

# On Intelligence Science

Zhongzhi Shi

shizz@ics.ict.ac.cn

*Institute of Computing Technology*

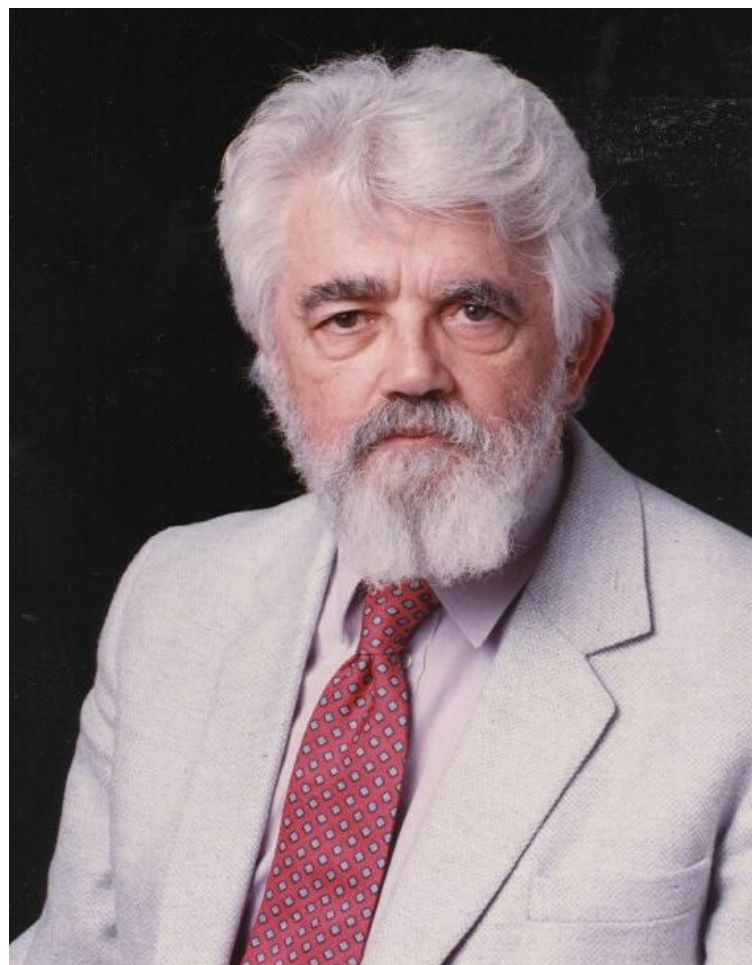
*Chinese Academy of Sciences*



中国科学院  
INSTITUTE OF COMPUTING TECHNOLOGY

# Human-Level AI

The long-term goal  
of Artificial  
Intelligence is  
human-level  
Artificial Intelligence.



# Intelligence Science

- Researches on basic theory and technology of intelligence.
- Intelligence science is an interdisciplinary subject mainly including brain science, cognitive science, artificial intelligence and others.
- Brain science explores the essence of brain, research on the principle and model of natural intelligence in molecular, cell and behavior level.

# Intelligence Science

- 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

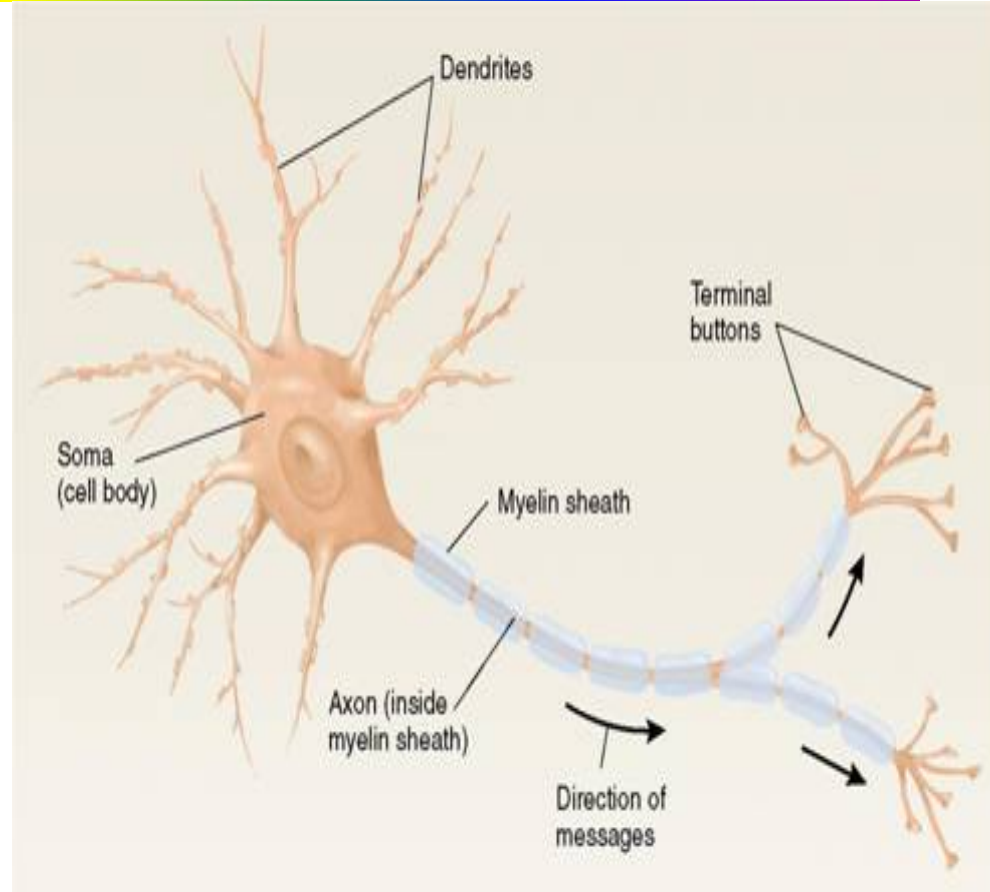
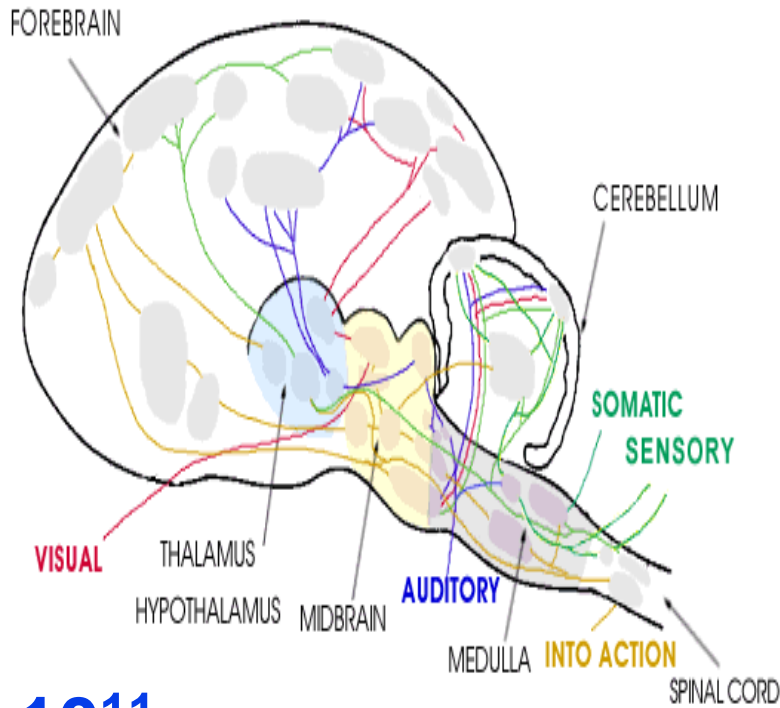
# Basic Scientific Problems

- **Signaling in the Nervous System**
- **Synaptic Plasticity**
- **Perceptual Representation**
- **Learning Emergence**
- **Coding and Retrieval of Memory**
- **Linguistic Cognition**
- **Formalizing of Commonsense knowledge and Reasoning**
- **Computational Instruction Set of Human Cognition**
- **Nature of Consciousness**
- **Architecture of Intelligent Systems**

