Quantum Model for EEG

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Abstract

In the previous chapter the overall TGD based view about EEG was discussed. According to this view, the basic function of EEG is to induce cyclotron phase transitions at the magnetic body and thus to produce what might be called higher level sensory qualia identified as emotions and cognitions. In this chapter the relationship between EEG and nerve pulse patterns is discussed in TGD framework.

The relationship between nerve pulse patterns and EEG (also ZEG) is one of the basic challenges of the theory. The question is whether nerve pulse patterns could give rise to EEG patterns and vice versa, and what could be the underlying mechanisms. The deep difference between TGD and the conventional neuroscience is the presence of the hierarchy of magnetic bodies, cyclotron transitions, and MEs. This makes possible to consider alternatives for the identification of EEG resonance frequencies as resonance frequencies of nerve circuits.

Nerve pulses generate EEG MEs and the frequency of the nerve pulses determines the rate at which EEG MEs are generated rather than the frequency of EEG MEs. Pendulum metaphor suggests how spike patterns amplify EEG waves at frequencies, which appear as resonances in the autocorrelation function of the spike sequence: when the pendulum is kicked at correct half of its period its oscillation frequency remains unchanged but amplitude and phase suffer discontinuous changes. The EEG waves generated by subsequent nerve pulses tend to interfere constructively resulting in amplification if the EEG frequency corresponds to a resonance frequency of the spike autocorrelation function.

1. Generalization of the model for sensory receptor and new view about hearing

The relationship between nerve pulse patterns and EEG (also ZEG) is one of the basic challenges of the theory. The question is whether nerve pulse patterns could give rise to EEG patterns and vice versa, and what could be the underlying mechanisms. In TGD framework on ecan consider alternatives for the identification of EEG resonance frequencies as resonance frequencies of nerve circuits and dark matter hierarchy challenges the earlier speculative TGD inspired models for sensory qualia and sensory organ. An updating of the capacitor model of the sensory receptor by replacing the capacitor with Josephson junctions between sensory organ and its magnetic body must be considered. The question arises whether sensory organs define not only sensory, but also corresponding cognitive and emotional representations. The fact that nerve pulses tend to destroy the temporal coherence of cognitive and emotional representations encourages the identification of glial cells and their magnetic bodies as carriers of higher level cognitive and emotional representations. The model of hearing leads to further ideas. For instance, the transformation of the sensory input to signals propagating along axonal microtubuli could make possible to feed sensory input into brain and possibly back to sensory organs at least in the case of vision and hearing.

2. Features

Walter Freeman has identified spatially amplitude modulated synchronous but non-periodic EEG patterns serving as correlates for conscious percepts. The identification as MEs is possible and the spectrum of durations for the synchronous time patterns encourages the interpretation of these patterns as an electromagnetic realization of genetic code words. A compression of memetic code words defined by the nerve pulse patterns giving rise to abstraction and classification would be in question. The representation would be achieved by the amplitude modulation of the alpha waves by higher harmonics of alpha frequencies. In the case of hearing the contraction seems to be un-necessary and memetic code could perhaps be realized also at the level of features. This would explain the completely exceptional role of the language in cognition.

3. Synchronization

Synchronization in and between various cortical areas is known to occur with millisecond precision. Also disjoint brain regions can be in synchrony. This is difficult to understand without synchronizing agent oscillating at kHz frequency. In TGD framework magnetic body is the natural agent inducing the synchrony and MEs could induce the synchronization. Synchronization would naturally occur at the frequency corresponding to a duration of the bit of the memetic code.

4. Stochastic resonance

Concerning the mapping of EEG frequencies to nerve pulse patterns, stochastic resonance promotes itself as a basic mechanism. In bistable systems stochastic resonance allows to amplify very weak periodic signals by utilizing white noise. Stochastic resonance is known to

be relevant also at the neuronal level as demonstrated by the autocorrelation functions for spike sequences exhibiting peaks at the harmonics of the signal frequency. Neuron is however far from being bistable system, and this raises the question whether bi-stability might be present at some deeper quantal level.

5. Temporal codings

The conventional view that the information content of conscious experience is determined completely by rate coding from nerve pulse patterns does not seem plausible in TGD framework. Indeed, p-adic cognitive codes define an entire hierarchy of binary codes associated with the p-adic frequencies and frequency coding would apply only to the average intensity of the sensory input. For high stimulus intensities the duration of the bit of the p-adic cognitive codeword tends to become shorter. This is comparable to the increase of the speech rate during a high state of arousal, and conforms with the observed shift of EEG towards higher frequencies in this kind of situation. There is a lot of experimental evidence supporting the existence of various kinds of temporal codings, and these codings are discussed in TGD framework.

6. Scaling law

Scaling law provides bird's eye view about transitions which can represent conscious-to-us qualia at given level of the p-adic self hierarchy. The law relates two levels of self hierarchy corresponding to mental images associated with magnetic bodies of astrophysical size and with physical bodies, the latter with size not much larger than brain size. Scaling law assumes that self sizes L at given p-adic level k are between the p-adic length scales $L(k)$ and $L(k(next))$. Scaling law is of form $L = v/f$ and relates ELF self size characterized by ELF frequency f to the self size L and to the effective phase velocity v of the EEG wave.

Scaling law is also suggested by the experimental work with the effects of ELF radiation in water. Scaling law can be explained in terms of phase transitions transforming large h_{eff} photons to ordinary ones and vice versa. The chapter ends with the discussion about possible implications of the scaling law concerning EEG.

TGD leads to a proposal that the values of h_{eff} are such that energy spectrum of the cyclotron photons does not depend on the mass of the ion. This implies a universal energy spectrum and there are reasons for the hypothesis that biophotons result in the energy conserving transformations of dark photons to ordinary ones.

1 Introduction

In previous chapter the overall TGD based view about EEG was discussed. According to this view, the basic function of EEG is to induce cyclotron phase transitions at the magnetic body and thus allows magnetic body to share the standarded mental images produced by brain via negentropic quantum entanglement. Magnetic body would also produce what might be called higher level sensory qualia identified as emotions and cognitions. In this chapter the relationship between EEG and nerve pulse patterns is discussed in TGD framework.

