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Astroglia as a Base for Holographic Short-Term Memory

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Abstract

Here is presented a model of holographic short-term memory formed in astrocytes by 3D interference of synchronized electromagnetic waves of proton oscillations in liquid water of intracellular and intercellular plasma. They are generated by spectral components of neuronal spikes. In this model, spikes of calcium concentration in astrocytes identify the obtained 3D holograms in the peaks of distributed intensity of the spatial-temporal interference pattern.

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Introduction

The brain always produces coherent actions and is adaptive to them when concentrates on one task in every moment of time because serial processing and storing of information is an advantage but not a limitation of the brainwork [1].

Just therefore, actions that occur naturally outside of our attention, for example, the breathing or riding a bicycle after learning becomes our second nature. Opposite, the movements of face, body, and limbs, or the respiratory modifications are the constituent elements and indispensable (selective, sustained, and divided) factors of attention that becomes the gate for sensory information entering the conscious experience [2, 3].

Thus, attention is the focusing of consciousness to learning at limited access to awareness in the premotor and prefrontal cortex at early stages of sensory-information processing, and an intention activates or represses attention of the brain at specific information search in the environment [1, 4].

At the same time, working memory (WM) requiring a high level of focused attention involves short-term storing the information for its processing as well as specific cognitive operations for working with this information, as the short-term neuronal plasticity associated with attention is different from a short sensory activation as a phasic modification [1, 4].

In this connection, short-term memory (STM) is distinct from long-term memory (LTM) by the limited storage capacity and a decay of content in seconds or hours without conscious efforts for retaining specific information here and in WM, i.e. STM can hold information longer only under attention and learning. Opposite, skills involving motor activation and results of its learning are in LTM and can facilitate ongoing cognitive operations without attention focus in contrast of new information processing. This process is the active one with involving of rehearsal and attention executive control. As WM is a temporary storing of information for manipulating in the brain connects that with other information in order to record modified information into a long-term storage, i.e. the brain is not just processing information but creates that [5].

This does the processing of information an active one and with feedback rather than simple passive storage. For obtaining new information, even Drosophila has an exact temporal structure of attention alternation to external signals just as plants sense the environment at synergetic modification by other signals [6, 7].

Thus, the structured memory is both WM and attention, both STM and perception with cognition and affection. The last ones can enhance emotions by the cognitive appraisal and vice versa [8, 9].

These functions operate synergistically at hierarchic levels of memory for manipulating information. At the same time, affects as their feedback stimulate a goal-directed activity of a living thing [10, 11].

Even insects possessing miniature brain demonstrate a sophisticated behavior with attention modulation and conceptual learning, i.e. single-celled and multi-celled living things with or without the nervous system have cognitive capability because liquid water in them as a general adaptive carrier of such information can be a part of WM [12-14].

Indeed, it plays an active role in communication of cells with exchanging of vital information, and strong dehydration of the brain causes cognitive deficits in memory and in perceptual ability [15].

In this paper, the author suggests a model of a holographic short-term memory formed in astrocytes by 3D interference of synchronized electromagnetic waves of proton oscillations in liquid water of intracellular and intercellular plasma [13].

These oscillations are generated by spectral components of neuronal spikes and 3D holograms are identified by waves of intracellular calcium ions Ca^{2+} in astrocytes.

Wave Packets for Representations

The oscillatory activity of brain is a prominent feature in controlling information flow because an ability to modulate signal transmission by frequency function supports this regulation [16]. During the cognitive processing in the brain, synchronized neuronal oscillations of different frequencies occur due to feedback between neurons. Although a local damage in the brain is negative in mental operations, the general stability of cognitive functions against such damage shows that different neuronal areas can support the same function by organizing a distributed network of such areas in the brain [17, 18].

Opposite, each mental operation works locally controlled by attention that synchronizes the activity of all these areas to create representations (thoughts, images, emotions, and intentions) in WM from memories, impressions, perceptions, affects, and feelings that serve as the interface between the mind and the external environment [18, 19]. For example, the neuronal synchronization in the visual system represents image in a distributed manner over different brain regions [20].

Therefore, binding of them into a coherent representation occurs when the neurons in these areas synchronously enhance the rate of sensory spikes due to attention to features of this image [21]. In addition, neuronal activity in the auditory system synchronizes with sound rhythms [22].