# Signaling in the Nervous System



中国科学院  
INSTITUTE OF COMPUTING  
TECHNOLOGY



**$10^{11}$  neurons**

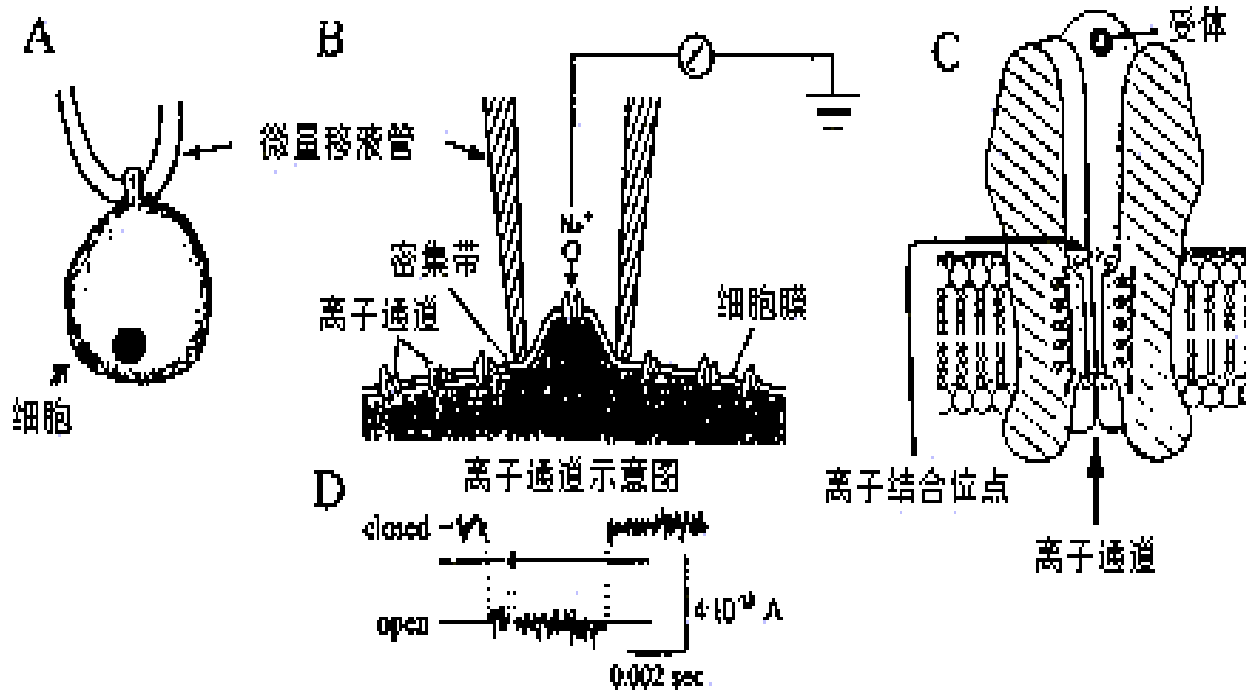
**$10^{14}$  synapses**

**cycle time:  $10^{-3}$  sec**

# Signaling in the Nervous System



中科院计算所  
INSTITUTE OF COMPUTING  
TECHNOLOGY

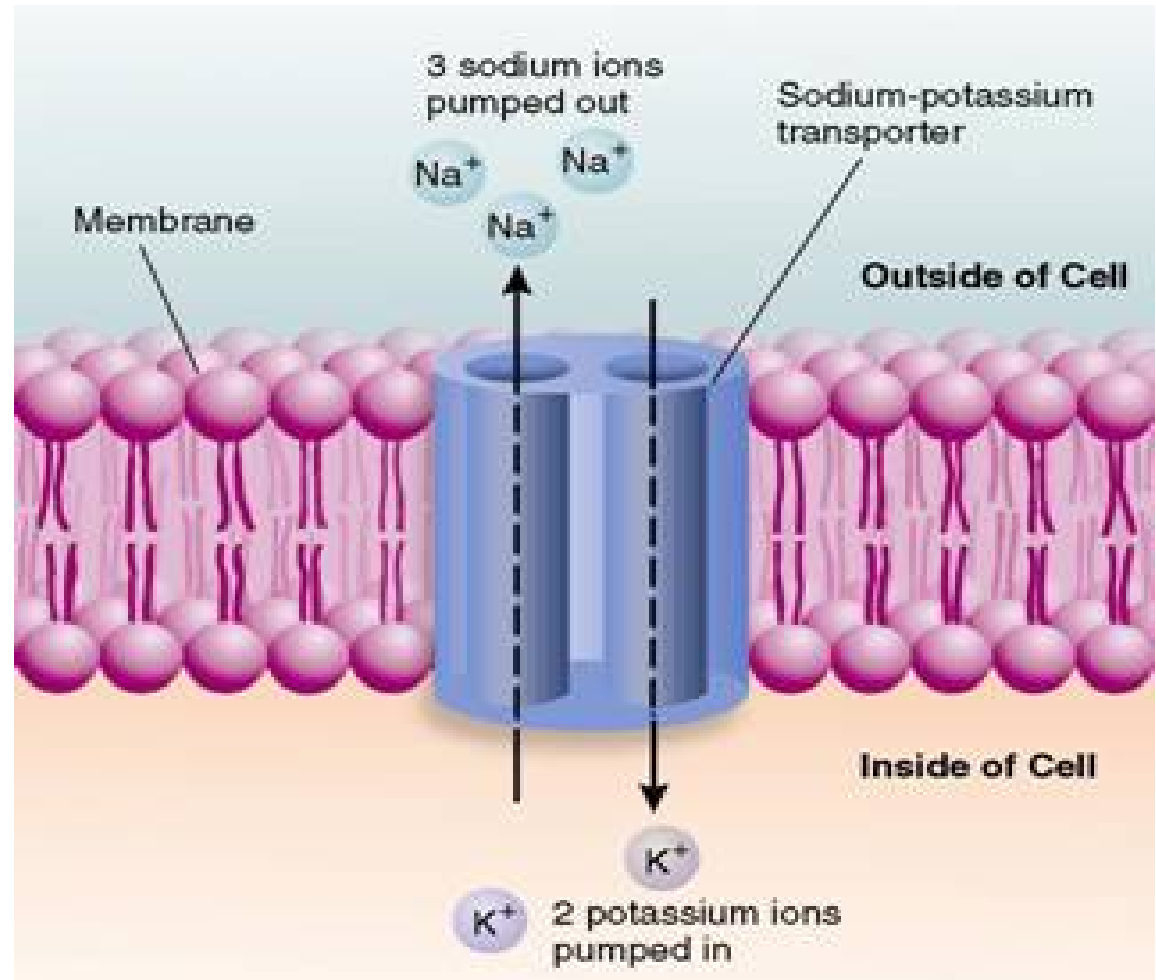


- **Ion Channels and Signaling**

# Signaling in the Nervous System



- **Transport across Cell Membranes**

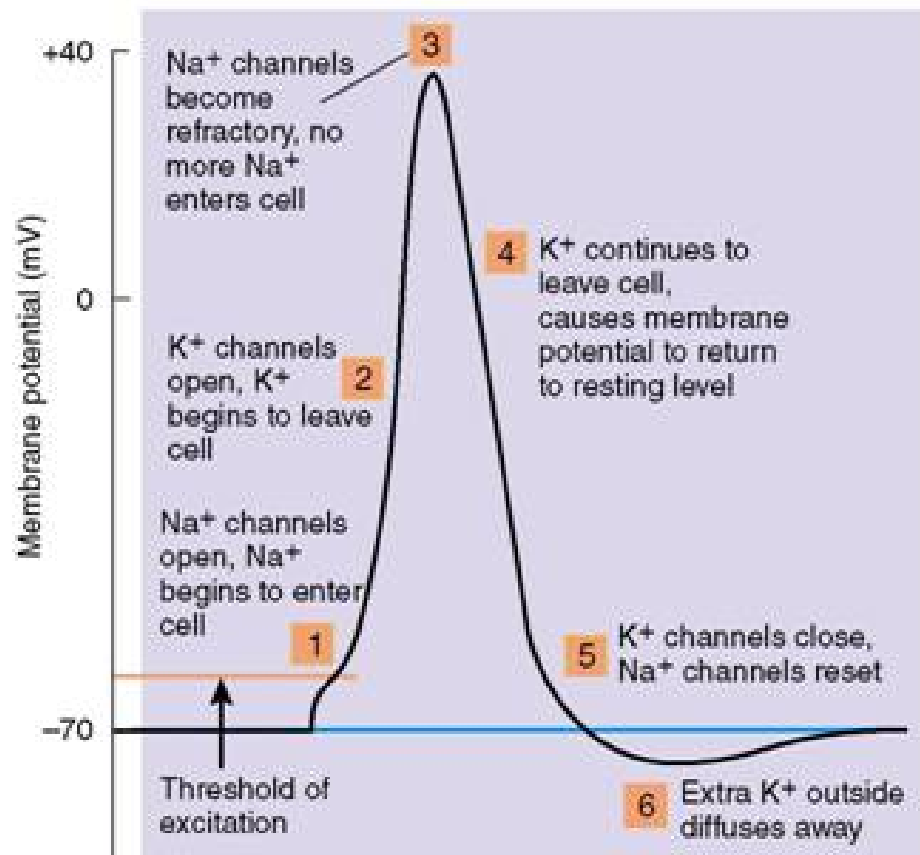
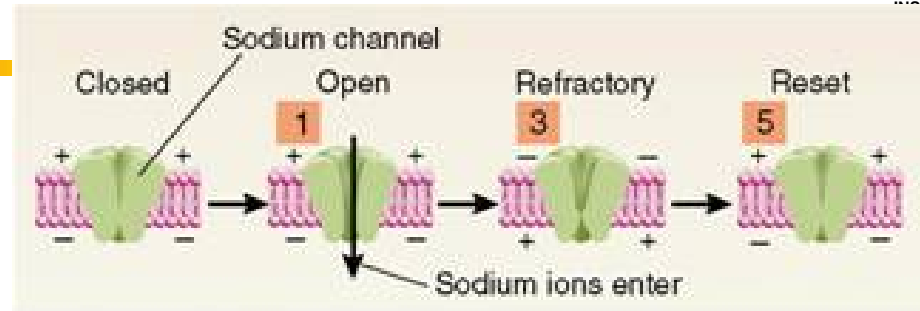


# Signaling in the Nervous System



中国科学院  
INSTITUTE OF COMPUTING  
TECHNOLOGY

- **Ionic Basis of the Action Potential**



# Signaling in the Nervous System



● How:

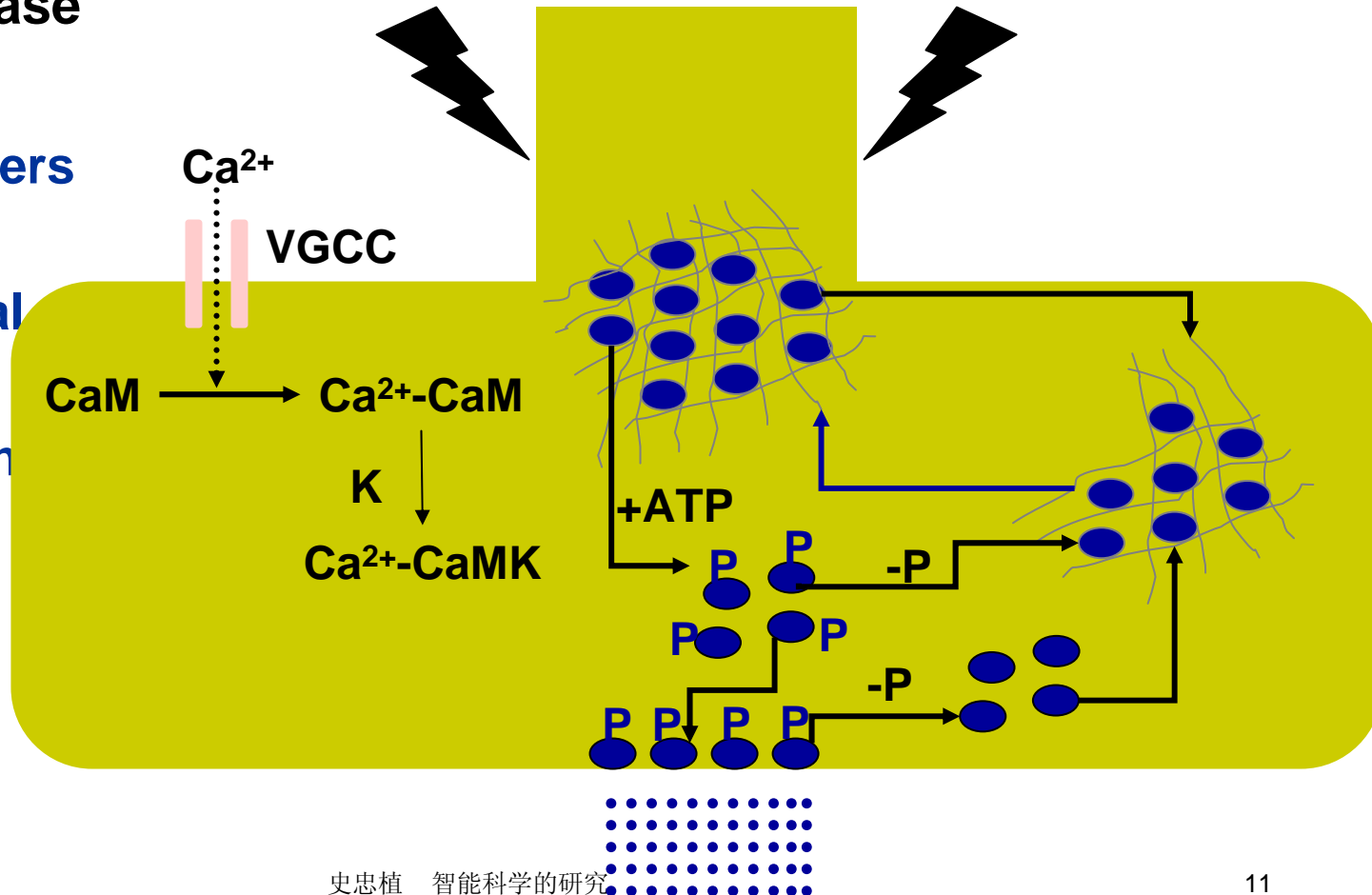
- - **AP comes down the axon.**
- - **At the synapses, VG Ca<sup>++</sup> channels let in calcium.**
- - **This triggers the release (exocytosis!) of the contents of vesicles in the axonal boton.**
- - **The contents are: NEUROTRANSMITTERS.**

# Signaling in the Nervous System



## Transmitter Release

- How are neurotransmitters packaged and released (signal transduction pathway, second messenger, transporters, receptors)?



# Synaptic Plasticity

## Hebb's Rule

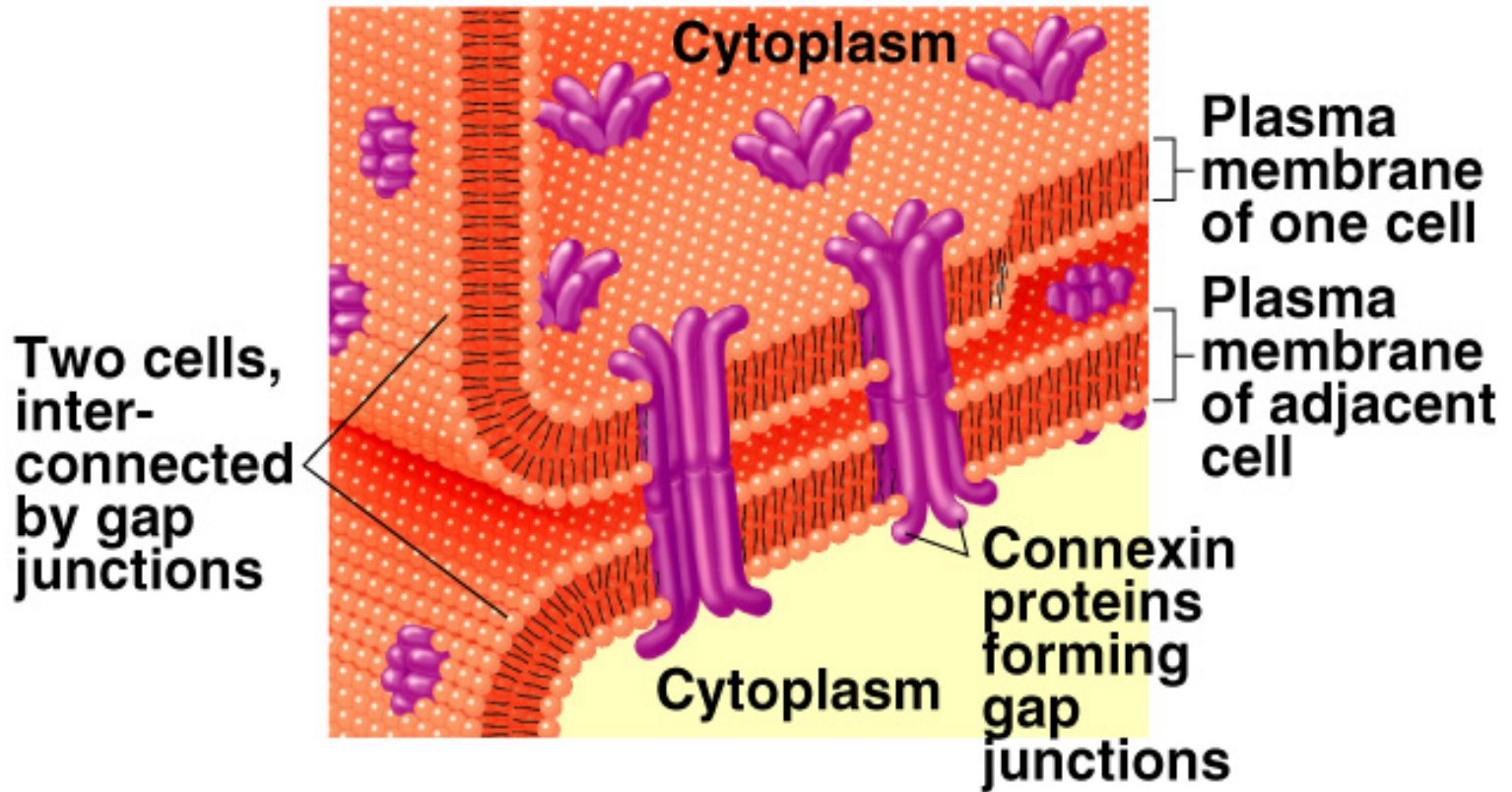
Connection Weights ~ Correlations

“When one cell repeatedly assists in firing another, the axon of the first cell develops synaptic knobs (or enlarges them if they already exist) in contact with the soma of the second cell.” (Hebb, 1949)

