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Cognitive Complexity and Language in Neuroscience

oral presentation in workshop: 121 Perspectives on Complexity (Shahin NEMATZADEH)

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Cognitive Complexity and Language in Neuroscience

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- **International Congress of Linguists (19ICL),**
- **21 -27 July, 2013,**
- **University of Geneva, Switzerland**

Cognitive Complexity and Language

- **Brain-based Epistemology/Cognition**
- **Conscious brain as it relates to language acquisition**

The Major Question of this Talk?

- **What type of relation is between brain and language?**
- **Different Answers**

1- Philosophical Models– and Modern Linguistics Models

2- Traditional Pathological Models

3- Computational Models

- **Brain – based cognition/Recent Neuroscience Model**

A Tribute to the Legacy of 2 great Linguists:

- Late Ferdinand de Saussure's &
- Professor Noam Chomsky
- de Saussure (1916): language system or "la langue" is a " concrete natural object in the brain"
- Chomsky : Language is a biological system, or a "Brain organ" (Chomsky, 1980),
- They both opened the gate to theoretical and biological investigations of language and claimed that language is a biological system, but their claims ended up into different interpretations.

Understanding The Human Mind

- **Bertrand Russell (1935)**
  - **"the sciences have developed in the reverse of what might have been expected. What was most remote from ourselves was first brought under the domain of law, and last of all (as yet very imperfectly) the human mind"**

Understanding the brain is one of our greatest challenges!

- Complexities and uncertainties of neuronal network function!
  - David Parker*

The Structure of my talk

A- A Short Introduction to traditional (linear) brain-language models

- Their Major shortcomings

B- Some biological features of brain and Language

C- An evolutionary selectional brain-based model of cognitive complexity

D- Conclusion:

-Two modes of thought

- Conceptual system & grammar

Linear models of Brain and Language

1- Modularity and Language:

- autonomous syntax in the brain

2- Traditional Pathogical brain and Language Models

- Major Language Centers

3- Computational models:

- Brain as a computer

1- Modularity Model of the Brain?

- **Chomsky's** Cartesian View of Language

- An "Autonomous **Syntax**" in the Brain

- Brain-Mind duality
- Syntactic modul

Neuroscience objection to Autonomy of Syntax

- **There is no *neural sub-network* in the brain that does not have neural input from other parts of the brain that do very different kinds of things.**

Gerald *Edelman*

- ***Syntax cannot be autonomous, that is, affected by no non-syntactic input.***

-George Lakoff

Properties of Cognitive Grammar?

- **Lakoff**
- **There is no Autonomous Syntax Completely Free of Meaning and Cognition.**

- **The Grammar of the Human Language is not an Abstract Formal System, but a Neural System. The Properties of Grammars are Properties of Humanly Embodied Neural Systems, not of Abstract Formal Systems.**

Syntax & Language *as a Cognitive System*

- Language is Not Independent of **Meaning**, but so as to **Express Meaning**
- Language is Not independent of **Communication**, but in Accordance with Communicative **Strategies**
- Language is Not Independent of **Culture**, but often in Accord with the **Deepest Aspects** of Culture
- Language is Not Independent of the **Body**, but Arising from Aspects of the **Sensory-Motor System**
- Language is **Not independent of emotions**

Major Properties of Human Mind? (Lakoff & Johson)

1. The Mind is Inherently Embodied.

(as opposed to disembodied mind)

2. Thought is mostly Unconscious.

(as opposed to conscious thought)

3. Abstract Concepts are largely Metaphorical

(as opposed to literal)

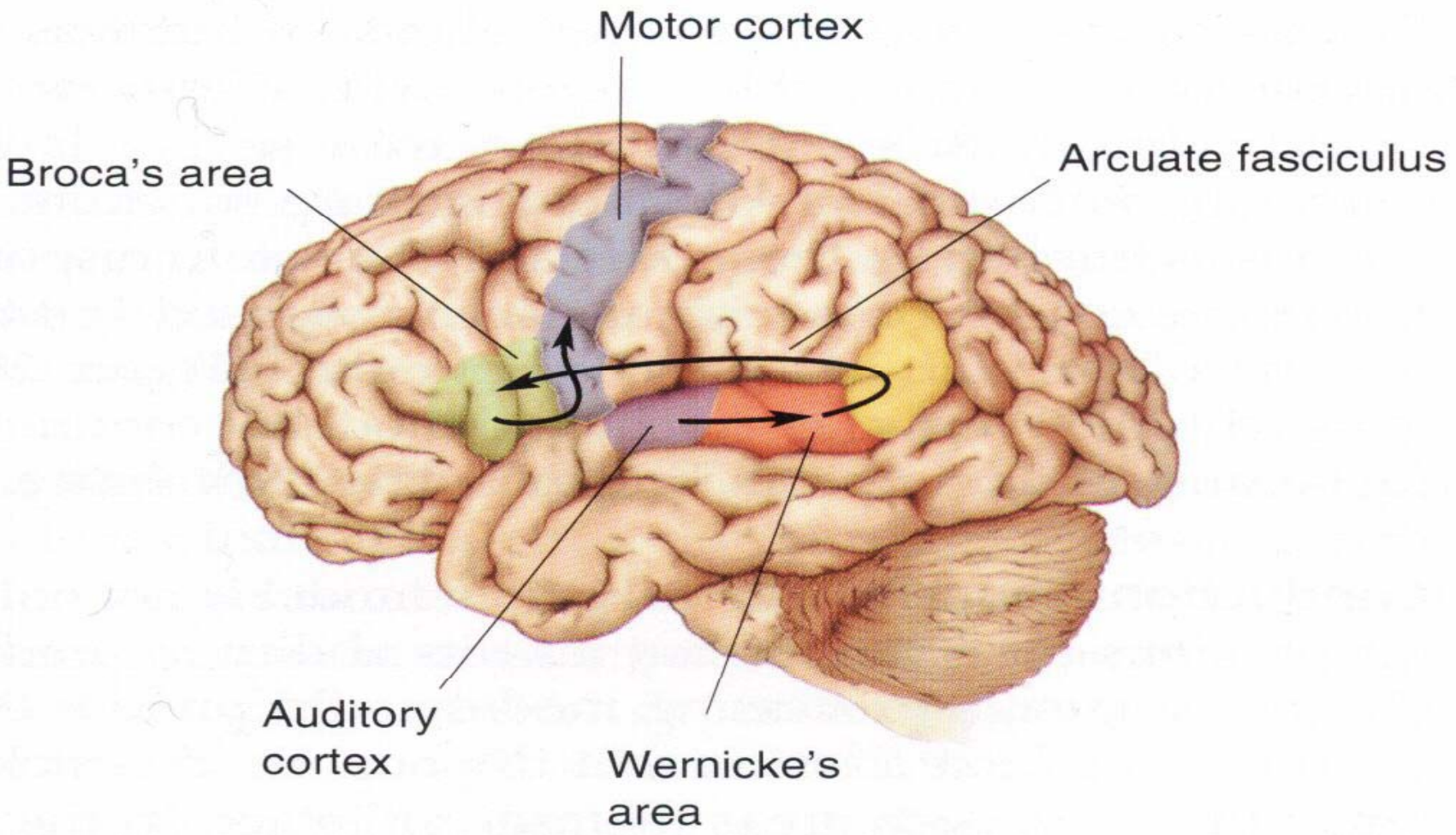
Traditional Pathological & Computational Models

