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Review Article

The Chemistry of Subjective Consciousness

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Abstract

To comprehend the phenomenon of consciousness expressed as memory and emotions, one needs to recognize that it emerges from the combination of cellular and molecular interactions. Though the phenomenon of conscious memory escapes our analytical grasp, we intuit that it based on biochemical processes expressed in all living entities. We look to evolutionary biology to identify the origins of neural signaling resulting in memory.

As for encoding memory, the proposed tripartite mechanism involves 3 compartments

a. Stimulated brain cells (neurons + glial cells) secrete

b. dopants (>10 metals and >80 neuro-transmitters (NTs) and glio-transmitters (GTs)) into the

c. extracellular matrix (nECM/PNN) enveloping all brain cells. The nECM/PNN performs as a "memory material".

Background: Metal-centered complexes formed by dopants ejected from neural vesicles, are the molecular correlates of cognitive units of information (*cuinfo*) that encode experience for subsequent recall. The transmitters (NTs + GTs) embody emotive states which affectively encode emotive states. The brain's neural circuits process entangled sets of distributed *cuinfo* to achieve the subjective experience of memory.

What remains is the puzzle of how metabolic energy is transposed into subjective experience. In spite of reductionist advances in physics, information theory, thermodynamics, chemistry and biology, we are still confronted by the mystery of conscious "life", which remains the bastion of theologeans, philosophers and the God of Spinoza.

Keywords: Neuron; Extracellular Matrix; Metals; Neurotransmitters; Emotive Memory; Metabolic Energy

Abbreviations

info: Information; cog-info: Cognitive Information; *cuinfo*: Cognitive Unit(S) of Information; nECM/PNN: Neural Extracellular Matrix/Perineural Net; NT: Neurotransmitter

Abstract

To comprehend the phenomenon of consciousness expressed as memory and emotions, one needs to recognize that it emerges from a combination of cellular and molecular interactions. Though the phenomenon of the brain's conscious memory escapes our analytical grasp, we intuit that is based on the same biochemical processes expressed in all living tissues.

Consider the computer memory chip as a material example of "memory". Here, the memory trace (i.e. bit) is embodied and encoded as dopants (metals) distributed within the Si matrix, it's "memory material". The external circuit electro-dynamically "reads" and decodes the chip's dopant-enciphered data and integrates it into sets of information. Operation of a laptop computer for 1 day requires the energy of 16 watt hours equivalent to 13800 calories. Loss of chip memory could be due to either a scrambling of the dopant distribution within the chip or a break in the external circuit. Note that the computer's binary memory processing is totally devoid of emotive quality (i.e., "demotive") [1-10].

Origins of biologic memory

Considering that brain memory is based on signals transmitted between brain and the body, we look to evolutionary biology to identify the origins of neural signaling.

Bacteria engage in signaling processes by employing signaling molecules. Though they have no neurons, bacterial colonies have been described as exhibiting *memory evidenced by adaptive responses to past experience*, recalled from seconds to minutes [11-15]. The molecules central to bacterial signaling are termed "modulators", or "biomediators" (Table 1).

These bacterial signaling molecules (biogenic amines) are still used by all evolved neural signaling creatures. Hydra and *c. elegans* are primitive examples of neural creatures employing chemodynamic signaling [16-19]. Evolved creatures augmented the original bacterial signaling repertoire with neuropeptides. In more complex animals, such molecules simultaneously elicit both physiologic responses and psychic states, which are remembered (Table 2, Figure 1).

Table 1: Bacterial Signaling Modulators.

Biogenic amines (8)
Dopamine
Epinephrine
Norepinephrine
Acetylcholine
Amino acids (>10)

Table 2: Signaling Modulators and Neurotransmitters (NTs in humans), which link memory to physiologic reactions entangled with psychic states.