- **Short-Term Changes in Signaling**
- **Long-Term Changes in Signaling**

# Synaptic Plasticity

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

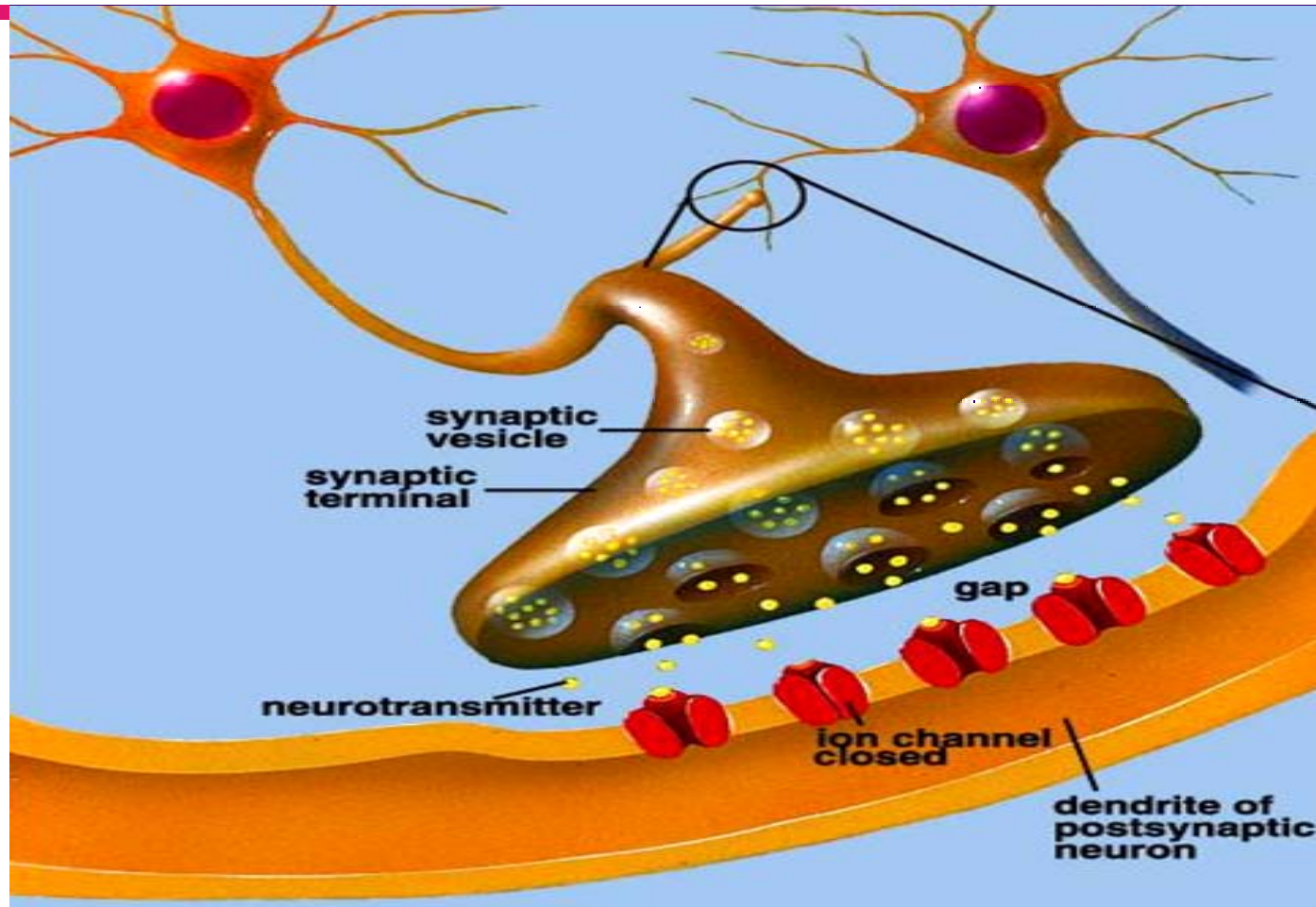


## ● Electrical Synapse

# Synaptic Plasticity



中国科学院  
INSTITUTE OF COMPUTING  
TECHNOLOGY



## ● Chemical Synapse

# Perceptual Representation



中科院计算所  
INSTITUTE OF COMPUTING  
TECHNOLOGY



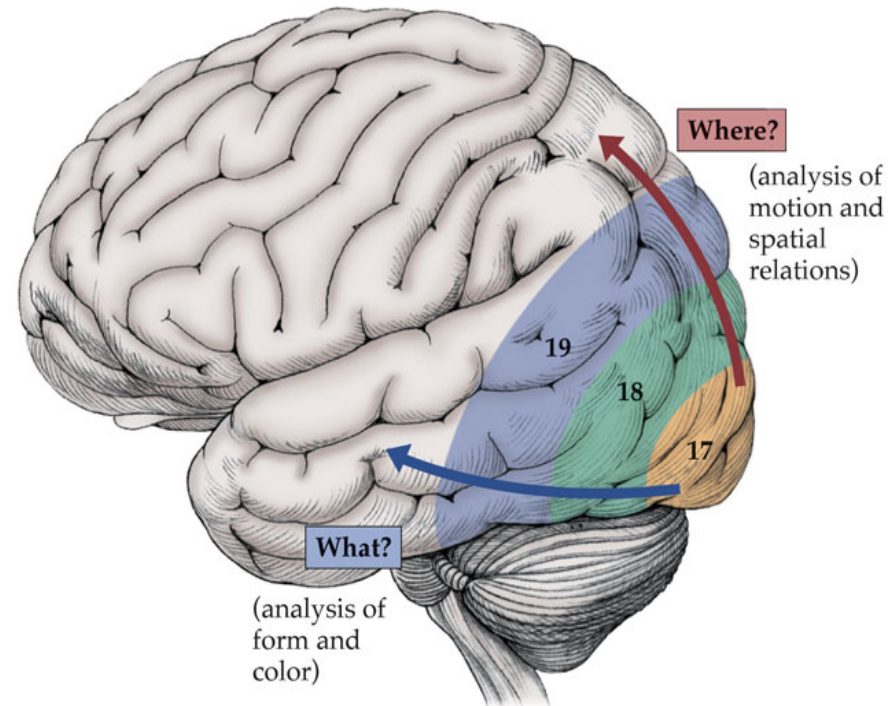
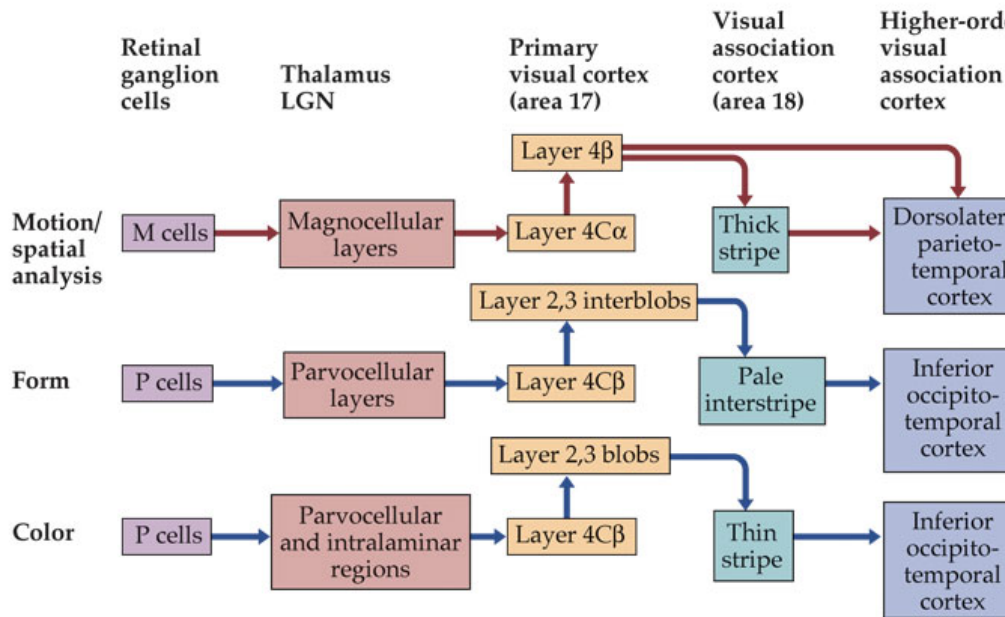
# Perceptual Representation

- At the lower level, the world is broken down into primitive features
- We perceive the world as a unified whole
- These holistic perceptions are the result of higher perceptual functions operating on these feature primitives
- Perceiving the world is connected with our knowledge of the world
- *A system that links the products of lower perception to memory*

# Visual Pathways

Dorsal pathways analyze motion and spatial relationships between the body and visual stimuli.

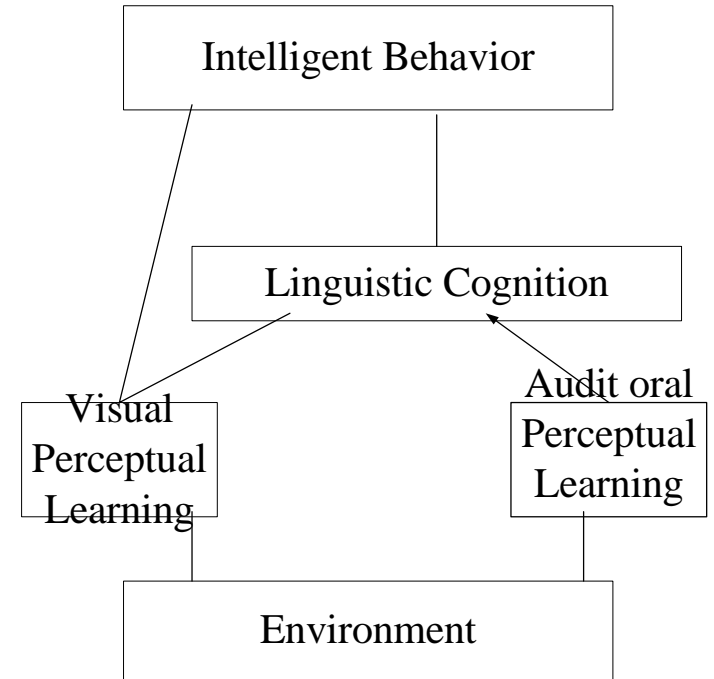
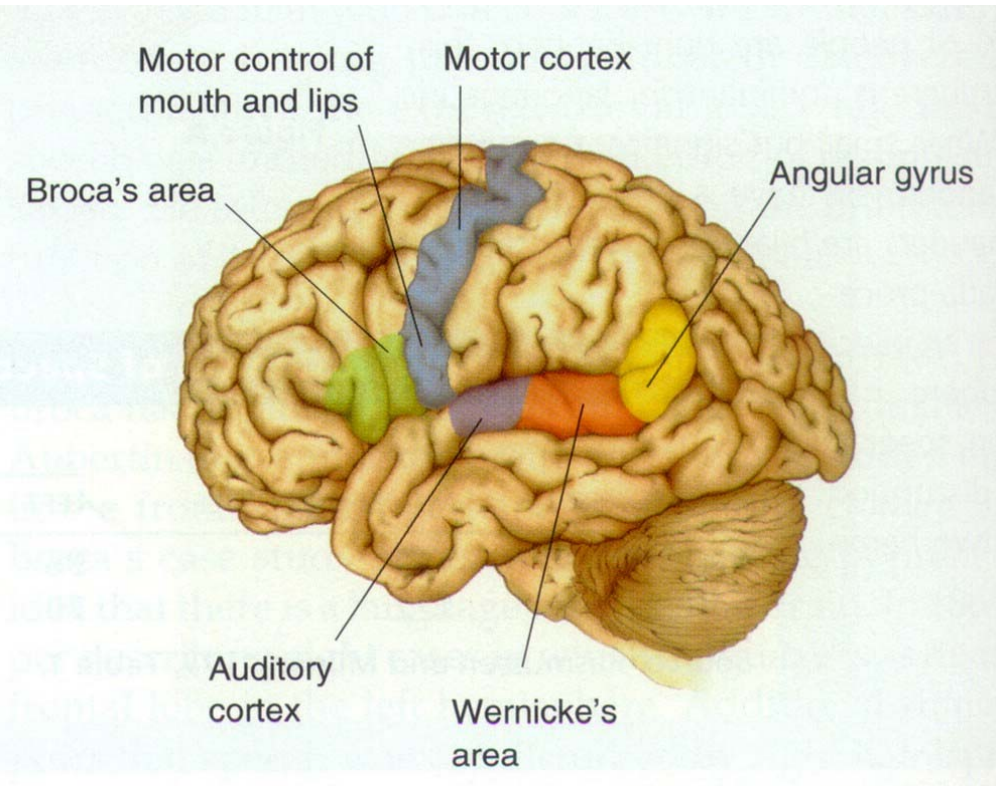
Ventral pathways analyze form with specific regions identifying colors, faces, letters and other stimuli.



© 2002 Sinauer Associates

© 2002 Sinauer Associates, Inc.

# Visual Information Processing



# Visual Perceptual Learning

## Goal

- Probe into visual system.

Visual perceptual learning should be considered as an active process that embeds particular abstraction, reformulation and approximation within the Abstraction framework.

- Model the vision information processing mechanism.

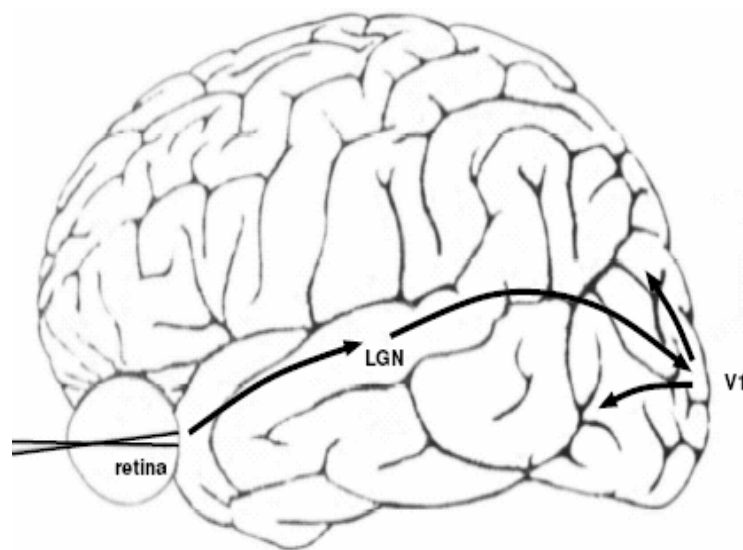
Neural representation, attention mechanism

- Guide the computer vision research.

Feature extraction

Feature binding

Object recognition



# Gibson's ecological theory

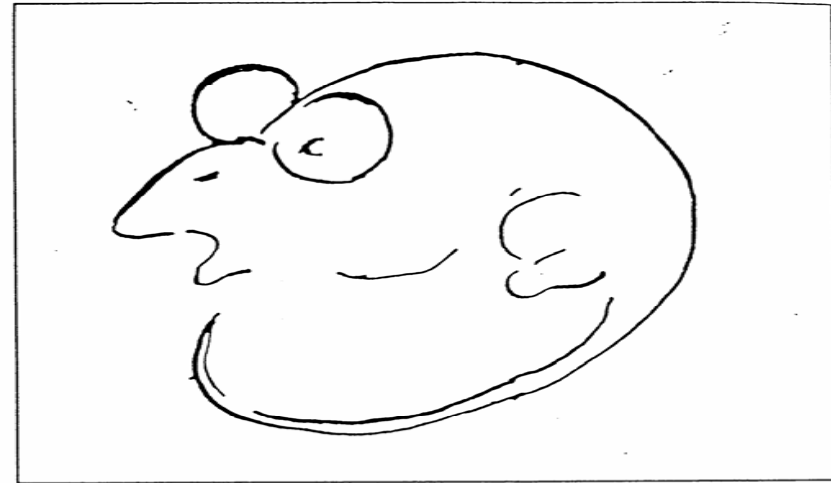
- Perception is entirely ***data driven***.
- “Non-constructivist” or **direct** perception.
- **Optic array** - patterns of light reaching retina
  - gives a **texture gradient**
  - -> **depth perception**.
- Visual perceptions have their own ‘affordances’.
- **Affordances** are salient perceptual characteristics that suggest the use of an object e.g., an umbrella.
- How could a three dimensional image be derived from affordances.

