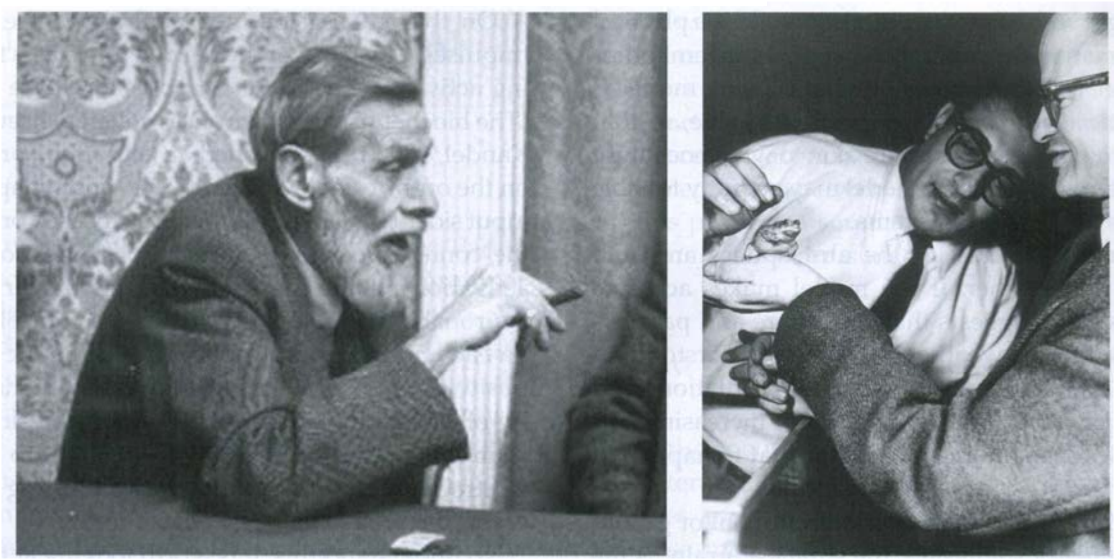
- Input (from other neurons)
- Transformed input (post synaptic potential PSP)
- Output

M-P Neural Model



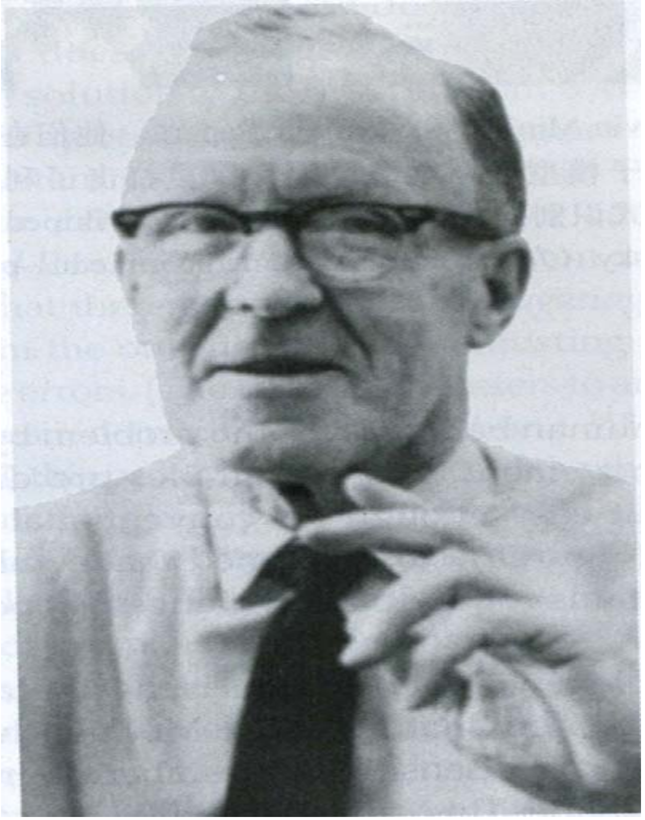
1943 - First artificial neuron model

Warren McCulloch (neurophysiologist) Walter Pitts (mathematician)



Hebbian Learning

Let us assume that the persistence or repetition of a reverberatory activity (or "trace") tends to induce lasting cellular changes that add to its stability…. When an axon of cell *A* is near enough to excite a cell *B* and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that *A*'s efficiency, as one of the cells firing *B*, is increased. (Hebb, The organization of behavior, 1949)



- Donald Olding Hebb 1904-1985

Synapses

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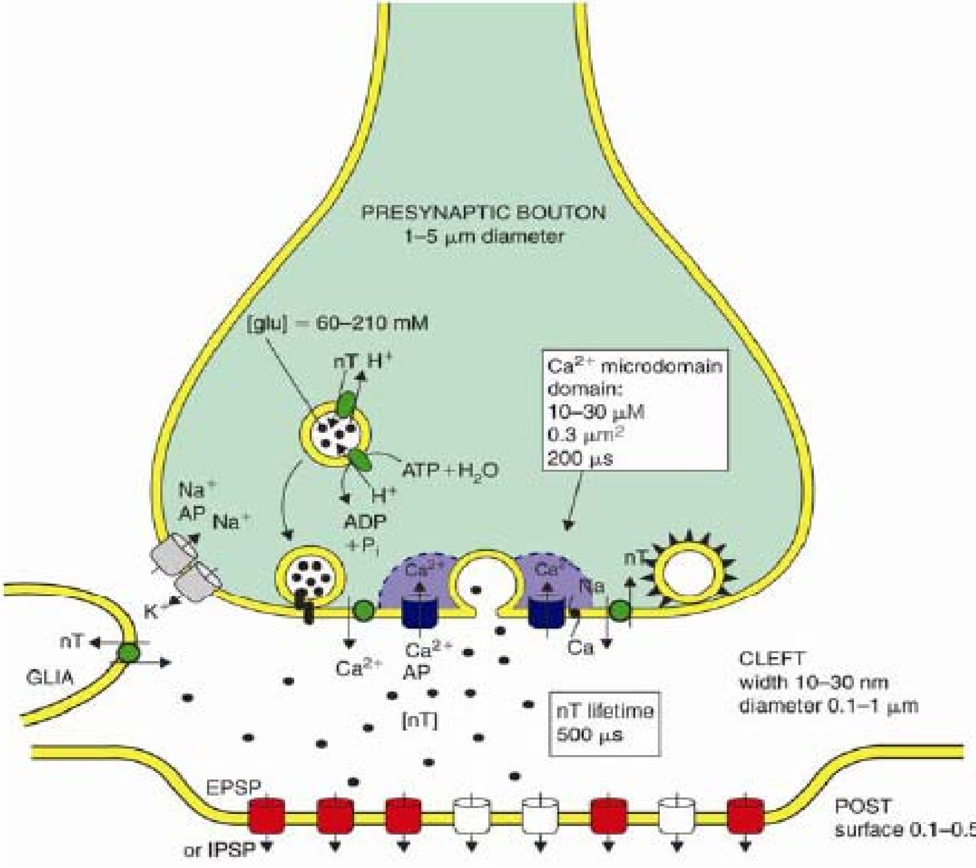
Synapses are the specific site for signal transmission from one cell to another. The major procedures are action potentials to presynaptic terminals, evoked presynaptic Ca2+ currents, Ca2+-evoked transmitter release, transmitters binding to postsynaptic receptors, ion channels' opening, postsynaptic currents (excitatory or inhibitory). The direction of postsynaptic currents depends on the ion-selectivity of channels and chemical-electrical gradient at a given membrane potential.



Resting Potential

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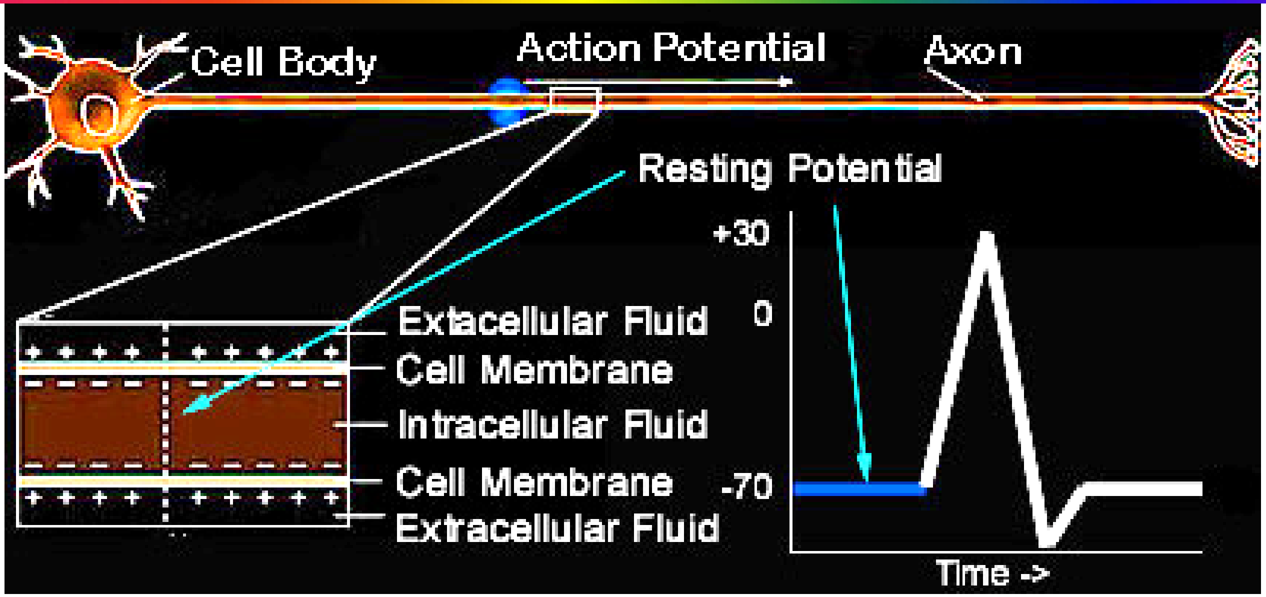

- At rest the inside of the cell is at -70 mV
- With inputs to dendrites inside becomes more positive
- if resting potential rises above threshold an action potential starts to travel from cell body down the axon
- Figure shows resting axon being approached by an AP

Functional state of voltage gated K+ channels

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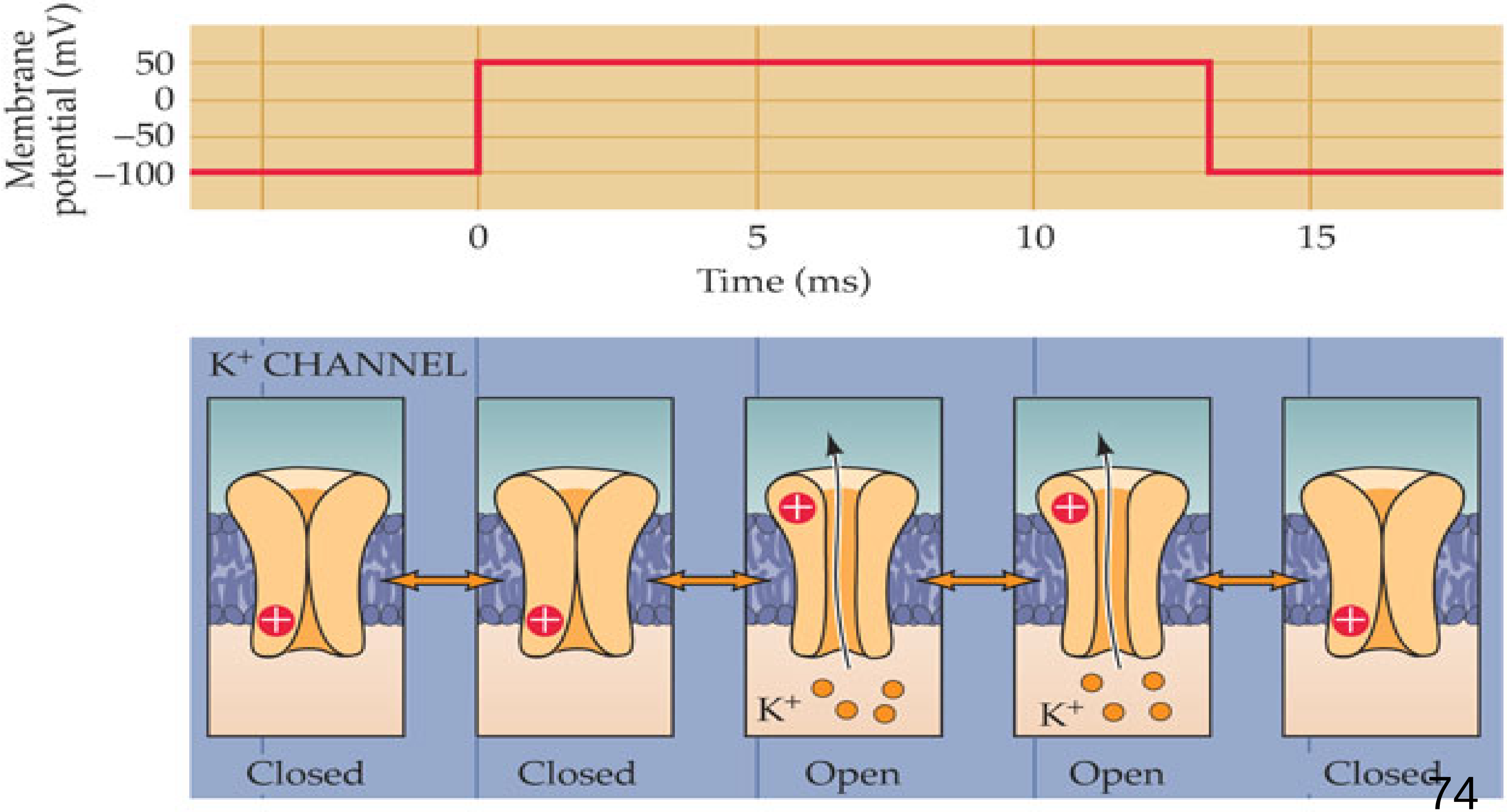
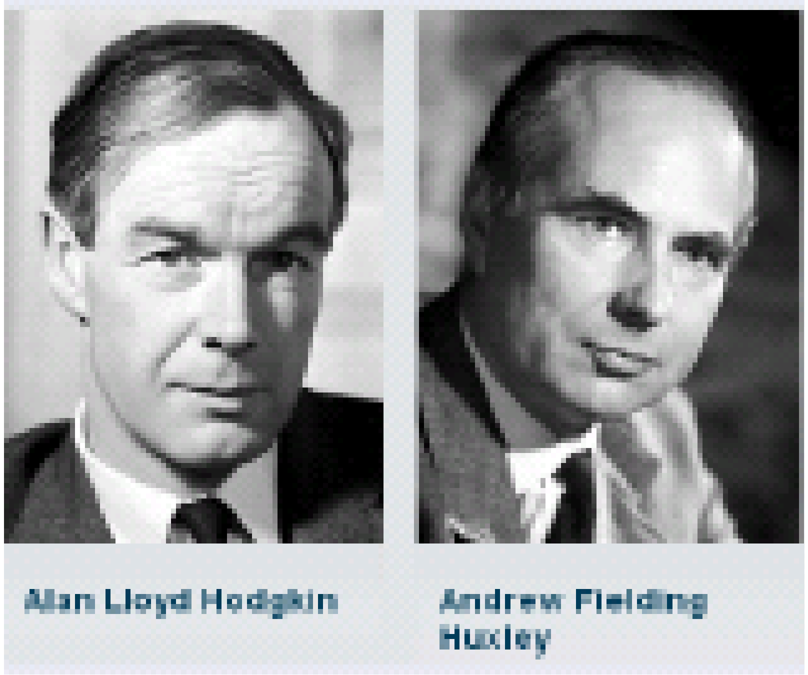


NEUROSCIENCE, Third Edition, Figure 4.3 (Part 2) © 2004 Sinauer Associates, Inc.