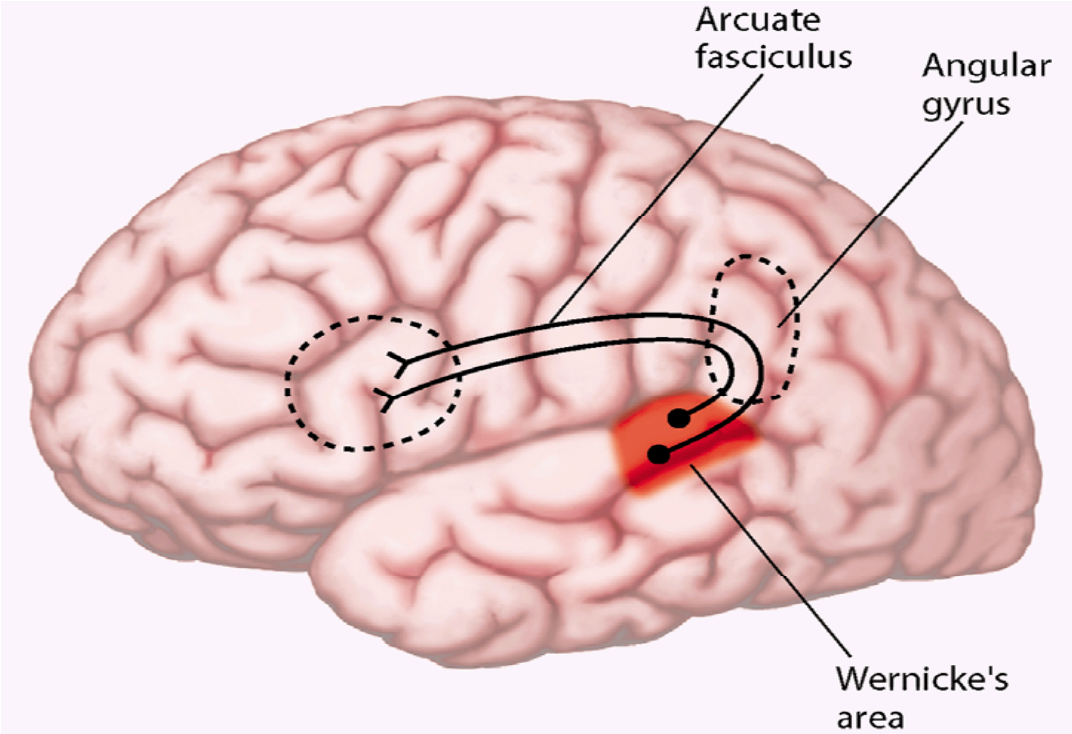
2- Pathological Models (data from aphasia and epileptic patients):

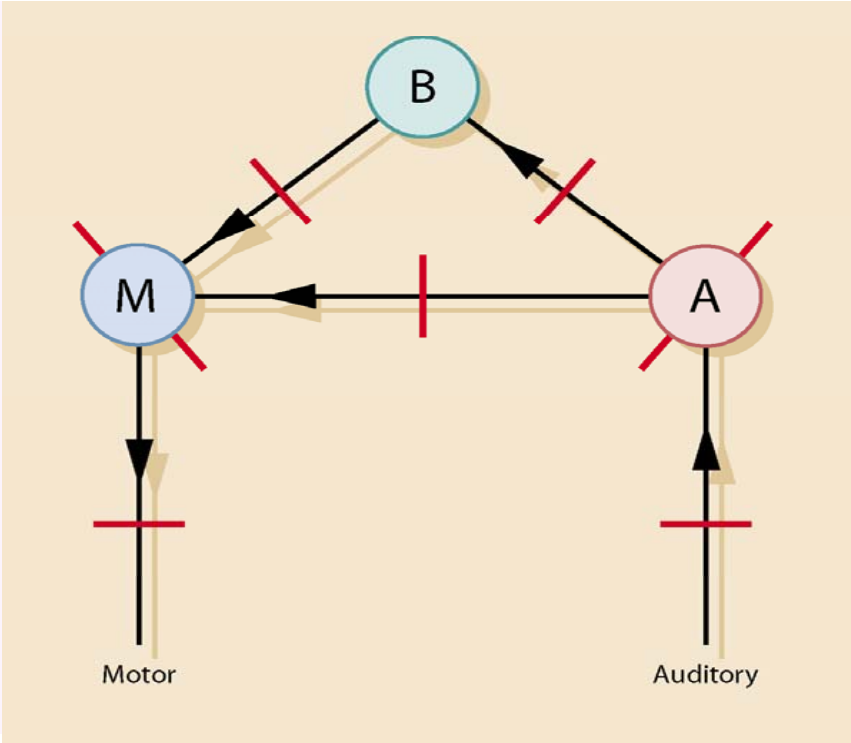
- Major Language centers

3-The Brain works as a Computer and the World is a piece of coded tape (The second Nature, Edelman)

Major Language Processing Centers







Wenicke-Lichtheim-Geschwind model of language processing. The area that stores permanent information about word sounds is represented by *A* (*Wernicke area*). The speech planning and programming area is represented by *M* (*Broca area*). Conceptual information is stored in area *B (supramarginal, angular gyri)*. From this model it was predicted that lesions in the three main areas, or in the connections between the areas, or the inputs to or outputs from these areas, could account for seven main aphasic syndromes (Caplan et al., 1994; Gazzaniga, 2002).

Major Shortcomings of pathological Models

Some Short Comings of Traditional Brain-Language Models

1. They are "**Linguistically**" & "**Neuroanatomically**" "underspecified"
2. Language centers of **Broca and Wernicke's centers** are **mutually functionally dependent**
3. They are **not the only cortical areas** contributing to and necessary for language processing
4. There are **cortical areas outside** of traditional language centers involved in language
5. The involvement of **sub-cortical areas** in language learning

More than one Question on Language as a biological system ?

- **"Where Question" :** In which areas of the brain is a particular process located?
- **"When"?** Before and after which other processes does the particular process occur?
- **"How"?** By which **neuron circuit** or which neuron network type is the particular process realized?
- **"Why"** On the basis of which **biological** or other **principles** is the particular process is realized by this particular network, at this particular point in time, and at these particular brain loci? (**Pulvemuller**)

But Why more than one question?