# Gestalt theory of perception



中科院计算所  
INSTITUTE OF COMPUTING  
TECHNOLOGY

- The **whole** visual percept is more than the sum of parts.
- Visual **illusions**.
- A visual percept can be interpreted in more than one way therefore we must have a **representation** of visual information in our mind.



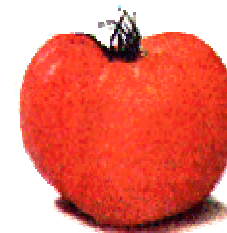
# Marr's theory of vision

Grey level description

Primal sketch.

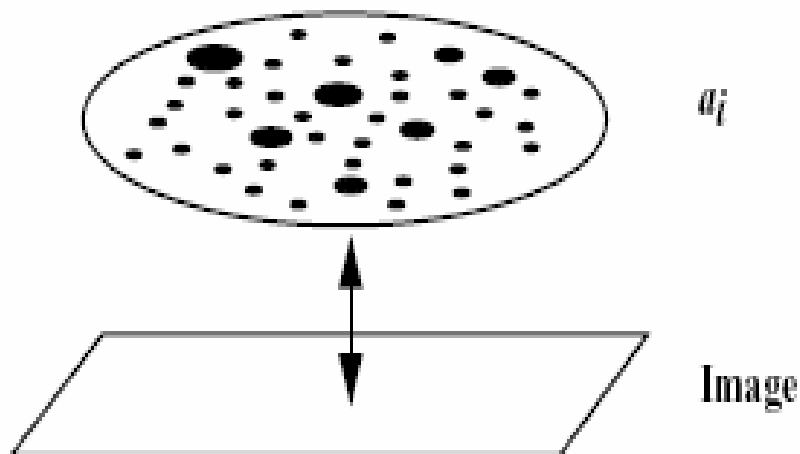
2.5 Dimensional sketch.

3 Dimensional model  
sketch

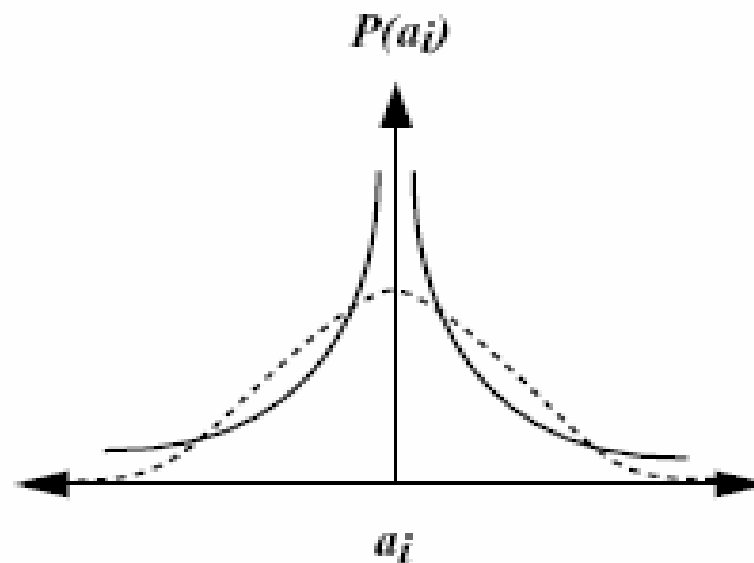


# What is sparse coding

## Sparse representation



An image would be represented by a small number of 'active' neurons,  $a_i$ , out of a large set. Which neurons are active varies from one image to another.



The distribution of activity on any given unit should be peaked around zero with heavy tails. Such a distribution will have low entropy, as opposed to a Gaussian distribution

# Why is sparse coding

---

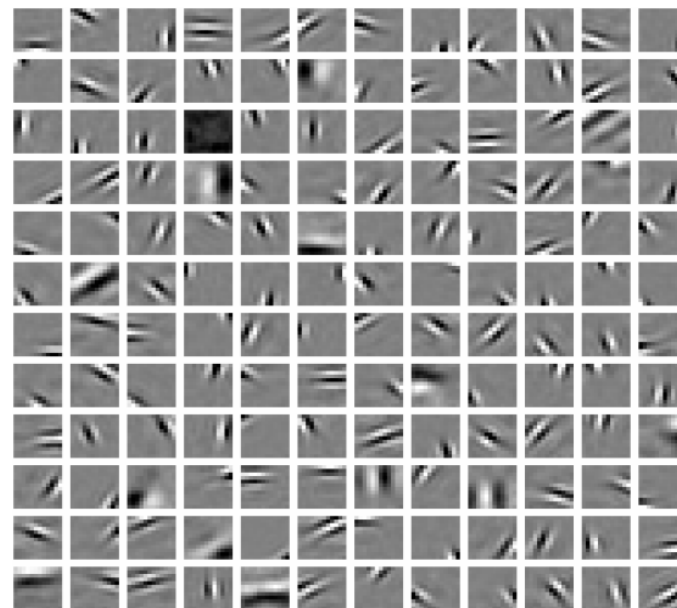
- It allows for increased storage capacity in associative memories;
- It makes the structure in natural signals explicit;
- It represents complex data in a way that is easier to read out at subsequent levels of processing;
- It saves energy.

# Sparse coding model(Field)

Olshausen pointed out a perceptual system is exposed to a series of small image patches, drawn from one or more large images, just like the CRF of neurons. Imagine that each image patch, represented by the vector  $I$  (numbered row-wise), has been formed by the linear combination of  $N$  basis functions. The basis functions form the columns of a fixed matrix,  $\mathbf{A}$ . The weighting of this linear combination is given by a vector,  $s$ . Each component of this vector has its own associated basis function, and represents a response value of a neuron in vision system. The linear synthesis model is therefore given by:

Linear superposition model with basis functions

$$I(x, y) = \sum_i s_i a_i(x, y)$$



# Sparse coding model(Field)

Olshausen and Field applied two criteria to seek the optimal basis vector and the coefficients

$$\text{Error}(s, A) = \sum_{x,y} \left[ I(x, y) - \sum_i s_i a_i(x, y) \right]^2$$

Sparseness cost function

$$\text{Sparseness}(s, A) = \sum_i S\left(\frac{s_i}{\sigma_i}\right)$$

Minimize the cost function

$$E(s, A) = \sum_{x,y} \left[ I(x, y) - \sum_i s_i a_i(x, y) \right]^2 + \lambda_s \sum_i S\left(\frac{s_i}{\sigma_i}\right)$$



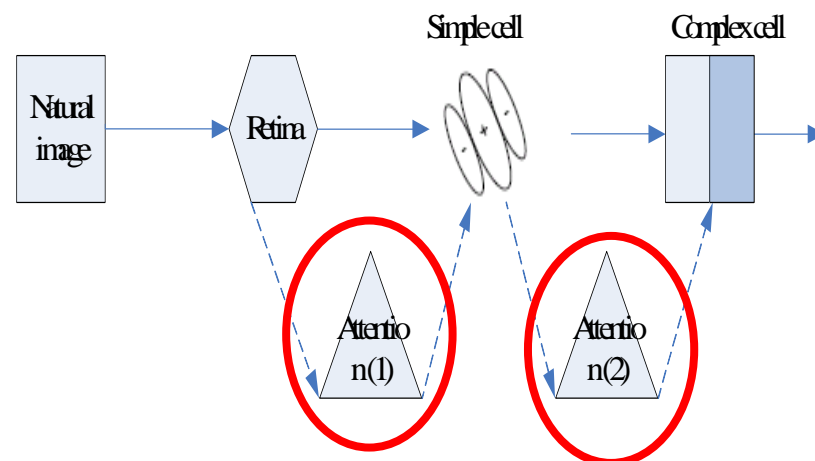
# Attention-guided visual sparse coding model

- The number of variable which has a large value produced by sparse coding model is relatively large compared with the computation capacity of neurons, though the kurtosis of every response coefficient is also high.
- A typical scene within the neuron's classic receptive field (CRF) contains many different patterns which compete for neural representation because of the limited processing capacity of neurons in the visual system.
- Vision attention mechanism is an active strategy in information processing procedure of brain.

# Attention-guided visual sparse coding model

## General model

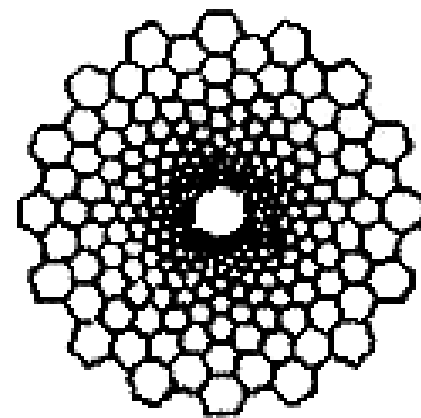
- The first attention module performs a transformation of the image into a 'retinal image', nonuniformly sampling the input visual stimuli.
- The second attention module performs the selective attention based on response saliency.



**The diagram of the model.**

# Nonuniform sampling model

- The density of photoreceptors in the retina is greatest in the central area (fovea) and decreases to the retinal periphery
- The resolution of the image representation in the visual cortex is highest for the part of the image projected onto the fovea and decreases rapidly with distance from the fovea center.



Vision sampling model

# Nonuniform sampling model

Recursive computation  
of the Gaussian-like  
convolution

$$R_{ij}^{(1)} = X_{ij}$$

$$R_{ij}^{(2)} = \sum_{p=-2}^{p=2} \sum_{q=-2}^{q=2} G_{pq} R_{i-p, j-q}^{(1)}$$

$$R_{ij}^{(l)} = \sum_{p=-2}^{p=2} \sum_{q=-2}^{q=2} G_{pq} R_{i-p*2^{l-1}, j-q*2^{l-1}}^{(l-1)}$$

$$[G_{pq}] = \begin{bmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 4 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 4 \\ 1 & 4 & 6 & 4 & 1 \end{bmatrix} * \frac{1}{256}$$

# Nonuniform sampling model

The input image patch is represented: within the central circle the pixels are full sampled just as the original image, with lower resolution within the first ring surrounding the central circle, and with the lowest resolution within the third circle.

$$X_{ij} = \begin{cases} R_{ij}^1 & \text{if } D(i, j) \leq R_0 \\ R_{ij}^2 & \text{if } R_0 \leq D(i, j) \leq R_1 \\ R_{ij}^3 & \text{if } R_1 \leq D(i, j) \leq R_2 \end{cases}$$

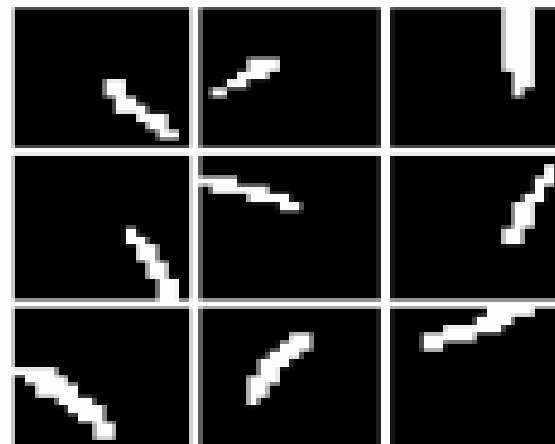
# Selective attention model

- **Definition : Response saliency** is the response extent for a neuron compared with a group of neurons which respond to the same stimulus.
- The purpose of the response saliency is to represent the conspicuity of every neuron in the same perception level for a stimulus and to guide the selection of attended neuron, based on the value of response saliency.
- The neuron response that has great response saliency value will be chosen to further process. On the contrary, the neuron that has small value will be omitted.

# Selective attention model

Every such pattern is  
selective for location,  
orientation and frequency

- Center of the excitatory subregion as the location selectivity
- Angle (in degree) between the x-axis and the major axis of the ellipse as orientation
- Area of the excitatory subregion as frequency



$$D(A_i, A_j) = W_1 * N \left( \sqrt{(L_{ix} - L_{jx})^2 + (L_{iy} - L_{jy})^2} \right) \\ + W_2 * N \left( |O_i - O_j| \right) + W_3 * N \left( |F_i - F_j| \right)$$

# Selective attention model

## ◆ Discrepancy between $A_i$ and $S$

$$Diff(A_i, S) = \left( \sum_{A_j \in S} D(i, j) * R_j \right) / \text{Count}(S)$$

## ◆ Response saliency (RS) value

$$RS(A_i) = N(|R_i|) + \lambda * (1 - Diff(A_i, S))$$

# Selective attention model

---

## Selection strategies :

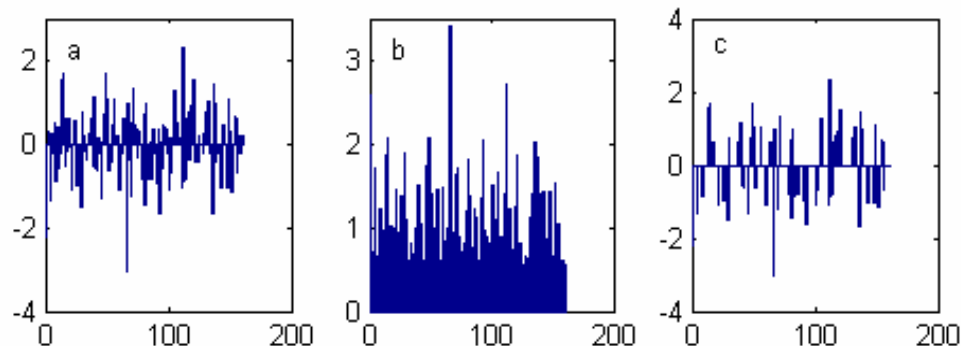
- Threshold selection mechanism (TSM)

TSM is a threshold filtering algorithm

- Proportion selection mechanism (PSM)

PSM is a bottleneck filtering algorithm

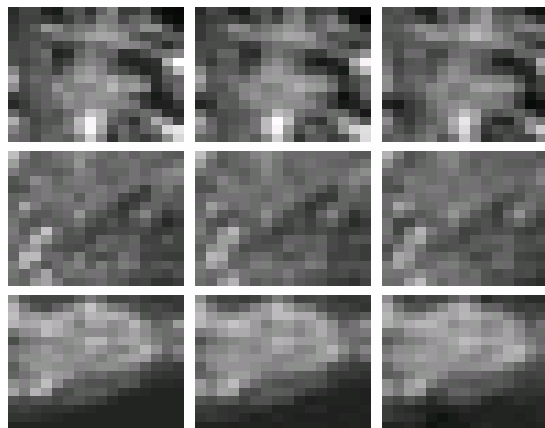
# Simulation results



Histogram of the coefficient in the model for an input image patch. (a) The original response coefficient produced by sparse coding. (b) The response saliency value. (c) The response coefficient after vision attention, selected the frontal 40% response coefficient sorted by response saliency descendly.