Nobel Prize in Physiology or Medicine in 1963



- Combination of experiments, theoretical hypotheses, data fitting and model prediction
- Empirical model to describe generation of action potentials
- Published in the Journal of Physiology in 1952 in a series of 5 articles (with Bernard Katz)

The Hodgkin-Huxley Model

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$$c_m \frac{dV}{dt} = -i_m + \frac{I_e}{A}$$

$$i_{\mathrm{m}} = \overline{g}_{\mathrm{L}}(V - E_{\mathrm{L}}) + \overline{g}_{\mathrm{K}} n^4 (V - E_{\mathrm{K}}) + \overline{g}_{\mathrm{Na}} m^3 h (V - E_{\mathrm{Na}})$$

$$\tau_z(V)\frac{dz}{dt} = z_\infty(V) - z$$

← **Gating equation**

Improving Hodgkin-Huxley Model

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Connor-Stevens Model (HH + transient A-current K+) **(E_A~ E_K)**

—type I behavior (continuous firing rate)

$$\overline{g}_A a^3 b(V - E_A)$$

transient Ca^{2+} conductance
(L, T, N, and P types.
E_{CaT} = 120mV)

$$i_{CaT} = \overline{g}_{CaT} M^2 H(V - E_{Ca})$$

— Ca2+ spike, burst spiking, thalamic relay neurons

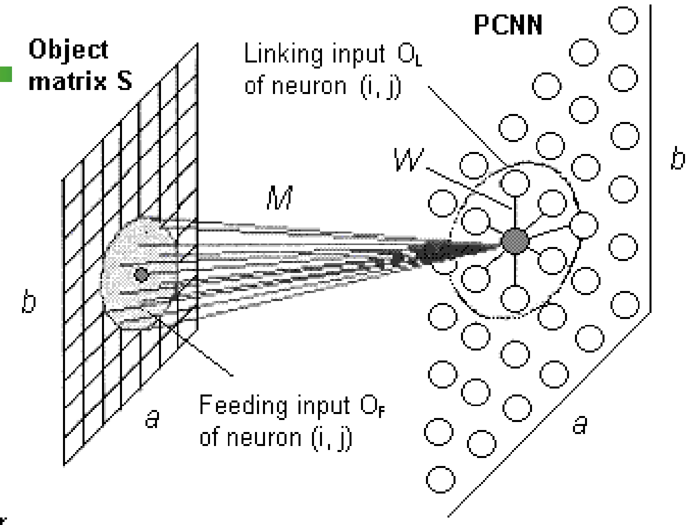
Ca^{2+}-dependent K^+ conductance

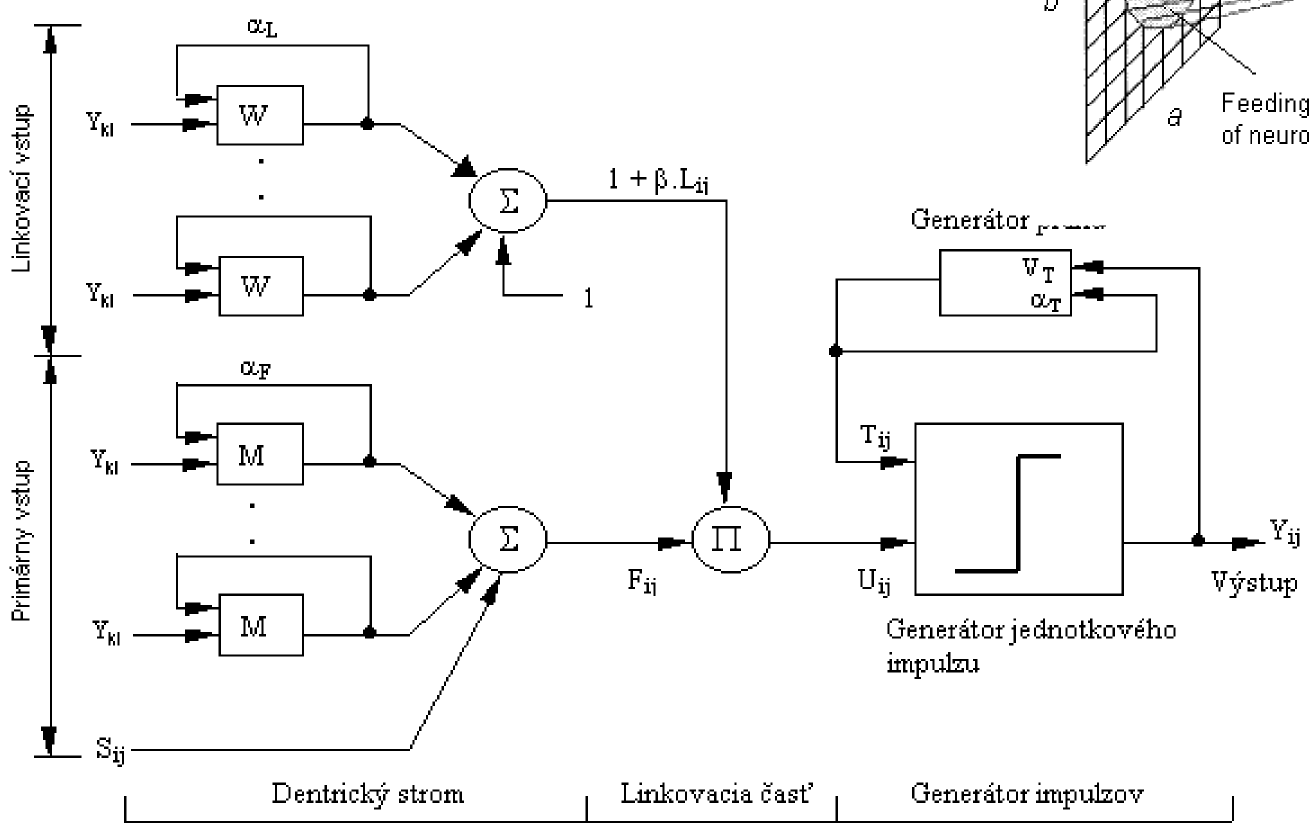
—**spike-rate adaptation**

$$i_{KCa} = \overline{g}_{KCa} c^4 (V - E_K)$$

Structure of PCNN neuron

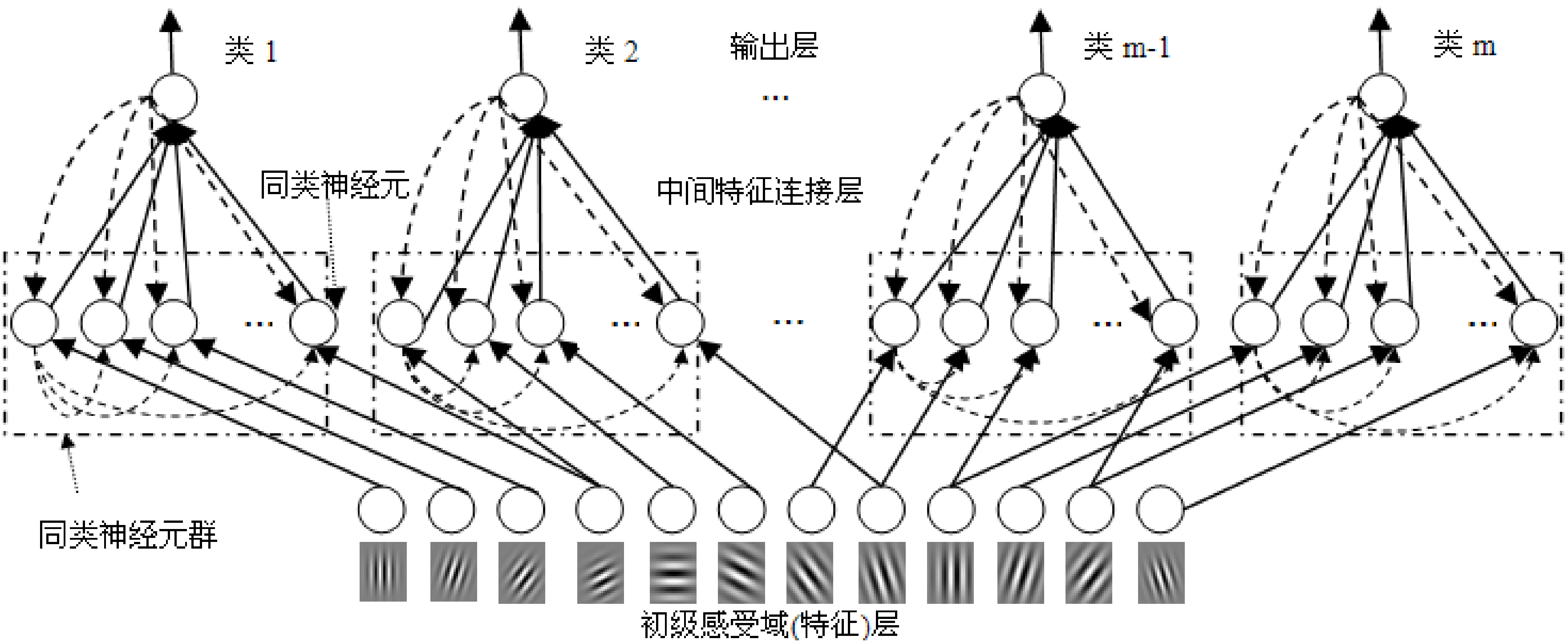
- Primary and Linking input
- Linking part
- Pulse generator





Computational Model for Feature Binding

Bayesian Link field Networks Model



Cortical Columns: Minicolumns

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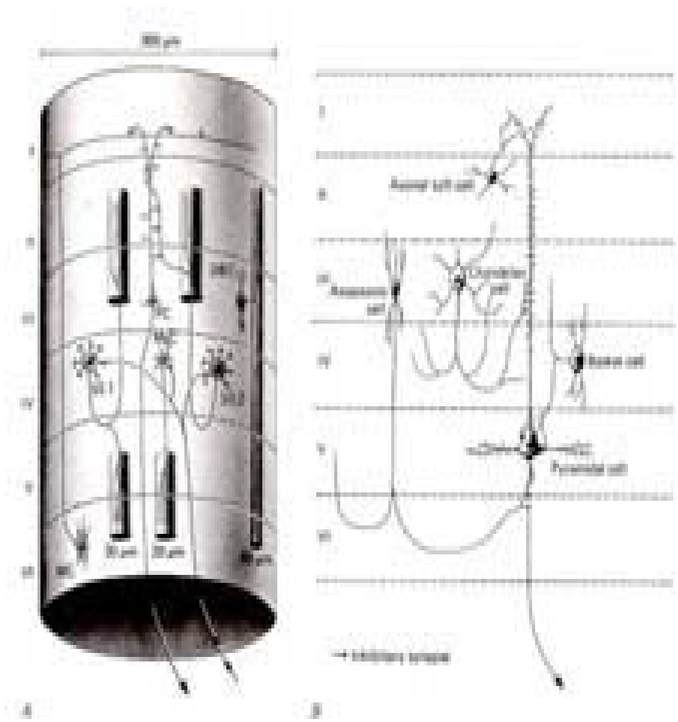
- The basic unit of cortical operation is the *minicolumn*.
- It contains of the order of 80-100 neurons except in the primate striate cortex, where the number is more than doubled.
- The minicolumn measures of the order of 40-50 μm in transverse diameter, separated from adjacent minicolumns by vertical, cell-sparse zones.
- The minicolumn is produced by the iterative division of a small number of progenitor cells in the neuroepithelium.



Columns: Functional

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Groupings of minicolumns seem to form the physiologically observed **functional columns**.

Best known example is orientation columns in V1.

They are significantly bigger than minicolumns, typically around 0.3-0.5 mm.

