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Consciousness, Memory and Intelligence: A Mechanistic Perspective

Gerard Marx[1]* and Chaim Gilon[2]

[1]*MX Biotech Ltd., Jerusalem, Israel.*

[2]*Institute of Chemistry, Hebrew University, Jerusalem, Israel.*

***Correspondence:**
Gerard Marx, MX Biotech Ltd., Jerusalem, Israel,
E-mail: gerardmarx@gmail.com

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ABSTRACT

We critically review a number of academic efforts to define consciousness and note that none addresses the physiologic or biochemical constraints on biologic systems that generate mentality. Many refer to "map", "structure", "framework", "schema" or "concept", but provide no graphic equivalent or physiologically credible mechanism.

Later, we forward our own biochemical Tripartite mechanism of brain memory. We suggest a mechanism whereby the encoding of cognitive information (cog-info) could be described as a process conceptually analogous to computer memory but with emotive context embodied as neurotransmitters (NTs) and gliotransmitters (GTs). The central proposition is that memory is encoded in the matrix (nECM/PNN) surrounding brain cells. Moreover, we recognize the brain astrocytes as the cellular components driving the process of mentation. Memory arises from a coordinated tripartite process. The chemographic shorthand for the tripartite mechanism permits one to consider the physicality of brain memory code as analogous to that proposed by Landauer for computer memory. Our augmented tripartite mechanism of memory enumerates the key components that enable such biochemical interactions. It is based on the interactions brain cells with the nECM/PNN encasing all cells and the dopants (metals, GTs and NTs). Thus, the cooperative interactions of brain astrocytes entangled with neurons enables the phase change that transcends caloric energy into mentality, manifest as emotive memory, consciousness and body reactions of muscles and glands. We may have recognized a fragment from the entangled mysteries of consciousness, memory, and intelligence, but the eternal enigma of Life remains.

Keywords

Memory, *Tripartite* mechanism, Astrocytes, Cognitive information, Mentation.

Background

Consciousness is powered by caloric energy though details remain mysterious. It is characterized by memory and in evolved creatures by intelligence. Many have attempted to identify the process that generates the consciousness of living beings. We note that consciousness and memory are entangled qualities. The former we experience, the latter we measure by time duration of recall.

Below we critically review a number of academic efforts to define consciousness [1-19]. We note that none addresses the physiologic or biochemical constraints on biologic systems that generate mentality. Later, we will forward our own biochemical Tripartite mechanism of brain memory.

Citations

Bergson [1] *provided a philosophic treatise on the relation between "matter" and "thought". His insightful discussion was interesting but he did not suggest a biologically relevant mechanism...no code, no process*.

McGinn [2] *discussed philosophic ideas (of Hume, Nagel, Locke, Chomsky, Fodor, Strawson); about the relation between mind and brain. He admited that there must be some natural property of the brains of organisms that generates consciousness, that it is just a further biological development. Consciousness is an epiphenomental property of biological systems. Ultimately concluded that for us to comprehend the psychophysical nexus of consciousnes:. "Consciousness is theoretically epiphenomental in the task of accounting for physical events".*

GM: This is not a solution. He throws up his hands admits to enigma.

Coter [3] *presented a symposium of some 14 "neuroscientists". Looking through all the essays, we did not detect a map, blueprint or schematic that could be understood in the common meaning of the word "structure". Rather, the various authors presented tables, lists, diagrams of clouds connected with lines, diagrams of pseudo-kinetics of human recall, of word memory retention and schematics, of the logical processing of lingual memory. None even approaches a mechanism that even mentions the physiology of the brain. Words missing in the index are: Chemistry. biology, emotions, neurons, astrocytes, animal, physiology. Nowhere is a "structure" presented as a diagram, blueprint or drawing. A forgettable series of misnamed essays.*

Dennet [4] *was a voluminous tome that explained nothing. Some quotes illuminate the morass of words, some of which he ascribed to Descartes:*
"It was only our non-mechanical, non-physical minds that make human beings intelligent and conscious".
"the representation of presence is not the same as the presence of representation".
The book is full of non-sensical discussions and diagrams that have nothing to do with clarifying the mystery of consciousness (i.e. Laffer curve of government taxation policy, Figure 5.5). These are hardly explanatory and render the book obtuse and hard to read.