1.1 Vision About Eeg

The general model for EEG relies on the idea that EEG frequencies correspond to Josephson frequencies defined by membrane potentials and provide cognitive and one might also say emotional representation of the sensory input at the magnetic body in terms of cyclotron transitions. The perturbations of the membrane potentials caused by spikes, neurotransmitters affecting alertness reducing the magnitude of the resting potential induced frequency modulations of the membrane potentials and one can say that the cell is like a singing whale with evoked potentials and nerve pulse patterns coded to the varying frequency. Song is expression of this singing but also speech involves frequency modulation as one learns by playing slowly recorded spoken language.

The scale of the frequency assignable to a given neuron is determined by the value of Planck constant. TGD inspired quantum biology and number theoretical considerations suggest preferred values for $r = \hbar/\hbar_0$. For the most general option the values of $\hbar$ are products and ratios of two integers n_a and n_b. Ruler and compass integers defined by the products of distinct Fermat primes and power of two are number theoretically favored values for these integers because the phases $exp(i2\pi/n_i)$, $i \in \{a, b\}$, in this case are number theoretically very simple and should have emerged

first in the number theoretical evolution via algebraic extensions of p-adics and of rationals. p-Adic length scale hypothesis favors powers of two as values of r.

The hypothesis that Mersenne primes $M_k = 2^k - 1$, $k \in \{89, 107, 127\}$, and Gaussian Mersennes $M_{G,k} = (1+i)k - 1$, $k \in \{113, 151, 157, 163, 167, 239, 241..\}$ (the number theoretical miracle is that all the four p-adically scaled up electronic Compton length scales with $k \in \{151, 157, 163, 167\}$ are in the biologically highly interesting range 10 nm-2.5 μm) define scaled up copies of electroweak and QCD type physics with ordinary value of $\hbar$ and that these physics are induced by dark variants of corresponding lower level physics leads to a prediction for the preferred values of $r = 2^{k_d}$, $k_d = k_i - k_j$, and the resulting picture finds support from the ensuing models for biological evolution and for EEG [K4].

This proposal will be referred to as Mersenne hypothesis and it leads to strong predictions about EEG since it predicts a spectrum of preferred Josephson frequencies for a given value of membrane potential and also assigns to given value of $\hbar$ a fixed size scale having interpretations as size scale of body part or magnetic body.

An essential assumption is that cell membrane corresponds to almost vacuum extremal so that classical Z^0 field proportional to em field is present and leads to the replacement of ionic charges with effective charges much larger than ionic charges so that that membrane voltage corresponds to a photon energy in visible or UV range and the energies of biologically most important ions span half octave. From this it follows that for given ion and membrane voltage the value of r fixes completely the Josephson frequency. For instance 5 Hz frequency corresponds to $r = 2^{k_d}$, $k_d = 47$.

Armed with this picture one ends up with a rather detailed quantitative model for EEG discussed already in [K4]. In this chapter this model is applied in more detail. Features, synchronization, stochastic resonance, temporal codings, and what I have used to called scaling will be discussed.

1.2 Features

Walter Freeman has identified spatially amplitude modulated synchronous but non-periodic EEG patterns serving as correlates for conscious percepts. The duration of features is in the range 80-120 ms and there is spatial coherence but no strict periodicity but 1 ms temporal resolution so that one can speak of spatial amplitude modulation of a temporal pattern which is same over the spatial cross section of the feature. The basic patterns recur with a period of 5-7 Hz. The sizes of features are in the range 1-2 cm.

The model of EEG and bio-photons in terms of large $\hbar$ Josephson radiation generated by cell membrane Josephson junctions predicts that the wavelength of Josephson photon with energy of visible or UV photon and scaling like $\hbar$ is dictated by the size scale of the structure generating ELF radiation with frequency scaling as $1/\hbar$. This hypothesis combined with the Mersenne hypothesis [K4] allows to build a picture about the values of Planck constant involved with the features. Also the fact the causal diamonds (CDs) of d quark and electron correspond to kHz and 10 Hz frequencies is expected to be relevant for the model.

1.3 Synchronization

Synchronization in and between various cortical areas is known to occur with millisecond precision. Also disjoint brain regions can be in synchrony. This is difficult to understand without synchronizing agent oscillating at kHz frequency.

Again kHz frequency brings in mind d quark CD. kHz Josephson frequency is second candidate. If this frequency is also realized as cyclotron frequency identifiable as a scaled up alpha frequency, the value of the magnetic field must be by a factor 2^7 stronger than $B_{end} = .2$ Gauss and thus about 2 mTesla. The model for hearing requires the hierarchy of magnetic field values so that this hypothesis might make sense.

In TGD framework magnetic body and hierarchy of Planck constants inducing the scaling of p-adic length scales is the natural agent inducing the synchrony and MEs could induce the synchronization. Synchronization would naturally occur at the frequency corresponding to a duration of the bit of the memetic code. kHz frequency corresponds to the size scale of head and makes possible the synchronization of cortical areas.

1.4 Stochastic Resonance

Concerning the mapping of EEG frequencies to nerve pulse patterns, stochastic resonance promotes itself as a basic mechanism. In bistable systems stochastic resonance allows to amplify very weak periodic signals by utilizing white noise. Stochastic resonance is known to be relevant also at the neuronal level as demonstrated by the autocorrelation functions for spike sequences exhibiting peaks at the harmonics of the signal frequency. Neuron is however far from being bistable system, and this raises the question whether bi-stability might be present at some deeper quantal level.

Nerve pulses generate EEG MEs and the frequency of the nerve pulses determines the rate at which EEG MEs are generated rather than the frequency of EEG MEs. TGD inspired model of nerve pulse assigns to the resting state of cell a propagating soliton sequence and nerve pulse corresponds to a perturbation which locally transformation propagation to oscillations. The states correspond to the states of the bistable system. The system in resting state is near criticality in the sense that rotation velocity is slightly above the minimum one so that reduction of membrane potential transforms rotation motion to oscillatory motion locally. Stochastic resonances makes itself visible in the autocorrelation function of the spike sequence and in this manner also in the membrane potential of say glial cells coupling to neurons. In fact, glial cells could play the role of listener of radio turning the knob (noise level) to tune the neurons to a particular spiking frequency.