# Simulation results

---



The input image patch and the reconstructed image. The first column is the original image; the second column is the image reconstructed by the full coefficients produced by sparse coding; the third column is the image reconstructed by the selected coefficient by this model.

# Simulation results

$$\text{Error}(s, A) = \sum_{x,y} \left[ I(x, y) - \sum_i s_i a_i(x, y) \right]^2$$

	Mean error	Maximum error	Minimum error
AGSC	0.1105	0.3913	0.0060
SC	0.1002	0.3209	0.0032

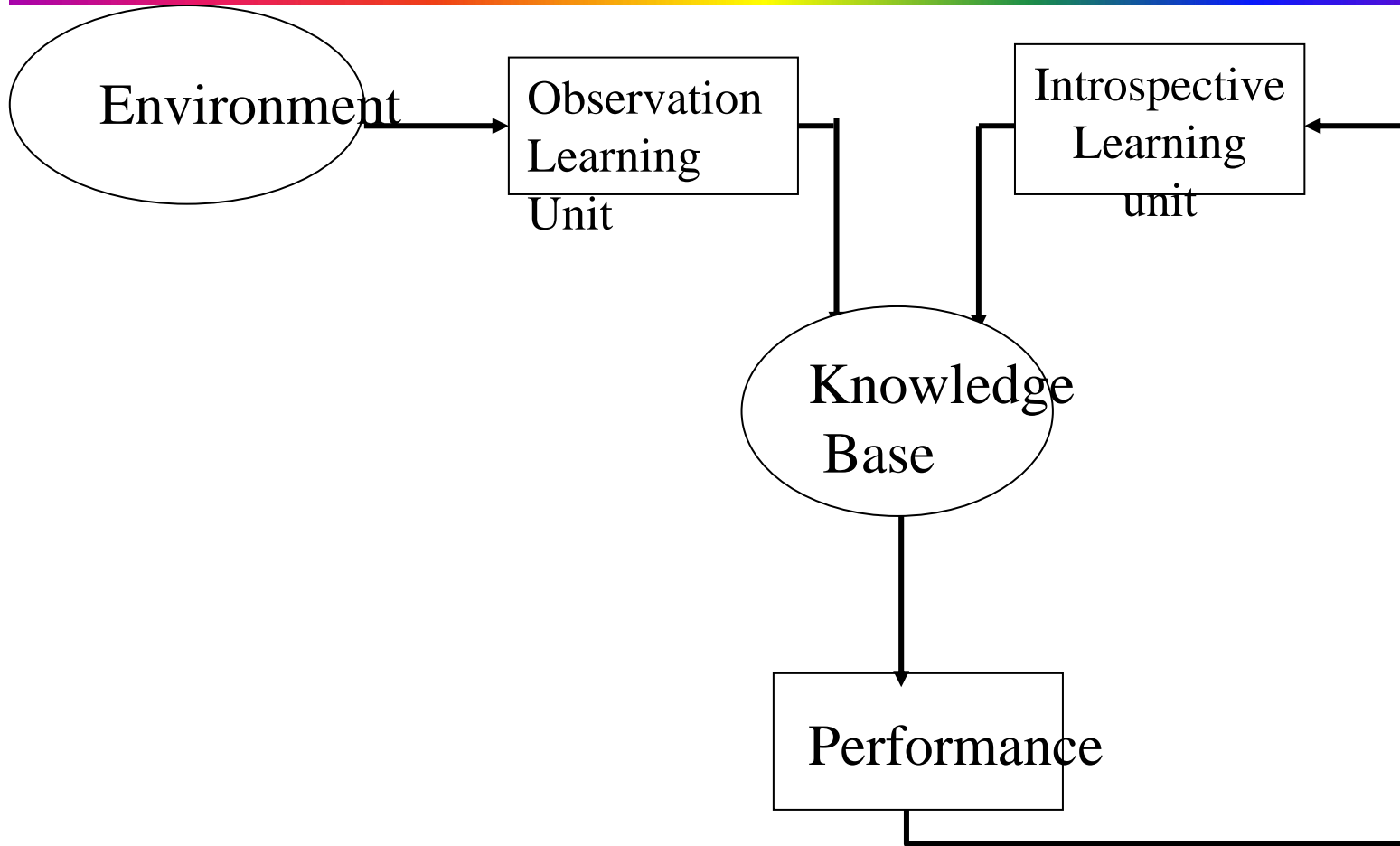
Reconstruction errors of the sparse coding model (SC) and attention-guided sparse coding model (AGSC)

# Learning

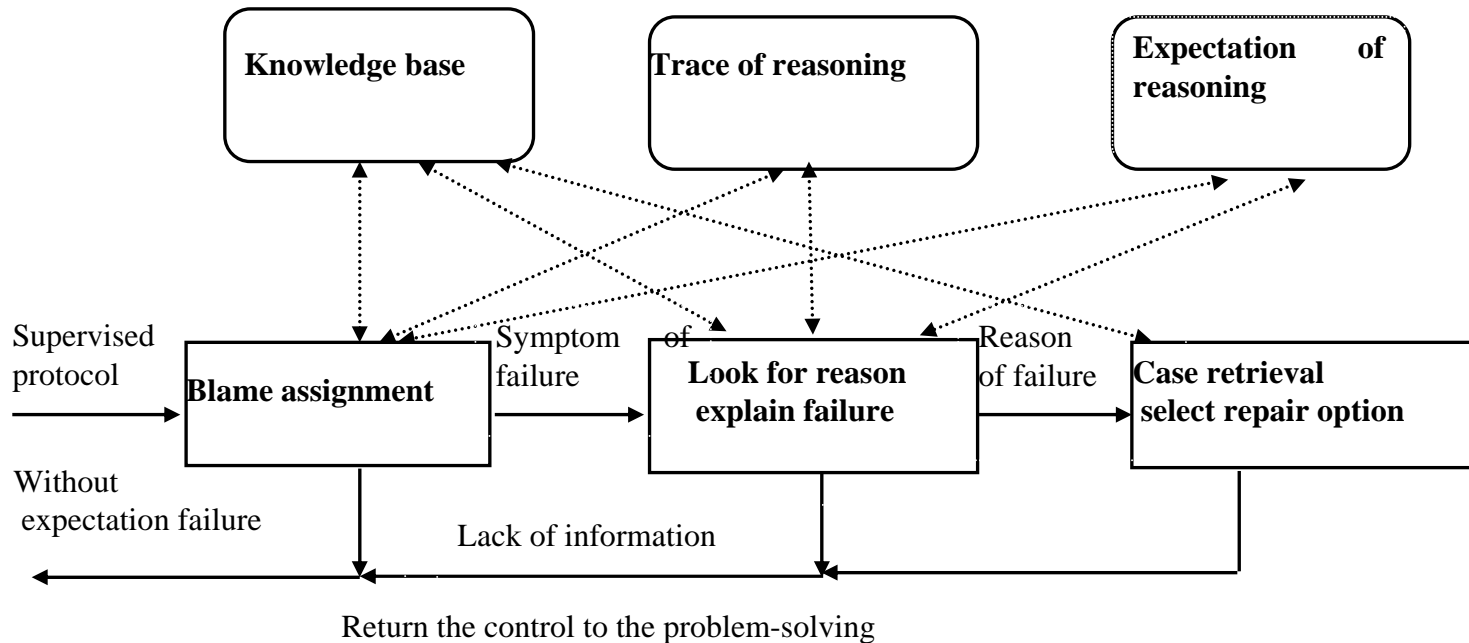
*“...relatively permanent changes in behavior produced by experience”*

- ❑ Learning involves changes in the nervous system produced by experiences
- ❑ Nervous system changes are physical
- ❑ Learning allows us to adapt our behaviors to the environment
- ❑ Learning involves interactions among the motor, sensory, and memory systems

# Learning Model



# A general model of introspective learning



**Figure1 a general model of introspective learning**

# Learning Emergence

- Clustering
- Case-based learning

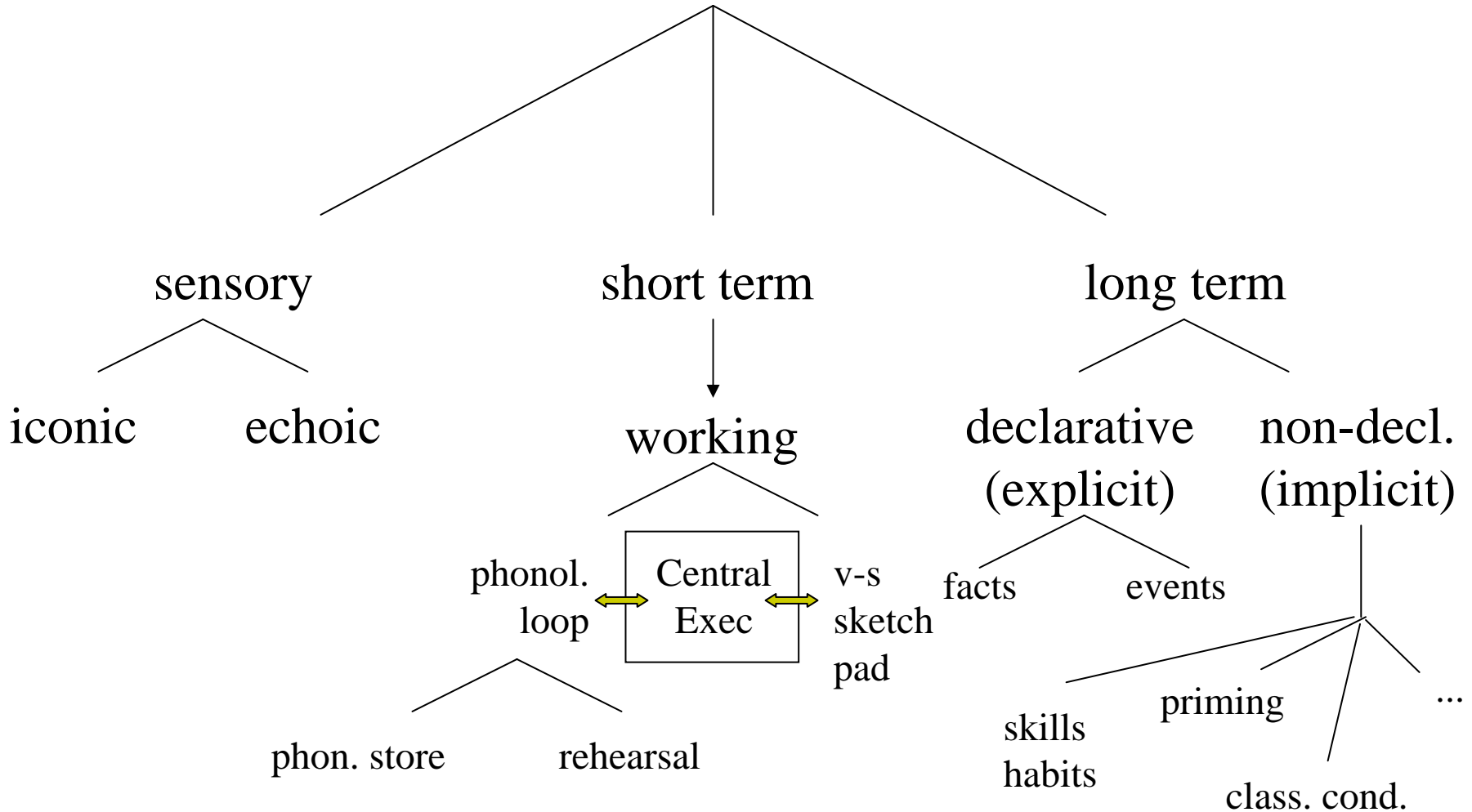
# Implicit Learning

The term implicit learning was coined by Reber to refer to the way people could learn structure in a domain without being able to say what they had learnt [9]. Reber first proposed artificial grammars to study implicit learning for unconscious knowledge acquisition. It will help us to understand the learning mechanism without consciousness. Since middle of 80's implicit learning become an active research area in psychology.