Linguitic Knowledge & four Different Neurofunctional Systems

1. **Left Hemisphere Implicit Linguistic Knowledge**
- ***Lexical Semantics, Syntax, Morphology, Phonology***

2. **Right Hemisphere** based **Pragmatic Knowledge**
- **Paralinguistic Knowledge, Inferences, Contextualization**

3. **Limbic System** Involvement
- **Motivation & Affect**

4. Diffusedly Cortical represented metalinguistic knowledge
- **General & Conscious Knowledge**

Complexity & Different Types of Learning?

- **Four Hierarchical Stages of Development:**

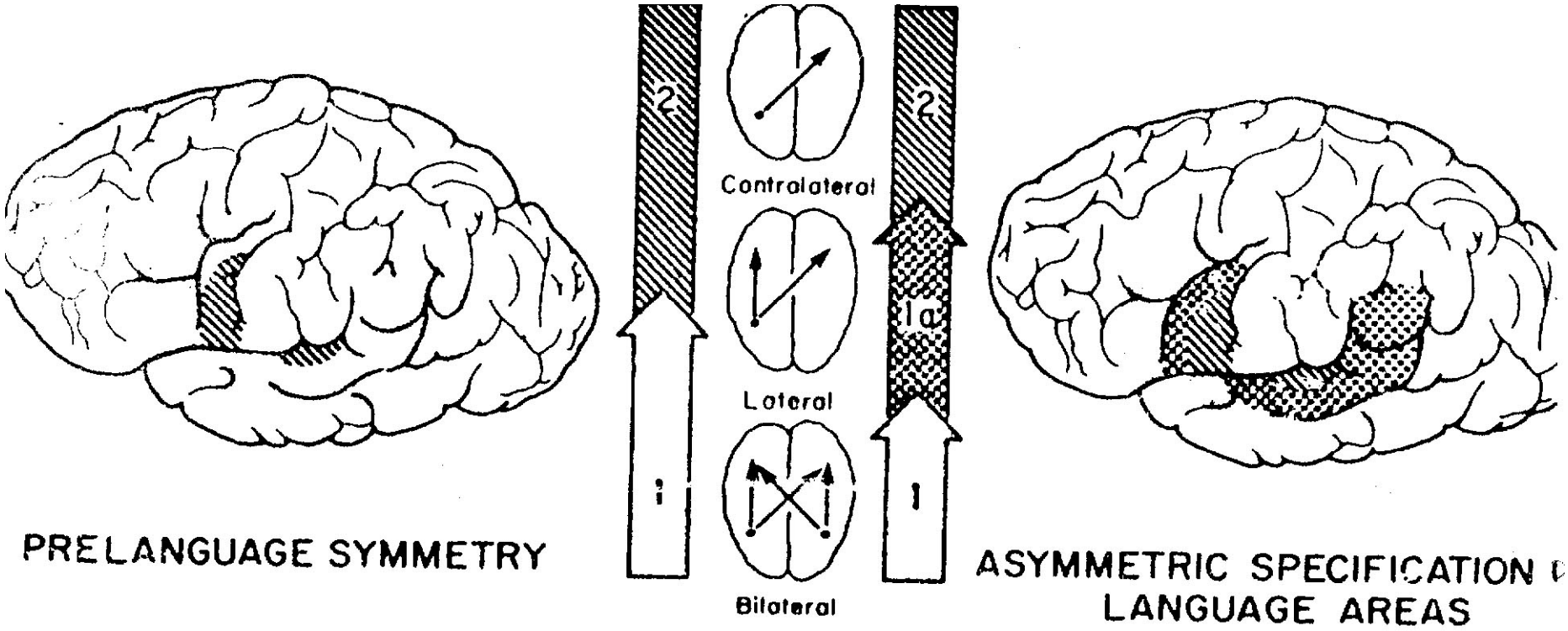
1- **Sensory-Motor Learning**

2- **Presentational learning**

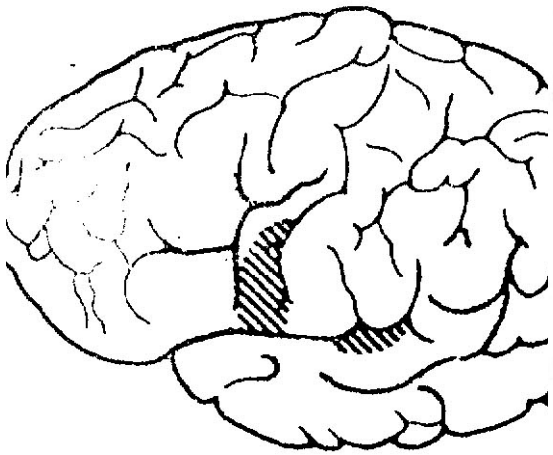
3- **Representational learning**

4- **Symbolic learning**

Development of *Language and Asymmetry of the Brain*



Developmental Reorganization of the Brain?



PRELANGUAGE SYMME

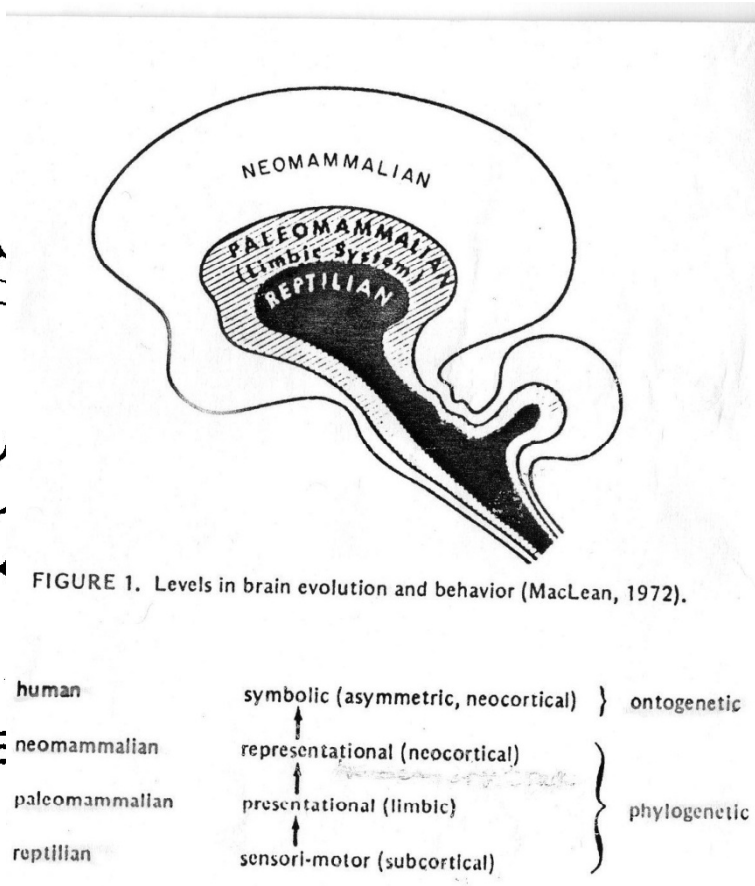
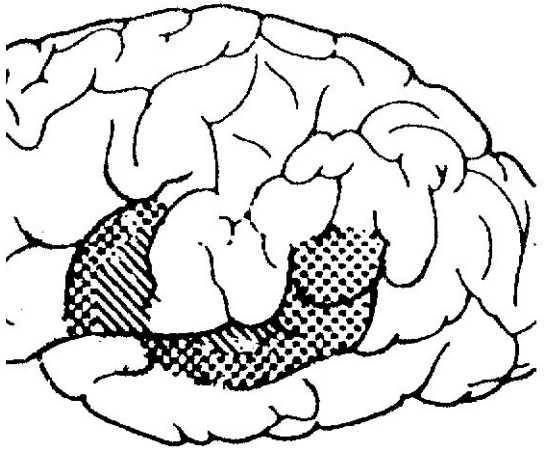


