The Dimension of Neural Memory and Consciousness

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ABSTRACT

The mental dimension is an experiential state achieved by neural circuits, that cannot be measured by physical means but that nonetheless affects the behavior of conscious neural creatures.

The "meaning" or "worth" of anything in the life of animals is based on emotive factors that are recalled from past experience. Emotive memory is the key to the "consciousness" that determines decisions and valuations. Even supposedly rational economic decisions are ultimately based on affective considerations.

From the Darwinian perspective, neural signaling evolved from bacterial signaling processes which employed small molecules (i.e. biogenic amines). The tripartite mechanism provides a chemodynamic rationale for considering the physiologic basis of such signaling, a key facet of "consciousness". We note that the original bacterial signaling molecules (i.e. biogenic amines), later termed "neuro-transmitters" (NTs)) were retained by and still used by all neurons.

To clarify the discussion, we de-limit the meaning of terms commonly used by both computer scientists and neurobiologists (i.e. "memory", "information", "feelings", "emotions" , "energy", "artificial intelligence", "logic" and "dimension").

Mind and body are a complex unity. The psyche emerges from the physiology and chemistry of interacting neurons, projecting an ensemble of physiologic sensibilities into a psychic (mental) dimension. Without memory, there are no emotions and vice versa…without emotive qualities, memory fades. Emotions and memory are linked facets of the psychic dimension of consciousness, encoded and decoded by the biochemically active neural net.

Keywords

Chemodynamic, Electrodynamic, Emotive memory, Tripartite, Neural code.

Background

Consciousness is the core enigma of biology (Tuszynski, 2006; Koch, 2012). Of it, one may ask:
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? Can electronic devices achieve that dimension?

Some of these points were addressed in a collection of essays regarding the philosophy and enigma of consciousness [1]. 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.

The enigma continues to haunt. More recently, a competition between the global workspace theory (GWT) and the integrated information theory (IIT) has been funded to experimentally test these theories of consciousness [2].

Evolution

From a Darwinian perspective, *where in biology is consciousness first manifest?* Can one consider a bacterial colony conscious? The

colony is "aware" in that it responds to external stimuli based on individual bacteria signaling one another. We call such responses "tropisms".

With regard to memory, it has been shown that bacterial biofilms can retain memory of changes of membrane potential instigated by light [3]. It was observed that bacterial memory is manifest in terms of chemotaxis and history-dependent behavior [4,5]. The molecules central to bacterial signaling have been identified and termed "modulators", or "biomediators" (Table 1) [6].

Table 1. Bacterial signaling modulators.

Modulator
Acetylcholine
Dopamine
Norepinephrine
Epinephrine
Serotonin
Histamine

Table 2. Neurotransmitters (NTs), which elicit both physiologic reactions and psychic states.		
Neurotransmitter (NT)	Physiologic reactions * (sensations, feelings)	Psychic states !
Biogenic amines (6) Amino acids (>10) Neuropeptides (>70) NO (1) Endocannabinoids (>10)	Breathing Blinking Blood pressure Blood coagulation Cold (feel) Contraction of muscles Coughing Cramps Crying Defecation Dilation of muscles Dilation of pupil Drooling Erection Evacuation Fever Goose bumps Heart beat Heat (feel) Hunger (feel) Immune reactions Itching Pain Retching Seeing Shivering Smelling Thirst (feel) Touching Vomiting	Anxiety Aggression Awareness Craving Curiosity Depression Desire Dread Dreams Fantasy Fear Hate Joy Love Paranoia Sadness Sex drive Sociability
	* No memory required.	! Emotions requiring memory

These bacterial signaling molecules (biogenic amines) were retained by and are still used by all evolved neurons, but are now termed "neurotransmitters" (NTs). Augmented by neuropeptides, such molecules simultaneously elicit both physiologic responses and psychic states (Table 2). Unlike bacteria, neurons do not exist as freely moving cells, but are static, embedded in an extracellular matrix (nECM) which serves as structural support [7]. We have proposed that the nECM also serves as a "memory material" wherein neurons encode cognitive information, the basis of memory [8].