Mountcastle's summation：

"Cortical columns are formed by the binding together of many minicolumns by common input and short range horizontal connections. … The number of minicolumns per column varies … between 50 and 80. Long range intracortical projections link columns with similar functional properties." (p. 3)

Cells in a column ~ (80)(100) = 8000

Cortical Columns

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Rose-Hindmarsh equation for single neuron:

$$\dot{x} = y + ax^3 - bx^2 - z + I_{syn} + I_{stim}$$

$$\dot{y} = c - dx^2 - y$$

$$\dot{z} = r\left[s\left(x - x_0\right) - z\right]$$

x: membrane potential

y: fast spiking variable

z: bursting variable

I_{syn} synaptic current

I_{stim} enter current

Synaptic Current

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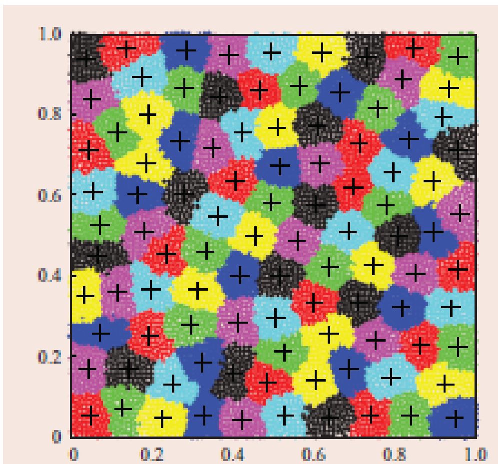
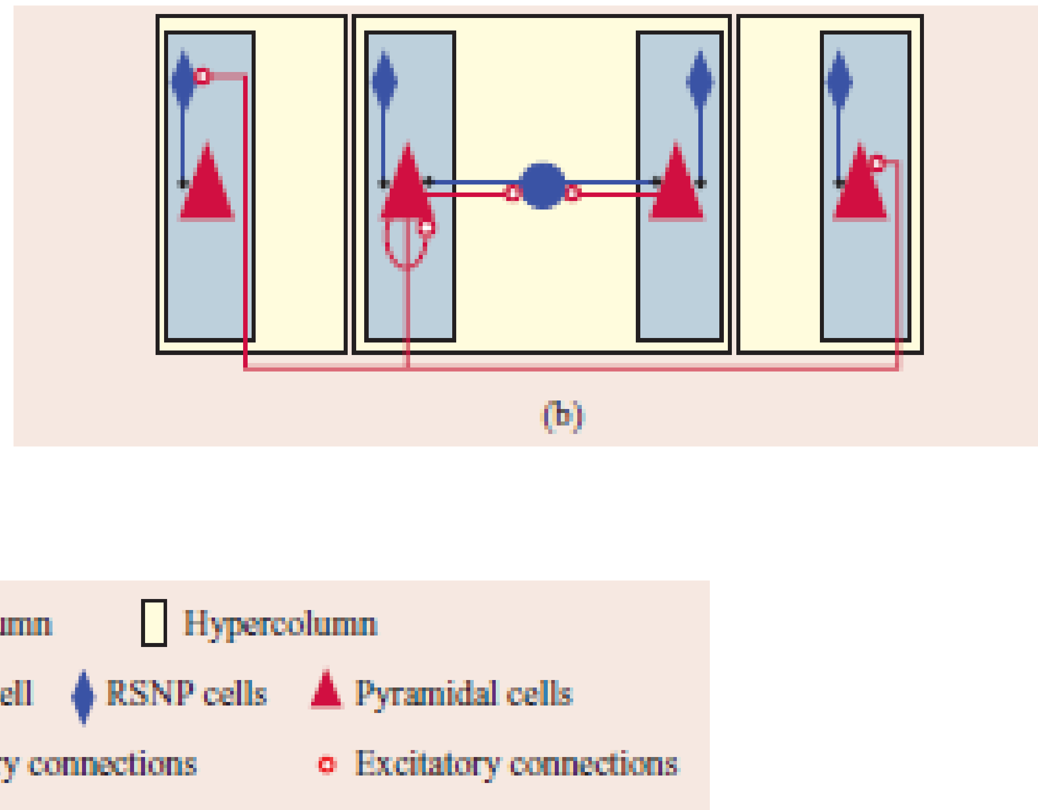
$$I_{syn} = g_{syn} V_{syn} (e^{-t/\tau_1} - e^{-t/\tau_2})$$

g_{syn} *membrane conductance*
τ_1, τ_2 time constants
V_{syn} *membrane post-potential*

Simulation



(a)



(b)

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3 Mind Models

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Mind Model

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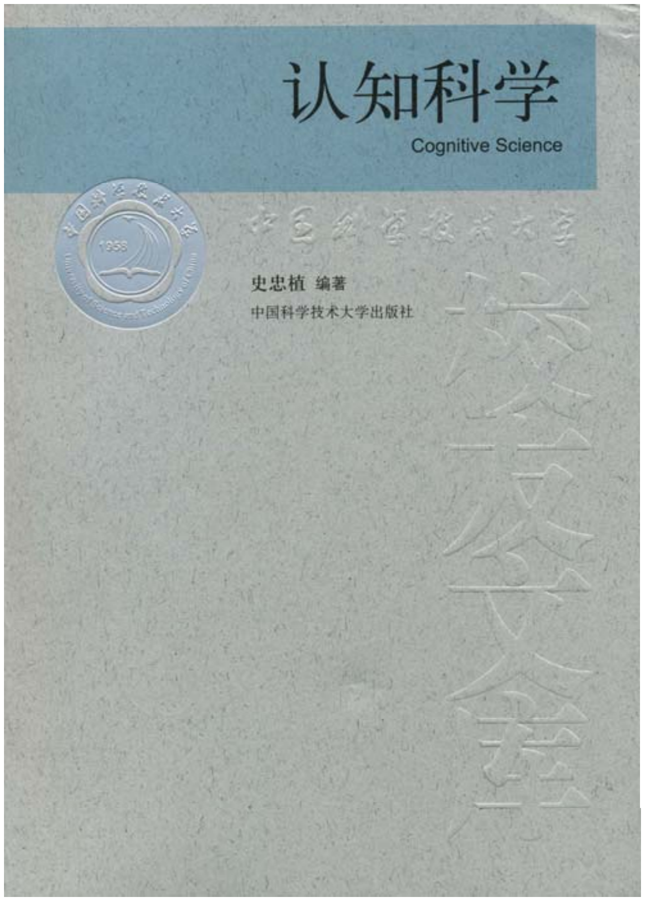

Cognitive Science

The mind means all spiritual activities of human being, including sensibility, perception, will, feeling, learning, memory, thinking and the intuition etc., in which the formation, the process and the principle of combining the non-rational psychology and the rational cognition of human being are studied through the modern scientific methods.

Model Name	Acronym/ Abbreviation	Pew and Mavor (1998)	Ritter, Shadbolt et al. (2001)	Present IDA Study
Atomic Components of Thought	ACT	Yes	No	Yes
Adaptive Resonance Theory	ART	No	No	Yes
Architecture for Procedure Execution	APEX	No	Yes	Yes
Artificial Neural Networks	ANNs	Yes	No	Noa
Business Redesign Agent-Based Holistic Modeling System	Brahms	No	No	Yes
Cognition and Affect Project	CogAff	No	Yes	Yes
COGnition As a NEtwork Of Tasks	COGNET	Yes	No	Yes
Cognitive Complexity Theory	CCT	No	No	Yes
Cognitive Objects within a Graphical EnviroNmenT	COGENT	No	Yes	Yes
Concurrent Activation-Based Production System	CAPS	No	No	Yes
Construction-Integration Theory	C-I Theory	No	No	Yes
Distributed Cognition	DCOG	No	No	Yes
Elementary Perceiver And Memorizer	EPAM	No	Yes	Nob
Executive Process/Interactive Control	EPIC	Yes	No	Yes
Human Operator Simulator	HOS	Yes	No	Yes
Belief-Desire-Intention architecture	BDI	No	Yes	Noc
Man-machine Integrated Design and Analysis System	MIDAS	Yes	No	Yes
Micro Systems Analysis of Integrated Network of Tasks	Micro SAINT	Yes	No	Yes
MIDAS Redesign		Yes	No	Yesd
Operator Model ARchitecture	OMAR	Yes	No	Yes
PSI	PSI	No	Yes	Yes
Situation Awareness Model for Pilot-in-the-Loop Evaluation	SAMPLE	Yes	No	Yes
Sparse Distributed Memory	SDM	No	Yes	Nob
State, Operator, And Result	Soar	Yes	No	Yes

The Physical Symbol System

Herbert A. Simon

was born in 1916 in Milwaukee, Wisconsin. He began his career at the Cowles Commission. In 1978 he was a Nobel Laureate in Economics. He is currently serving as a Richard King Mellon University Professor of Computer Science and Psychology at Carnegie Mellon University.

The Physical Symbol System

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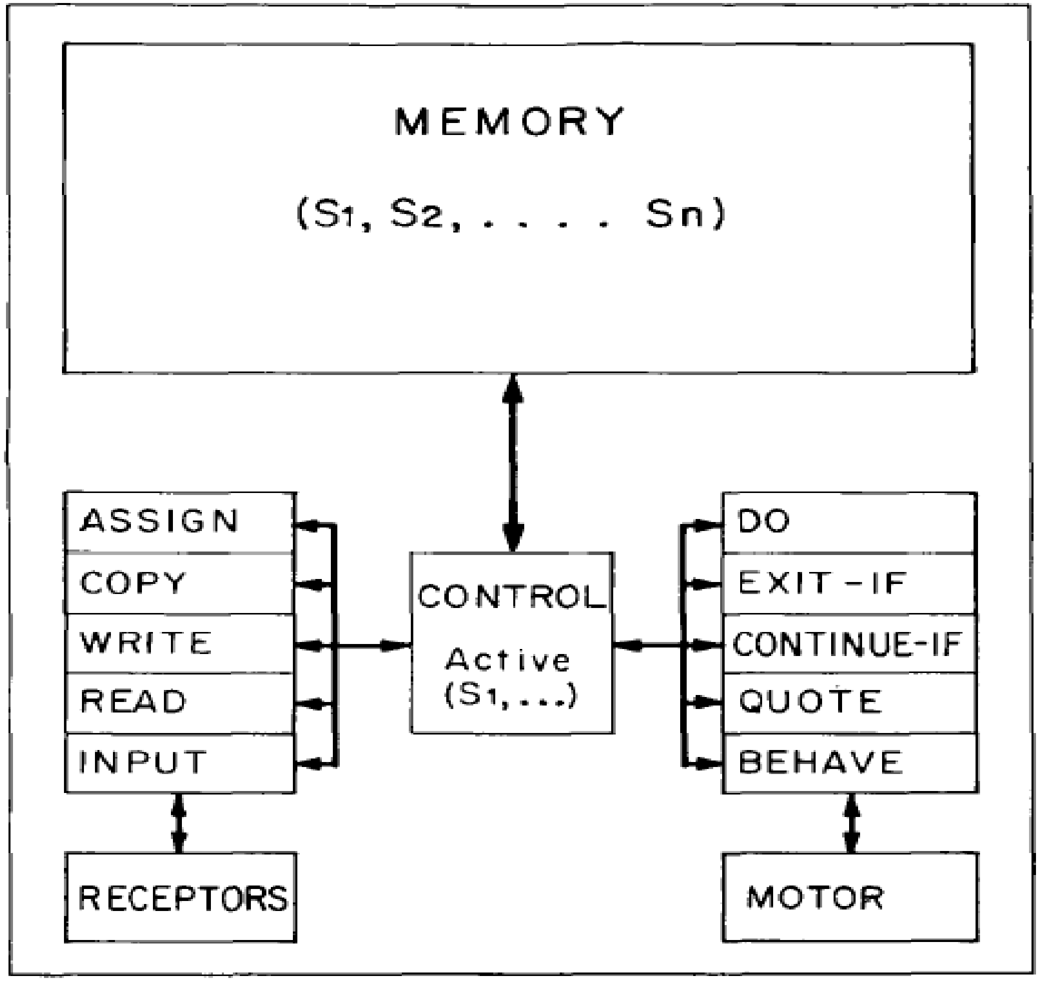
- **A physical symbol system consists of a set of entities, called symbols, which are physical patterns that can occur as components of another type of entity called an expression (or symbol structure). Thus, a symbol structure is composed of a number of instances (or tokens) of symbols related in some physical way (such as one token being next to another). At any instant of time the system will contain a collection of these symbol structures. Besides these structures, the system also contains a collection of processes that operate on expressions to produce other expressions: processes of creation, modification, reproduction and destruction. A physical symbol system is a machine that produces through time an evolving collection of symbol structures. Such a system exists in a world of objects wider than just these symbolic expressions themselves.**

The Physical Symbol System



The Physical Symbol System

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Assign symbol S_1 to the same entity as symbol S_2 Produces S_1 with new assignment	(assign S_1 S_2)
Copy expression E (create new symbol) Produces newly created expression and symbol	(copy E)
Write S_1 at role R_1,. . . in expression E Produces the modified expression nil is the same as doesn't exist	(write E $R_1 S_1$ . . .)
Read symbol at role R of E Produces the expression or nil	(read R E)
Do sequence S_1 S_2 S_3 . . . Produces the expression produced by last S_1.	(do S_1 S_2 . . .)
Exit sequence if the prior result is E Produces prior expression	(exit-if E)
Continue sequence if the prior result is E Produces prior expression	(continue-if E)
Quote the symbol S Produces S without interpretation	(quote S)
Behave externally according to expression E Produces feedback expression	(behave E)
Input according to expression E Produces new expression or nil	(input E)

Physical Symbol System Hypothesis

Physical Symbol System Hypothesis: The necessary and sufficient condition for a physical system to exhibit general intelligent action is that it be a physical symbol system.

Necessary means that any physical system that exhibits general intelligence will be an instance of a physical symbol system.

Sufficient means that any physical symbol system can be organized further to exhibit general intelligent action.

General intelligent action means the same scope of intelligence seen in human action: that in real situations behavior appropriate to the ends of the system and adaptive to the demands of the environment can occur, within some physical limits.

ACT Model

J. A. Anderson

ACT* is a general theory of cognition developed by John Anderson that focuses on memory processes.

ACT* distinguishes among three types of memory structures: declarative, procedural and working memory. Declarative memory takes the form of a semantic net linking propositions, images, and sequences by associations. Procedural memory (also long-term) represents information in the form of productions; each production has a set of conditions and actions based in declarative memory. The nodes of long-term memory all have some degree of activation and working memory is that part of long-term memory that is most highly activated.