FIGURE 1. Levels in brain evolution and behavior (MacLean, 1972).



ETRIC SPECIFICATION
LANGUAGE AREAS

Language Learning & 3 Different Memory Systems

Declarative Memory **Hippocampus**

Procedural Memory **Striatum**

Emotional Memory **Amygdala**

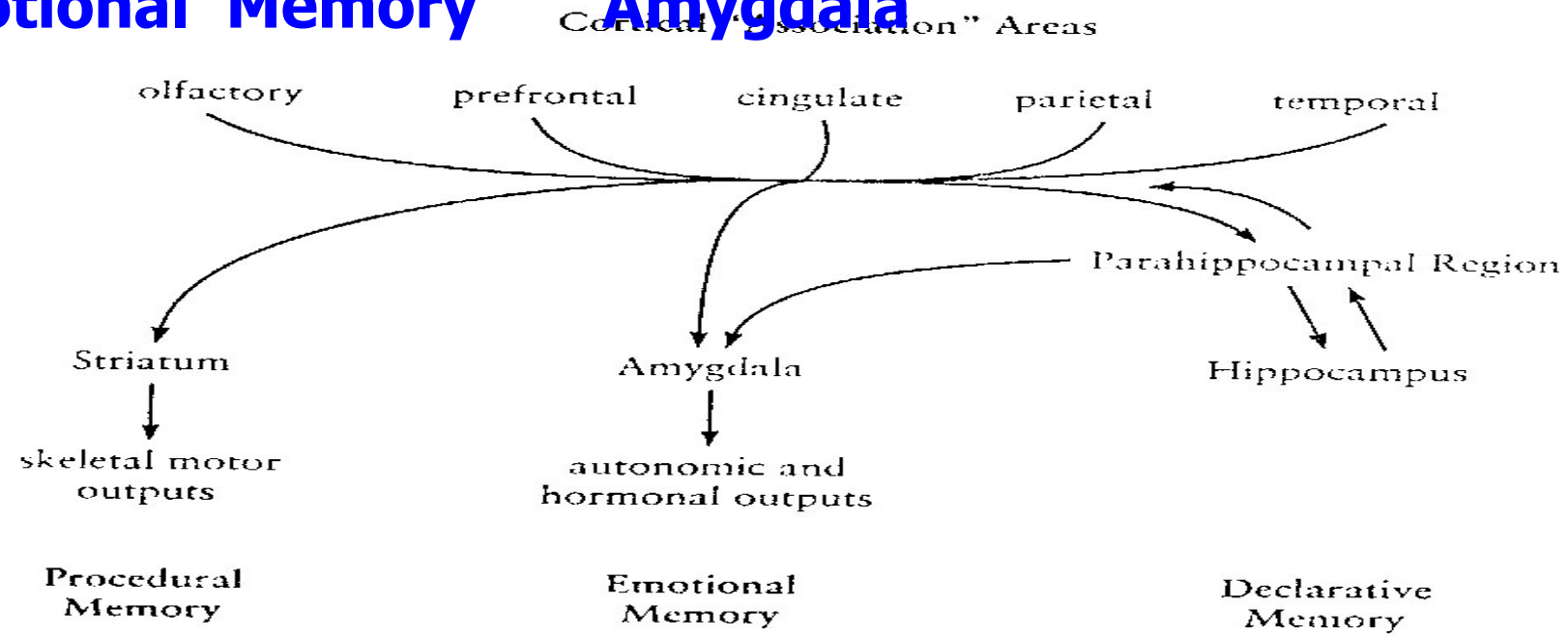


Figure 6.5 The anatomical pathways supporting different types of memory.

Brain-based Cognition?

- **An Evolutionary Selectional Brain-based Model of Cognition?**

Two Functional Properties of Complex System

1. Differentiation
2. Integration

The Brain as a Complex System?

- **Small Parts** which are relatively independent
- But **heterogeneous** in **Structure and Function**

- **As they connect by means of various kinds of neuroantomy, they tend to become integrated across a large number of states generated by the functional connectivity within that anatomy.**

Main Properties of Complex Systems

- **Definition**
- A system that consists of a variety of smaller parts, each of which may be segregated.
- As these heterogeneous parts interact in various combinations, there is a tendency to give raise to system properties that are more integrated.
- **Two Major Properties:**
- **1- Differentiation**
- **2- Integration**

Brain & Complexity

- Complexity originates from **continuing interactions between the brain and external environment** of much greater potential complexity.
- Everything else being equal, **the more complex the environment, the larger the complexity** of the system.
- It is thus the adaptation of the brain's reentrant circuits to the demands posed by a **richer environment**, based on principles of **natural, developmental , and neural selection that leads to high complexity,** as reflected by increased values of matching and degeneracy

Four Properties of Complex Systems?

1- **Independence**

2- Entropy

3- Mutual Information

4- Integration

- **“Statistical Information Theory”**

Two Extreme Systems that are not Complex as opposed to Brain?