Consider that consciousness requires emotions as well as memory (Rosenfield, 1988). But in the context of this discussion, the facts of bacterial awareness (sensation) or bacterial memory do not constitute bacterial "consciousness". Thus, we jump to neurons which signal one another with molecules (i.e. biogenic amines and neuropeptides, Table 2) that impart emotive quality to the mental capability we call "memory".

What is "consciousness?

Consciousness involves awareness, memory, emotive states as well as logical thinking, with emotive memory being key to all decisions and valuations. Some suggest that it results simply from connections between neurons [9-11]. But it may represent a new dimension of biodynamic energy. The "value", "meaning" or "worth" of anything in the life of animals is based on recalled emotive qualities [12,13]. The emotive "coloring" or "flavoring" of basic units of memory (*cuinfo*) with NTs is not available to the von Neumann/Turing machine [14]. Even supposedly rational economic decisions are ultimately based on affective considerations.

Nevertheless, many attempts are underway to build robots that emulate human emotion…robots that are "conscious", based on presumed analogies between complex electronic circuits and biological neural nets, as exemplified by:

"*The route to theoretic neuroscience lies through the application of the techniques for understanding extremely complex, electronic systems.*" [65].

But this attitude, which focuses on electrodynamic signaling, ignores the biochemical basis of neural signaling and memory. For example, it identifies 5 different types of memory, namely:

semantic
episodic
working
priming
procedural

But all these memory types relate only to human memory, not to animal memory. One would expect a universal neural memory code to apply to all neural creatures [12,15,16]. It should account for its evolution and be phylogenetically conservative.

As for computers, binary formatted algorithms cannot elicit conscious emotive states in electronic circuits which are forever "demotive" (i.e.bereft of emotive quality) [10]. As best we know, neurotransmitters (NTs) are the only neuro-available molecules capable of eliciting emotive responses from animals (Table 2). There are also drugs (i.e. Ritalin, Prosac, sedatives, LSD, etc.) which elicit emotive reactions and anaesthetics which render

animals unconscious. These all point to a chemodynamic process underlying the phenomenon of consciousness.

Definition of some terms seems appropriate.

Dimension
The words "consciousness" and "mentality" are equivalent terms that encompass terms such as "awareness", "cognition" and "thinking". The metrics of neither classical physics nor quantum mechanics describe the dimension of mentality [17-19]. We should be courageous in confronting the enigma of consciousness which manifests a novel dimension in the firmament of Nature. 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.

Information
The above cited Coward quotation proposed an "information model" with a graphic schema (his Figure 8.14) that identified "recommended weights" of information, effectively digital emanates from the cortex or the hippocampus system. But such a system of information cannot express "weight"; all digital information (i.e. 0 1) is inherently weightless. Or expressed otherwise, digital information is "demotive", lacking any subjective quality of worth or value i.e. weightless. But it is physical in that it is encoded by metal dopants distributed in a Si matrix making up the memory chip [20].

How can weightless information be "recommended" for action by a neural creature?
We propose that only "information" with subjective value is evaluated experientially to induce action by a living being.

What imparts "meaning" or "value" to neural signals and recall?
Coward parses information into 2 types, one which determines an output action potential, another which changes the "algorithm" by which future action potentials are determined. Frankly, none of this makes biological sense. The approach is modeled on an electronic device where "input" and "output" action potentials are electric voltage signals.

In the context of neural information processing, it identifies neurotransmitters (NTs) and their cognate membrane receptors as relevant to neural signaling. But it totally avoids mention of how the mental dimension involving feelings, emotions and neural memory are achieved.

Another view of consciousness is that it relates to a system's capacity for information integration, the information being "*generated by complex mechanisms specifying both the quantity and quality of experience*" [21].

The liberal use of the term "*affective computing*" [22] merely masks incomprehension of neural signaling processes that generate the mental dimension of subjective consciousness. In a similar vein, the liberal use of terms such as "*neural net*" and "*deep neural learning*" used by technologists confounds rather than informs neurobiologists. The algorithms apply only to the history of masses of humans making economic decisions [23,24] or averaging the options of specialists (i.e. clinical diagnosticians). They do not apply to all neural creatures or clarify the affective basis of emotive valuation. The technologists have not considered emotions or comprehended the meaning of neural morphology [25]. Thus, the terms "*affective computing*", "*deep neural learning*" and "*neural net*" cloud rather than clarify.