Modulator (bacteria)/Neurotransmitter (NT)	Physiologic effects * (feelings, sensations)	Psychic effects # (emotions, moods)
Acetylcholine (bacteria >)	Breath	Anxiety
Amino acids (bacteria >)	Blink	Aggression
Biogenic amines (bacteria >)	Blood pressure	Awareness
Trace metals (bacteria >)	Blood coagulation	Craving
	Cold	Curiosity
Neuropeptides (>70)	Contraction of muscles	Depression
Endocannabinoids (>10)	Cough	Desire
	Cramps	Disgust
	Crying	Dread
	Defecate	Dreams
	Dilation of muscles	Fantasy
	Dilation of pupil	Fear
	Drool	Hate
	Erection	Joy
	Evacuation	Love
	Fever	Lust
	Goosebumps	Paranoia
	Heartbeat	Sadness
	Heat	Sex drive
	Hunger	Sociability
	Immune reactions	
	Itch	
	Pain	
	Panic	
	Reflex reactions	
	Retch	
	Salivate	
	See	
	Shiver	
	Smell	
	Thirst	
	Touch	
	Vomit	
bacteria > = universal	* No memory required.	# Require memory.

Energy

The phenomenon of mentation emerges from the activity of a viable neural network. Like other organs and glands, brain activity that generates memory and consciousness is fueled by the metabolic energy generated by the neural net [20,21].

From the time of Descartes to now, the transposition of metabolic energy into mentality has been the core enigma puzzling philosophers and neuroscientists. There are no tools to measure emotive states analogous to those used by material scientists. The discipline of thermodynamics only deals with a few types of energies: potential or kinetic energies related to moving particles, [22,23]; heat measured as temperature, light, chemical reactions and mass. But possibly the formalism of thermodynamics has been mis-used to ascribe binary information coding to neural signaling [24-27].

Info (bit) = $Tk_B \ln 2$

Where kB is the Boltzmann constant (1.38 × 10-23 J/K.) and T is the absolute temperature (K). However, the discipline of psychology does not lend itself to describing the biochemical events that underlie mentality. Many neuroscientists feel that the exponential connectivity of synaptic contacts between neurons instigates the emergence of a new phase of biologic energy, manifest as a mental state, "subjective consciousmess" recalled as emotive memory (Figure 1).

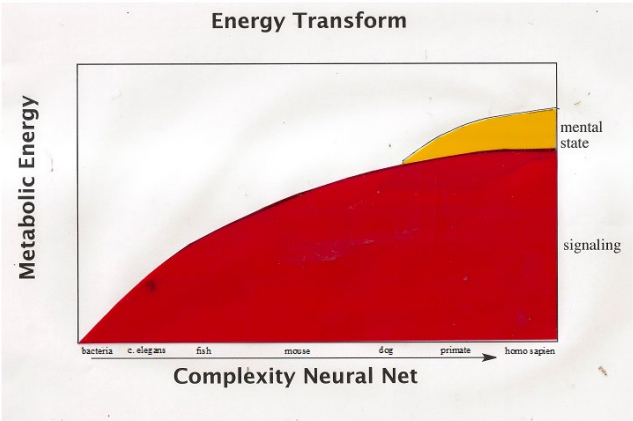

Figure 1: The evolution of neural signaling processes whereby part of the metabolic energy of ever more complex neural nets is phase changed to emerge as mental states.

Mentality

Attempts to conceptualize biologic mentality abound

- Atkinson-Shiffin (AS) [28] proposed mathematical algorithms and formulae to describe memory.
- **Critique:** Unhappily, the formula of AS mathematics cannot credibly characterize the process of instigating or recalling emotive states.
- Coward [29] suggested that understanding of neuroscience could be achieved through the application of techniques used to design electronic systems.
- **Critique:** Coward assumes"computational neuroscience" and employs enigmatic concepts i.e. "*cable theory of electric signal propogation*", "*feedback and feed forward architecture*", "*artificial neural networks",* "*adaptive resonance theory (ART*)", "*Bayesian interface method"*, etc, all terms conceptually modeled on the electronic computer, a totally "demotive" device.
- Ascoli and Samsonovich [21] proposed a radical paradigm shift to incorporate subjective consciousness into the realm of objective empirical science. Pointing to electrophysiology and synaptic plasticity, they invoked "*neuro-informatics*" and *"computational neuroscience*" to explain the physical nature of sensory perception.
- **Critique:** Neither the principles of physics nor those of Information Theory can dissolve the mystery of subjective consciousness. Making up new words and phrases is not explanatory.
- Tegmark [23] undertook a very ambitious program to pierce the veil of consciousness by alluding to a "*state of matter*". The approach was replete with obscure mathematical constructs (i.e. "*Hilbert space*", "*Hamming code matrices*", *Hamiltonian separability*", "*potential energy function*", "*diagonality theorem".* etc).
- **Critique:** Rather than addressing the biologic puzzles of emotional memory and how metabolic energy is transposed into mental dimensions, Tegmark dives into mathematical tricks which have no bearing on neurobiology.
- Craddoch., *et al.* [30] suggested a "*quantum underground*" invoking scale invariant hierarchies in the brain based on electron resonances in the microtubules within neurons.