1.5 Temporal Codings

The conventional view that the information content of conscious experience is determined completely by rate coding from nerve pulse patterns does not seem plausible in TGD framework where massless extremals suggest a coding preserving phase information and based essentially on coherent summation of perturbations of membrane voltages coming from presynaptic neurons. The superposition of contributions to membrane voltage imply interference effects. It is known that spike interval statistics allows to regenerate recognizable speech artificially by stimulating neurons electrically. The destruction of phase information while keeping spike rate as such lhowever eads to a loss of experienced emotional content of artificial spike patterns. This suggests that the interference effects code for the emotional content of nerve pulse pattern and the outcome is cognitive and emotional representation at the magnetic body.

One can consider also cognitive codes for which only spike patterns are significant and analogous to the rhythmic patterns of music. Indeed, p-adic cognitive codes define an entire hierarchy of binary codes associated with the p-adic frequencies and frequency coding would apply only to the average intensity of the sensory input. For high stimulus intensities the duration of the bit of the p-adic cognitive codeword tends to become shorter. This is comparable to the increase of the speech rate during a high state of arousal, and conforms with the observed shift of EEG towards higher frequencies in this kind of situation. There is a lot of experimental evidence supporting the existence of various kinds of temporal codings, and these codings are discussed in TGD framework.

1.6 Scaling Law

Scaling law provides bird's eye view about transitions which can represent conscious-to-us qualia at given level of the p-adic self hierarchy. The law relates two levels of self hierarchy corresponding to mental images associated with magnetic bodies of astrophysical size and with physical bodies, the latter with size not much larger than brain size. Scaling law assumes that self sizes L at given p-adic level k are between the p-adic length scales $L(k)$ and $L(k(next))$. Scaling law is of form $L = v/f$ and relates ELF self size characterized by ELF frequency f to the self size L and to the effective phase velocity v of the EEG wave.

Scaling law also suggested by the experimental work with the effects of ELF radiation in water [I1]. As discussed in [K7] scaling law can be explained in terms of phase transitions transforming large $\hbar$ photons to ordinary ones. The chapter ends with the discussion about possible implications of the scaling law concerning EEG.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. There are concept maps about topics related to the contents of the chapter prepared using CMAP realized as html files. Links to all CMAP files can be found at `http://tgdtheory.fi/cmaphtml.html` [**?**]. Pdf representation of same files serving as a kind of glossary can be found at `http://`

tgdtheory.fi/tgdglossary.pdf [?]. The topics relevant to this chapter are given by the following list.

- Bio-anomalies [?]
- Biophotons [?]
- Cell membrane anomalies [?]
- DC currents of Becker [?]
- ELF effects on brain [?]
- Quantum antenna hypothesis [?]
- Two models for cell membrane [?]
- Pollack's observations [?]
- Quantum model for nerve pulse [?]
- Quantum model of EEG [?]

2 Eeg, Meg, Nerve Pulse And Mini-Potentials

In this section the basic facts about EEG, MEG, nerve pulse and mini-potentials are briefly reviewed.

2.1 EEG

E(lectro)E(ncephalo)G(ram) is the study (or graphing) of the electric potential on the surface of the skull [J7]. EEG waves are oscillations of the membrane potential with frequency varying in the range 1-100 Hz. The amplitude of the oscillating membrane potential is typically 10^{-4} Volts and by a factor 10 smaller than postsynaptic potential. EEG waves is a vertebrate phenomenon, insect ganglia do not exhibit comparable potentials.

Four basic rhythms have been identified in EEG wave spectrum and their amplitude and frequency correlate strongly with the state of awareness [J7]. It must be emphasized that the the boundaries of frequency ranges vary by few Hz depending on author.
i) α rhythm. f = 8-13 Hz and amplitude is about 20 micro-volts. α dominates in rest but not in the sleep state. A sudden illumination by light leads to the disappearance of the α component of EEG.
ii) β rhythm. f = 14-30 Hz with amplitude about 40-100 micro-volts. β dominates during a conceptual thinking.
iii) γ rhythm. f = 30-90 Hz with. Gamma rhythm is associated with temporal coding of sensory information.
iv) θ rhythm. f = 4-7 Hz. θ dominates during sleeping without dreams. Dreams in turn correspond to β waves.
v) δ rhythm. f = 0.5-3 Hz. δ corresponds to deep sleeping without dreaming.
In general the amplitude is smaller the larger the frequency is.

EEG reflects also alarm reaction and sensory responses. Various mental disorders, brain tumors and brain injuries reflect themselves in EEG. Epilepsy, which corresponds to hyperexcitability of some part of the nervous system induces characteristic changes in the EEG pattern. EEG varies also considerably during the development. EEG appears at the age of year as occasional bursts with frequency 4-8 Hz and the adult form of EEG is established before the age of 19.

The question whether all EEG waves genuinely propagate or not is not resolved experimentally yet. It is known that alpha waves propagate and that the propagation velocity is about $v \sim 10$ m/s. There is also evidence for the propagation of 40 Hz EEG waves [J20, J15].

There is no doubt that EEG waves are deeply involved with the basic functioning of the brain but the origin and the exact function of EEG has remained a mystery. The EEG waves associated with two distant neurons are strongly correlated and this supports the view that EEG waves are related to the properties of the brain as a coherent quantum system.

2.2 MEG

This subsection gives a brief summary about magnetoencephalography (MEG). The motivation is that brain could act with MEs by acting effectively like magnetometer somewhat in the same way as SQUID magnetometer measures the magnetic fields generated by brain.

2.2.1 SQUIDs

SQUIDs [J14, J6, J32] are instruments used to measure extremely weak magnetic field in the case that the resolution needed is below the magnetic flux quantum $h/2e$ ($\hbar = c = 1$) for magnetic flux in super conductor. An important application of SQUIDs is to the measurement of the weak magnetic fields generated by brain and having strengths as weak as fT. SQUID technology has been used to detect the weak magnetic fields created by brain (10^{-13} Tesla region) and quite an impressive knowledge exists about the magnetic correlates of the brain activity in ELF region [J32].

A rough description of SQUIDs goes as follows.

1. The current in SQUID measures the deviation of the external magnetic field from a multiple of magnetic flux quanta which is reflected as a presence of a current in SQUID which creates magnetic field compensating this deviation.