Chalmers DJ [5]
A run-on philosohical treatise that purports to ascribe "qualia" (phenomental qualities) to the experience of consciousness. Suggests that consciousness is a concomitant of physical systems. However, the tome remains vague as to the physicality of the system that generates mental states. Chalmers runs head-on into the enigma of consciousness and cites many historical decriptions of the enigma. However, he does not provide an evolutionary trail of the biologic emergence of mentality as evinced by memory. He does provide a reproduced schema (from Edelman) of higher order of consiousness that only applies to verbal humans but provides no mechanistic guide. Contrary to the title, he does not provide a fundamental theory that comports to the evolution, physiology, and biochemistry of the brain of all animals that experience consciousness.

Crick & Koch [6,7] *attempted to find the neural correlate(s) of consciousness. They were interested in the general nature of neural activities that produce a particular aspect of consciousness, focusing on the visual system of primates. They mentioned "framework" but did not provide a visual structure or a biologically credible logical schema. Later, Koch mentioned integrated information theory, global holistic properties, qualia and a blueprint for building sentient machines, but not one diagram or schematic that purports to be a blueprint. Lacked any discussion relevant to the physiology of biological systems. A glaring unrecognized assumption was that the neurons they presented are "naked neurons", ignoring the nECM/PNN surrounding all brain cells, as well as the presence of other cells, namely astrocytes.*

Hobson [8] *provided short bios of >30 neuroscientists, psychologists and physiologists, but no biochemists. There was slight mention of neurotransmitters and some chemically defined molecules (i.e. atropine, acetylcholine). But no description of a chemically defined process for encpding experience into memory. Note, they all assumed a "naked neuron".*

Searle [9] *suggested a strictly non-physiologic process; the cover presented a human head with 3 eyes. Admited that consciousness is an "ordinary" biological phenomenon. Reviewed propositions offered by Crick, Hertz, Edelman, Penrose, Godel, Chalmers and Dennet. Concluded by stating: "The syntax of the program mis not intrinsic to the physics of the hardware, but rather required an outside interpreter who assigns a computational interpretation to the system." Note also the silly cover...a man with 3 eyes.*

Tononi [10] *proposed thought experiments to claim that consciousness is integrated information. Suggests probability distribution between points representing the informational relationships among elements generated by causal mechanisms (connections). Provided many diagrams and schemas, though none had physiologic relevance.*
Comment: *Talked about "information" but did not propose how such is rendered operational in a physiologic context. Also did not refer to the emotive context of cognitive informtion.*

Fingelkurts et al. [11] *suggested that the basic essence of brain functional architecture constitutes a theory of consciousness. The problem of producing man-made"machine" consciousness and "artificial" thought was a matter of duplicating all levels of the operational architectonics hierarchy (with its inherent rules and mechanisms) found in the brain electromagnetic field.*
Comment: *The above has no relevance to brain physiology, anatpmy or biochemistry.*

Churchland [12] *was a good review of the problem of defining consciousness in ontological or epistemological or computational terms. Provided diagrams of brains but only presented "naked" neurons for consideration. No credible physiologic discussion of mentality.*

Dehaene [13] *attempted to develop objective mechanism of subjectve states. Presented correlations of anatomical electrical responses to psychological states. Considered synaptic spines as repositories of memory.*

Hobson [14]. *Short bios of >30 neuroscientists, psychologists and physiologists, but no biochemists.*
There is slight mention of neurotransmitters and some chemically defined molecules (i.e. atropine, acetylcholine). But no description of a chemically defined process for encpding experience into memory.
Note also 'Naked neuron".

Chang, [15].
Chang aims to enrich our understanding of inorganic chemistry in

living systems. He cites references to the roles of inorganic metals on various processes that govern the operation of living systems. His laboratory monitored various techniques to monitor metals in brain tissue, particularly Cu. The work focused on neuronal depolarization at synapses and expanded this concept to general signaling in the entire body.