# Coding and Retrieval of Memory

- **Explicit Memory** - requires conscious recollection of previous experience:
- **Implicit Memory** - assessed without reference to specific learning event:
  - 
  -

# Memory



# Five Memory Systems (Schacter et al., 1994, 2000)

- Working Memory
- Episodic Memory
- Semantic Memory
- Perceptual Representation
- Procedural Memory

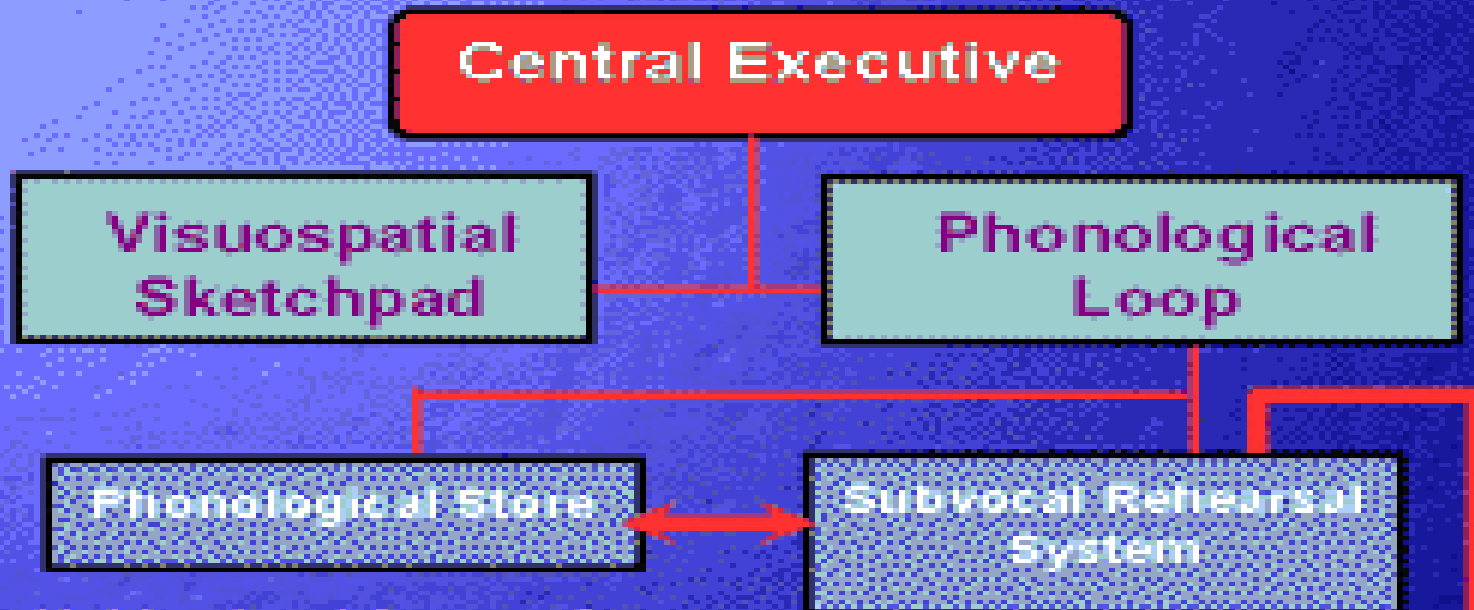
# Working Memory

---

Working memory will provides temporal space and enough information for complex tasks, such as understanding speech, learning, reasoning and attention. There are memory and reasoning functions in the working memory. It consists of three components: that is, central nervous performance system, video space primary processing and phonetic circuit.

# Working Memory

## A Diagram of Working Memory



- Holds about 2 sec. of phonological (acoustic) information

- the 'inner voice' speaking to the 'inner ear' refreshes phonological store

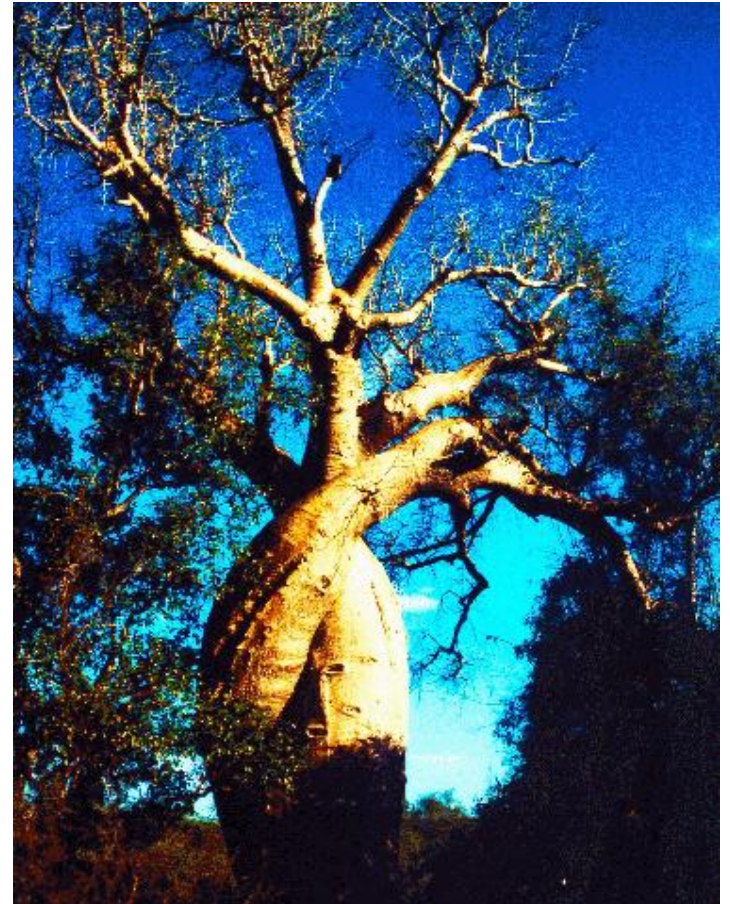
# Linguistic Cognition

- **Language is fundamentally a means for social communication. Language is also often held to be the mirror of the mind. Chomsky developed transformational grammar that cognitivism replaced behaviorism in linguistics .**

-

# Linguistic Cognition

- Under what conditions can (aspects of) syntactic or grammatical structures emerge?
  - Nativist accounts
  - Cultural accounts
  - Hybrid accounts
  - Grounding



# Formalizing of Commonsense knowledge and Reasoning

- **Nonmonotonic reasoning**
- **Mathematical logic**
- **Incomplete reasoning**

# Computational Instruction Set of Human Cognition

- **There is a large and growing body of knowledge about the operations of human intelligence, that is, human brain circuitry.**
- **Operators will be comprised the “instruction set” of the brain which constitute the basic mental procedures**
- **Instruction set will construct all major behavioral and cognitive operations.**
- **Richard Granger: Engines of the Brain, AI Magazine, 27(2): 15-31**

# Nature of Consciousness

---

Weiten defines consciousness as "...the awareness of internal and external stimuli."  
but by this he means

1. awareness of stimuli in the external environment
2. awareness of stimuli in the internal environment
3. awareness of "self" as having these experiences
4. awareness of the thoughts you have about these three other things

# Functions of Consciousness

---

## 1. Define and Set Context

- define a stimulus and remove ambiguities from perception

## 2. Adaptation and Learning

- more novelty = more conscious involvement for successful learning and adaptation

## 3. Prioritizing and Access Control

- prioritizing more imp. Info, making it more conscious more often

# Functions of Consciousness

---

## 4. Recruitment and Control of Mental and Physical Actions

- conscious goals recruit subgoals and motor systems to organize and carry out actions

## 5. Decision Making and Executive Function

- minimizes indecision by directing our efforts toward choice points

## 6. Error Detection and Editing

# Functions of Consciousness

---

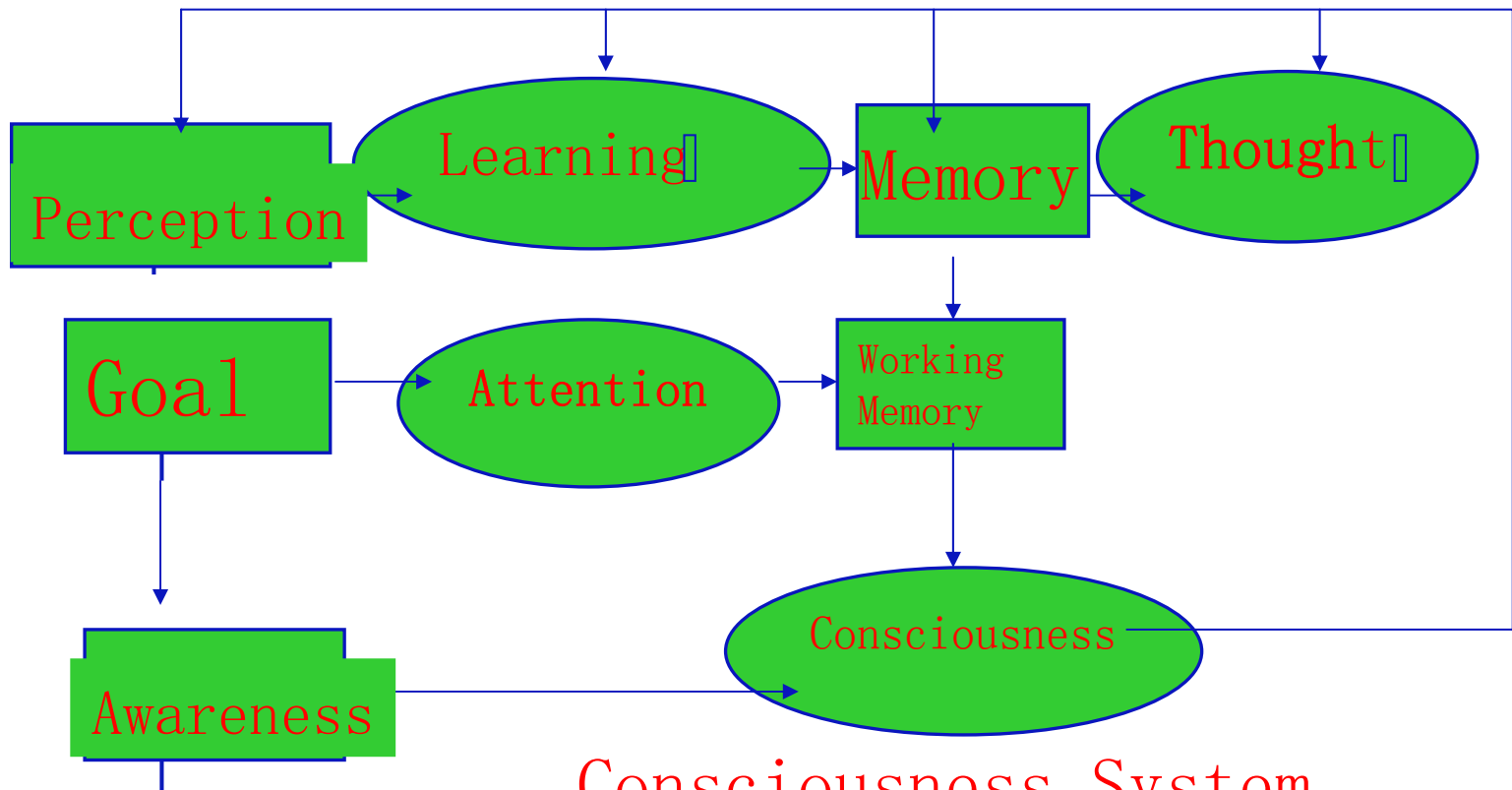
7. Reflective and Self-Monitoring Function

8. Optimizing the Trade-off between  
Organization and Flexibility

- consciousness plays role in unpredictable situations; unconsciousness governs predictable situations

# Consciousness Model

## Cognitive System



## Consciousness System

# Architecture of Intelligent Systems



*Mind* is here defined as our thinking faculties as well as the arena where we process, store, and manage mental activity. In humans, mind is a faculty and/or location where imagination and intellect, image and idea, percept and concept, body and soul, matter and spirit contact, interact, and intermingle.

# Mind Development

## Mind Development

- Simple condition reflection
- Condition reflection
- Tool employment
- Linguistic symbol

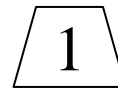
# Alan Turing



Alan Turing  
(1912-1954)

- *On computable numbers with an application to the Entscheidungsproblem* (1936)
- Church, Kleene, Post

# 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		

# Turing Test

Turing's 1950 paper in *Mind*, *Computing Machinery and Intelligence*:

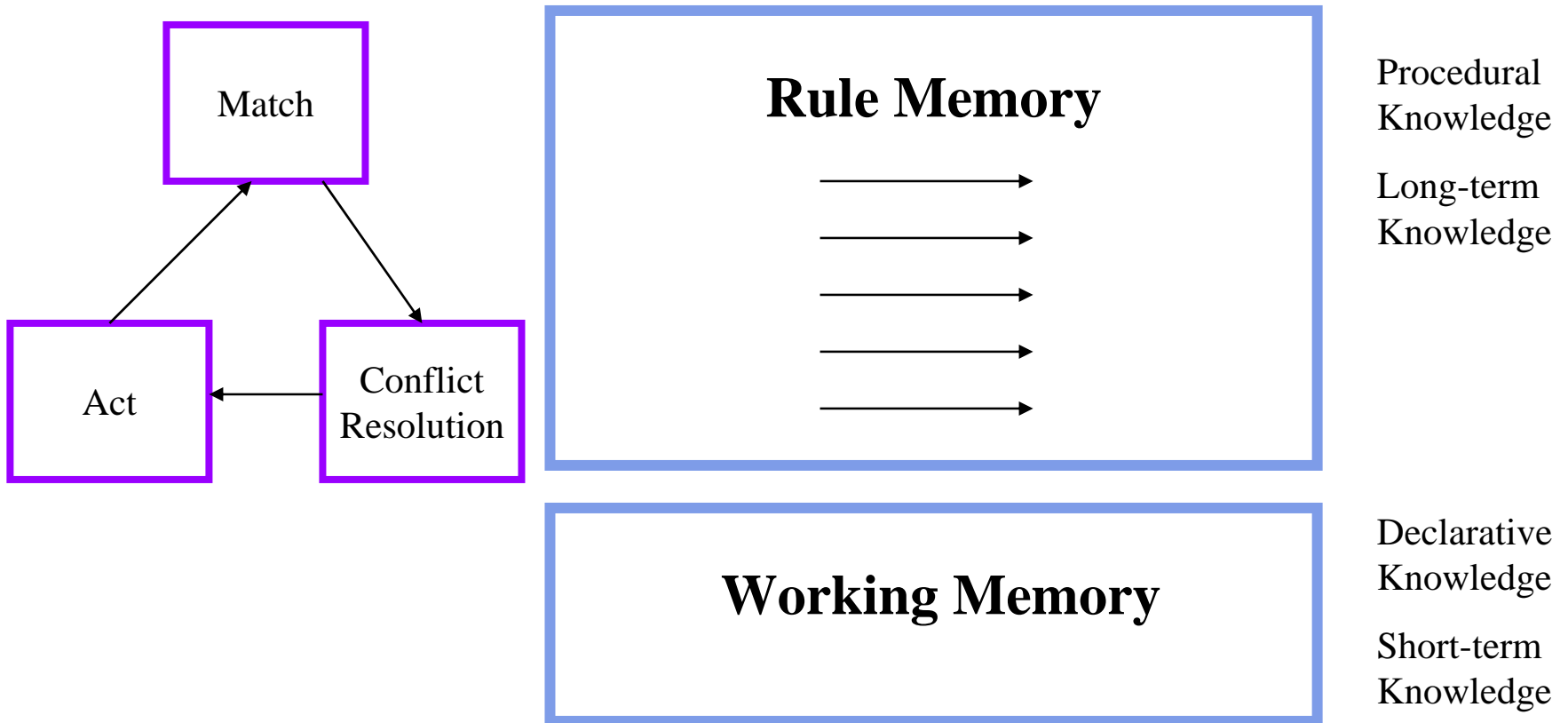
'imitation game', in which a human being and a computer would be interrogated under conditions where the interrogator would not know which was which, the communication being entirely by textual messages. Turing argued that if the interrogator could not distinguish them by questioning, then it would be unreasonable not to call the computer intelligent.