2. The circuit equations can be written for the magnetic flux through SQUID and differ from the equations for RCL resonance circuit only by the presence of Josephson current non-linear with respect to the magnetic flux. If the super current is accompanied by a white noise with a correct intensity, SQUID amplifies the periodic signal in resonant manner. The stochastic resonance in SQUIDs has been demonstrated experimentally [J13].

3. SQUID consists of a closed current loop decomposing to two parts connected by thin non-super-conducting insulators. This makes possible rapid dissipation of the current to the minimal value needed by flux quantization. Small deviations from the quantized flux can be accurately measured by measuring the persistent supra current.

The basic equation governing the behavior of SQUID relies in the following simple model. SQUID is characterized by inductance L relating magnetic flux to current ($\Phi = LI$ modulo integer number of flux quanta). The potential difference around SQUID is by Faraday's induction law equal to $eV = d\Phi/dt$. SQUID can be regarded as a capacitor (capacitance C) formed by the two halves of SQUID coupled by the insulators to which one can assign internal resistance R. Insulating parts serve as Josephson junctions through which ordinary Ohmic currents run besides the Josephson current depending sinusoidally on the magnetic flux. The equation for the time derivative of the potential difference around the SQUID loop reads as

$$\begin{aligned} LC\frac{d^2\Phi}{dt^2} &= -\tau\frac{d\Phi}{dt} - \Phi - \beta sin(\Phi) - \xi \ , \\ \beta = \frac{Li_c}{\Phi_0} \ &, \quad \tau = \frac{L}{R} \ , \quad \Phi_0 = \frac{\hbar}{2e} \ . \end{aligned} \tag{2.1}$$

Here ξ denotes the white noise contribution to the Josephson current. Φ is measured in units of Φ_0 and in the equation above Φ denotes the deviation of Φ from an integer multiple of Φ_0. The equation is obviously invariant under the symmetry $\Phi \to \Phi + n2\pi$. i_c denotes the critical current for which the super current in the circuit becomes dissipative. Usually also an additional external current guaranteeing a slight over-criticality is added. If the inertial term proportional to LC can be made small, the system rapidly dissipates to equilibrium configuration. For small deviations of Φ from a valued corresponding to a quantized magnetic flux system indeed exhibits stochastic resonance [J13].

2.2.2 Magnetic fields associated with brain activity

SQUIDs (super-conducting quantum interference devices) have made it possible to measure the magnetic fields associated with the brain activity. The magnetic fields accompanying the evoked responses [J31] and the background activity of brain are in the range $10 - 10^3$ fT, in general below the level of the geomagnetic noise but above the thermal magnetic noise produced by body which

is roughly .1 fT. The frequency range is typically between 0-100 Hz in these measurements and corresponds to the frequency range of EEG. alpha rhythm at 10 Hz generates a sharp peak with a peak value about 1-2 pT, which is slightly above the level of the geomagnetic noise. Eyes create static magnetic fields of about 10^{-11} T. Heart creates an oscillatory field with somewhat stronger intensity below 10^{-10} T and with the frequency of heart beat: this field is in the intensity region of the geomagnetic noise having frequencies above .01 Hz. Sensory stimuli generate typically responses with a strength of few hundred fT consisting of oscillations which start few tens of milliseconds after the stimulus and end few hundreds of milliseconds after the beginning of the stimulus (natural time scale is .1 seconds for the duration of the magnetic response.

The simplest model for the magnetic field associated with an evoked response is as being generated by a point like magnetic dipole or a collection of point like magnetic dipoles. This means that the measured fields are essentially superpositions of radiation fields generated by dipoles. It is possible to determine rather accurately the positions of these effective dipoles in brain and thus to localize various brain functions. Also the dependence of the shape of the frequency spectrum on brain function can be studied and the distribution of the net power in a given frequency range as a function of the location can be studied. Often the ratio of the responses before and after stimulus is measured as a function of position near the surface of the skull.

The simplest hypothesis is that far-away radiation fields decompose into MEs propagating in the radial direction. In TGD based model of EEG, brain is in electromagnetic bath provided by "free" ELF MEs moving along the surface of cortex with the velocity of nerve pulse, and generating electromagnetic responses which decompose in far-away region into MEs propagating into the radial directions. In the induction region more complex flux quanta are possible. The criterion for the radiation region reads as $r \geq \sqrt{\lambda L}$ and relates the distance r between observation point and source, the size L of the source region, and the wavelength. For a point like source this criterion holds everywhere.

Dipole approximation is used in the analysis of the data to determine the position of evoked response. If λ corresponds to the wavelength of 10 Hz radiation and L is of order 10 microns, the the criterion for faraway region is roughly $r > 10$ meters and classical radiation fields measured in the region near brain are induction fields. Hence one cannot regard the magnetic fields induced by the brain activity as consisting of MEs in the measurement region. This is of course natural, since in radiation region a lot of information is lost since the system looks point like in this region.

On basis of EEG one can expect that the intensities of the magnetic fields associated with MEs providing the electromagnetic bath for brain are weaker than the intensities of the evoked fields. The intensity of ELF em radiation in delta band, which is of the same order of magnitude as the radiation associated with [F1] [F1], provides the first guess.

2.3 Nerve Pulse

Nerve pulse is the tool used by the nerve cells to communicate information to each other [I2], [J23]. Nerve pulse is generated, when the potential difference through the cell membrane, rest potential, changes from its rest value about of -80 millivolts to about -50 millivolts, the threshold potential: after this the action potential about 40 millivolts is generated and begins to propagate along the axon with approximately constant velocity varying between 1-100 meters.

For resting potential the concentration of Na_+ ions, Ca_{++} and Cl_- concentrations are much larger outside the cell than in its interior whereas K_+ concentration is larger inside the cell. Thus in absence of constraints ($Na_+ - K_+$ pump) forcing membrane potential to its resting value Na_+, Ca_{++} and Cl_- would flow to cell interior: obviously, the flow of first two tends to reduce the resting potential. K_+ in turn would would flow out of cell interior. Nerve pulse is indeed generated when Na_+ conductance increase and Na_+ rush to cell interior, the return to resting state involves temporal flow of K_+ ions to cell exterior.