All these results show the importance of spectral characteristics of temporal fluctuations for driving neuronal synchronization, highlight its sensitivity to predictable stimuli, and indicate the pivotal role of phase synchronization of oscillations in different brain regions for the working-memory functioning [23].

Thus, the phase synchronization of neuronal signals leads to coordinating spatial-temporal activity of neurons [24]. This provides precise and flexible communication between neuronal spikes and cognitive functions: information transfer, perception, motor controlling, and working memory. Therefore, the phase coherence of neuronal oscillations in the brain in the form of spike trains becomes the neuronal correlate of selective attention [25, 26].

Then, one can determine consciousness as getting representations in the multidimensional space of thoughts, visual images, emotions, and intentions for carrying out adaptive behavior. The brain implements this transformation outside the specific neurons that synchronize their own spikes with internal states as if they are independent entities [27, 28]. Such transition shows that the mental essence goes out beyond the neurons [29].

The remaining mass of brain (about 75 %) is aqueous solution. It can serve as the mental base and working memory because helical clusters of hydrogen bonds in liquid water can be activated by the mentioned neuronal oscillations and generate corresponding electromagnetic waves [13]. Their synchronization can naturally provide data processing and informational transduction in the quantum brain dynamics [30].

Indeed, protons oscillators in liquid water act as quantum systems because have coherent moving protons in helixes of hydrogen bonds. These properties can give rise to memory of frequencies and long-range effects as a phase coherence phenomenon [31]. Just the phase bears direct connection with the quantum nature of consciousness, and its coherence is a means of neuronal communication in living things [32].

The neuronal modulation bases on fundamental concept, which views cognition as synchronous electrophysiological rhythms in spatial and temporal scales. These synchronized rhythms control neurophysiological dynamics to facilitate precise and flexible communication between neurons necessary for goal-directed action and cognition. Phase synchronization is the cyclic repetition of two or more rhythmic neuronal signals with relative phase as leading neural coding motif for coordinating spatiotemporal neuronal activity [24]. The temporal correlation is versatile, economical, flexible and elegant for perceptual processes [33]. Therefore, the sensory system encodes an initial information $I_s(z,t)$ about any event as a set of short electrical impulses (~1 ms) generated into the axon of s-neuron for transmitting into the brain the spike train shown in figure. 1.

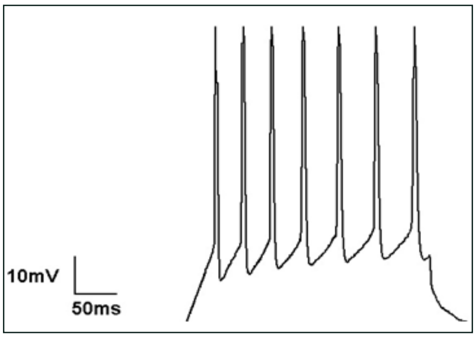

Figure 1: Information pattern $I_s(z,t)$ of sensory neuron as a specific spiking activity [34].

One can present the moving pattern $I_s(z,t)$ by the Fourier transformation [35] as a spectrum of synchronized electromagnetic waves in the form of a real sum of exponential functions in the bandwidth $(\omega_{\min}, \omega_{\max})$ of Terahertzes [36]:

$$I_s(z,t) = \sum_{\omega=\omega_{\min}}^{\omega_{\max}} a_\omega^s e^{i(\omega t - 2\pi z/\lambda_\omega + \varphi_\omega)} \tag{1}$$

where $|a_\omega^s|$ is the constant amplitude of wave with the corresponding angular frequency ω independently of time t and coordinate z along the s-axon; λ_ω is the length of this wave; φ_ω^s is its shift of phase in the s-axon, and i is the imaginary unit. These waves extend at the speed of light in water directly near s-axon and activate oscillators $\Theta_k = \mathrm{H_3O^+(H_2O)_{2\mathit{k}-2}OH^-} \leftrightarrow \mathrm{OH^-(H_2O)_{2\mathit{k}-2}H_3O^+}$ with discrete angular frequencies $\omega_k \in \{\omega_{\min}, \omega_{\max}\}$ of k pairs of protons in the double helix of hydrogen bonds with $2k$ water molecules [13]. These vibrators form 3D imaginary grating in variable points $\vec{r} = \vec{r}_{kl}(t)$ with the amplitudes $|a_k^w|$ of electromagnetic waves and compose instantaneous representations $R_s(\vec{r},t)$ expressed by the real sum of exponential functions

$$R_s(\vec{r},t) = \sum_{k=6}^{\infty} a_k^w e^{i\omega_k t} H(n_k^s(t)-1) \sum_{l=1}^{n_k^s(t)} e^{i\varphi_{kl} - 2\pi i(\vec{\mathbf{1}}_{kl}(t)\cdot[\vec{r}-\vec{r}_{kl}(t)])/\lambda_k} \tag{2}$$