History of the ACT-framework*

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Predecessor	**HAM**	**(Anderson & Bower 1973)**
Theory versions	**ACT-E**	**(Anderson, 1976)**
	ACT*	**(Anderson, 1978)**
	ACT-R	**(Anderson, 1993)**
	ACT-R 4.0	**(Anderson & Lebiere, 1998)**
	ACT-R 5.0	**(Anderson & Lebiere, 2001)**
Implementations		
	GRAPES	**(Sauers & Farrell, 1982)**
	PUPS	**(Anderson & Thompson, 1989)**
	ACT-R 2.0	**(Lebiere & Kushmerick, 1993)**
	ACT-R 3.0	**(Lebiere, 1995)**
	ACT-R 4.0	**(Lebiere, 1998)**
	ACT-R/PM	**(Byrne, 1998)**
	ACT-R 5.0	**(Lebiere, 2001)**
	Windows Environment	**(Bothell, 2001)**
	Macintosh Environment	**(Fincham, 2001)**
	ACT-R 6.0	**(Bothell, 2004??)**

ACT-framework*

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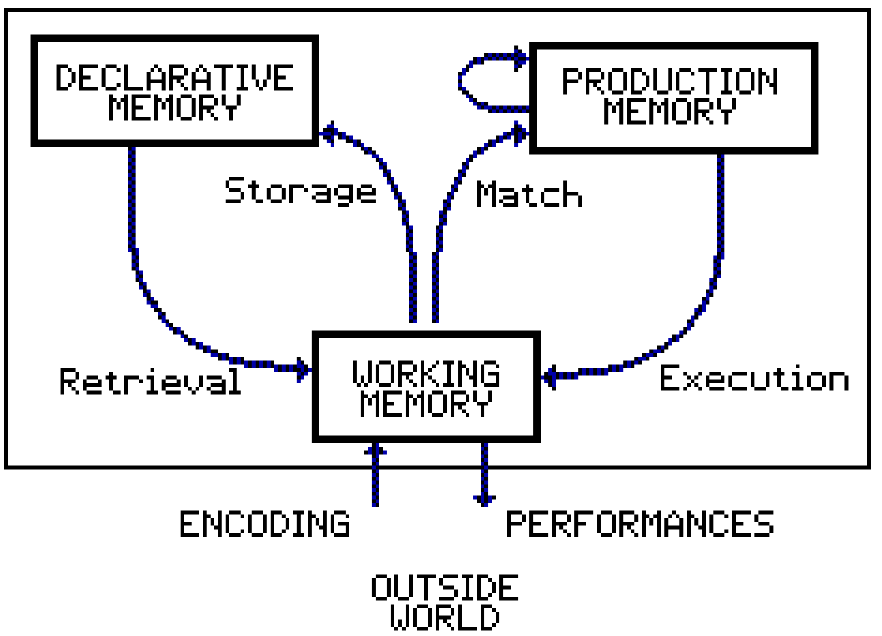
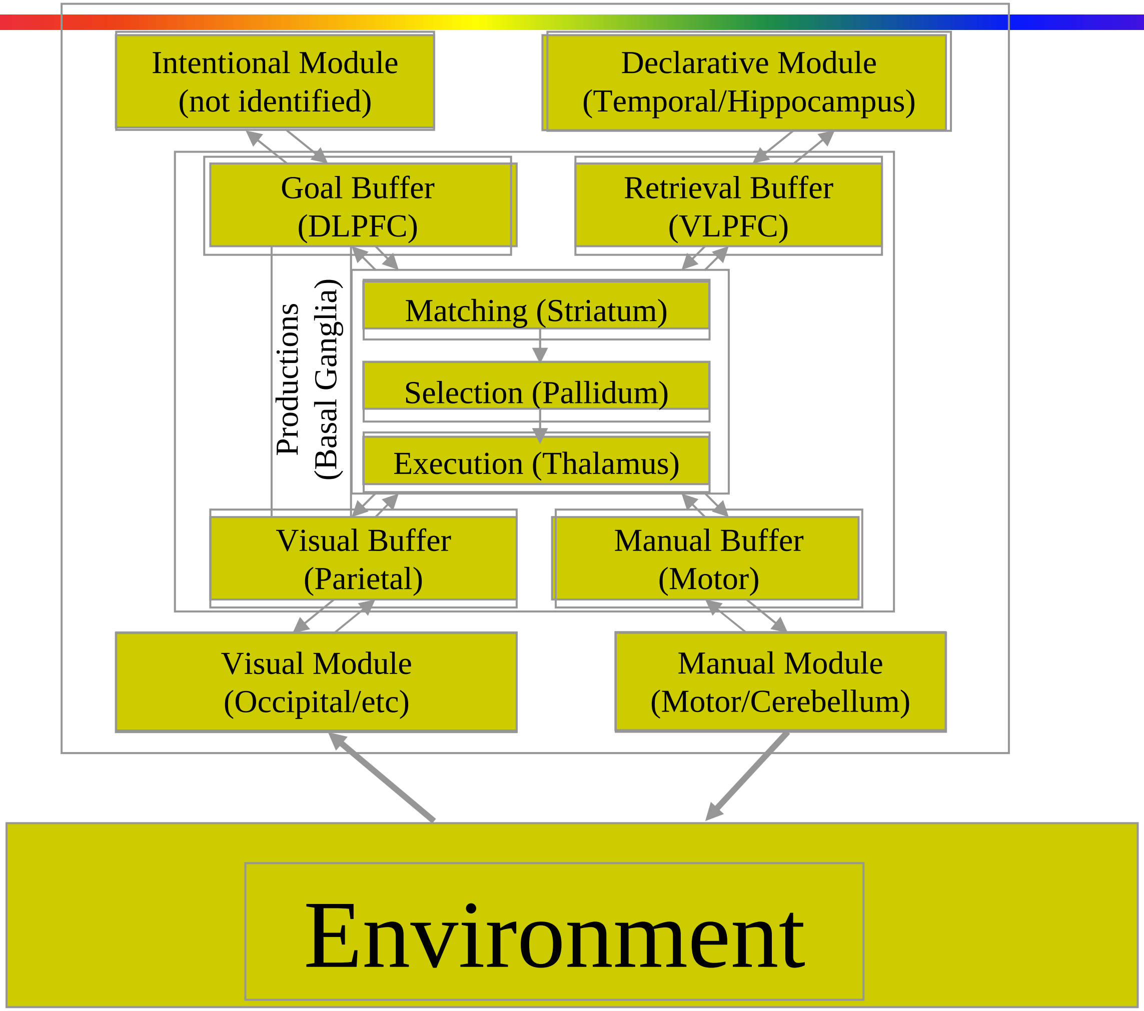
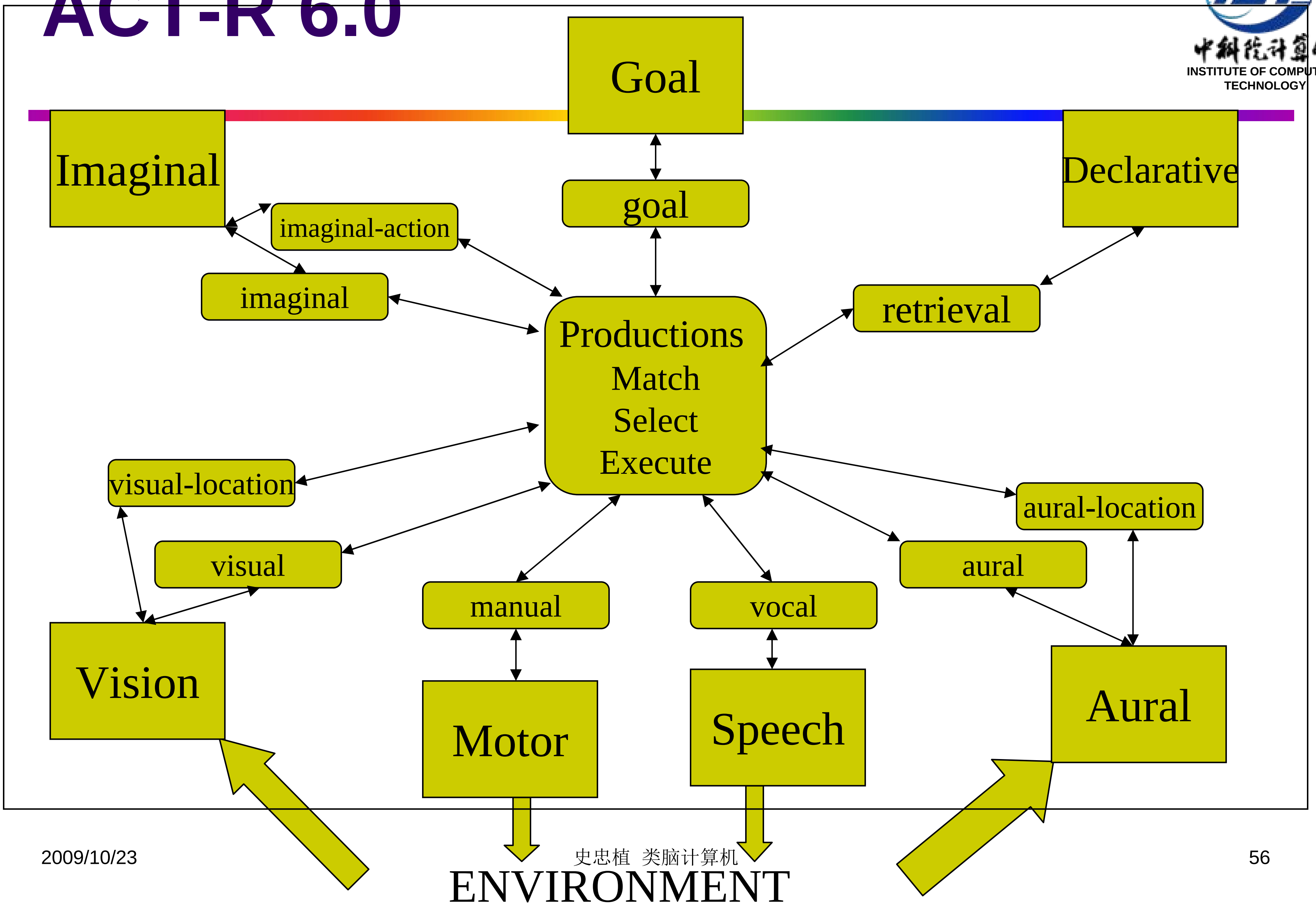


- Procedural vs Declarative Knowledge
- Declarative
  - Aware of
  - Can describe to others
  - Facts
- Procedural
  - Display in behavior
  - Not conscious of
  - e.g. language

ACT-R 6.0 Mapping to the Brain*

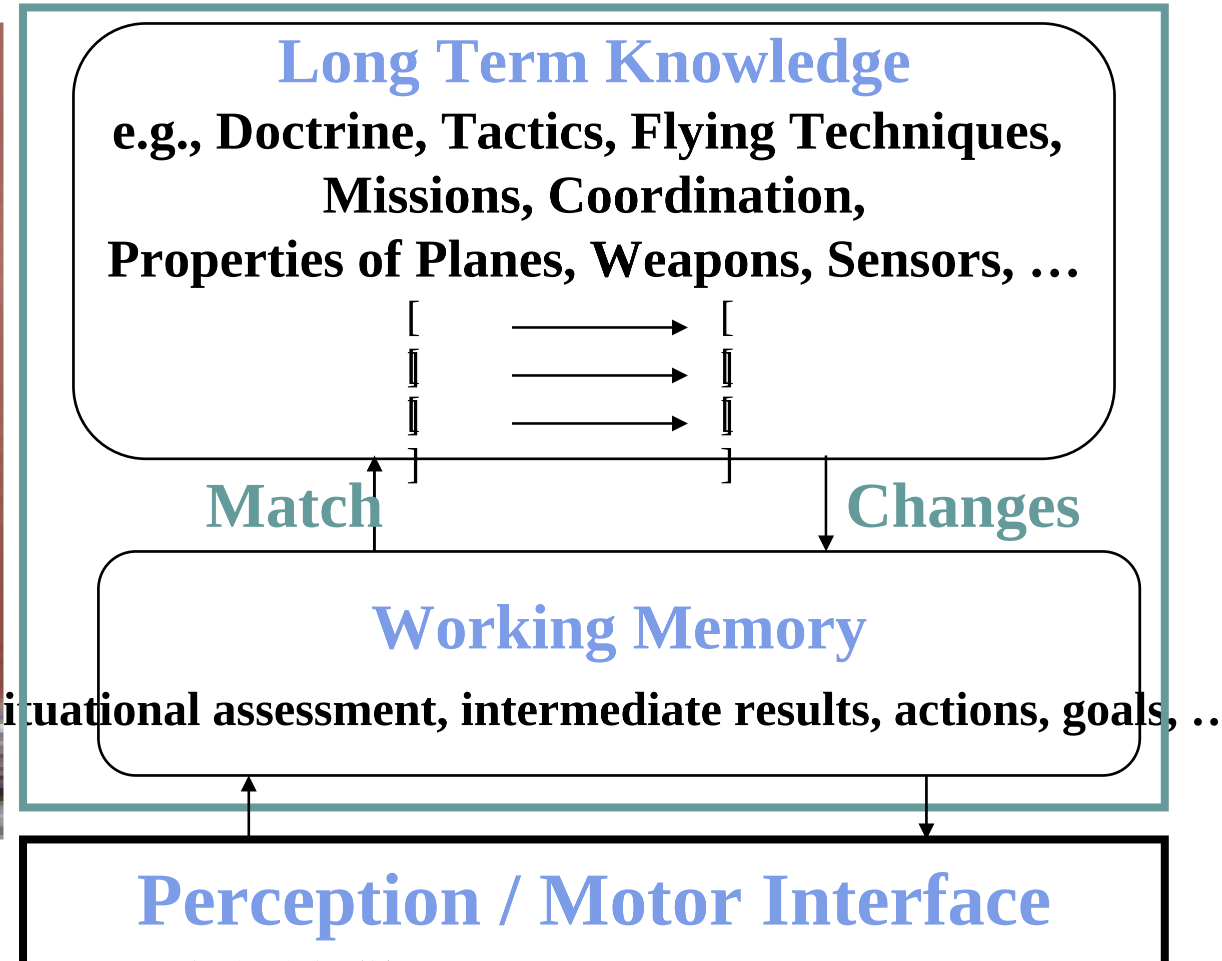


ACT-R 6.0



Goal
goal
Imaginal
imaginal-action
imaginal
Declarative
retrieval
Productions
Match
Select
Execute
visual-location
visual
manual
vocal
aural
aural-location
Vision
Motor
Speech
Aural
ENVIRONMENT