Comment: *While this approach is useful as an overview of biological processes that regulate body functions, it does not address the specific phenomenon of consciousness. He expands on the concept that transition metals as diverse signaling elements but does not apply this to the phenomenon of consciousness. Rather, he focuses on the role of copper on lypolysis and cAMP redox signaling. Overall, his heart is in the right place but his mind is not focused on mentation.*

Miller Jr, [16].
Evolutionary biology is an epiphenomenon of integrated self-referential information managemen, framed as a complex reciprocating interactome that consists of the assessment, communication and deployment of information by self-referential organisms. Refers to "informational architecture" but does nøt identify the physicality of such in a biologic system.

Hawkins [17] *a biography of auther's husband, the psychologist David Hawkins.*
Contrary to the title, no map was sketched out, only one table was presented that applied only to humans.

Rappoport [18] *suggested a "well-defined response (R) process" though it has no bearing on biological events. He presumed his argument to be "supported by distinct excitatory networks located in different cortical layers, hippocampal fields and by distinct molecular agents". None of these was defined. He arbitrarily assigned discrete emotive tasks to molecules and named, but did not define operational neural circuits.*

Zilbergerts [19] *Discusses many talmudic views of consciousness, touching on idols, Golems, zombies (i.e. Frankenstein) and free will. Intellect is considered as a Godlike talent even referred to in the early chapters of the Torah (Bible). Challenges rationalist traditions that elevate the intellect as the most divine aspect of human nature, possessing an inner sense of agency (i.e. curiosity, desire, emotions), totally lacking in electronic devices and associated software (AI). Expresses concern that AI is increasingly replicating human capabilities and severing humanity's considerations of God.*

NB: None of the theologic discussions relates to the physiologic basis of consciousness.

Overall Comment

As many of the titles in the above cited works suggest,, they attempted to conceptualize a framework to comprehend the physiologic process that results in brain consciousness. But a critical reading of the above reveals that they employed a linguistic "slight of hand". They refered to a "map", "structure", "framework", "schema" or "concept", but provided no graphic equivalent or physiologically credible mechanism. They exhibited epidemic failure to recognize basic physiology by focusing on "naked" neurons, ignoring the other cells (i.e. astrocytes) and the extracellular matrix (nECM/PNN) that engulfs them all. Overlooking the emotive context of cognitive information reflects an imperfect understanding of brain processes. We note that a formula or equation that ignores 3 parameters out of a 6 parametric model cannot be solved. Similarly, their ignoring 3 physiologic compartments of the brain that empower mentality renders comprehension of brain processes beyond their ken (See tripartite mechanism of memory discussed below).

The linguist Noam Chomsky [18], verbalized criteria regarding any theory of how the brain generates mentality:

- *"Since the subject is a physical organism, the system attributed to it must have finite representations."*
- *"An empirical argument must be brought to bear."*

In the following, we pursue this path.

Mentality

The brain is a complex organ whose mental talents we have yet to plumb. Our life experience is funneled through the brain, its mentation processes are manifest as memory, emotions and thought. But somehow, we cannot grasp the mechanism of material cells generating mental ability, also termed "mind". The metrics of physics, thermodynamics as well as biology do not apply (Tables 1-3). We note that brain activity is constrained by a physical skull and has metabolic needs identical to those of other anatomic compartments (i.e. liver, kidney, blood, heart, etc). Its unique ability to achieve mentality are necessarily constrained by cellular capabilities. and biochemical processes. Below we summarize some metrics that may have bearing on brain processing cognitive information (cog-info) (Tables 1-3).

Table 1: Metrics of Physics and Quantum Mechanics.

Force
Distance
Speed
Mass
Momentum (linear, angular)
Density
Magnetic Field
Electric signal
Resistance
Wavelength, flux
Quantal units (Schroedinger, Heisenberg)
Constants (**k** Boltzmann; **h** Planck; **g** gravity)

Table 2: Metrics of Thermodynamics.

Heat
Energy
Entropy
Work
Chaos

Table 3: Metrics of Biology and Bio-Analytics.