Feelings and Emotions
These words are often used interchangeably, notably in romantic songs or philosophic discourse [26]. However, we choose to delimit their meaning as follows:

Feelings- sensations perceived by special receptors on the body of the neural creature (i.e. sight, smell, touch, balance, pressure) which do not require memory. Feelings involve both bodily reactions and mental states (i.e. pain, pleasure)

Emotions – are psychic states based on recalled feelings. Thus, emotions operate through the memory of previous experience.

"Is the connectosome model of neural (synaptic) memory adequate to explain the process by which emotive memory is encoded?
A wiring diagram cannot describe the causative process underlying neural mentation or emotive memory [11]. Feelings" are defined as mental states that co-mingle immediate physiologic reactions with psychic experience. "Emotions" would be the recall of previously experienced "feelings".

Consciousness or equivalent terms (i.e. subjectivity, experiential state, mentality, cognitive state) could be described as the psychic dimension achieved by a network of interactive neurons which remember prior experience [27]. The example of nematodes suggests that a minimum of 300 neurons are required to achieve the mental dimension of neural memory [28]. It is obvious that the conscious neural circuit is based on many neurons connected to one another. Indeed, the major thrust of the popular "connectosome" code of neural cognition is based on many synaptic contacts between neurons [9,11,29]. As an alternative, we look beyond synaptic connections and attempt to describe the more basic biochemical nature of the persistent neural code (see tripartite mechanism described below).

Energy
In physics, energy is rationalized in terms of measurable movement, temperature and mass with the 4 basic forces: Gravity, electro-magnetism, weak and strong nuclear interactions [18]. But the mental dimension is yet uncharted by physics (Figure 1). Possibly, a new paradigm is needed to account for the ability of the neural net to project metabolic energy into a new dimension, that of subjective experience [7,30,31].

Figure 1: Transformations of energy manifest as Force and Mind.
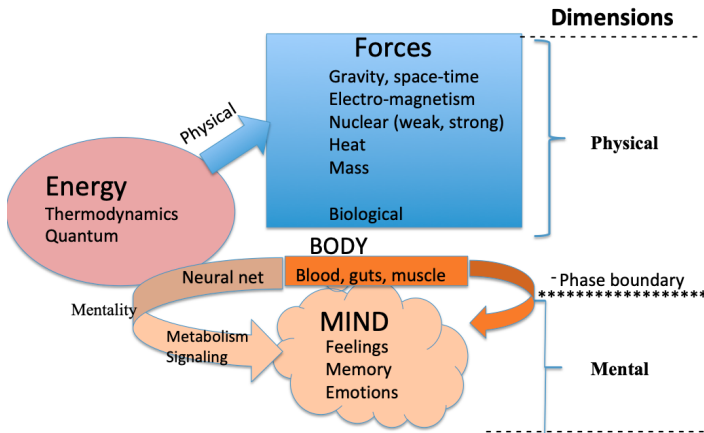
Dimensions

What is a mental dimension?
In common parlance, "dimension" relates to a measurable property (i.e. length, height, mass, velocity, temperature, luminescence, etc); is a fundamental measure of a physical state of mass or volume of space [32].

Is "free will" a psychic degree of freedom?
In mathematics and physics, each individual parameter or degree of freedom in a system enables another dimension. The experience of consciousness is not an expression of force or mass, but a capability that emerges from the unique organization of groups of viable, signaling cells (neurons). For mental processes which are modulated by NTs, each NT enables a unique facet of the mental dimension. One could describe the mental dimension as a state that cannot be measured by physical means but can be modulated by drugs. It is experienced by the neural creature, sensing and remembering its past environment so as to act to survive.

The achievement of mental dimension could be detected by electrophysiologic techniques (EEG, fMRI) or facial/ voice recognition programs [33], but these do not grasp the nub of mental experience; they are mere shadows of physiologic states.