The generation of the nerve pulse involves the increase of Na and K conductivity through the cell membrane so that a flow of K and Na ions through cell membrane takes place and action potential is generated. The increase of the conductivity is caused by the opening of Na and K channels. According to the classical model of Hogkin and Huxley [I2] the opening of the Na channels involves the participation of three so called m particles and one so called h particle. The rapid increase of Na conductivity is possible to understand only provided the charge of the m particles is -2 and they are electron pairs [I2]. A possible identification is as Cooper pairs.

The axon consists of two kinds of segments. The first segment having typically a length of the order of 10^{-3} meters is surrounded by a myelin shell: in this region no Na and K currents appear. The velocity of the nerve pulse is of the order of 10^2 m/s in these regions. Between the myelinated regions appear unshielded regions, where Na and K flow appears: these have length of order of 10^{-6} meters: velocity is in general smaller in these regions. The function of the unmyelinated regions is probably to refresh the nerve pulse since the dissipation causes the decrease of the height of the pulse during the propagation through the myelinated regions. The completely unshielded propagation is not economical since metabolic energy gets wasted.

Nerve pulse either ends up to a muscle or is transferred to a neighboring cell through a synaptic connection. There are two kinds of synaptic connections. Gap junctions are direct contacts between two cells and the nerve pulse is transferred electrically to the second cell. In chemical synapses the axon is separated from the dendrite of the receiving cell by a synaptic cleft having width of the order of $10^{-8} - 10^{-7}$ meters. The nerve pulse is transferred chemically via the so called synaptic transmitter substance. The nerve pulse generated in the dendrite can be either excitatory or inhibitory depending on whether the sign of the voltage difference is favorable for the generation of the action potential or not. The value of the postsynaptic potential is about 10 millivolts.

Whether the nerve pulse is generated depends on the inputs received by the nerve cell. In neural network models the output is generated provided the sum of the inputs exceeds a certain threshold value. It is not at all clear however whether the inputs correspond to potentials or something else, but closely related to postsynaptic potentials. What seems to be clear is that this quantity can have only two values corresponding to exhibitory and inhibitory inputs respectively. The nerve pulses coming from the sensory organs obey frequency coding. The stronger the sensory input the greater the frequency of the nerve pulses. The duration of the nerve pulse, about few milliseconds, sets of course a limit for the frequency of the pulses.

To summarize, the propagation of the nerve pulse is a well understood process and the interpretation of the action potential as one bit of information is attractive. The idea that nerve pulse is generated, when the sum of inputs (in some sense) exceeds some threshold value seems to be well established. The details related to the generation of the threshold potential and the relationship of the nerve pulse generation to the general state of awareness and memory content of the brain is however unclear. Also the relationship between nerve pulses and EEG waves is unclear.

2.4 Miniature Postsynaptic Potentials

Miniature postsynaptic potentials have quantized amplitude of order .5 mV to be compared with the value of the rest potential, which is roughly 100 times larger [J23]. Miniature potentials are generated in the postsynaptic neuron, when it has received nerve pulse. The quantized packets of neurotransmitters such as ACh give rise to the emission of miniature potentials. According to [J23] miniature potentials might consist of superpositions of much smaller micro-potentials of amplitude of order .3 μV generated by single neurotransmitter molecule. One could however consider also the possibility that the minimum size for the quantized packet of neurotransmitter is dictated by the requirement that the packet is able to generate the mini-potential.

3 Features And Synchronization

The model for sensory receptor discussed in the previous section is inspired by the general vision for how magnetic body controls biological body and receives information from it. The model generalizes straightforwardly to a model of features. What is new that features would most naturally be induced by W MEs affecting glial cell groups which in turn would induce the synchoronous neuronal firing.

Cyclotron phase transition at appropriate magnetic body induced by cyclotron and Josephson radiation generated by the corresponding biological body defines the feature. Both Josephson and cyclotron frequencies associated with scaled up EEG would scale as $r = \hbar/\hbar_0$. The modulated cyclotron frequency could place code a position of the representation at magnetic body representing some geometric quantity, say the distance of the object of perceptive field. The temporal modulation pattern of the amplitude of cyclotron radiation by some EEG frequency in turn would define the feature assigned at this position. One can distinguish between speech and song like features

responsible for cognitive and emotional aspects of perception. Also spatial modulation is present but temporal pattern is same at all points of feature.

Genetic and and perhaps even memetic codons with duration of.1 seconds are good candidates for the "phonemes" of speech like features. Recurring feature corresponds to a plasma oscillation with frequency below 10 Hz generated by the charge entanglement by W ME inducing exotic ionization. Ca^{2+}, Mg^{2+} and possibly also other bosonic ion waves are physiological correlates of the features.

1 kHz synchronization frequency reduces in this picture to DNA cyclotron frequency associated with the scaled up variant $\lambda B \simeq .02$ Tesla of the magnetic field $B = B_{end}/2 = .1$ Gauss assignable to the right brain hemisphere and having cyclotron frequency.5 Hz and carrying single flux quantum $h_5 = 5h_0$. Also 2 kHz synchronization frequency is highly suggestive. The dark photons of this radiation could result as DNAs drop to excited cyclotron states at the magnetic flux sheets traversing through the sequences of DNA double strands defining lines of a page of a book represented by the flux sheet. The text line has an interpretation as a supergene expressed collectively during synchronous firing.

Also fractally scaled up variants of features with duration of short term memory and realized as modulations of EEG frequencies are predicted with alpha band taking the role of 1 kHz synchronization. Scaled up variants of memetic/genetic codons would code for information now. In this case the size scale of the features would be $\lambda \times .02 = 40$ m suggesting that collective mental images involving several brains are in question.

3.1 Features

The notion of p-adic cognitive representation seems to have an impressive explanatory power. These representations are however local in the spatial degrees of freedom, and the further challenge is to understand how the p-adic codons from various points of cortex are combined to more complex features/symbolic mental images. The work of Freeman with odor perception gives valuable guidelines in this respect [E1]. The findings of Freeman suggest that neurons in a given cortical area define temporally synchronous patterns, features. The temporal synchrony would mean that all spatial points correspond to the same p-adic codon in the temporal domain. There is however an arbitrary dependence of the feature on the two transversal coordinates of the cortical surface for a given time value. Hence the situation is 3-dimensional but the third dimension is time rather than space.