- **Critique:** To us, this seems improbable as microtubules assemble and dissolve in rapid order to effect mitosis, cell motility, intracellular transport, and cell shape. Due to their fluid construction, microtubules are inherently unsuitable for storing persistent memory. Also, they do not account for emotive states. In summary of their own reductionist approach (28), Craddoch., *et al.* admited to hopelessness for developing a reductionist simulation of brain consciousness.
- Ochiai [31] posited that understanding the "*cognitive world*" is possible only through the quantum mechanical construction of "micro worlds" of atoms and molecules.
- **Critique:** There was not even one mention of neurons, or brains, or biology. Rather, Ochiai employed mal-defined words and phrases to aid understanding i.e. "*context relative dispositional attribute", "constructive realism*", "*strangification"* to bring about deeper understanding. None of this made biological sense and did not clarify the enigma of consciousness.

- Seth and Bayne [32] reviewed four theoretical approaches to mentality:

  - Higher order theories
  - Global workspace theories
  - Re-entry and predictive processing.
  - Integrated information theory.

- **Critique:** This was a brave attempt to secure an explanatory link between neural activity and consciousness. However, it neglected to distinguish between emotive "cognitive information" from the demotive "information". Also, it did not broach neurochemical processes that underlie neural activity or discuss how subjective emotive states are instigated in neural creatures.
- Kandel., *et al*. [33] reviewed the scope of memory research. They focused on the work of Milner and others that seemed to identify two major types of memory, namely:
  - **Explicit memory:** For facts, events, people, places and objects, involving the hippocampus and adjacent cortex.
  - **Implicit memory:** For perceptual and motor skills, relying on the cerebellum, the striatum, the amygdala and the reflex pathways.
  - They emphasized that memory storage is not the result of a linear sequence of events that culminate in long term memory, but the outcome of several interactive processes, notably the encoding of new information reulting in altered synaptic connections.
- **Critique:** Kandel., *et al.* refer to "coding", but never specify details. They did not refer to Semon's *engram*, the physical trace of memory (34) but only referred to synaptic signaling. That the strength of synaptic connections could serve as a basis of a neural code for persistent memory has been accused of being "sinful" (35). For example, no electronic memory device employs circuit connectivity for memory storage. Rather, they are based on chemical doping of a matrix. Thus, we have no workable model of a connectivity memory device. Also, Kandel., *et al.* do not broach the issue of emotive states, though they use the animal model of pain-stimulated Aplysia to demonstrate memory recall.
- Labatut [36] posits that concsciousness is not a constitutive property of all matter. Rather, it emerges from the operation of memory experienced by neural creatures.
- **Critique:** Labutat avoids discussing biochemical details of the mechanism of memory.
- Herzog, W (Dir). Popular iinterest in mentality and throught processes is exemplified by a recent film, Theatre of Thought [37].
- *Critique:* This was an overview of various scientific approaches to measure or describe mental functions, It was interesting but did not really clarify any mechanism of memory or consciousness. But it underlined the general interest in the subject.

Tripartite mechansim

Neural processing is based on chemodynamic as well as electrodynamic signaling processes. Morphologically, the individual neurons (i.e., processors) are surrounded by a tangle of glycosaminoglycans comprising an extracellular matrix engulfing a perineural net (nECM/PNN). This matrix functions as a "memory material". The neurons employ metal cations and neurotransmitters (NTs) to encode cognitive units of information (*cuinfo*) from which the neural circuit consolidates meaningful memory. The NTs serve as the elicitors and encoders of emotive states, as they entangle physiologic reactions with psychic states (Figure 2) [38-49].