"Intelligence" has multiple definitions depending on its intended meaning i.e. military, industrial, neural and artificial (AI). We have discussed this previously. Essentially, each definition relates to a unique process and field of interest. This confounds the ease of discourse and comprehension by neuro- and cognitive- scientists [34].

Robotics and Artificial Intelligence (AI)
Often, the term AI is used to imply consciousness or the eventual achievement thereof.
There have been numerous attempts to engineer a subjective mental state into robotic devices [10,27,35-42]. They consider that "emergent intelligence in AI involves higher level capabilities that spontaneously emerge from ever more complex machines; that simple robot complexities could build on one another to evolve "human intelligence".

The work of Rodney Brooks (MIT) was singled out [43,44], as one who considers "emergent intelligence in AI" and builds autonomous robots. He stated:
"Biochemistry shows that we are collections of tiny machines".

He is an agnostic who posited that robots could feel, love, worship and have souls i.e. humanoid robots. Brooks predicted that as the systems become more complex, they would evolve not only intelligence, but consciousness as well.

We point out that robots only measure or detect measurable, objective phenomena (such as vision, hearing, balance, etc.) that lack inherent subjective quality. They may have memory and perform tasks dictated by memory-driven algorithms, but they cannot achieve the emotive dimension experienced by neural creatures. To quote:
"They have mouths but cannot speak, they have ears but cannot hear" ….
And those who make idols are just like them, as are all who trust in them".
Psalms 115: 5-8:

We leave the issue of souls to theologians.

Quantum Mechanics
What kind of neural code is available to encrypt the experience of NOW in a biologically credible form that is rapid and readily available for recall?
One is periodically confronted by the proponents of quantum mechanics (QM, including quantum chemistry, quantum physics and quantum field theory) to address the enigma of consciousness. Some provide an explanatory rationale that claims that a mental state can be achieved and remembered by neurons employing quantum mechanical processes. Some refer to "quantum cognition" [45-48]. Some aim to build quantum computers that achieve consciousness.

We point out that the binary reality (01) of Turing machine is inadequate for this task. One cannot employ the metrics of physics or the Information Theory of computers to formulate consciousness [49-51].

Similarly, QM reality is bereft of emotive qualities and does not provide a coding effector for emotive states. As far as consciousness is concerned, the fatal flaw of quantum computing is that it cannot emulate the processes underlying neural memory, namely physiologic responses linked to emotive states.

Ambiguity
The above exemplify the ambiguities of words, such as "memory", "information" and "intelligence". For example:

Memory
For the computer, memory relates to the disposition of dopants (such as metals) in a matrix (such as silicon) which encode binary formatted information (ref). But such memory is "demotive", without affective import. The arbitrary division of neural memory into different types (i.e. semantic, priming, episodic, procedural

(Coward, 2013) is not biologically credible; nor does it apply to all conscious neural creatures.

By contrast, neural memory is rife with emotive context. We have extensively discussed this in our previous works (see tripartite mechanism, discussed below). Thus, the term "memory" is ambiguous.

Information

For the computer, "information" can be reduced to a series of bits which organize into an algorithm qhich can perform a function or generate output. The bits are inherently "demotive", as is the integrated output "information". Though capable of being organized as information, the 0 1 bits cannot encode an emotive state.

By contrast, neural system of processing stimuli is basically emotive, chemically impacted by neurotransmitters (NTs). Thus, one must distinguish between the demotive "information" of the computer and the emotive "cognitive information" of the neuron. Thus, the term "information" is ambiguous.