Here, $H(n_k^s(t)-1)$ is the Heaviside function

$$H(x) = \begin{cases} 1, & x \geq 0 \\ 0, & x < 0 \end{cases}, \tag{3}$$

where $x+1 = n_k^s(t)$ is the variable number of Θ_k oscillators activated by neuronal signals of sensory axons; $\vec{\mathbf{1}}_{kl}(t)$ is the unit vector ($|\vec{\mathbf{1}}_{kl}(t)| = 1$) along the axis of l^{th} helical oscillator Θ_k; $\omega_k \in \{\omega_{\min}, \omega_{\max}\}$ is the discrete angular frequency; φ_{kl} is the shift of phase for l^{th} helical oscillator Θ_k out of the set $\{\varphi_{kl}\}_{n_k^s}$; $(\vec{\mathbf{1}}_{kl}(t)\cdot[\vec{r}-\vec{r}_{kl}(t)])$ is the scalar product of $\vec{\mathbf{1}}_{kl}(t)$ and $\vec{r}-\vec{r}_{kl}(t)$.

The representations (2) are a natural response of oscillators Θ_k in a 3D model of disordered diffraction grating under monochromatic plane waves with discrete angular frequencies ω_k. Then, in the general case, one can get a moving pattern $R_{sam}(\vec{r},t)$ for representations of thoughts, visual images, emotions, and intentions in the intercellular water (the basic working memory [14]) by a coherent mixture of synchronous oscillators Θ_k [37–40].

$$R_{sam}(\vec{r},t) = \sum_{k=6}^{\infty} a_k^w e^{i\omega_k t} H(n_k^{sam}(t)-1) \sum_{l=1}^{n_k^{sam}(t)} e^{i\varphi_{kl} - 2\pi i(\vec{\mathbf{1}}_{kl}(t)\cdot[\vec{r}-\vec{r}_{kl}(t)])/\lambda_k}, \tag{4}$$

in result of joint neuronal activity of sensory system (s), of attention system (a), and by impulses of the memory (m) with variable number $n_k^{sam}(t) \geq 2$ of the activated helical oscillators Θ_k in water. Their vibrations are short-term without external excitation due to their fast energy relaxation. Indeed as soon as information encoding by neurons cuts out, the water immediately goes back to its normal chaotic state as an adaptive information medium [13].

However, motivational and emotional modulations, mental imagery emerging in the working memory (in liquid water), all they can maintain activity of the synchronized (coherent) representations (4) and naturally provide informational transduction in the quantum brain dynamics [41]. They can act as a source of information strengthening the precision of sensory predictions (s) by fine-tuning frequencies of the interference filter into spectrum $\{\omega_k\}$ by myelin axons [36]. Then, one can present this source together with neuronal activity of the attention system (a) and with the brain memory (m) in the form of expanded sum of exponential functions.

$$I_{sam}(\vec{r},t)=\sum_{k=6}^{\infty}[S_k(\vec{r},t)+A_k(\vec{r},t)+M_k(\vec{r},t)] \qquad (5)$$

$$\left.\begin{aligned} S_k(\vec{r},t)&=\sum_{p=1}^{n_s}a_{kp}^{s}e^{i(\omega_k t-2\pi(\vec{\mathbf{1}}_p^s\cdot[\vec{r}-\vec{r}_p^{\,s}])/\lambda_k+\varphi_{kp}^{s})}\\ A_k(\vec{r},t)&=\sum_{p=1}^{n_a}a_{kp}^{a}e^{i(\omega_k t-2\pi(\vec{\mathbf{1}}_p^a\cdot[\vec{r}-\vec{r}_p^{\,a}])/\lambda_k+\varphi_{kp}^{a})}\\ M_k(\vec{r},t)&=\sum_{p=1}^{n_m}a_{kp}^{m}e^{i(\omega_k t-2\pi(\vec{\mathbf{1}}_p^m\cdot[\vec{r}-\vec{r}_p^{\,m}])/\lambda_k+\varphi_{kp}^{m})} \end{aligned}\right\} \qquad (6)$$