Soar Architecture



SOAR Decision Cycle

Perception | *Cognition* | *Motor*

Elaboration Phase

- Fire rules
- Generate preferences
- Update working memory

Input Phase

- Sense world
- Perceptual pre-processing
- Assert to WM

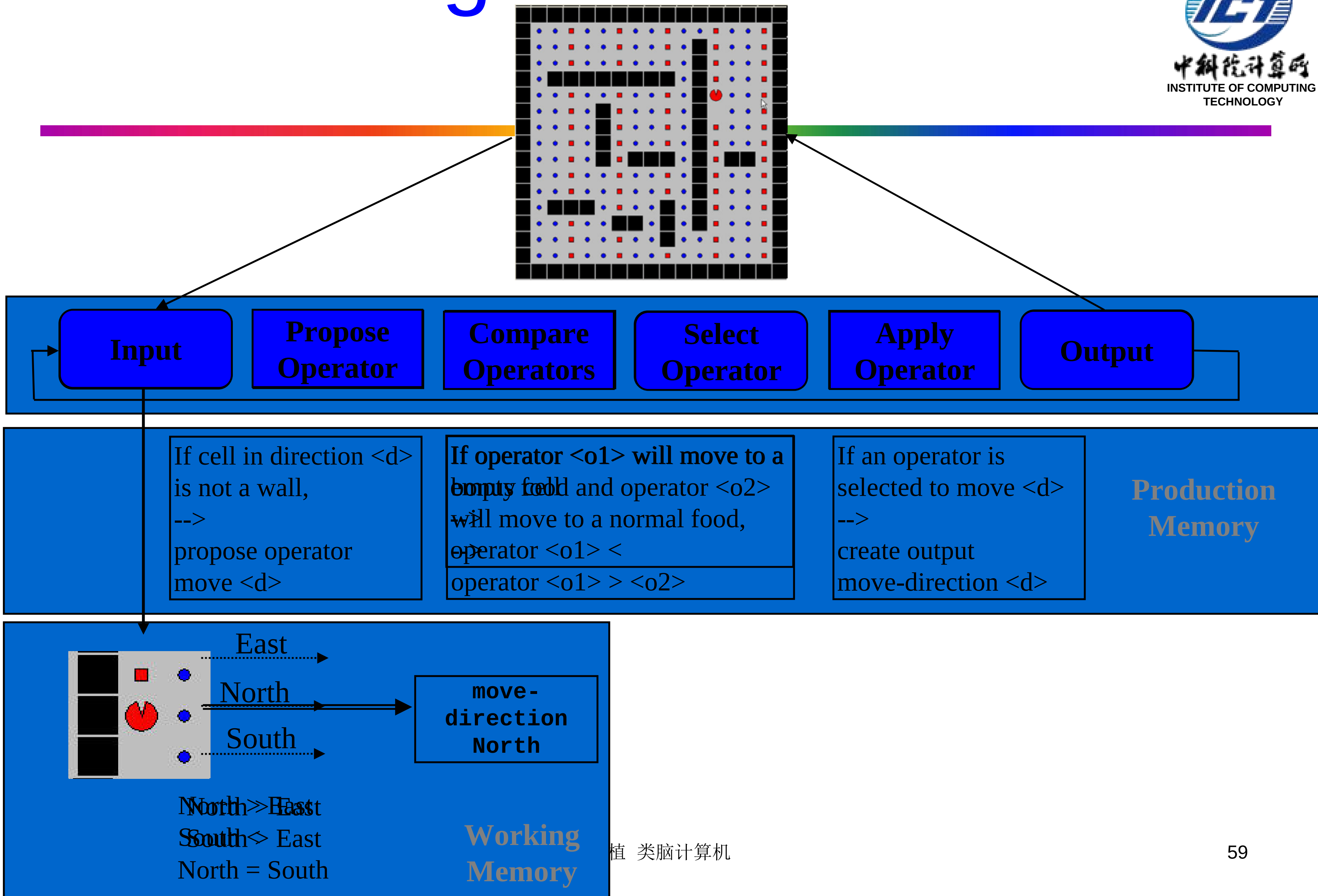
Output Phase

- Command effectors
- Adjust perception

Decision Phase

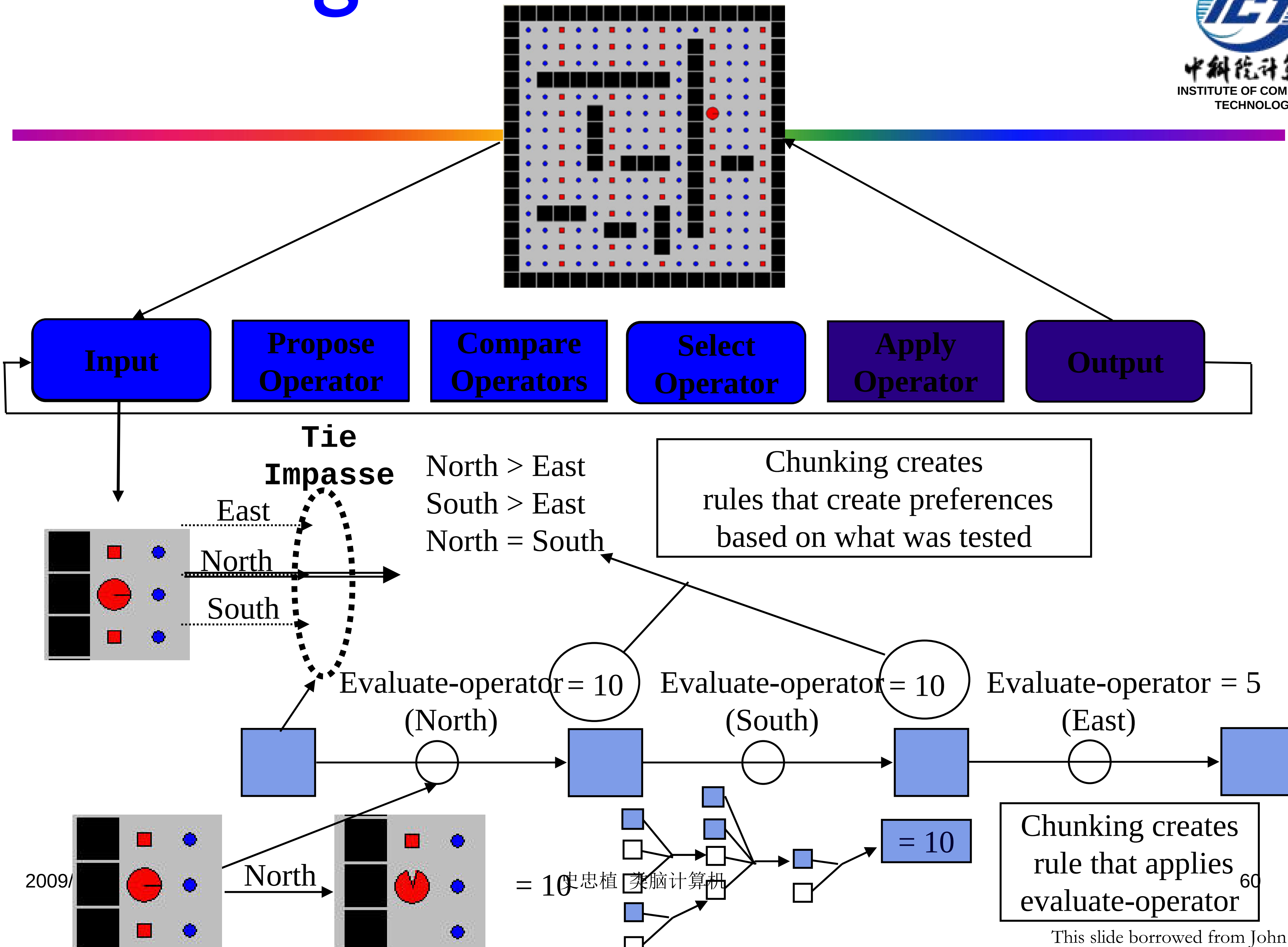
- Evaluate operator preferences
- Select new operator   OR
- Create new state

Processing



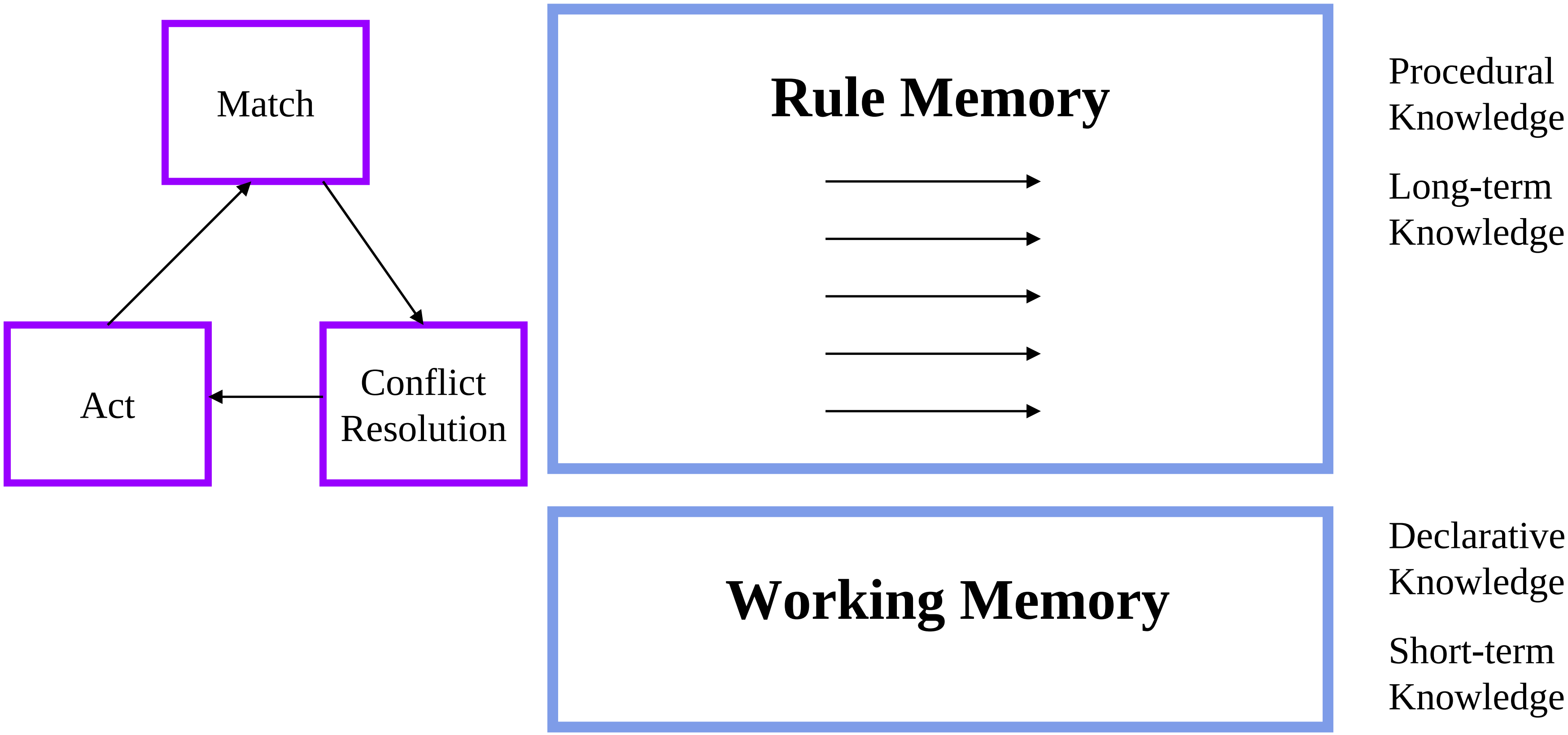
This slide borrowed from John Laird

Learning



This slide borrowed from John Laird

SOAR Memories



This slide borrowed from John Laird

Society Theory of Mind (STM)

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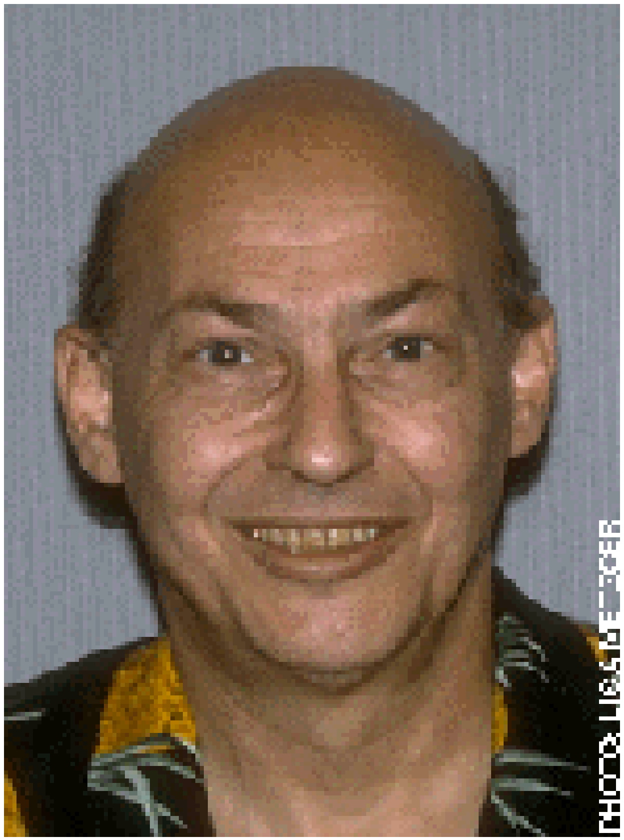


- Mind is made of many smaller processes, called *mental agents*.
- Each agent can only do a simple (almost *mindless*) task by itself.
- When agents are joined in special ways (in *societies*) we get intelligence.

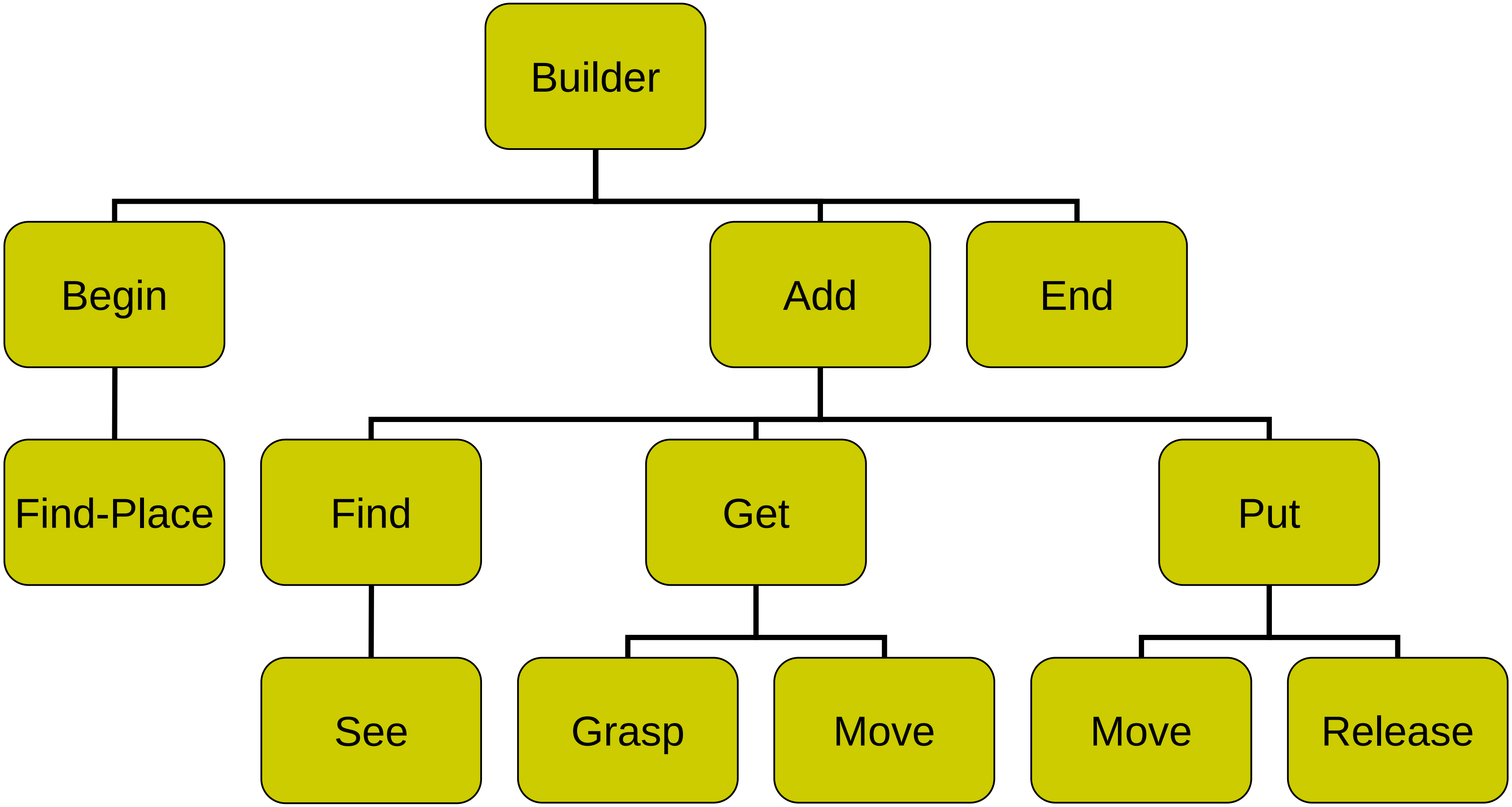
6) Minsky, Marvin, 1986, *The Society of Mind*, Simon and Schuster, New York, NY.