Intelligence

Algorithms that learn from experience lie at the basis for what is called artificial intelligence (AI). Generally, a 'goal' is imposed by the programmer so that the learning algorithm can achieve the programmer's goal. But the binary-based "intelligent" algorithms lack an empathic facet and are bereft of emotive context ('demotive'). They are certainly not "wise", the standard for true intelligence. The crux of neural intelligence (NI) lies in emotive states that help optimize survival. The totality of NI engages emotive qualities which ultimately confer "worth" to all stimuli Thus, the term "intelligence" is ambiguous.
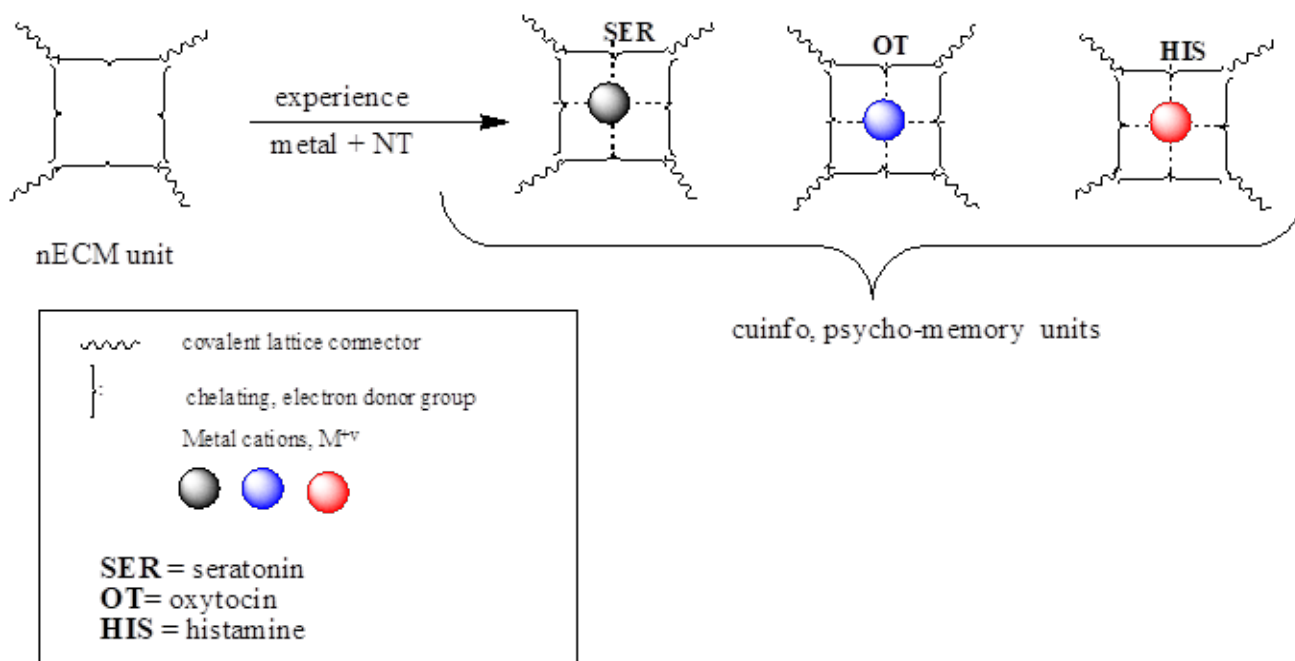
Tripartite mechanism

Our mental capabilities depend on our physical constitution. The tripartite mechanism [8,52-56], provides a concept relevant to neural physiology. It provides a biochemical description of a mental talent, neural memory. It invokes physiologically relevant materials available to the neuron, notably the hydrogel surrounding the neuron, the "neural extracellular matrix" (nECM), functions as a "memory material" to encode and store cognitive units of information (*cuinfo*). The dopants (>10 neuro-metals, >90 neuro-transmitters (NTs)) provide the neuron with Avogadro scale ($Å=6x10^{23}$) "effectors" for encoding emotive information in memory (Figure 2). As discussed above, these neuro-chemical "effectors" evolved from the signaling modulators of bacteria.

Consciousness and Memory

We are still confronted by the enigma of the causal mechanism of neural consciousness [1,34]. Proponents of AI and quantum mechanics (QM) predict that computers will eventually achieve the consciousness of living beings. But we point out that without the metabolism of flesh and blood [45,57]; not be initiated by the vital force of life (elan vital) associated with emotions and the drive to survive [58], the emotive state is not achieved. Effectively, they wish for conscious "machine slaves" directed by human programmers. This recalls the hubris of the long past civilization (> 3000 years ago) when inhabitants of Babel thought "*to build a tower that could reach to heaven and make us a name*".
Bereshit, Genesis 11:1-9, chapter Noah.