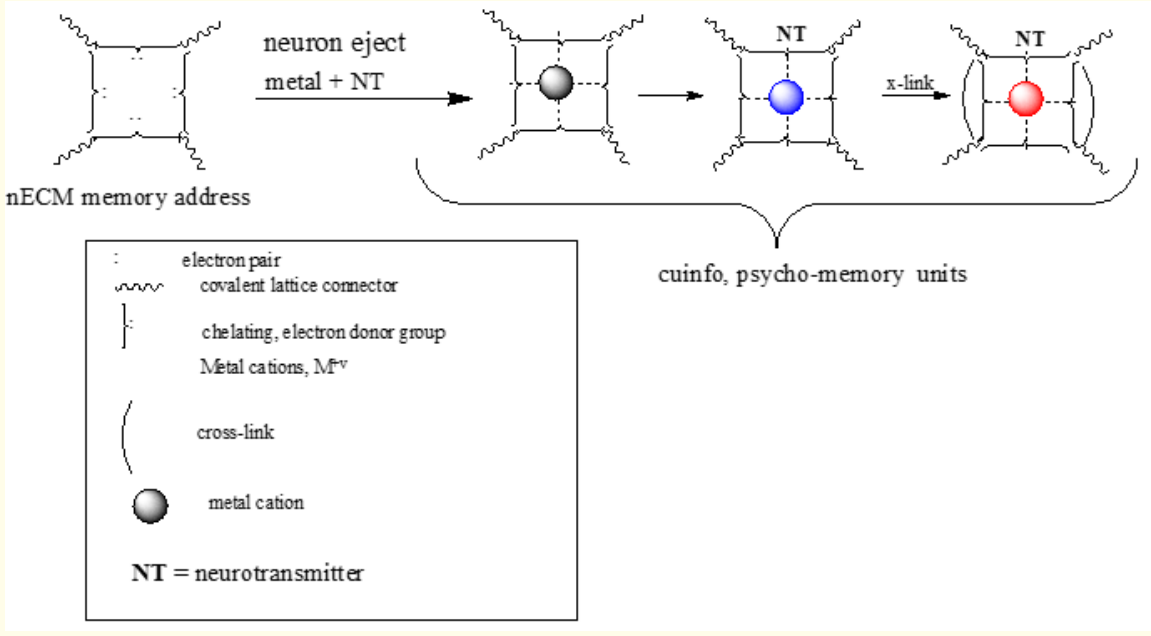

Figure 2: Chemographic representations of the reaction of a nECM/PNN binding site for a metal cation, an electron rich site ("address"}. The binding of a neurotransmitter (NT) to the metal-centered cognitive unit of information (*cuinfo*) confers emotive context.

While it has not been possible to measure the energy content of individual *cuinfo*, it is noteworthy that a human brain requires some 400 cal/day to function and achieve conscious states, compared to the 14,000 calories to run a "demotive" laptop for 1 day.

Mental chemistry

Memory is the core enigma of biological consciousness. Of it, one may ask

- Quality Memory?
- Of what quality is consciousness?
- Is it a force?
- Is it a form of energy?
- Or is it a dimension achieved by neurons signaling one another with electric pulses and molecules?

Only chemistry can pierce the veil of neurophysiologic processes. For example, emotive states can be modulated by chemicals, such as "neurotransmitters" (NTs), recreational drugs and sedatives. The pharmacopia of modern medicine is replete with molecules which modulate conscious mood and memory (Table 3).

Some of these points were addressed in a collection of essays regarding the philosophy and enigma of consciousness [52]. The authors of the 52 essays ranged from William James to Francis Crick, with contributions from many worthy philosophers, psychologists, linguists, neurobiologists and neurophysiologists, but not one biochemist. In the absence of a biochemical perspective, the enigma of conscious memory continues to haunt neurobiologists.

Legal	Illegal
Alcohol	Cannabis
Barbiturates	Cocaine
Caffeine	Heroin
Prozac*	Ecstacy
Ritalin*	LSD
Lithium salt	Smack
Anasthetics*	

Table 3: Examples of Mood Altering Drugs.