3.1.1 Features as AM modulated EEG patterns

The coherence lengths for EEG inside cortex are in general much shorter than at the surface of the skull and complex patterns are encountered. In particular, synchronous cortical EEG patterns with coherence length of order 1-2 cm appear (size of Brodmann's areas). Freeman identifies these patterns as basic units, "features", of perceptual activity (the activity related to subjective experience rather than sensory input) [E1], and calls these patterns mesoscopic activity as opposed to the microscopic activity represented by nerve pulse patterns. According to Freeman these patterns are observed besides olfactory bulb also in visual, auditory and somatic cortices.

These synchronous EEG patterns have a non-periodic time dependence which does not depend on position: this would be consistent with the frequency coding of the time span of declarative memory. The amplitude is spatially amplitude modulated. The AM patterns are measured at two-dimensional surface so that the question whether the spatial amplitude modulation is 3-dimensional or 2-dimensional remains open. The patterns are recurring 2-7 times per second, which corresponds to theta band in frequency space. This conforms with the assumption that memories are coded by the same features as direct experiences and that carrier frequency is in theta range unlike for purely symbolic representations of sensory experiences for which it is in gamma range. The duration of the patterns is $T = 80 - 120$ ms.

3.1.2 How to understand the time and length scales associated with the features

The first thing to be understood are the time scales and here TGD inspired model for EEG based on the identification of EEG and bio-photons in terms of Josephson radiation generated by

cell membrane acting as Josephson function is the natural starting point. This model is made quantitative by the Mersenne hypothesis to which TGD inspired model of EEG and also biological evolution is based [K4].

1. The time scales bring in mind the causal diamonds (CDs) of d quark and electron with time scales of 100 ms and 1/1.28 ms. For u quark the time scale is 6 ms which corresponds to 160 Hz cerebellar synchrony. What is disturbing is the large relative variation of the durations. These time scales are in rest system of CD and Lorentz transform of CD scales up the time scale. The needed Lorentz boosts look however unrealistic since they would require relativistic velocities for electrons and would explain only the interval 100-120 ms but not 80-100 ms.

2. A more promising hypothesis is that the duration relates to the Josephson frequency of the cell membrane proportional to the resting potential which varies in rather wide limits: -40 mV for visual receptors and -80-90 mV for glial cells. The ratio of the neuron resting potential -70 mV to the critical potential -55 mV for firing and average resting potential -70 mV is 1.2 whereas the ratio for durations is 1.5. The Josephson frequencies of the basic biological ions for almost vacuum extremal cell membrane are modified by the contribution of classical Z^0 field correspond to half octave range and the ratio of maximum to minimum membrane voltage is is quite near to $\sqrt{2} \simeq 1.4$ not too far from 1.5. This option looks the most promising one and would predict a discrete spectrum for the durations smoothed out partially by the variation of the resting potentials.

3. kHz frequency could correspond to Josephson frequency of membrane potential inducing an additive modulation of membrane voltage in turn inducing frequency modulation of Josephson frequencies of in nearby cells. For instance, glial cells could induce this modulation. The model for EEG would suggest that also 5-7 Hz frequency corresponds to a Josephson frequency for cell membrane and thus to $r = \hbar/\hbar_0 = 2^{k_d}$ if one accepts the Mersenne hypothesis to which TGD inspired model of EEG and also biological evolution is based [K4]. This would suggest a hierarchy involving the Josephson frequencies 5-7 Hz, 8.4-12.5 Hz, and 1 kHz.

   A three-level hierarchy could be in question with the slowest frequency assignable to hippocampus, next frequency to the higher sensory areas, and kHz frequency possibly to head itself. The identification is supported by internal consistency: kHz frequency defines synchrony in the size scale of entire brain and corresponds to the p-adic length scale assignable to brain. This picture would conform with much more general hypothesis about brain as an orchestra with neurons and glial cells as instruments whose octave is specified by the value of Planck constant restricted by Mersenne hypothesis.

4. The question about interpretation of frequencies assignable to $\hbar_0$ CDs remains. One possibility is that the kHz Josephson radiation with large Planck constant decays to bunches of ordinary kHz quanta as its leaks to $\hbar_0$ page of the Big Book. Other transition would be a transformation to single $\hbar_0$ visible or UV photon having identification as a bio-photon.

One should also understand the size scale of features. Suppose in accordance with Mersenne hypothesis that Josephson wavelength define the structures as scaled up variants of the wave length assignable to $\hbar_0$ Josephson frequencies of basic biological ions, which corresponds to $k_{eff} = 163$ for 2 eV energy. This implies that 5 Hz Josephson frequency corresponds to to $k_{eff} = 210$ - a p-adic length scale, which is roughly 15 meters. 1 cm sized features would correspond to Josephson frequency of about 2×10^5 Hz rather than kHz frequency but one could argue that these features integrate to a larger structure during kHz synchrony making possible binding of mental image in the scale of entire brain. Of course, nothing prevents the presence of also 100 kHz frequency scale and for bats and sea mammals the hearing range extends up to 2×10^5 Hz [J18, J30] .

3.1.3 MEs as AM patterns representing features

The identification of massless extremals (MEs) as representations of the features is suggestive since for MEs the time dependence is same for all points in the 2-D transversal cross section. Temporal coherence in turn corresponds to the arbitrary but synchronous dependence of the field pattern on

the temporal coordinate at this cross section. Thus MEs are ideal for the communication of the information contained by features to the magnetic body.

MEs allow arbitrary direction and magnitude of transversal polarization and arbitrary time dependence which does not depend on position. 2-dimensional instead of 3-dimensional AM patterns are predicted but this is consistent with empirical data. Note that MEs in question are like light fronts going through the two-dimensional surface where the measurement is performed. One might argue that the character of MEs as topological field quanta of classical radiation means that they are not sufficiently general to model the nearby ELF fields in brain. This might be the case. On the other hand, the solution ansatz defining MEs is extremely general [K11]. In geometric optics picture this means that paths of light rays inside MEs can be also curvilinear light like curves expressible as gradient lines for a Hamilton Jacobi functional S whereas the transverse polarization is defined by a gradient of a polarization function E.