Cell types
Cell groupings
Cell Morphology
Connectivity
Signaling (electric, chemical)
Temperature
Caloric energy
Metabolism
Drugs
EEG
PET
CT
fMRI

Many efforts have been made to model the brain as a type of computer [19-28]. The root commonality of the brain and computer was suggested as being based on recall (memory). Both computers and brains perform feats of memory, though the relevant processes are necessarily different and operate with vastly different energy requirements. For example, in a computer chip, information (info) is physically encoded in a matrix with inorganic dopants representing a pattern of 0 and 1 in the chip's matrix, translatable by the processor circuits into memory and algorithms (Table 4). But contrary to some efforts [21-28], it has no code for empathic states (i.e. emotions).

Table 4: Metrics of computer memory chip.

Matrix (Si, Ge, WO_3 film, MnO_2)
Dopants (As, Sb, Cd, B, Ga, In)
Voltage
Hard-wired connections
Clock speed
Algorithms

Q: What is the physicality of the brain's memory talent? Is there a biologic equivalent to Landauer's physicality of computer info [18] that applies to the brain's cognitive information (cog-info)?
A: See *tripartite* mechanism below.

Sci-Fi

A recurring idea forwarded by films and science fiction stories, as well as a few scientific articles, is that computers, bots, robots (and so on) can possess consciousness [29-31]. Some have questioned whether AI devices can be deemed conscious, can experience emotions and have "rights" afforded to other conscious living beings.

But it seems to us that that science itself does not yet even have the beginning of an answer to the question of what defines consciousness. Consciousness, which earthly life possesses, appears to be of a totally different order phenomena than all other physical effects of matter (Tables 1-3). Thermodynamically speaking, mentality reflects a "phase change", whereby biologic systems convert caloric energy into consciousness.

Tripartite Memory Mechanism [34-41]

We suggest an alternate mechanism whereby the encoding of cognitive information (cog-info). Biologic memory could be described as a process conceptually analogous to computer memory. The central proposition is that memory is encoded in the matrix (nECM/PNN) surrounding brain cells [40-46]. Moreover, we recognize the brain astrocytes as the cellular components driving the processing of cognitive informstion [47-61]. Memory arises from a coordinated *tripartite* process enabled by the below itemized compnents:
Cells (astrocytes entangled with neurons)
Matrix (nENM/PNN)
Dopants (metal cations, gliotransmittters and neurotransmitters, GTs, NTs).

The chemographic shorthand for the *tripartite* mechanism permits one to consider the physicality of brain memory code analogous to that proposed by Landauer for computer memory (ref). Though a hexagonal shape more properly represents a saccharide unit, for notational convenience, we adopted a square image with electron pairs, to represent the nECM "*address*" (Figure 1).

Clusters of brain astrocytes entangled with neural circuits perform the mentation process [46-60]. Neurons connect to sense organs and to one another by electrodynamic synaptic contacts. These elongated, dendritic neurons permit long distance signaling between the brain and the body's distal sensors, muscles and organs. By contrast, the many rounded clusters of astrocytes in the brain are intimately attached to neurons and to each other, all engulfed in the nECM/PNN process cognitive information [52-61]. The cells contacts are immediate with synaptic and direct membrane connections between astrocytes and neurons as well as intimate, contacts with the nECM/PNN.

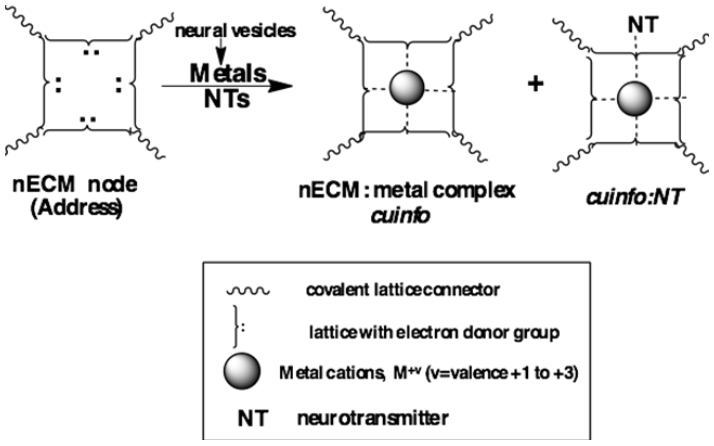

Figure 1: *Tripartite*_mechanism of the chemical formation of emotive memory units with metal cations and NTs, of which there are more than 5 and 100 respectively ($n_{metal} > 5$; $n_{NT} > 100$).