1. perfect Crystal:
2. An Ideal /Perfect Gas

- Particles randomly collide in elastic collisions is not a complex system
- Each particle is independent (does not stick to others
- BUT There is no gain or loss of information (no mutual Information in such a collision)

Perfect Crystal & Gas

1- Perfect Regularity:

2- **High degree of Integration & Mutual Information** among units

3- But ***no new information*** is gained in passing to any other unit cells

- **In gas, no such integration occurs where as**
- **With crystal there is high integration but no variety**

INTEGRATION & DIFFERNTIATION AT THE SAME TIME

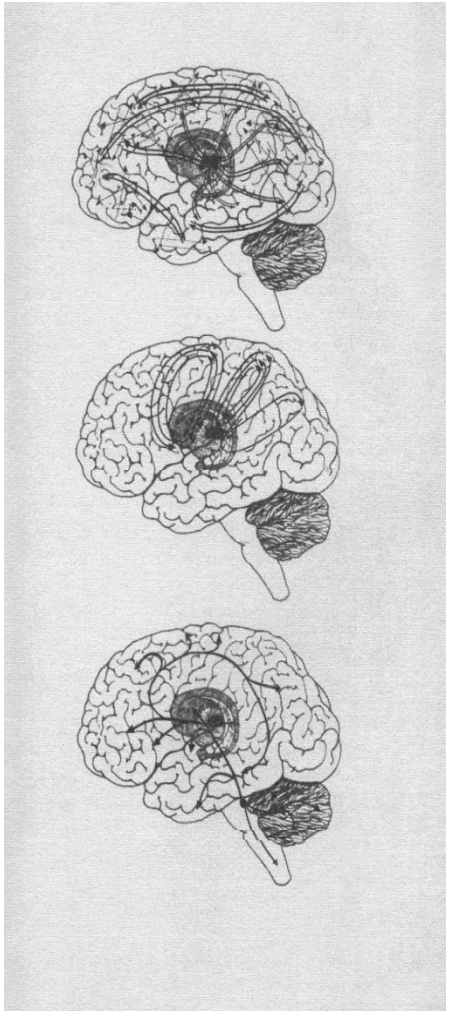
- **INFORMATIONAL ENTROPY**:
- RELATIVE PROBABILITITIES OF OCCURANCE
- **INTEGRATION** IS THE **SUM OF ENTROPIES** OF EACH OF THE PARTS OF A SYSTEM MINUS THE SYSTEM AS A WHOLE
- In the case of **Gas**: Entropy is **zero**= **no new information**
- **Crystal**: **The entropy of the system is less than the entropies of its parts, and integration takes on a positive value. The value is as high as it can be.**

Manifestations of Neural Complexity

Interacting networks of the brain

- **Cortical functional segregation & Integration**:
- **V1: orientation**
- **V4: color**
- **V5: Object motion**
- Through binding via reenrty , they become **integrated-** they exhibit **unitary properties** as they are linked together.

Three major kinds of neuroanatomical Networks



3 Major Networks

- **Top Network**: Thalamocortical Network
- **Middle Network**: Cortex to Sub-cortex Basal ganglia
- **Lower Network**: Distribution of networks all over the brain

Development of Three Major "Selectional Neuronal Networks" in the brain

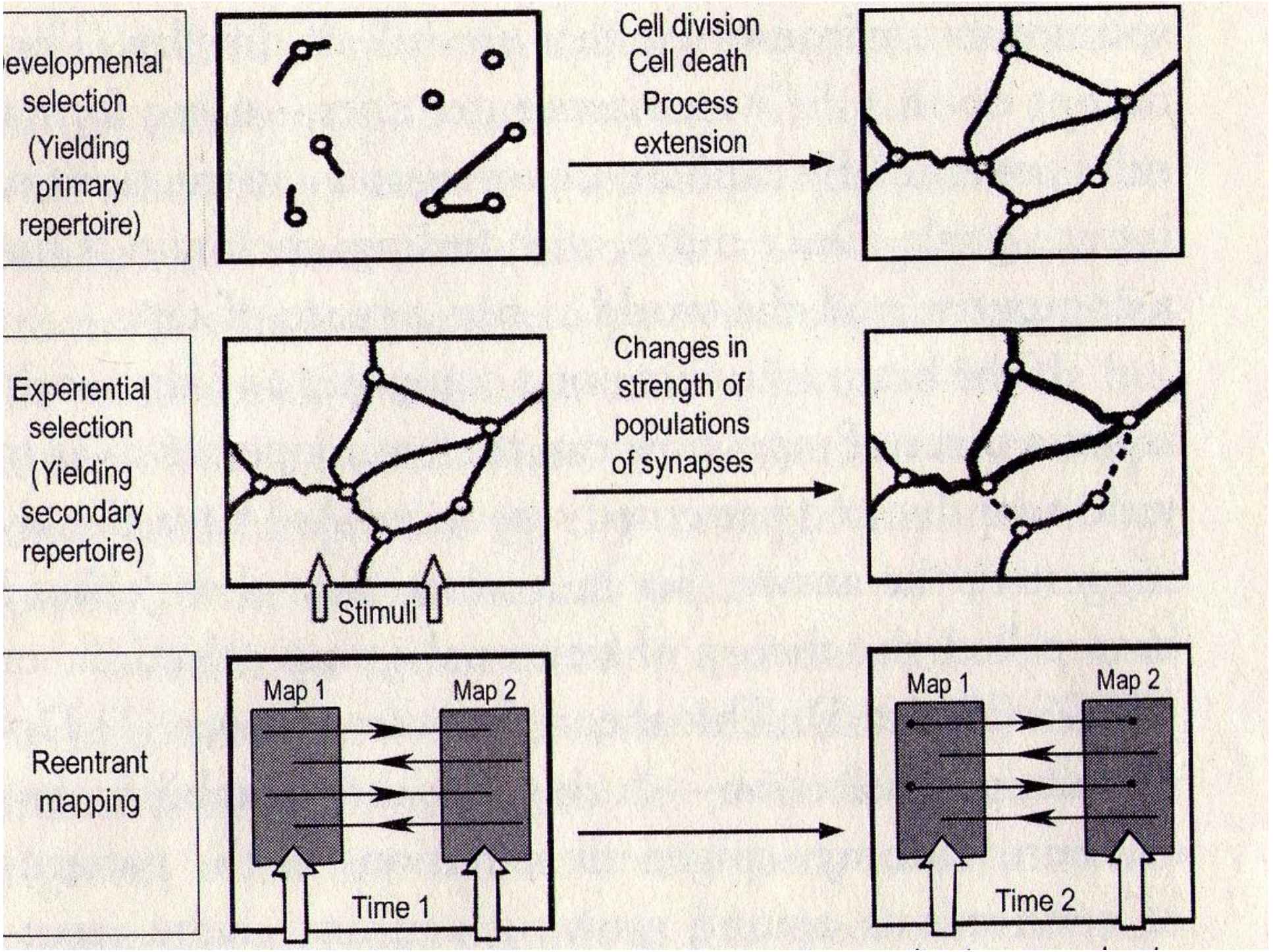
1. Biological selectional: **formation of initial networks based on:**

   "wire together fire together"

2- Environmental selectional: **formation of networks based on experience and :**

   "use it or loose it"