where p is the serial number of corresponding axon in the synchronized sum (5); $\vec{r}_p^{\,s}$, $\vec{r}_p^{\,a}$, $\vec{r}_p^{\,m}$ are the vectors of the beginning of corresponding axons. Then, the spectral component $a_{kp}e^{i(\omega_k t-2\pi(\vec{\mathbf{1}}_p\cdot[\vec{r}-\vec{r}_p])/\lambda_k+\varphi_{kp})}$ of coherent wave packet in specific axon $\vec{r}_p$ from the set (6) activates oscillators Θ_k in the myelin water. They can diffuse into the intercellular water and form a 3D instantaneous superposition of the variable plane waves near the axon.

$$w_k^p(\vec{r},t)=a_k^w e^{i\omega_k t}\sum_{l=1}^{n_k^p(t)}e^{i[\varphi_{kl}-2\pi(\vec{\mathbf{1}}_{kl}(t)\cdot[\vec{r}-\vec{r}_{kl}(t)])/\lambda_k]} \qquad (7)$$

This sum is the contribution of axon $\vec{r}_p$ into “information beams” of the coherent wave packet (4) with the frequency $\omega_k=2\pi\tilde{v}_w/\lambda_k$ generated by all axons from the sum (5) where $\tilde{v}_w$ is the phase velocity of electromagnetic wave in liquid water. Then, the coherent waves from (4) with the frequency ω_k produce 4D spatial-temporal interference pattern with distributed intensity depending on time.

$$|w_k^{sam}(\vec{r},t)|^2=2|a_k^w|^2\sum_{l=2}^{n_k^{sam}(t)}\sum_{l'=1}^{l-1}\cos[(\varphi_{kl}-\varphi_{kl'})+2\pi\{(\vec{\mathbf{1}}_{kl}(t)\cdot[\vec{r}-\vec{r}_{kl}(t)])-(\vec{\mathbf{1}}_{kl'}(t)\cdot[\vec{r}-\vec{r}_{kl'}(t)])\}/\lambda_k] \quad (8)$$

The coordinates $\vec{r}_{kll'}(t)$ of its main peaks are defined at $l\neq l'$ by the equation

$$\lambda_k\frac{\varphi_{kl}-\varphi_{kl'}}{2\pi}+(\vec{\mathbf{1}}_{kl}(t)\cdot[\vec{r}_{kll'}(t)-\vec{r}_{kl}(t)])-(\vec{\mathbf{1}}_{kl'}(t)\cdot[\vec{r}_{kll'}(t)-\vec{r}_{kl'}(t)])=0 \qquad (9)$$

Holographic Mechanism of Short-Term Memory

In the brain, the number of astrocytes is 50 times more than of neurons. A characteristic shape of these glial cells is star as shown in fig. 2. Many facts indicate astrocytes participate in signal transmission and information processing at cellular level and in extensive network linked by astrocyte-mediated bridges and short-term changing of intracellular calcium concentration [42-44].

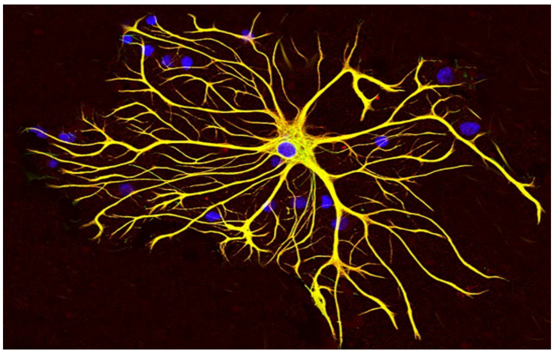

Figure 2: An astrocyte from a rat brain grown in tissue culture and colored by proteins (red and green). Both proteins are present in large amounts in the intermediate filaments of this cell, so the cell appears yellow. The blue color shows the nucleus of this astrocyte and of others [43].

Thus, astrocytes do not communicate by electrical impulses but participate in complex cognitive functions (as perception and memory). They serve in broad spatial integration and long-term temporal regulation for increasing information processing and changing cortical activity during sleeping and working memory by variation of the concentration $[Ca^{2+}]$ in the cytosol of glial cells [45, 46].