Mental Agents

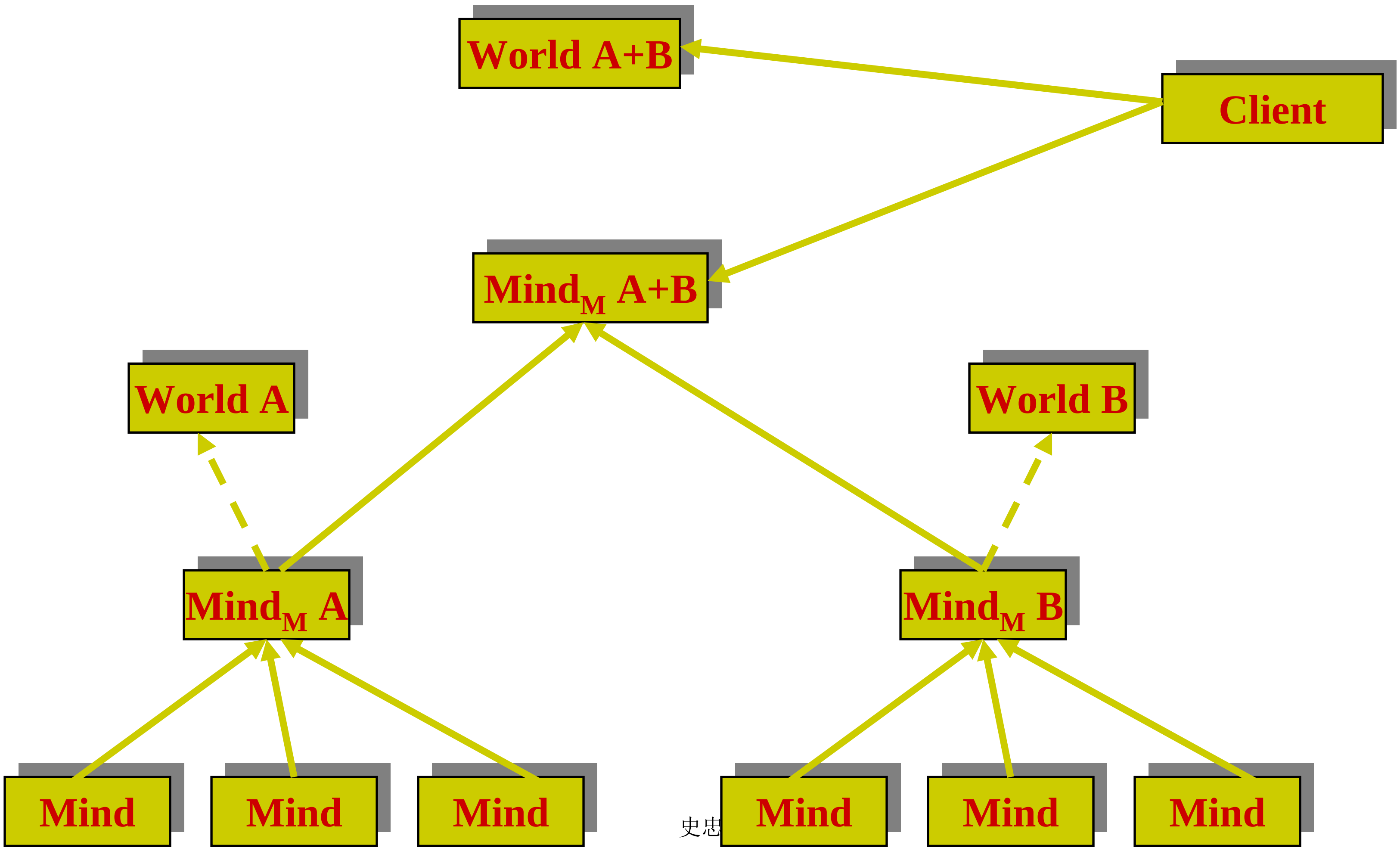
- Task: Make a tower from blocks
- Some of the agents involved in task:

- Builder
- Begin
- Add
- End
- Find
- Get
- Put
- See
- Grasp
- Move
- Release
- Find-Place

Mental Agents in a *Bureaucracy*



Society of Mind



Constructing complex minds, online

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Ciarán O'Leary
Dublin Institute of Technology
22nd May 2003

Technology for automated assessment:
The World-Wide-Mind

The Jolly Little Creature's Mind

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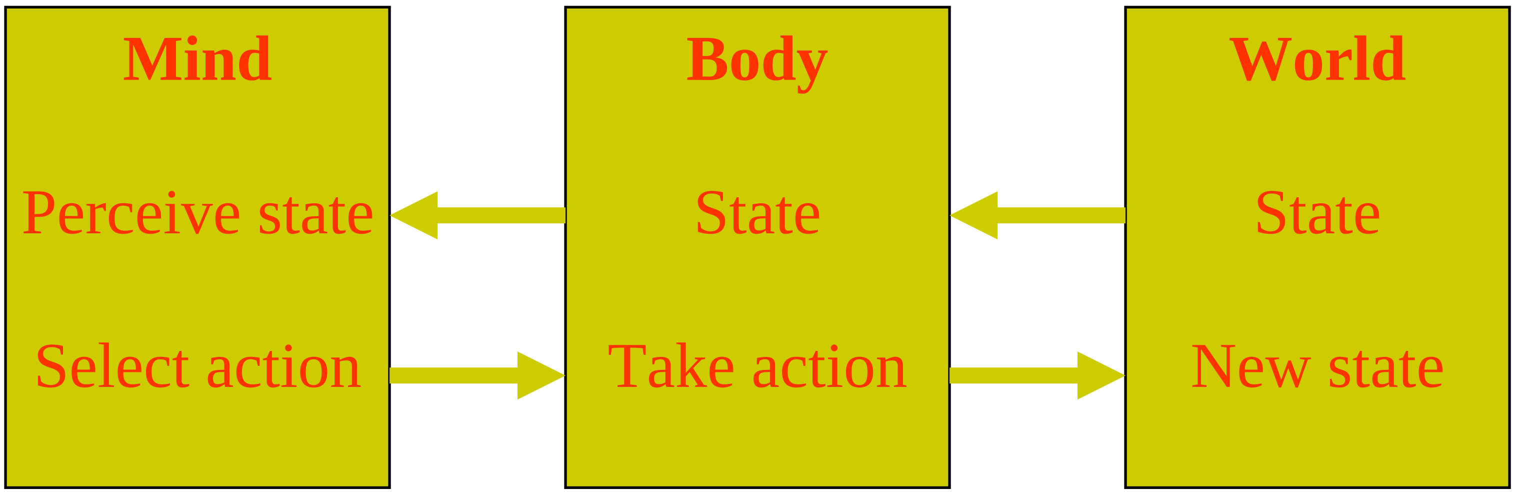
- Multiple (massively diverse) modules
- *Since, according to faculty psychologists, the mental causation of behaviour typically involves the simultaneous activity of a variety of distinct psychological mechanisms, the best research strategy would seem to be divide and conquer: first study the intrinsic characteristics of each of the presumed faculties, then study the ways in which they interact*
    - Jerry Fodor – The Modularity of Mind, p1.

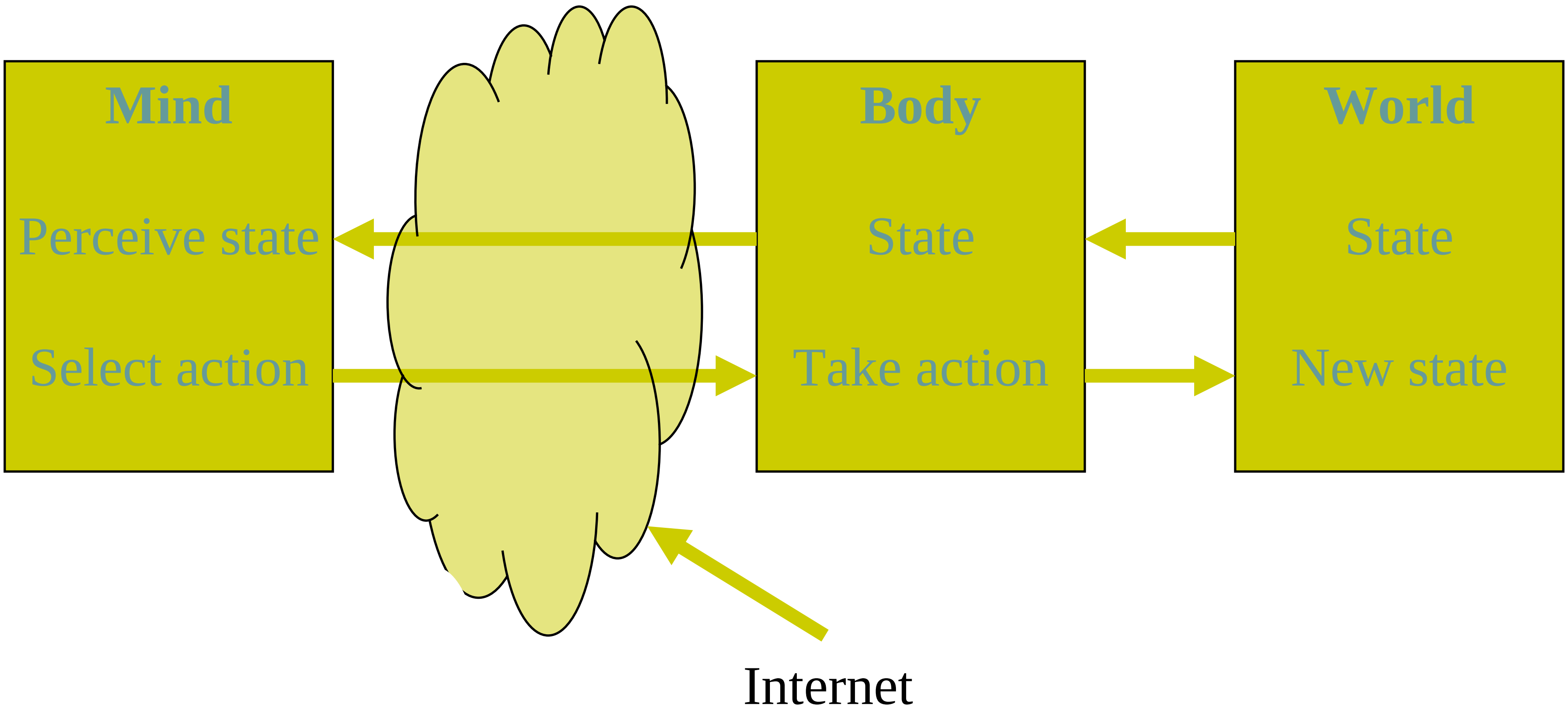
Building JLC's Mind

- Requirements
  - Architecture
  - Standard/protocol to use to integrate components
- Requirement for protocol
  - No barriers to entry
  - Simple
  - Not tied to any platform