# Physical Symbol System Hypothesis



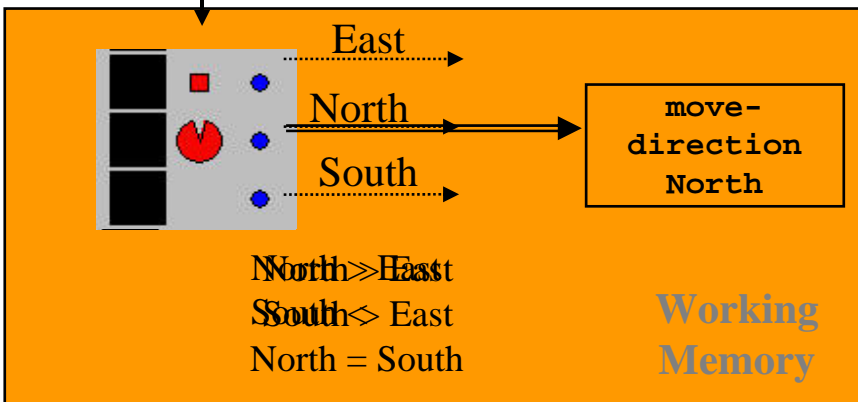
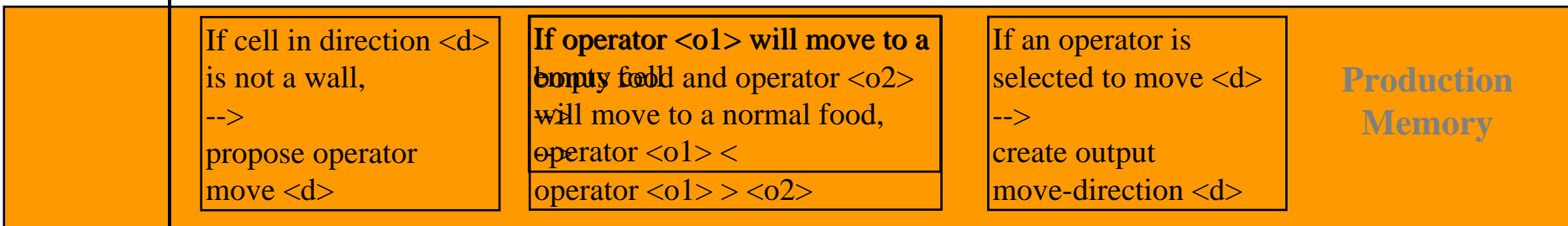
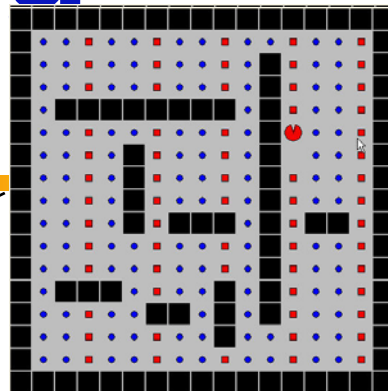
- Newell and Simon's paper "Computer Science as Empirical Inquiry: Symbols and Search" which define the essential ideas of the Physical Symbol System Hypothesis:  
**"A physical symbol system has the necessary and sufficient means for intelligent action."**

# SOAR

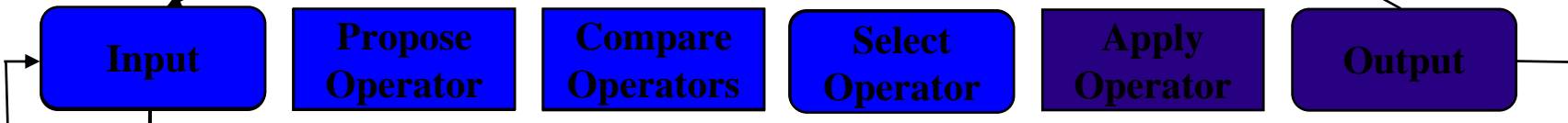
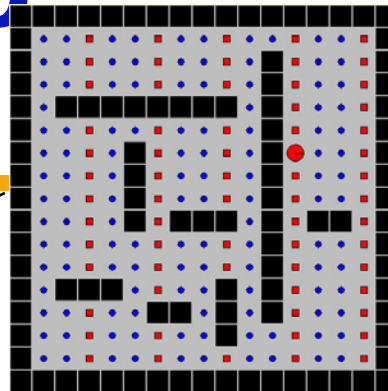


- **Computational Structure**
  - Encode knowledge
  - Access encodings
  - Produce actions
  - Achieve goals

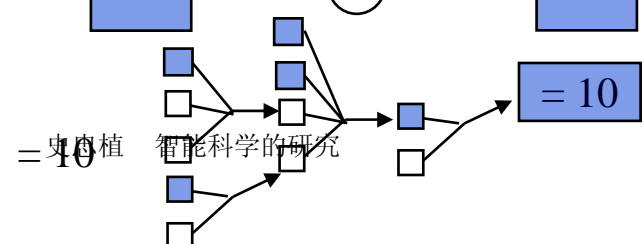
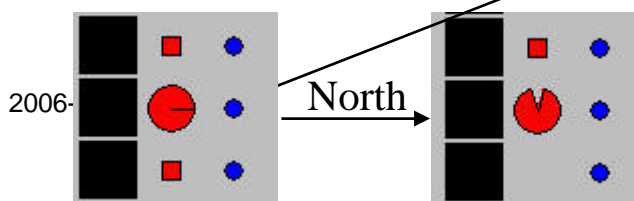
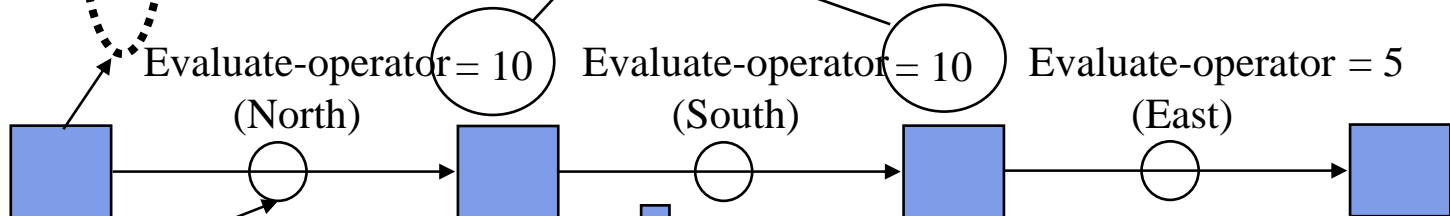
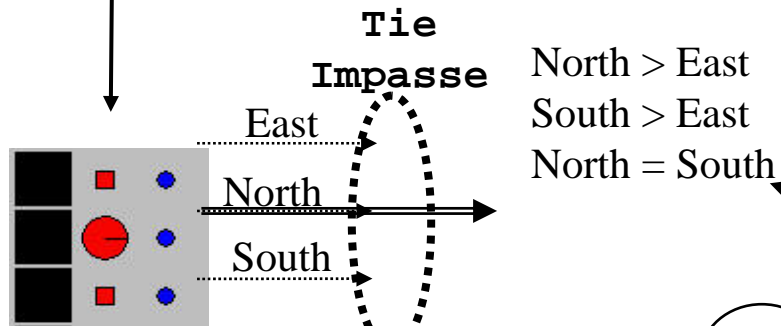
# Processing



# Processing

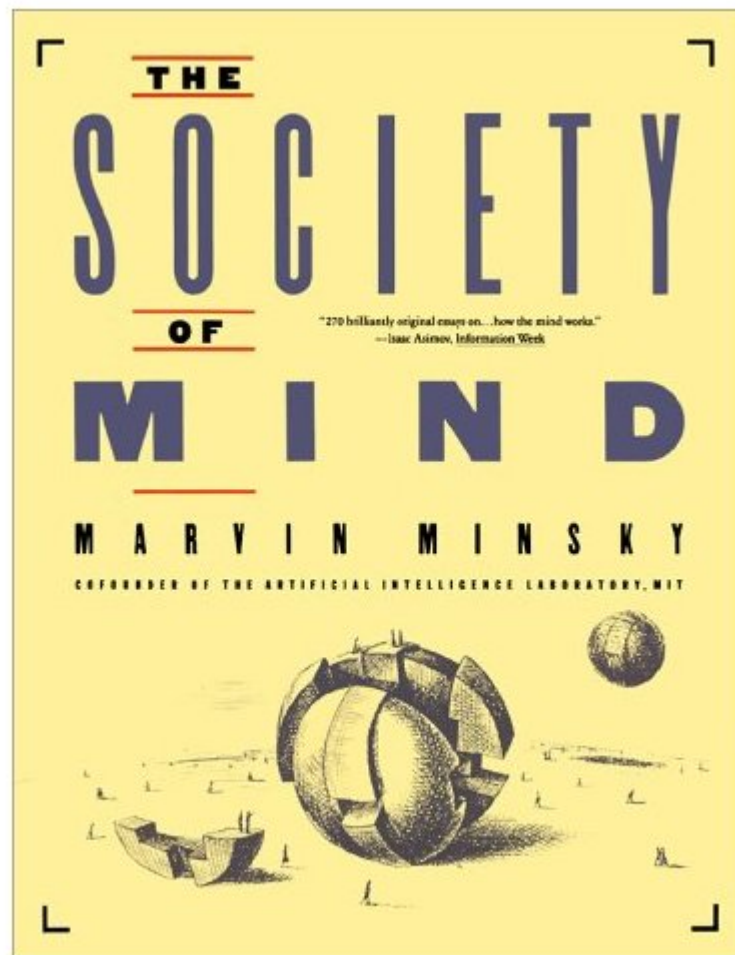
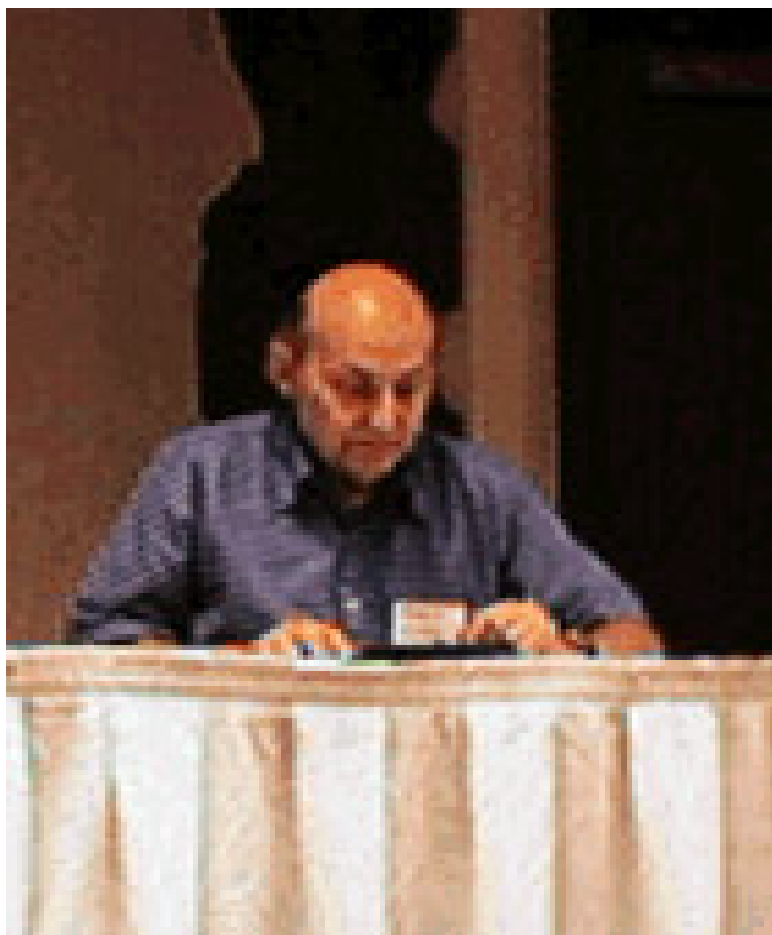