Indeed, the content of astrocytes in the brain is up to 40 % of all glia. This allows generating intercellular waves of Ca^{2+} at long distances and propagating them as the information messengers between cells using organelles that release and accumulate Ca^{2+} in response to specific cellular events. This process is possible because the intracellular normal concentration of $[Ca^{2+}]$ is low (~0.1 mM) with respect to its extracellular concentration equal to approximately 1.0 M [47]. However, only 0.1 % of cellular Ca^{2+} is free in the cytosol due to the unique ability of calcium ion interlinking by proteins [48].

One can easily increase the calcium concentration in astrocytes up to 10 mM during various cellular functions through various calcium pumps in plasma membrane as well as a large storage of intracellular compartments (endoplasmic reticulum and mitochondria). Peak of $[Ca^{2+}]$ in these cells can propagate as intercellular wave, which does not change a membrane potential and synchronously travels with speed of ~25 mkm/s through astrocytes by gap junctions between them [49]. At the same time, calcium waves in astrocytes can be random and creative, develop consciousness and conduce to the processing of thoughts spread from the point of stimulation of one astrocyte to all other astrocytes in volume much more than volume of the original astrocyte.

As mentioned above, Ca^{2+} is an ideal reagent for carboxyl in complex molecules such as proteins to buffer free Ca^{2+} in cells at low concentration. These unique properties distinguish Ca^{2+} from other cations. Therefore, nature evolutionarily has selected this cation as a signal carrier in eukaryotes and multicellular organisms. Despite the lack of a nervous system, plants have also evolved a long-distance signaling mechanism based on Ca^{2+}. Research in the past several decades has established that Ca^{2+} signals are encoded by spatial and temporal patterns of $[Ca^{2+}]$ in glial cells as a diffraction grating into 3D hologram of 4D interference pattern (8) with the main peaks (9) recorded by local fast release of Ca^{2+} from proteins [48, 50].

Indeed, intracellular calcium cation (Ca^{2+}) reversibly is bound to a protein and the law of mass action defines the equilibrium concentrations of free Ca^{2+}, unbound protein (P^{2-}), and their compound (PCa) by the reaction [51].

$$[Ca^{2+}]+[P]\Leftrightarrow[PCa^{2+}] \qquad (10)$$

having the equilibrium dissociation constant

$$K_d=\frac{[Ca^{2+}][P]}{[PCa^{2+}]} \qquad (11)$$

which is very sensitive to excitation energy (local temperature) due to the unique coordination ability of Ca^{2+} easily binding with proteins even in the presence of large excesses of other cations. Just therefore, the concentration of this information agent is maintained within cells at very low level to prevent prohibitive energy expenses to modulate its signaling function for reversible binding to proteins. Such advantage of calcium cation is caused by its large size (0.99 Å), low polarizability of $CaCO_3$ micro-particles, and their high optical absorption that facilitates their decomposition [52–54]. The last is caused by existing the interstitial energy band with the width of 0.83 eV in the band gap of $CaCO_3$ (see fig. 3) due to a strong hybridization of

Ca, C, and O with a major contribution of C atoms. In contrast, the conduction band above ~1 eV is mainly originated by Ca and O with a small contribution of the C atoms [55].

The optic transition of electron e from the first band to the second one is very efficient due to a strong absorption of electromagnetic energy $\Delta\varepsilon > 1\,\mathrm{eV}$ and luminescence according to the smallish energy difference between these bands [56]. Formally, one can represent such transition by the equation

$$\mathrm{Ca}_n\mathrm{C}_{n+1}\mathrm{O}_{3n-1} \xrightarrow{\Delta\varepsilon,\, e} \mathrm{Ca}^{2+} + (\mathrm{CaCO}_3)_{n-1}(\mathrm{CO})_2 \tag{12}$$

with releasing calcium cation Ca2+ into intracellular water and metallization of CaCO3 conduction band by deep deoxidation of nanoparticles of calcium carbonate by molecules CO.

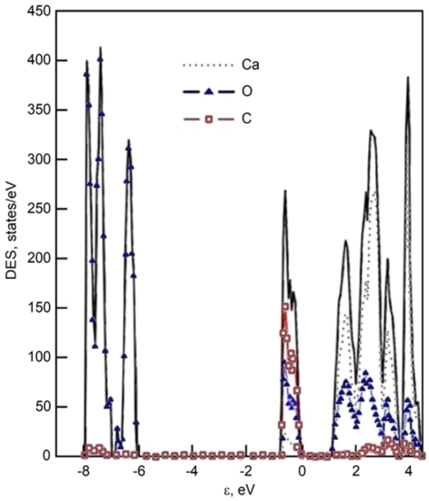

Figure 3: The density of electronic states (DES) in crystalline particles of $CaCO_3$ with the corresponding contribution of their components Ca, O, and C depending on the energy ε of electron with zero at the Fermi level in the top of the interstitial band [55].