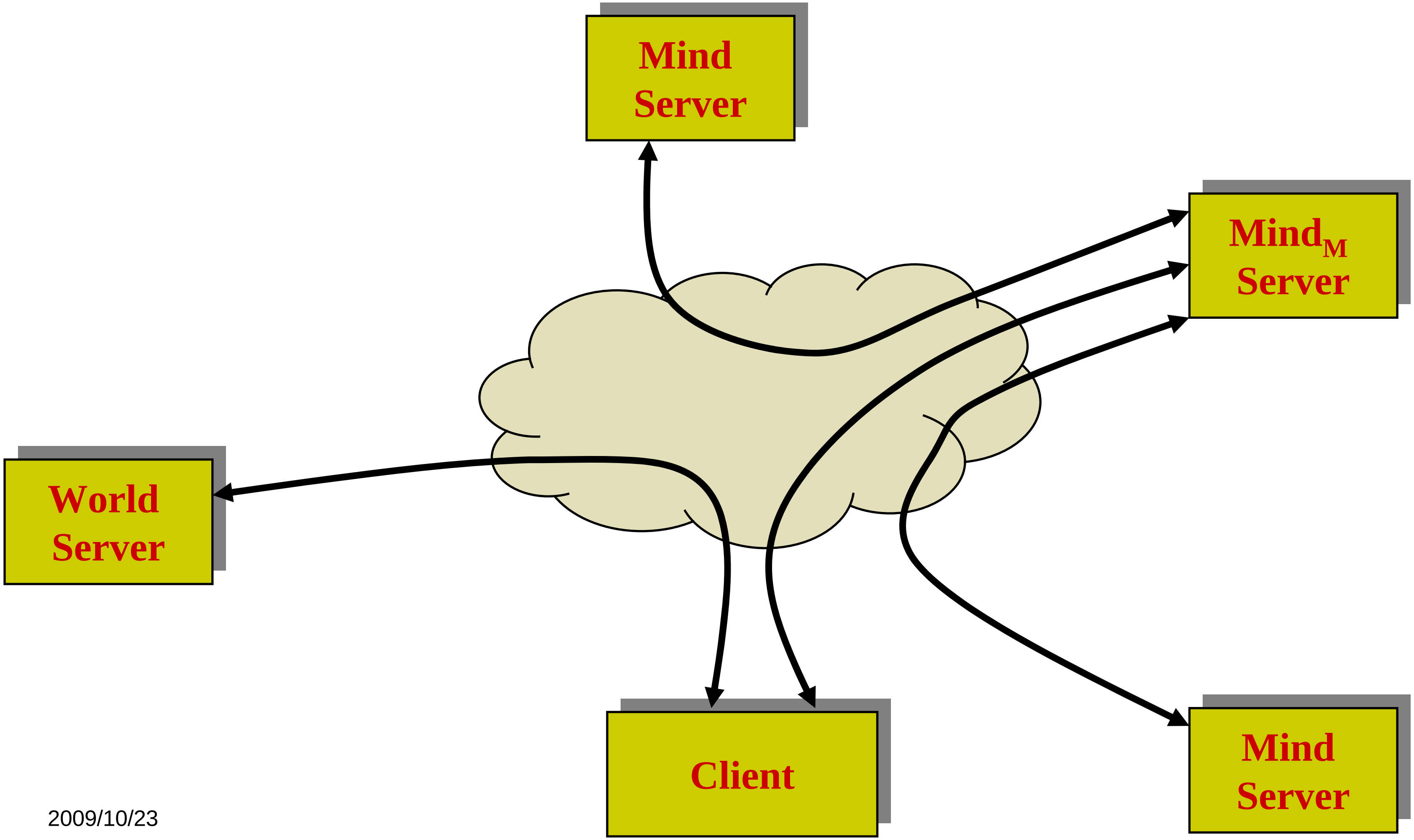
JLC's Mind


Mind
Perceive state
Select action
Body
State
Take action
World
State
New state

JLC's Mind Online



Constructing complex minds, online



Service Methods

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World Service

- newrun
- getstate
- takeaction
- endrun

Mind Service

- newrun
- getaction
- endrun

World-Wide-Mind Protocol

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- “The term Web services describes a standardized way of integrating Web-based applications using the XML, SOAP, WSDL and UDDI open standards over an Internet protocol backbone. XML is used to tag the data, SOAP is used to transfer the data, WSDL is used for describing the services available and UDDI is used for listing what services are available”
  - http://www.webopaedia.com
- Society of Mind Markup Language (SOML)
  - Lightweight Web Services

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Brain-like computing

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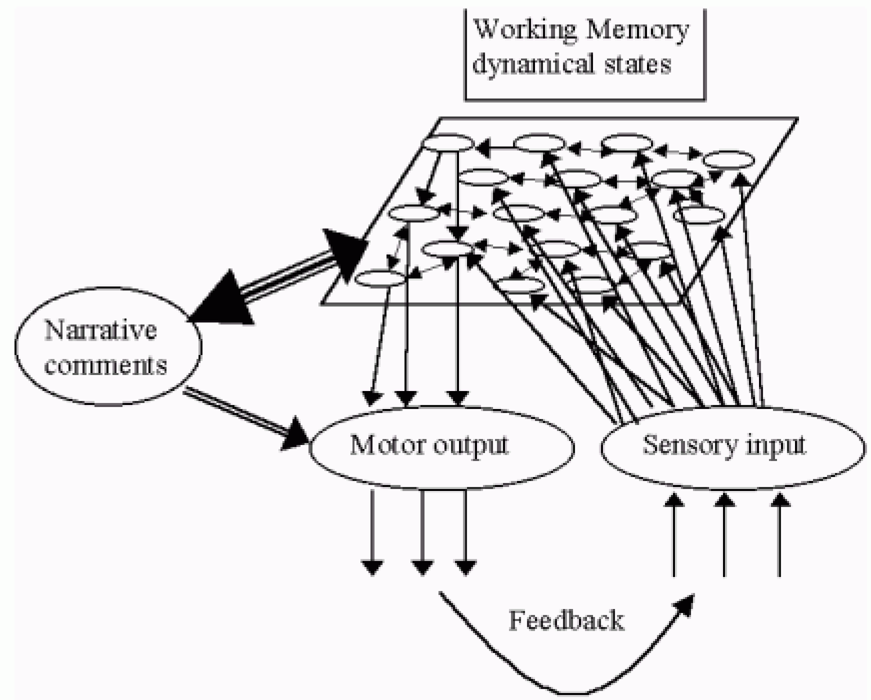
Brain states are physical, spatio-temporal states of neural tissue.

- We can see, hear and feel only my brain states! Exchange blindness.
- Cognitive processes operate on highly processed sensory data.
- Redness, sweetness, itching, pain ... are all physical states of brain tissue.

In contrast to computer registers, brain states are dynamical, and thus contain in themselves many associations, relations.

Inner world is real! Mind is based on relations of brain's states.

Computers and robots do not have an equivalent of such WM.



Blue Brain

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The Blue Brain Project was launched by the Brain Mind Institute, EPFL, Switzerland and IBM, USA in May'05, now over 120'000 WWW pages.

The EPFL Blue Gene is the 8th fastest supercomputer in the world.

Can simulate about 100M minimal compartment neurons or 10-50'000 multi-compartmental neurons, with 10^3-10^4 x more synapses. Next generation BG will simulate >10^9 neurons with significant complexity.

First objective is to create a cellular level, software replica of the Neocortical Column for real-time simulations.

The Blue Brain Project will soon invite researchers to build their own models of different brain regions in different species and at different levels of detail using Blue Brain Software for simulation on Blue Gene. These models will be deposited in an Internet Database from which Blue Brain software can extract and connect models together to build brain regions and begin the first whole brain simulations.

Blue Brain

Models at different level of complexity:
http://bluebrainproject.epfl.ch/

1. The Blue Synapse: A molecular level model of a single synapse.
2. The Blue Neuron: A molecular level model of a single neuron.
3. The Blue Column: A cellular level model of the Neocortical column with 10K neurons, later 50K, 100M connections.
4. The Blue Neocortex: A simplified Blue Column will be duplicated to produce Neocortical regions and eventually and entire Neocortex.
5. The Blue Brain Project will also build models of other Cortical and Subcortical models of the brain, and sensory + motor organs.

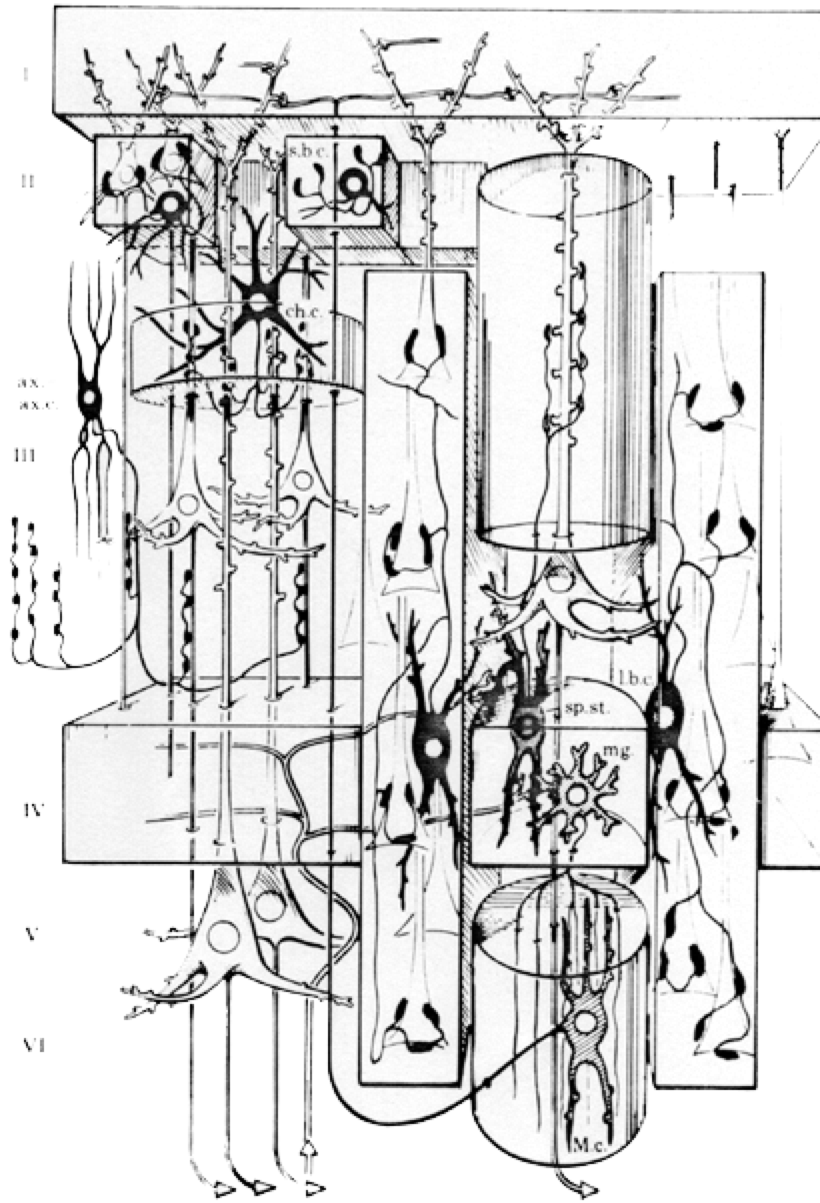
Blue Column

A detailed and faithful computer re

It will first be based on the data ob
at 2 weeks of age. Once built and
and experiments, comparative data
different brain regions, ages and sp

BC will be composed of 10^4 morph
active ionic channels, interconnect
10^7 -10^8 dynamic synapses, receiv
generating 10^3 -10^4 external outpu

Neurons use dynamic and stochas
learning, with meta-plasticity, supe
for all synapses.



Blue Column

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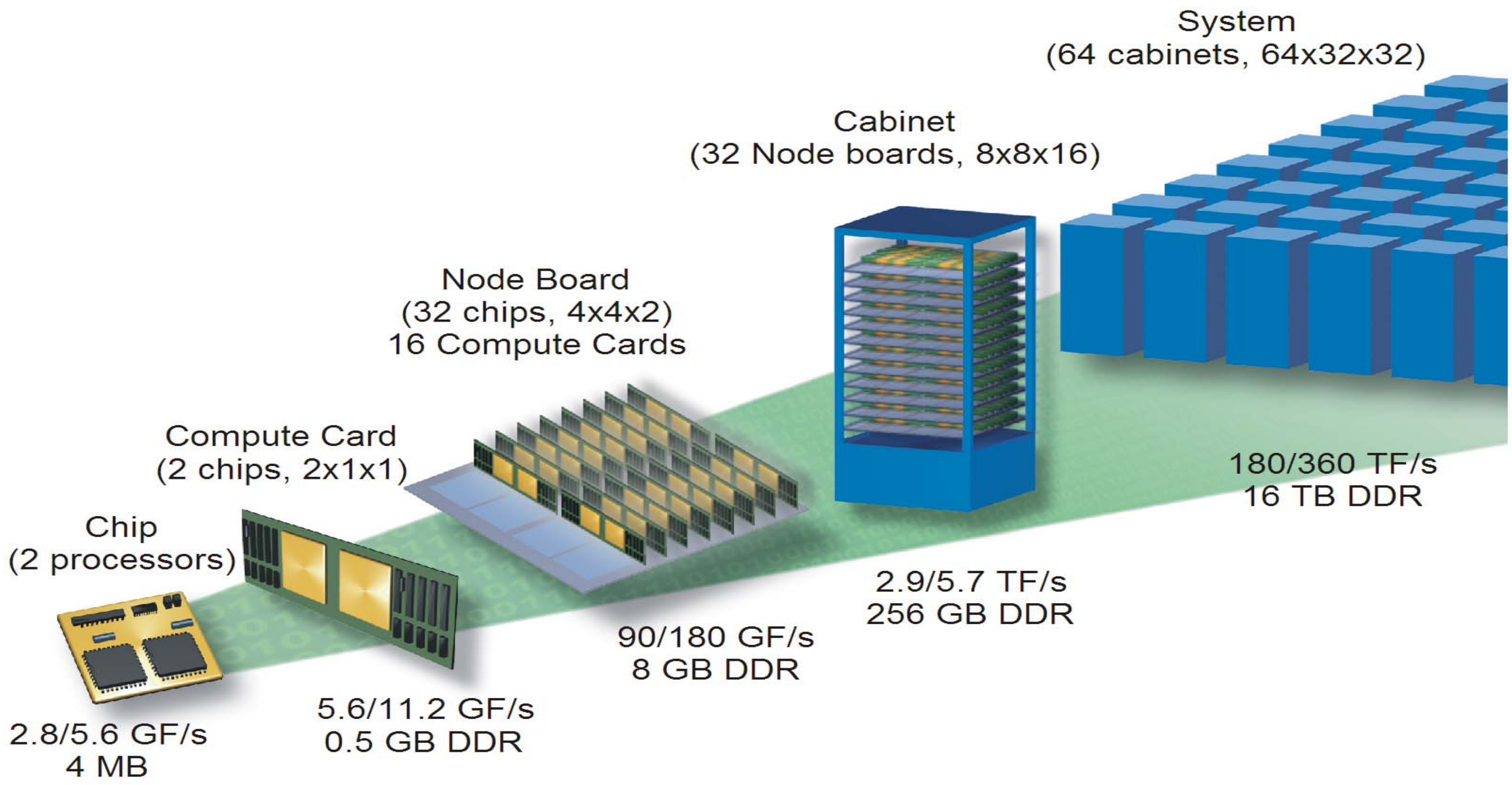
Project will include creation of:

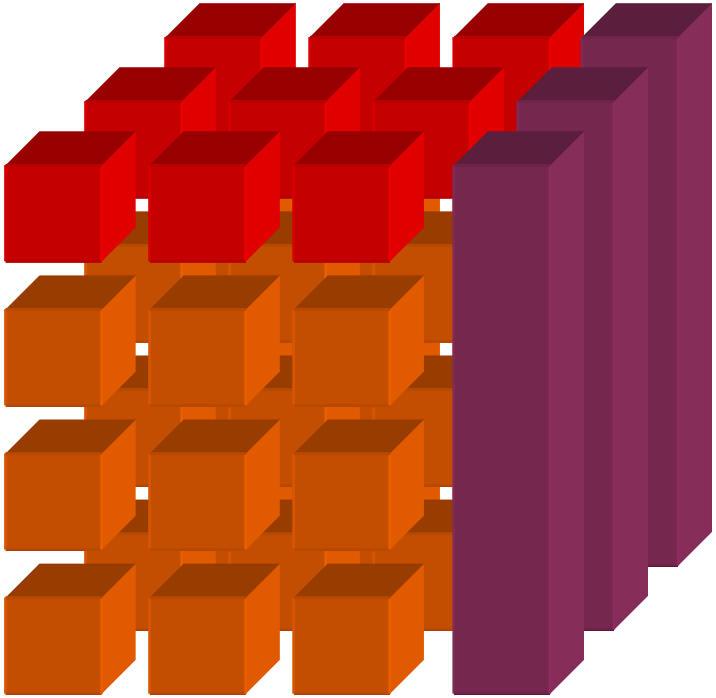
- Databases: NOBASE holds 3D reconstructed model neurons, synapses, synaptic pathways, microcircuit statistics, computer model neurons, virtual neurons.
- Visualization: BlueBuilder, BlueVision and BlueAnalsysis. 2D, 3D and immersive visualization systems are being developed.
- Simulation: a simulation environment for large scale simulations of morphologically complex neurons on 8000 processors of IBM's Blue Gene supercomputer.
- Simulations & experiments: iterations between large scale simulations of neocortical microcircuits and experiments in order to verify the computational model and explore predictions.