The spectrum of durations for the synchronous time patterns encourages also to consider an interpretation of these patterns as an electromagnetic realization of genetic code words. Also more general p-adic codes can be considered. A compression of the memetic code words defined by the nerve pulse patterns giving rise to abstraction and classification could be in question. The representation would be achieved by the modulation of the alpha waves by higher harmonics of alpha frequencies analogous to ripples. Essentially an interference of slow alpha wave with faster wave containing frequencies up to kHz would be in question.

In the case of hearing the contraction could take place but one can also consider the possibility that entire 126 bit memetic code is realized and that the the large number of bits codes for information relation to delicate factors like the emotional coloring of the speech. This would explain the completely exceptional role of the language in cognition.

MEs need not nor cannot be purely electromagnetic and for far from vacuum extremal MEs with vanishing classical Z^0 field classical W fields are necessarily present. W MEs as possible realizers of the generalized motor actions of the magnetic body could induce plasma oscillations and ionic waves define also candidate for the inducers of AM patterns.

3.1.4 Genetic code and odors

The interpretation of AM patterns as sub-selves representing standardized mental images is natural. The average duration of these sub-selves is of 100 ms which is the duration of the memetic codeword [K6]. According to Freeman, the time dependence of AM patterns is chaotic: this does not however mean that it is random. That also time coding is involved looks plausible because both temporal and spatial patterns of nerve pulses are crucial for the neural coding of odors [J22].

The first thing to come in mind that temporal patterns correspond to memetic code words having length of almost 127 bits ($2^{127}-1$ patterns are possible) with bits represented by a pulse or absence of it. The presence of pulse would correspond to some minimum intensity of field. The first bit would be always 1 to signify the beginning of the codon which would give 126 bits. Also a formal representation as superpositions of Fourier components with frequencies $f_n = n/T$, $n = 1, ..., 127$ with coefficients can be considered but would not be so natural than pulse representation.

There are however objections against this identification.

1. p-Adic length scale hypothesis would predict duration of 100 ms for AM patterns representing memetic code words if.1 second time scale corresponds to the time scale assignable to electron CD. Quite wide length variation for MEs is however possible and 100 ms MEs predicted by p-adic length scale hypothesis could be interpreted as resonant MEs in this picture, ELF frequency counterparts of on mass shell particles whereas other durations would correspond to off-mass shell "virtual" MEs. This interpretation is consistent with the generalization of the ideas of Jaynes [K16, K17].

2. That memetic code could be represented also in terms of MEs conforms with the computer metaphor which suggests myriads of representations of the memetic code. On the other hand, the highest frequency involved would be of order kHz and outside EEG range. Furthermore, AM patterns should represent abstraction and classification of temporal nerve pulse patterns associated with the memetic code words. The generalization of EEG to a fractal hierarchy of EEGs allows however to circumvent the objection.

The simplest thing one can imagine is that a compression of the $2^{127} - 1$ neuronal memetic codewords to genetic code words having length of 7 bits giving 127 code words occurs: in this case the the highest frequency would be in the range $58.3 - 87.5$ Hz which relates very naturally to the EEG frequency range and is above the 40 Hz band and various lower bands related to the place coding. One can argue that just as at DNA level only the 64 mutually consistent Boolean statements amongst the $2^7 - 1 = 127$ Boolean statements are realized physically.

Genetic code could be also realized as nerve pulse patterns. This option looks natural in the case of rate coding with almost random time intervals between nerve pulses. If stochastic resonance forcing the autocorrelation function of the nerve pulse pattern to have peaks at the multiples of the forcing frequency is involved, then the number of distinguishable code words would be also around 64. Also the discrete values of the pulse rate varying from 0 to 64 pulses per.1 seconds could define genetic codons.

3.1.5 Magnetic representation of the genetic codewords

Genetic code for odors is consistent with the assumption that the modulation frequencies are in the range $20 - 80$ Hz. The cyclotron frequencies of all biologically important ions including DNA are above 1 kHz so that amplitude modulations at EEG frequencies are slow.

The modulated cyclotron frequencies would naturally represent carrier waves coding for some geometric data, for instance the distance of the object of perceptive field on the sensory magnetic canvas. This prediction could be tested by looking whether the attention directed to a moving object is accompanied by a shift of some cyclotron frequencies.

EEG waves with well defined frequencies would have interpretation in terms of frequency coding by sequences of "notes" whereas chaotic EEG waves such as beta waves might be assignable to the speech like representation. For "note" representation trivial code word would correspond to a mere alpha wave modulation. alpha wave begins to dominate when eyes are closed which suggests alpha wave modulation represents "no sensory input". In the case of vision alpha wave would assign the color quale black and the mental image "darkness" to the region of the perceptive field. In the case of hearing the trivial codeword would represent the experience of silence, something different from the absence of auditory experience.

3.1.6 Data compression as frequency cutoff and threshold coding

Some comments about the compression process and about the plausibility of the representation of Boolean statements at the level of conscious experience are in order.

1. The compression process simply drops away the bits corresponding to the frequencies above 80 Hz. This kind of frequency cutoff is precisely what is carried out in quantum field theories when the effective action for low energy theory is constructed. For quantum field theorist this means functional integral over the frequencies and wavelengths above the cutoff frequency and cutoff wavelength. Thus brain would apply the counterpart of the same procedure as quantum field theorist or statistical physicist uses to build simplified models applying in time and length scales above the inverse of the cutoff frequency and cutoff wavelength.

2. The values of the EEG potentials need not be discrete to yield bit representation at the level of the conscious experience if magnetic quantum phase transition is induced only if the intensity of the oscillatory magnetic perturbation defined by ME is above certain threshold value. Threshold coding is actually what is expected since phase transitions should occur as a kind of domino effect. There is also an upper bound for the harmonics of the cyclotron frequency which can be amplified to a macroscopic quantum phase transition. This yields automatically frequency cutoff even in absence of a frequency cutoff for EEG waves.