3- Reentrant selectional Networks: **spatiotemporal networks between "developmental" & "environmental" networks**

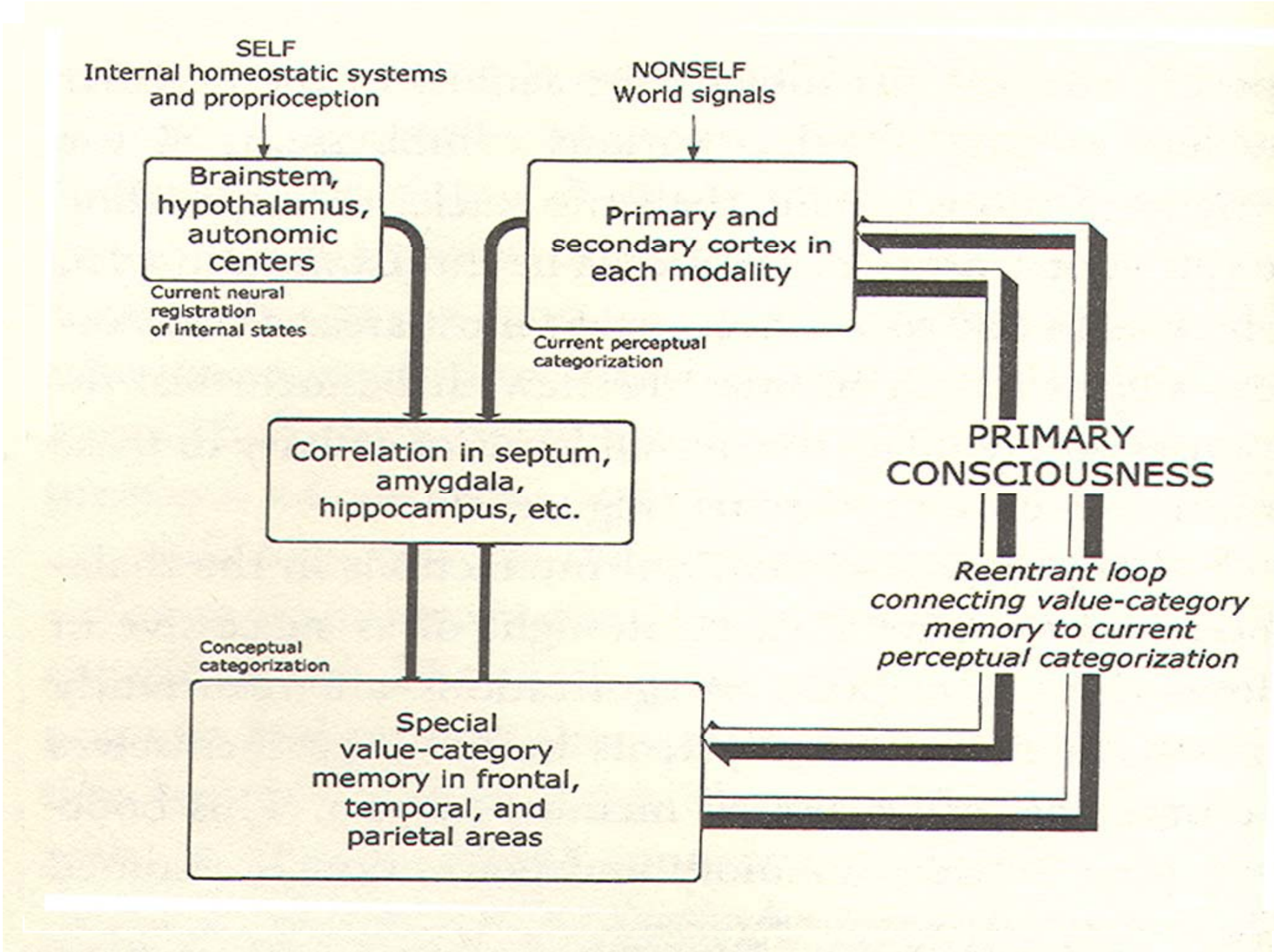

evelopmental selection (Yielding primary repertoire)
Cell division
Cell death
Process extension
Experiential selection (Yielding secondary repertoire)
Changes in strength of populations of synapses
Stimuli
Reentrant mapping
Map 1
Map 2
Time 1
Map 1
Map 2
Time 2