The metallized nanoparticles are impresses from recording 4D spatial-temporal interference pattern (8) of the coherent synchronous oscillators Θ_k (4) in a short-term holographic memory, which until now is considered as hypothesis (more than half a century) [57].

In this concept, the holographic memory may be only short-term because metal states of $CaCO_3$ clusters in recording the 4D spatial-temporal interference pattern (8) can exist only for a short time. Probably therefore, sleep is necessary to consolidate this information in long-term memory.

In the holographic memory, one can present brain functioning as a distributive action of different cognitive processes. Then, any portion of the hologram can reconstruct the entire original scene [58].

Discussion of Results

One can see from (9) that the wave packet

$$w_k^{scm}(\vec{r},t) = a_k^w e^{i\omega_k t} \sum_{l=1}^{n_k^{scm}(t)} e^{i[\varphi_{kl} - 2\pi(\vec{\mathbf{1}}_{kl}(t)\cdot[\vec{r} - \vec{r}_{kl}(t)])/\lambda_k]} \tag{13}$$

is decayed over time when $\left|(\vec{\mathbf{1}}_{kl} \cdot \vec{\mathbf{1}}_{kl'})\right| < 1$ for $l \neq l'$, and the lesser scalar product, the faster this decay. Opposite, any cognitive function (for example, attention) can improve the efficiency and accuracy of perceptual information processing by selective concentrating in a part of information of the wave packet (13) with $\left|(\vec{\mathbf{1}}_{kl} \cdot \vec{\mathbf{1}}_b)\right| \to 1$ and ignore remaining information [59, 60].

This concentration can be implemented by the oscillators Θ_k in myelin water of the basic neuron $\vec{r}_b$ from (6) because these internal generators operate by means of precise activity codes of the basic neuron in extracellular water as in a material substrate of consciousness [36, 61, 62].

Additionally in the case of $\left|(\vec{\mathbf{1}}_k \cdot \vec{\mathbf{1}}_{k'})\right| \to 1$ for $k \neq k'$, we will obtain the wave packet (4) in the form of soliton [63] as a self-reinforced localized electromagnetic field, which is stable at propagation in the medium and represents the concentrated thought consisting of verbal, visual, aural, sensitive, and emotional components together with memories and intentions. Such symbiosis occurs because people cannot override their emotions that leak out nearly into everything, they do. Moreover, this occurs despite their attempts to do otherwise. Cognition is filling by emotions [64].

Thus, the cognition presents functions of synchronous oscillations in various frequency domains that are responsible for regulation of specific behavior and action. These functions encompass language and imagination, perception and planning that are embodied because the intelligent system of living things interfaces directly with the outside things by perception and action [14]. At the same time, human forms thoughts with emotions and memories that activate frontal and posterior areas from many neurons irrespective of whether the stimuli are spatial, verbal or visual objects [19].

Thanks to their phase synchronization, it is natural to store this information in short-term memory by holographic way in recording information by its distribution on the all-registration elements. Then, a partial damage of them will not lead to loss of the entire recorded 4D interference pattern (8) but only decreases its quality by loss of clearness when the reference wave illuminates the recorded pattern. This is confirmed by results of investigating the memory in rats trained to seek a food reward in the maze [65]. The removing of parts of rat brain did not eliminate the memory of the maze.

Just the holography allows describing sophisticated phenomena of perception and cognition by 1) randomization of information and 2) a spectral representation of holograms [66]. The first reflects the fact that perceptual processes depend on the expectations and the previous knowledge of perceiver as well as the information available in the stimulus itself. The second as Fourier transformation reflects the possibility to encode information about the image as a whole. Moreover, the holographic data storage is effective because of super-high storage capacity, superfast data transfer rate, compact structure, simple operation and strong compatibility [67].

The high-capacity data storage is provided by records information in the volume of the medium and is capable of recording multiple patterns in the same volume, in the parallel fashion, and with higher speed when utilizes the different combinations of coherent synchronous oscillators [4].