As neuroscientists, we cannot encourage a proposition which flies in the face of biology. Consciousness and all the mental talents associated with viable neural nets cannot be mimicked by demotive electronic devices, however complicated. Binary-formatted algorithms cannot encode emotive states, or lead to the

Figure 2: Tripartite mechanism of the chemical formation of emotive memory units with 3 typical NTs of which there are more than 80.

achievement of subjective consciousness by robots. By contrast, neural nets powered by the Life Force of metabolism are inherently emotive, their sensorium sensitized by molecular processes involving trace metals and NTs, as chemographically described by the tripartite mechanism (Figure 2).

Logic

A discussion about logical thought seems appropriate. Like emotions, logical thought requires memory, though bereft of emotive quality. It is a skill that springs from language, a uniquely human capability [59], though there are examples of logical thought in animals [15].

Interestingly, logical theories, such as "prospect theory" (PT) have employed "machine learning" algorithms to model human risky choice decisions, as in economics. Without considering emotive factors, the theorists of PT and its variants (expected utility (EU), neural PT, etc.) consider that they employ AI to model "*deep neural network*" applications related to risk perception, moral judgement and strategic choice [23,24,60,61]. We point out how these systems illustrate how illogical decisions on risk are made by presumably logical humans.

One is hard-pressed to discern a biological principle that is illuminated by robotic algorithms deciding on a course of action. While machine learning algorithms may be able to predict decisions of many humans involving a statistical averaging of historical behavior, the algorithms do not inform regarding the neurological mechanism whereby individual valuation of "worth" is based. We are inclined to the idea that most animal decisions are driven by emotive factors whose metrics cannot be reduced to graphs and whose calculus we cannot discern with numbers, but describe in poem and song. The appropriation of neurobiological terms, such as "*neural net*" and "-", by such theorists of AI throws little light on biological neural processes, notably the achievement of mentality expressed as emotions and memory.

In the tripartite mechanism, the molecular correlate of a logical memory unit could be notated, where the memory units (*cuinfo*) are not embellished with NTs, the molecular encoders of emotive states (Figure 2).

In short, the tripartite mechanism posits that emotive neural memory units are encoded in the nECM by metals combined with NTs. In this scheme, logical memory units could be encoded without NT molecules, simply by the interaction of trace metals with the nECM surrounding the neurons (Figure 3). Such memory units (*cuinfo*) would be deficient in subjective quality, but be capable of being processed by neural net processing. Such a process would need to be learned and honed with experience, unlike emotive reactions which spontaneously emerge from interactions with the environment. For example, feelings of pain, hunger or thirst, etc. do not have to be learned through rote repetition and rules of behavior, but are inherent in all neural biology.
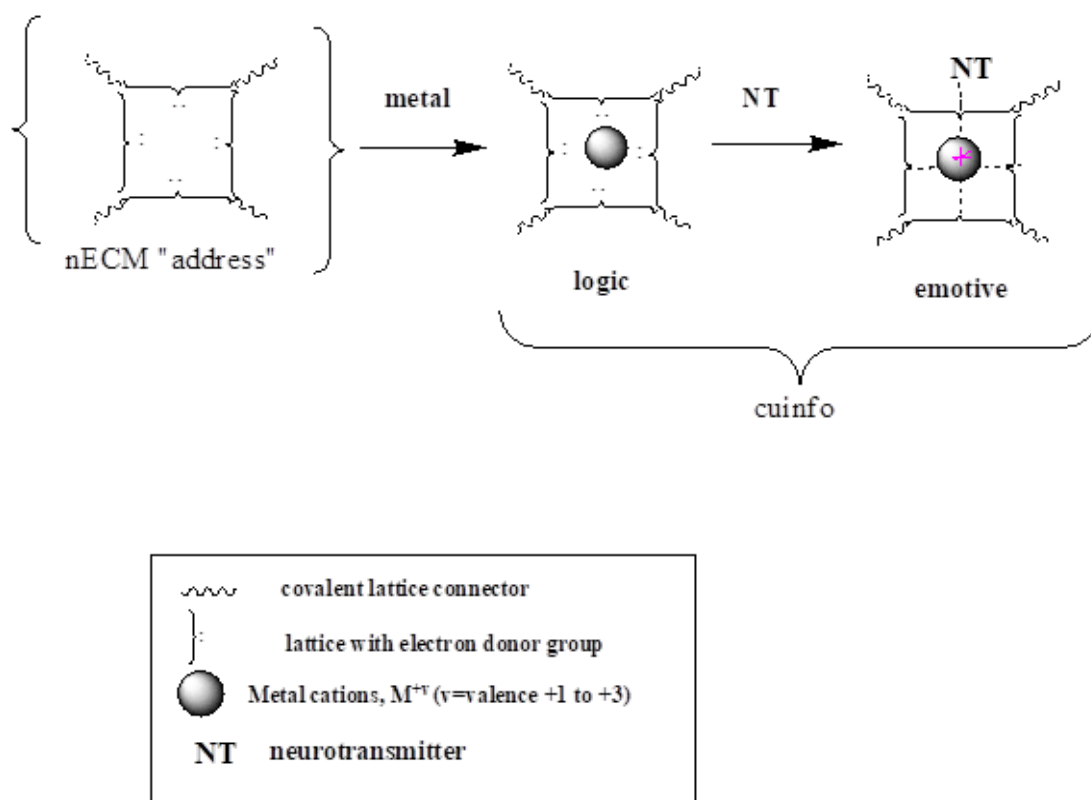