Intelligence: Native and Artificial (AI)

Consciousness is the wellspring of memory and intelligence. From the perspective of biology, consciousness and awareness are synonymous descriptions of the subjective experience of living

beings. It is evident in bacterial colonies which remember good and bad environments [65-68]. To seek the biologic source of intelligence which employs memory, we look to primitive neural creatures, *c.elegans* [69-73] from which all other complex neural creatures evolved (see Darwin). That being said, intelligence cannot be described as simple consciousness. Intelligence is a characteristic of complex recalled sensory stimuli powered by the processing talent of neural nets operating in tandem with clusters of other cells, such as astrocytes and microglia [49-64]. Such interactive cell groups, organized as ganglia or brains, recall memory of past experience to instigate adaptive behaviour ensuring survival. In that context, intelligence is twinned to memory.

In humans, a measure of intelligence is expressed as an IQ number based on a linguistic test, though other capabilities are manifest as intelligence, such as a talent for music, or mathematics or art. For non-verbal animals, intelligence is manifest by the actions of groups (ants, bees, birds, bats) that ensure survival of the group. Individual animals manifest intelligence by using tools or by communicating to each other (dolphins, whales, elephants, wolves).

Electronic devices actuating AI considered care inherently "demotive", incapable of achieving the emotive states characteristics of biologic creatures. Thus, they cannot be considered as "conscious" or "intelligent", no matter how many connections their circuits make or how convoluted their algorithms.

We may not be able to describe the process of consciousness in reductionist terms, but we can identify memory as a key aspect of a mental talent expressed as intelligence. In that regard, we provide a Molecular Information Theory in which brain cells (i.e. neurons and astrocytes) interface with a matrix which embodies a biochemical memory code as the above-described Tripartite Mechanism of Memory. We may have recognized a fragment from the entangled mysteries of consciousness, memory, and intelligence, but the eternal enigma of Life remains.

Conclusion

A code or data without "recognition" is just noise posing as "information". We incline to the proposition that the astrocyte clusters in the brain transform sensation (cog-info) into encoded memory. They "read" and "recognize" the memory encoded within the nECM/PNN, from which they recall and impart meaning. Thus, the astrocytes perform the mentation functions manifest as memory and emotive reaction. The neurons provide the sensory "input" from the body and perform as actuators of body (glands and muscles) responses ("*output*"), instigated by the astrocytes with which they are anatomically entangled.

Just as any clinical description of a body organ (i.e. spleen, liver, lungs, blood, etc) requires a biochemical characterization, so too the brain's biochemical operation that underlies mentality, must be recognized. Our augmented tripartite mechanism of memory enumerates the key operative components of this biochemical process. It is based on the interactions of **cells** (astrocytes entangled with neurons), of the **nECM/PNN** encasing all cells and of **dopants** (metals, GTs and NTs) that perform as encoders of cognitive information. Thus, the cooperative interactions of brain cells enables the phase change that transcends caloric energy into mentality.

Memory is a critical facet of the survival of conscious creatures. Not with standing our mechanistic understanding of memory, the enigma of conscious life remains.

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Conflict of Interest

GM is a founder of MX Biotech Ltd., with the commercial goal to develop new "memory materials" and devices.
CG is an emeritus professor at the Institute of Chemistry, The Hebrew University of Jerusalem. He is active in developing technologies for the conversion of peptides and active regions of proteins into orally available drugs.

Notwithstanding, the ideas forwarded here are scientifically genuine and presented in good faith, without commercial clouding of the concepts expressed therein.

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