Thus, any hologram will reproduce the initial information by the beam needed for forming the holographic memory. It can be used for its self-retrieving by means of the recorded pattern (8), which contains frequency and amplitude of the initial information. Such technology is the ability to retain newly acquired information for short duration, demands rapid alterations and short-term protein synthesis [13, 68].

Therefore, it can be used only as holographic short-term memory (HSTM). There is reason to believe that HSTM is formed in the online training period and depends on the action of astrocytes that form highly organized domains of an extensive network with a short-term increase of intracellular concentration of calcium ions [8, 12, 69] due to reaction in the intracellular protein as recording 4D spatial-temporal interference pattern. As noted in section 2, a change of the concentration of this ion reflects the encoding of information by many astrocytes during their activating in wakeful state of the brain and lowest at sleeping [70].

Thus, sensory transducers direct a steady stream of information about the environment in processing structures that form additive memories posed on each other. These additive (associative) memories are holograms [71].

It is interesting that plants also use calcium as a messenger in transducing external signals because the concentration of its free ions does not top the level of 200 nM in the cytosol of plant cells due to the high binding of Ca^{2+} in proteins [72]. Such cellular response to different stimuli of the environment (temperature and light, touch and pathogenic elicitor, hormones and stresses including high salinity, cold, and drought) represents a universal information code in plants where Ca^{2+} signals are translated by an elaborate toolkit of Ca^{2+} with binding proteins as Ca^{2+} sensors [73–75]. Following from the above, one can assume that elements of the holographic memory are formed in plants by calcium carbonate in the key proteins (Ca^{2+} ATPases and H+/ Ca^{2+} antiporters) because there is evidence that Ca^{2+}-signatures of a previous experience are diminished upon repetitive stimulation by the same environmental cue and the signatures elicited by one environmental challenge can be modified by the contrasting one [76].

Thus, the attenuated response of $[Ca^{2+}]_c$ after repeated stimulation by various elicitors forms a part of cellular memory and the cells are able to retain the previous information. This “memory” is significant and helps the plant cells to respond better to a particular stress without disturbing the delicate balance of Ca^{2+} levels.

Conclusions

Information has physical components (data storage and transmission) and the non-physical one as a semantic exchange that has a value only in context. The translational mechanisms of the human mind, the “mutation” of ideas and the “conversations” of our social intercourse, have allowed a limited set of symbolic descriptors to evolve exponentially expanding semantic heritage [77]. However, sensory identification of this content on well-defined neurons [36] as the information pattern (1) allows expanding the physical domain of information in the form of the wave packet (4) for representations of thoughts, visual images, emotions, and intentions by the coherent mixture of synchronous oscillators Θ_k in liquid water [13].

Then, this mixture as the superposition of the variable plane waves with the frequency ω_k can produce 4D spatial-temporal interference pattern with distributed intensity (8) in the form of the self-reinforced localized electromagnetic field. It is stable at propagation in the medium and represents the concentrated thought consisting of verbal, visual, aural, sensitive, and emotional components together with memories and intentions having the main peaks of electromagnetic intensity in coordinates defined by the equation [9, 13].

Ions Ca^{2+} as the ideal reagents for carboxyl in proteins can record this interference pattern in a hologram (3D map). This hologram should be built by local electron transitions into the excited state due to a strong absorption of electromagnetic energy $\Delta\varepsilon > 1\,\mathrm{eV}$ in the main peaks of 4D spatial-temporal interference pattern with releasing calcium cations Ca^{2+} there into intracellular water and with metallization of the conduction band of calcium carbonate in proteins according to the reaction [12].

Such hologram allows reconstructing one of the diffracted waves when the other plane wave illuminates the 3D map of recorded pattern (8). This holographic map in astrocytes can present only the short-term holographic memory because excited states of metallic clusters in proteins recording the 4D spatial-temporal interference pattern can exist only for a short time. Such technology is the ability to retain newly acquired information for short duration, demands rapid alterations and short-term protein synthesis [8].

The holographic data storage is effective because of high storage capacity, superfast data transfer rate, compact structure, simple operation and strong compatibility due to recording information in the volume of the medium and recording multiple patterns in the same volume, in the parallel fashion, and with higher speed when utilizes the different combinations of coherent synchronous oscillators [4]. Holograms form a steady stream of information about the environment as additive memories posed on each other. These additive memories are associative.

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