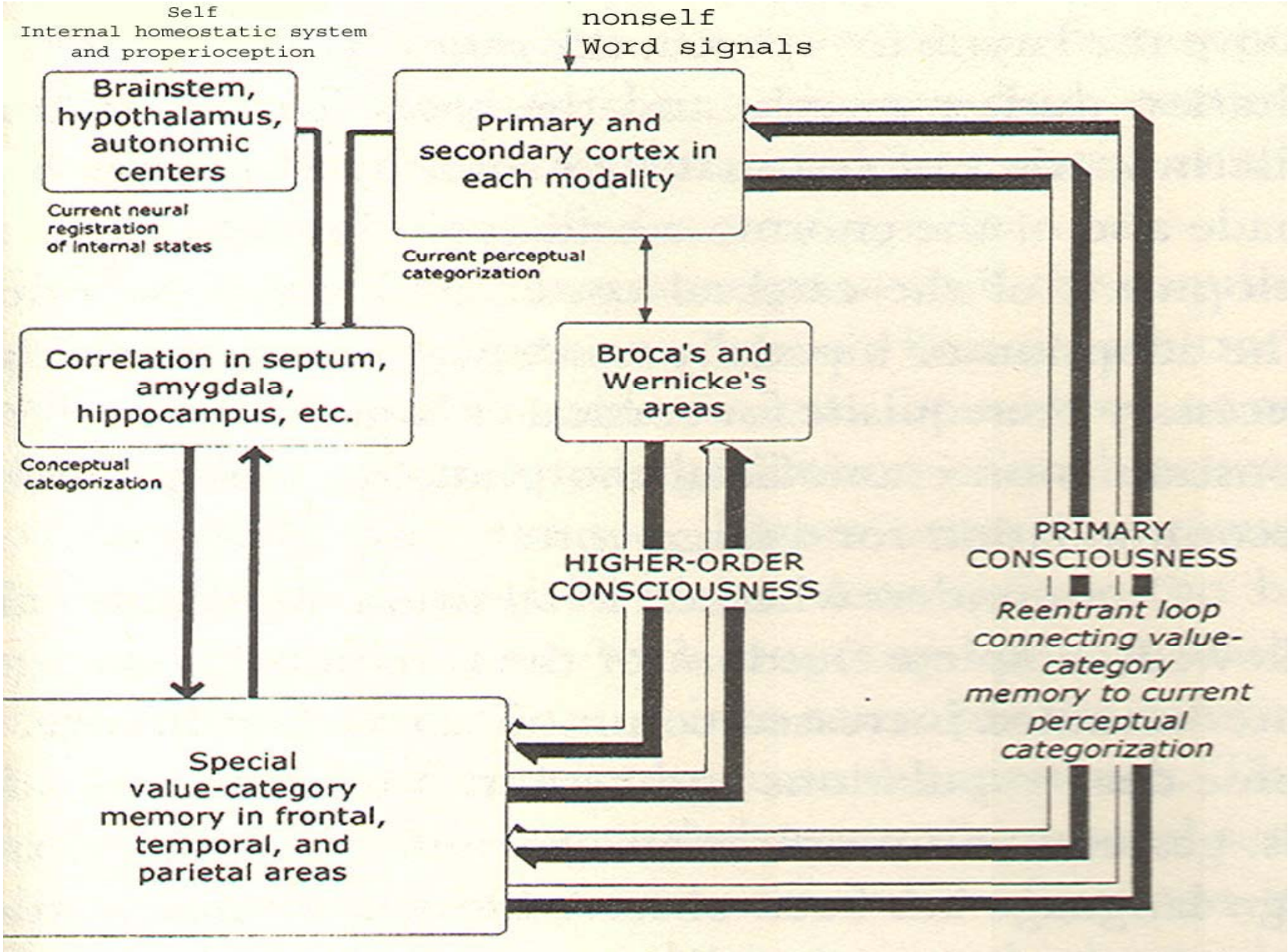
Major features of a true language

- **Phonetic and semantic** capabilities
- A major feature in humans: **Syntactic Abilities**
- The brain is **capable** of going beyond the information given
- The acquisition of a new kind of memory, exploiting semantic capabilities and ultimately true language with **syntax leads to a conceptual explosion**

Language & Cognitive Complexity

1. Primary Consciousness
2. Higher-order Consciousness


SELF
Internal homeostatic systems and proprioception
NONSELF
World signals
Brainstem, hypothalamus, autonomic centers
Current neural registration of internal states
Primary and secondary cortex in each modality
Current perceptual categorization
PRIMARY CONSCIOUSNESS
Correlation in septum, amygdala, hippocampus, etc.
Reentrant loop connecting value-category memory to current perceptual categorization
Conceptual categorization
Special value-category memory in frontal, temporal, and parietal areas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HIGHER-ORDER CONSCIOUSNESS
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Major Features of Primary Consciousness in Animals

- **Lack A concept of the past**
- **A concept of the future**
- **A concept of a socially defined and nameable self**

Mechanisms of Primary Consciousness

- **Memory in Conceptual areas**/ Conceptual Categorization in : Frontal, Temporal and Parietal Areas
- **Current Perceptual Categorization**:

- Primary and Secondary cortex in each modality

Emergence of a true Language

- **The Acquisition of a new kind of memory, exploiting semantic capabilities and ultimately true language with syntax leads to a conceptual explosion**
- **Properties of consciousness emerge as a result of the properties of the brain as a complex system**

Language acquisition

- **With the acquisition of language new dimensions related to language and their integration in the dynamic core, higher-order consciousness appears in humans**

higher-order consciousness & neural changes

- **The neural changes that lead to language are behind the emergence of higher-order consciousness.**
- **Once higher-order consciousness begins to emerge, a self can be constructed from social and affective relationships.**
- **The emergence of the self leads to a refinement of phenomenological experience, tying feelings to thoughts, to culture and to beliefs.**

higher-order consciousness & Language

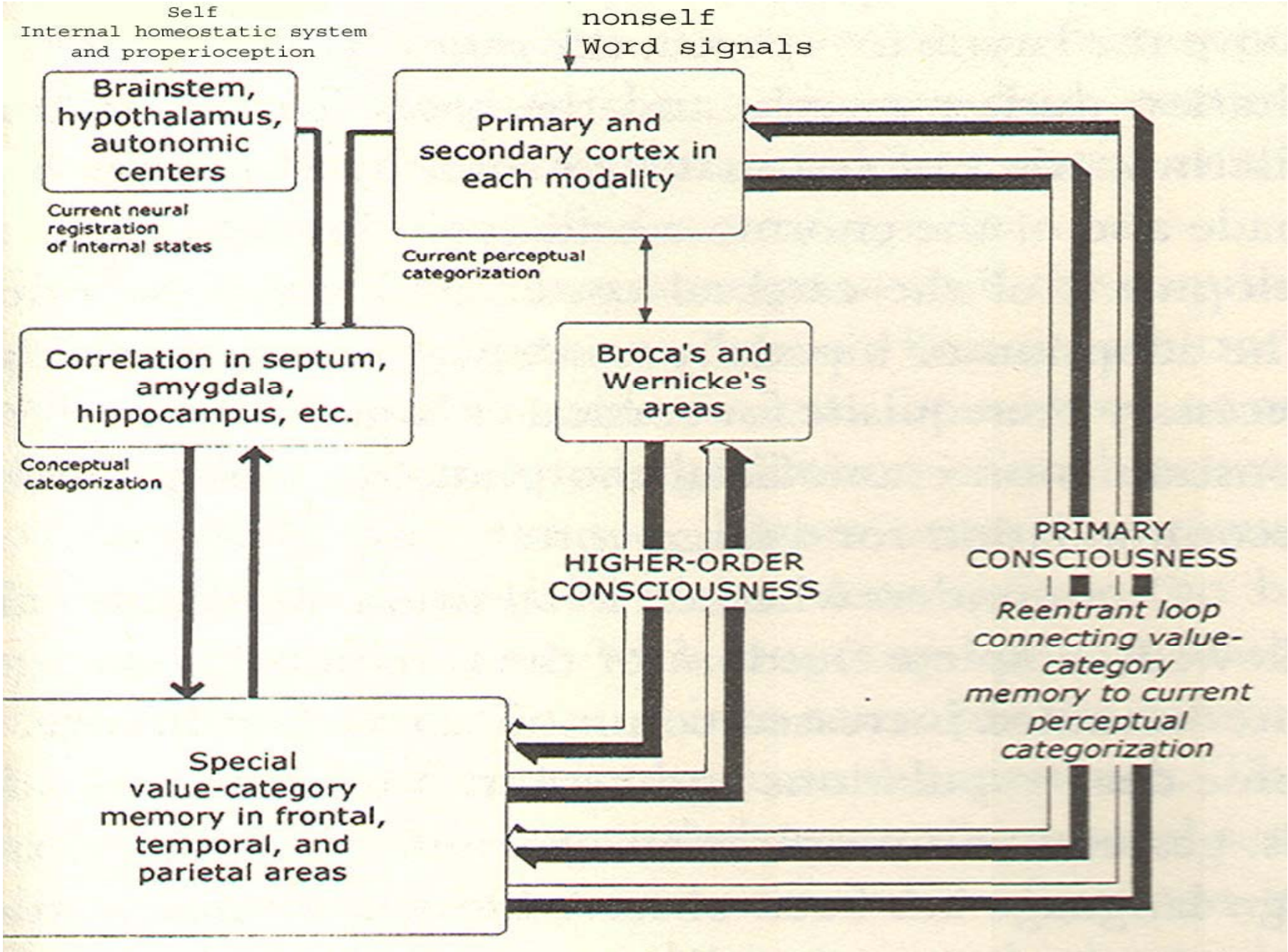
- **Syntactic and semantic systems of language provided a new means for symbolic construction and a new type of memory mediating higher-order consciousness. Thus conscious of being conscious became possible.**

Higher-order Consciousness?