Figure 3: Tripartite mechanism: Formation of logical and emotive memory units (*cuinfo*), nECM complexes with metal cations without and with NTs.

Conclusion

"Chemistry is the only physical science that offers a pathway to understanding animate biology." [62].

Mind is an expression of consciousness that requires active awareness. Mind may be applicable only to humans, as it springs from our talent for language. Consciousness is a biological phenomenon of all neural creatures, whose process we have not quite figured out, as for example metabolism [31]. An explanatory account should explain how mental characteristics are linked to biological reactions and follow the evolution of ever more complex neural nets. We avoid here a consideration of the "origin of life", but focus on a possible biochemical mechanism whereby life was rendered conscious through memory. As discussed above, our physico-chemical rationale began with bacterial chemical signaling with biogenic amines (Table 1). Through the evolution of neural-net signaling, this emerged as memory and consciousness (Figure 4), still employing identical bacterial signaling molecules (see tripartite mechanism).
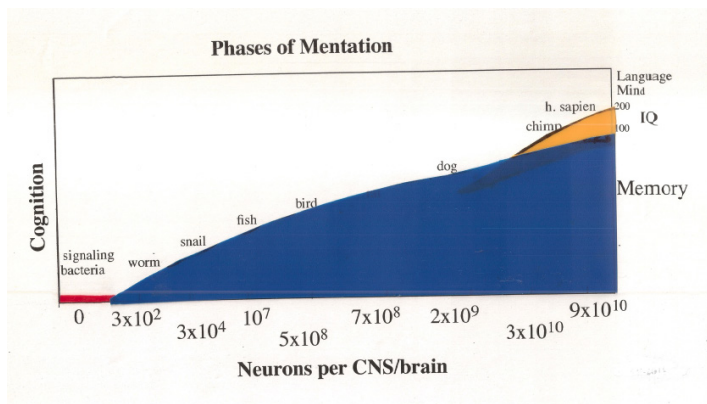
Figure 4: The evolution of mental states evolved from bacterial signaling to ever more complex neural net signaling in central nervous systems (CNS).

Expectedly, a combined electro- and biochemical approach, exemplified by our work with oxytocin-coated electrodes [63,64] will provide experimental entry into the causal mechanism by which the dimension of conscious mentality is encoded in memory.

Mind and body are a complex unity. The psyche emerges from the physiology and chemistry of interacting neurons projecting an ensemble of physical sensibilities into a mental dimension. Without memory, there are no emotions and vice versa…without emotive qualities, memory fades. Emotions and memory are linked facets of the psychic dimension of consciousness, encoded and decoded by the biochemically active neural net.

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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