*Require medical prescription

Physicists working with photonic materials have adopted the term "*neural networks*" to refer to devices inspired by their concept of the brain, though it is far from biologic reality [53]. Rather, they describe modulating photon propagation as a route to develop devices capable of scalable machine learning.

The words "consciousness" and "mentality" are equivalent terms that encompass concepts such as "awareness", "cognition" and "emotions". The metrics of classical physics or quantum mechanics cannot describe the dimension of emotive mentality [4,53]. In combination with neurotransmitters which operate as signaling molecules (Table 3), mosaics of molecules are embedded in the neural membrane which perform as sensors (Table 4). It is apparent that neural circuits can instigate a phase change of energy, projecting "metabolic energy" into a new dimension of subjective mentality i.e. consciousness. One must admit that the enigma of consciousness manifests a novel dimension in the firmament of natural forces.

GPCR
K channel
Acetylcholine receptors (AchR)
Cannabinoid receptors

Table 4: Cognate NT receptors on neural membranes.

Outstanding issues

Memory is central to the achievement of subjective consciousness, also referred to as "mind". One can measure the temporality of memory as a "handle" on mentality. It raises a few issues relating to the achievement of mental states as follows:

- **Energy**: How is the conversion of metabolic energy into mentality effected?
- **Information:** Can the synaptic and ephaptic signals generated by neurons be considered under the rubric of Landauer's Information theory (3), where every bit is accounted for in terms of energy i.e. kTln 2?
- **Feelings and emotions**: Feelings (sensations) are hardwired in the sensorium and do not require a memory function, as do emotions. Feelings are reflected by immediate behavioral responses. Bacterial feelings, reflected by "tropisms" to or away from a particular stimulus employ signaling molecules termed "biomodulators" [15-19]. Bacterial colonies have been described as exhibiting memory, though they have no neurons. Thus, *e. coli* has been shown to optimize their adaptive responses, evidencing their memory lasting from seconds to minutes. The molecules that are central to bacterial signaling have been identified and termed "modulators", or "biomediators" (Table 1).

In the absence of a creature with a single neuron, it boggles the mind to consider that consciousness is a talent of a single neuron [54-56]. The example of biology indicates that a minimum of 300 neurons (i.e. *C. elegans*) is required to achieve the emergence of a mental talent, namely memory [18-20]. One could consider that the mental talent of emotive memory, evolved along with the increasing complexity of neural interactions

Neural memory involves a phase change of metabolic energy into mental experience. Mentation and memory are merged qualities instigated by the neural net that transcends metabolic energy into a mental dimension. The neural net generates memory by melding physiologic processes driven by chemo-electric biochemical reactions, as schematized in figure 3.

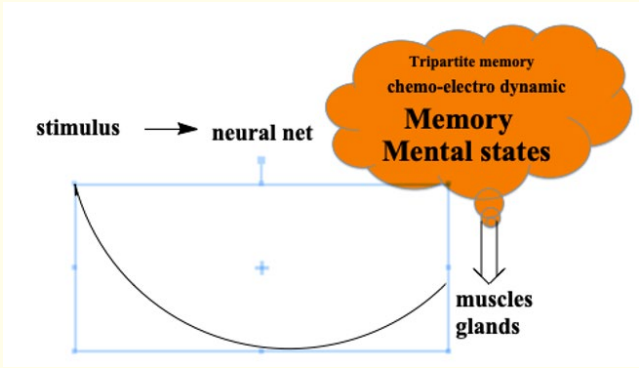

Figure 3: A schema which illustrates the of chemo-electric dynamic signaling relevant to memory.

Conclusion

The reductionist approach to consciousness [4,57,58] is not very revealing. We have made some progress in comprehending the biochemical basis of memory. But there seems to be a limit to our ability to rationalize the prime characteristics of conscious animate life. This limitation is analogous to cosmological physicists' inability to penetrate the laws of black holes beyond the "*event horizon*". In spite of many advances in information theory, physics, thermodynamics, chemistry and biology, we are still confronted by the enigma of subjective consciousness. Pondering the mysteries of existence. we are still confronted by the mystery of conscious "life", which remains the bastion of philosophers, theologeans and the God of Spinoza [59-63].

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