- The capability to **be conscious** of being conscious:

1. **Semantic Abilities** (chimpanzees) or
2. **Linguistic Abilities**:

- **Social Concept of the self** &
- **Concepts of the past & Future**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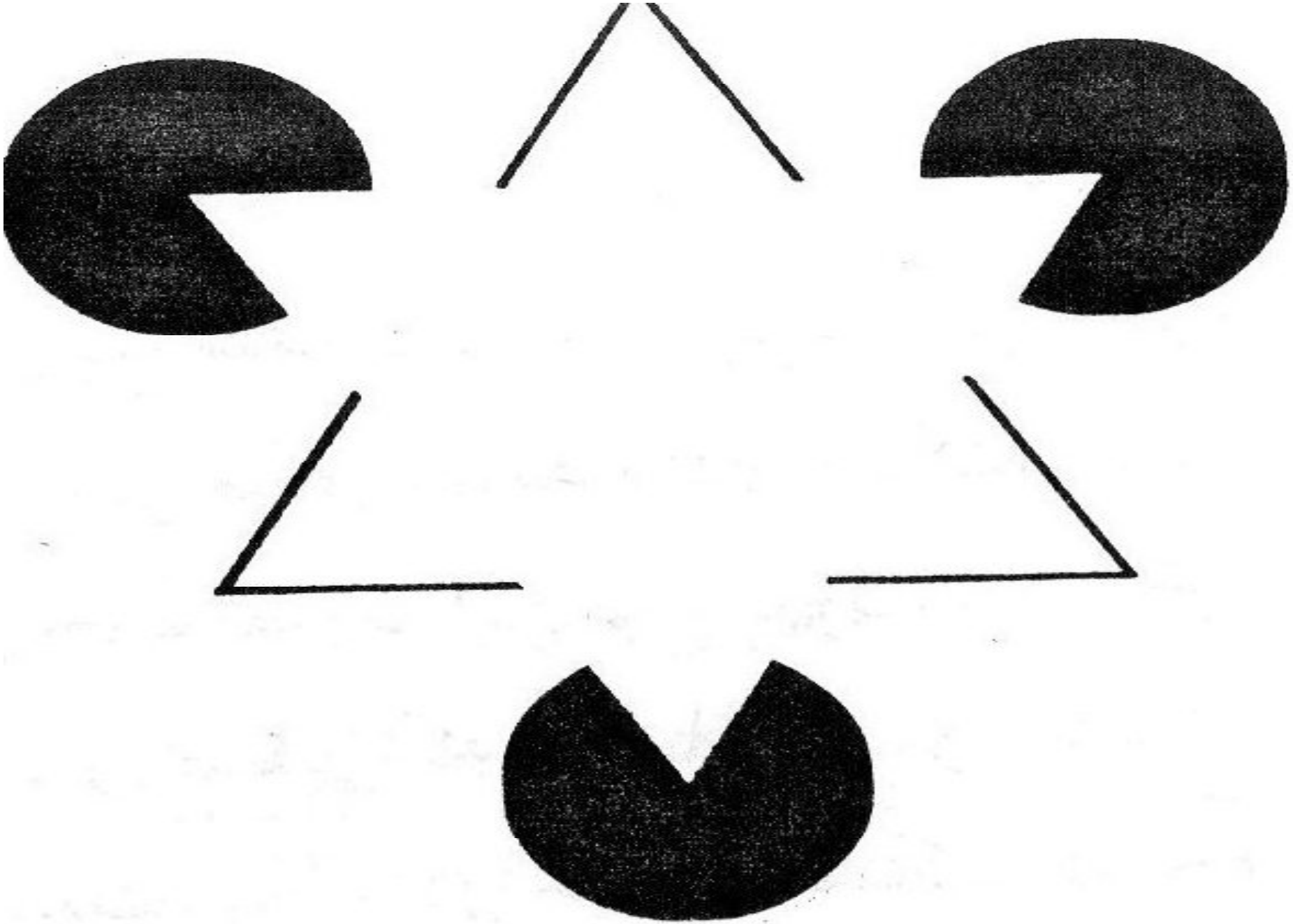
Two Modes of Thought

- **Logic:** Can prove theorems when embedded in computers
- **Selectionism (Pattern Recognition**): Can lead to creativity
- The Brain can function by **pattern recognition** even prior to language



Conclusion

3 Principles for a Brain-based Epistemology?

1. Being is prior to Describing

2. Selection is prior to Logic

3. In the development of thought:
   - Doing is prior to Understanding

Edelman's Final Question

"Are we Prisoners of Description or Masters of Meaning"? Edelman

"Are we Prisoners of Description or Masters of Meaning"? Edelman

- "As a result of our individual embodiment and mutual grammatical exchanges that allow us to experience higher-order consciousness"
- While we remain prisoners of description, our freedom is in the grammar."

Pattern Recognition & Logic

- **Mistress & House keeper**
- **If Selectionism (pattern recognition)** is the **mistress of our thoughts**, **logic is their house keeper**. A balance between these two modes of thoughts and the endless richness of their underlying neural substrates can be sampled through **conscious experience**.
- Even If , someday, we are able to embede these two modes of thoughts in the construction of a conscious artifact and thus further extend our comprehension, the particular forms of consciousness that that we possess as humans **will not be reproducable and will continue to be our greatest gift.**

Gerald Edelman

- **Gerald Edelman** is a **Noble Prize Winner in Medicine and** noted for his **theory of mind**, published in a trilogy of technical books, and in briefer form for a more general audience in *Bright Air, Brilliant Fire* (1992) and more recently in ***Wider than the Sky*** (2004). ***Neural Darwinism*** (1987) contains a theory of **memory** that is built around the idea of plasticity in the neural network in response to the environment. ***Topobiology*** (1988) contains a theory of how the original neuronal network of a newborn's brain is established during development of the embryo. *The* ***Remembered Present*** (1990) contains a **Theory of consciousness**.

Gerald Edelman's short Bibliography

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با سپاس از توجه شما

- Thank you for your Attention