- Verification: in vivo = in silico?

The Blue Gene/L Architecture

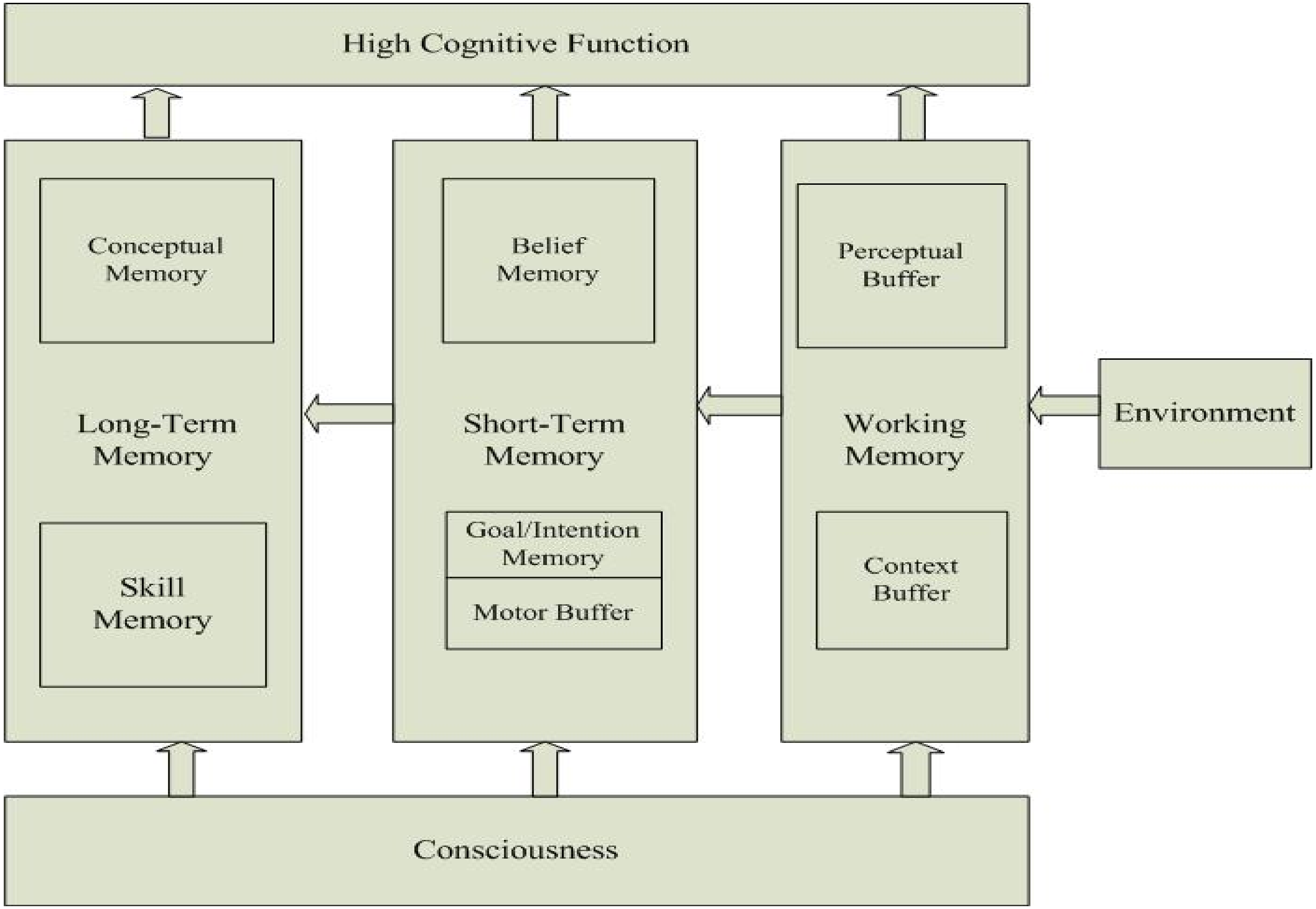


BlueGene/L System Software Architecture



- User applications execute exclusively in the **compute nodes**
  - avoid asynchronous events (e.g., daemons, interrupts)
- The outside world interacts only with the **I/O nodes**, an offload engine
  - standard solution: Linux
- Machine monitoring and control also offloaded to **service nodes**: large SP system or Linux cluster.

Brain-like Computer



Dawning-5000A

1956 →
1958 →
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2000 →
2004 →
2008 →

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Blade Cluster

The Fastest HPC in China
233.5x10^{12}/S
November 2008

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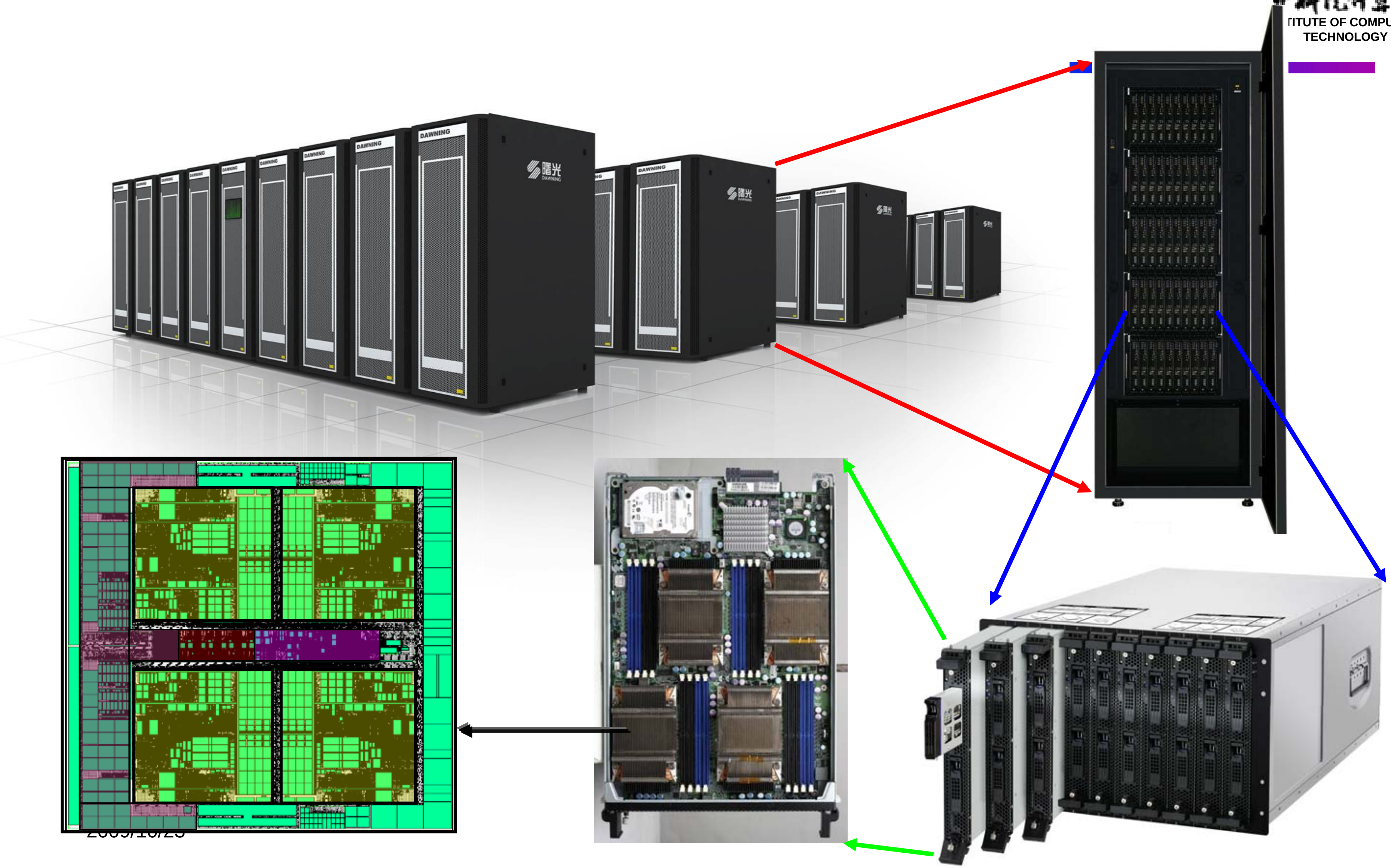

32nd List: The TOP10

HPC ASIA 2009

March 2 - 5 , 2009
in Kaohsiung, Taiwan

Rank	Site	Computer	Country	Cores	Rmax [Tflops]	Rmax/ Rpeak	Power [MW]	MF/W	
1	DOE/NNSA/Los Alamos Nat Lab	IBM / Roadrunner - BladeCenter QS22/LS21	USA	129600	1105.0	76%	2.48	445	Cluster
2	DOE/OS/Oak Ridge Nat Lab	Cray / Jaguar - Cray XT5 QC 2.3 GHz	USA	150152	1059.0	77%	6.95	152	MPP
3	NASA/Ames Research Center/NAS	SGI / Pleiades - SGI Altix ICE 8200EX	USA	51200	487.0	80%	2.09	233	MPP
4	DOE/NNSA/Lawrence Livermore Nat Lab	IBM / eServer Blue Gene Solution	USA	212992	478.2	80%	2.32	205	MPP
5	DOE/OS/Argonne Nat Lab	IBM / Blue Gene/P Solution	USA	163840	450.3	81%	1.26	357	MPP
6	NSF/TACC/Univ. of Texas	Sun / Ranger - SunBlade x6420	USA	62976	433.2	75%	2.0	217	Cluster
7	DOE/OS/NERSC/Lawrence Berkeley NL	Cray / Franklin - Cray XT4	USA	38642	266.3	75%	1.15	232	MPP
8	DOE/OS/Oak Ridge Nat Lab	Cray / Jaguar - Cray XT4	USA	30976	205.0	79%	1.58	130	MPP
9	DOE/NNSA/Sandia Nat Lab	Cray / Red Storm - XT3/4	USA	38208	204.2	72%	2.5	81	MPP
10	Shanghai Supercomputer Center	Dawning 5000A, Windows HPC 2008	China	30720	180.6	77%	0.8	225	Cluster

Jack Dongarra

Perspectives

- Intelligence Science is an interdisciplinary subject
- Intelligence Science can reach Human-Level AI
- Creating brain-like computer needs Intelligence Science

Thank You

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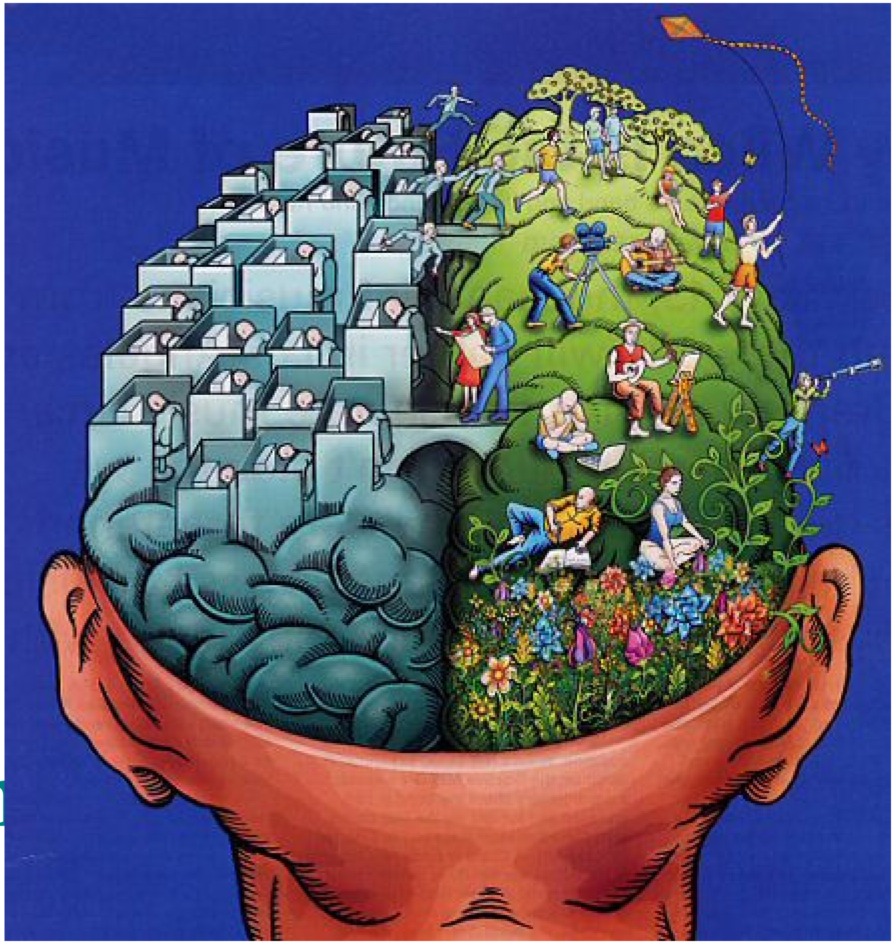
Question!



Intelligence Science

http://www.intsci.ac.cn