Chunking creates rules that create preferences based on what was tested

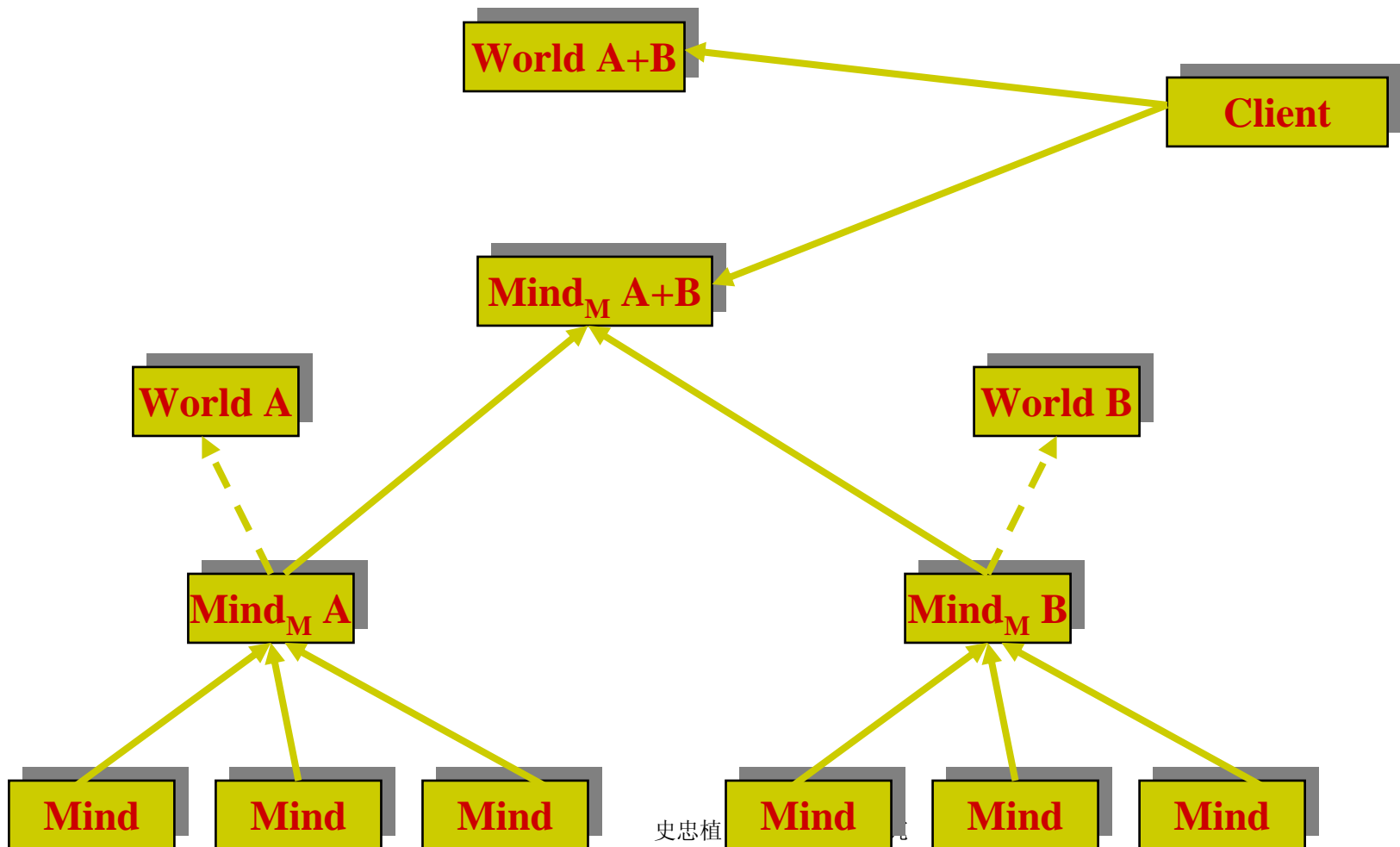


Chunking creates rule that applies evaluate-operator

# Society of Mind



# Society of Mind



# Constructing complex minds, online

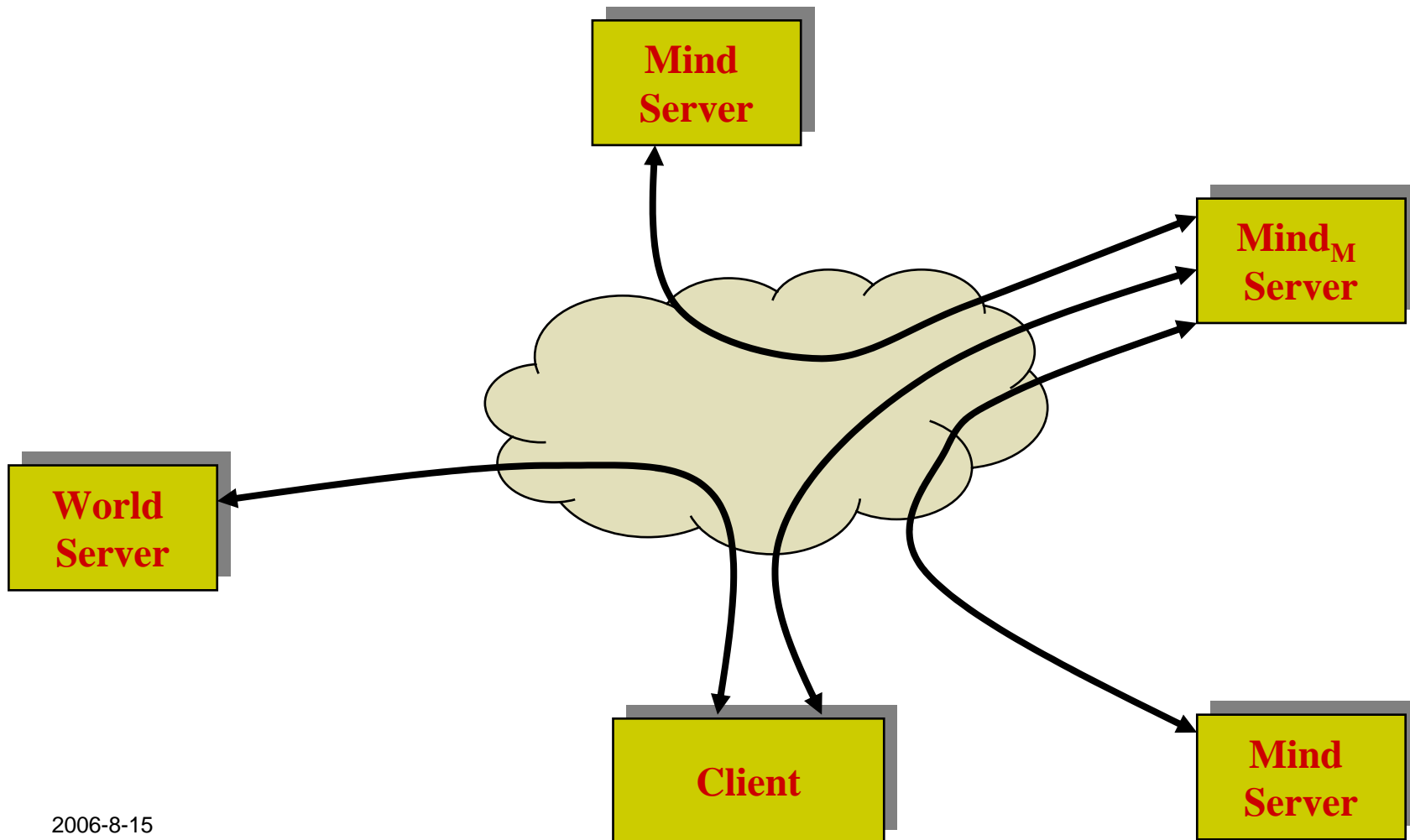
---



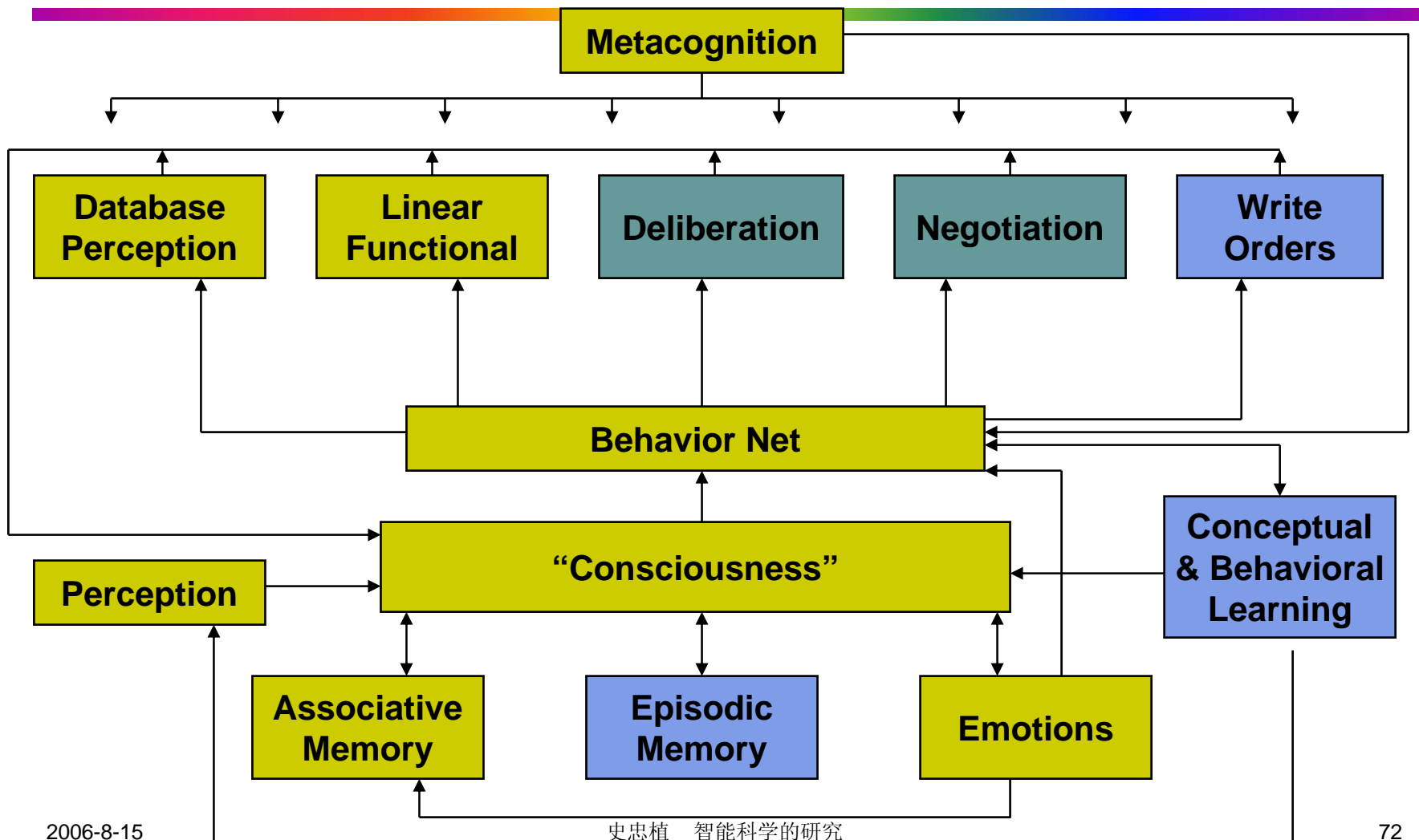
Ciarán O'Leary  
Dublin Institute of Technology  
22nd May 2003

## Technology for automated assessment: The World-Wide-Mind

# Constructing complex minds, online



# IDA's Architecture ( Stan Franklin )



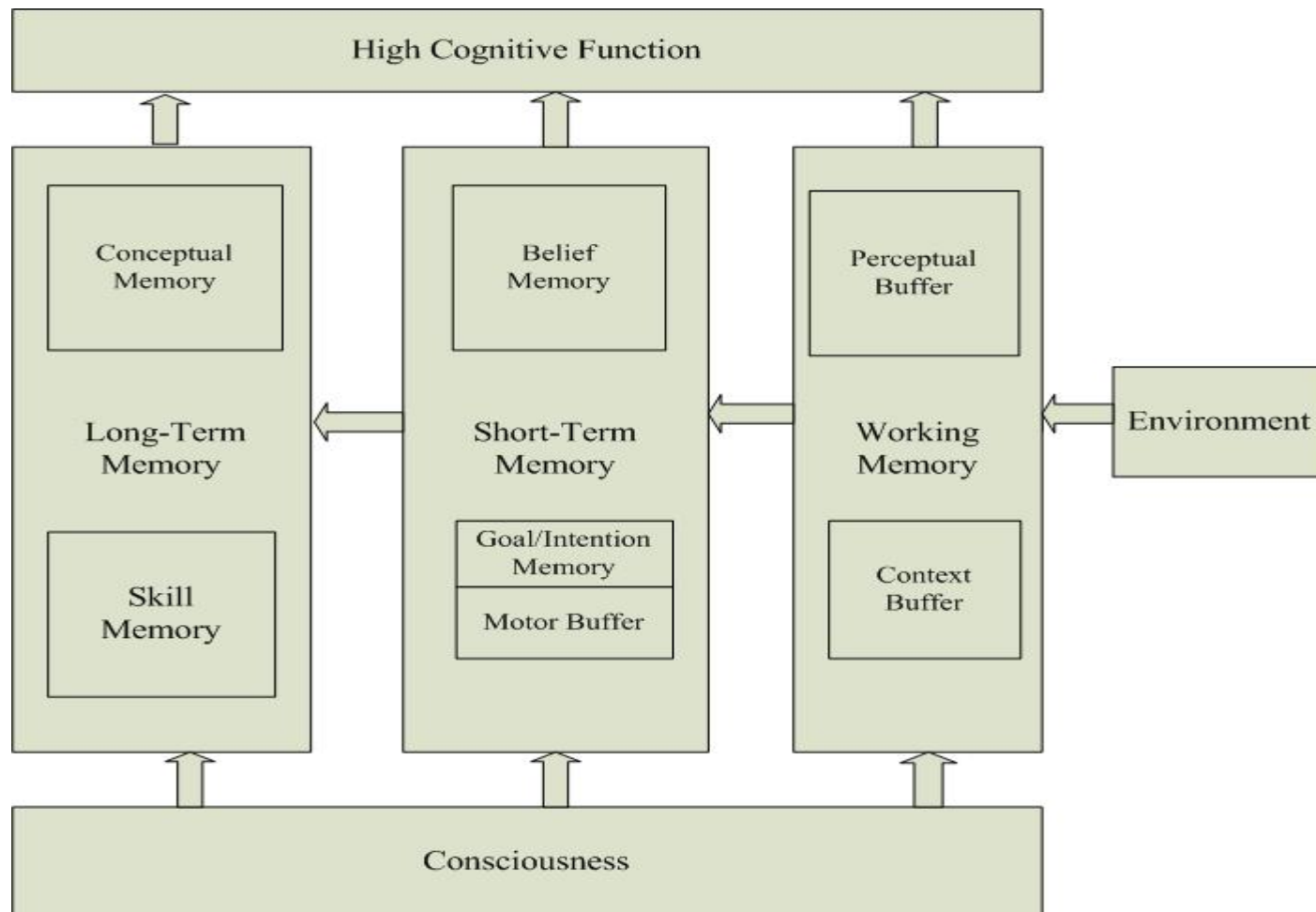
# IDA: an Intelligent Distribution Agent ( Stan Franklin )



## Modules and Mechanisms

- Perception—Copycat Architecture—Hofstadter
- Action Selection—Behavior Net—Maes
- Associative Memory—Sparse Distributed Memory—Kanerva
- Episodic Memory—Case-based Memory
- Emotions—Pandemonium Theory—Jackson
- Metacognition—Fuzzy Classifier Systems—Holland, Zadeh
- Learning—Copycat Architecture, Case-based Reasoning
- Constraint Satisfaction—Linear Functional
- Language Generation—Pandemonium Theory
- Deliberation—Pandemonium Theory
- “Consciousness” —Pandemonium Theory

# Consciousness Machine



# Perspective

**Intelligence Science Researches on basic theory and technology of intelligence**

- **New concept**
- **New theory**
- **New Method**
- **New Technology**

**Will get very important achievement in the 21 century.**

# Thank You

Question!

Intelligence Science

<http://www.intsci.ac.cn/>