3.2 Synchronization

Cognitive functions like perception, memory and language are based on parallel and highly distributed information processing. What brain does is the analysis of the sensory input into bits. One of the major unresolved questions of brain science is how the information these bits can be integrated to sensory percept and how coherent representational states can be established. Temporal

binding has been suggested as a mechanism making this possible. The synchronized neuronal firing has been proposed as an underlying mechanism of temporal binding inside and between various cortical areas. The assemblies of neurons firing synchronously could even define neuronal correlates for objects of perceptive field. Synchrony mechanism would apply also to motor actions and allow selection of perceptually and behaviorally relevant information. Temporal binding has been proposed by Crick and Koch as a necessary and sufficient condition for the generation of conscious percepts. It however seems that 40 Hz synchrony corresponds to generation of information.

In TGD framework the synchronously firing neuronal assemblies are excellent candidates for sub...selves. Synchrony should result from the presence of a TGD counterpart of a computer clock ticking with a frequency of order kHz associated with the memetic code.

3.2.1 Empirical evidence for kHz synchronization

Neuronal synchronization is by now a well established phenomenon (see [J10] and references therein).

1. Synchronization inside and between sensory, motor and associative areas has been established. Synchronization has been observed also inside subcortical structures such as lateral geniculate nucleus, superior colliculus and brain stem and even in retina [J10]. Synchronization has also found even between areas belonging to different hemispheres.

2. Synchronization in visual system predicts synchronization inside visual areas and between areas across large cortical distances. These predictions have been verified. For instance, two neurons fire synchronically only if they respond to the same visual object but not otherwise. It has been found that the basic criteria for the gestalt formation (such as continuity and coherent motion), shown to support by perceptual grouping, are also important for the formation of a synchrony between the neurons of the visual cortical. Synchronization has been studied also in non-visual modalities: synchronization in the olfactory systems of various vertebrate and invertebrate species has been found and both auditory and somatosensory cortex has been demonstrated to show precise synchronization. Synchronization has been observed also in hippocampus and frontal cortex.

3. Synchronization has been observed in motor areas and between areas of sensory and motor system. For instance, the study of cats performing visuomotor tasks has shown that the synchronization between visual and parietal as well as visual and motor areas occurs in those task epochs where the animal processes attentively information to direct the required motor response.

4. Synchronization seems to serve as a neural correlate for conscious percepts [J10]. For instance, in binocular rivalry, the neuronal activity in V1 does not change when the consciously perceived stimulus changes. However, highly synchronous firing is what distinguishes the perceived stimulus from the non-perceived one.

In TGD framework this would mean that the entanglement with magnetic body serving as the correlate for the directed attention would have synchronization as a neural correlate. The interpretation would be that without synchronization no coherent cognitive or emotional mental image is formed at the magnetic body.

Charge entanglement involving W MEs makes possible superpositions of several sensory percepts and state function reduction would select one of them. The possibility to build quantum superpositions of alternative percepts means metabolic economy since only single percept need to be realized in a given quantum parallel universe. The selection of percepts in binocular rivalry might be a basic example about state function reductions at the level of perception. Information processing resembling quantum computing could be realized using quantum superpositions of nerve pulse patterns. Same picture applies also to motor action. When a large number of similar systems (say sensory receptors) is involved, quantum statistical determinism guarantees reliable perception.

EEG and MEG studies demonstrate that high frequency components of sensory evoked potentials exhibit precise neuronal synchrony in the awake state but disappear in deep anesthesia [J10]. A possible interpretation is that Josephson radiation at 1 kHz frequency ceases as a consequence

of anesthesia. This conforms with the fact that anesthetes affect cell membrane. For instance, a phase transition changing the Planck constant associated with 1 kHz cell membranes by the action of anesthate could lead to the disappearance of 1 kHz frequency.

Also gamma (40 Hz) synchronization is enhanced during arousal and focused attention as well as during a conscious perception of distinct auditory events and of coherent visual stimuli during attentive visual search. Again the interpretation would be in terms of Josephson currents which get more intense or appear as a phase transition increasing the Planck constant by factor 4 for neuronal membranes with 10 Hz Josephson frequency. Note that 40 Hz Josephson frequency corresponds to Josephson wavelength of about 3 meters.

Dark Josephson frequencies and corresponding parts of the magnetic body scale like $r = \hbar/\hbar_0$ whereas the corresponding body parts would scale like $\sqrt{r}$. This gives the map of wavelengths to the sizes of the body parts suggested by the findings about water memory and which I have used to refer to as scaling law. Scaling law will be discussed in the last section.

3.2.2 Temporal binding by synchronization

The article of Engel *et al* [J10] provides an excellent representation about the development, motivations and the recent empirical status of temporal binding by neuronal synchrony. The article contains also references to the original work and the references to the results represented below can be found from this article and are not separately mentioned.

There are many reasons why for binding by synchronization. Later also empirical evidence suggesting that synchronization accompanices only the formation of percept rather than percept itself is discussed.

1. Synchrony provides the counterpart of computer clock making possible a precise presynaptic summation of the neural inputs in turn implying fast and precise and fast neural processing. Synchrony makes also possible coordinated changes of the synaptic efficacies: this is of obvious importance for the associative learning at synaptic level. Also the robustness of neural processing is implied: army does not need single man.

2. Synchronized neuronal assemblies define natural candidates for the neural correlates of conscious percepts and synchronization might be a basic mechanism of attention.

3. The information processing in brain is known to be highly parallel and distributed: for instance, there are about 30 distinct visual areas in monkey brain. Synchronization between various sensory, motor and associative areas has been proposed as a candidate for the mechanism generating coherent gestalts.

4. Synchronization has been proposed as key element for functions like learning and short term memory. Quite generally, it seems that non-synchronized brain regions are analogous to a computer without a global computer clock and thus seats of neural chaos.

5. Synchronization has been also suggested by Crick and Koch to be a necessary and sufficient condition for conscious experience to occur. From the TGD point of view and on general philosophical grounds this hypothesis seems to be too far-fetched. Rather, synchronization seems to provide the counterpart of computer clock in TGD framework feeding order in neuronal chaos. Synchronized regions define however natural correlates for sub...selves.

3.2.3 What is the dynamics of volition and thought?

The proposed simplified view leaves open some fundamental questions which basically relate to how the geometric correlate of intentional action. There are two basic questions.

1. How the dynamics of thought generation is realized?

The understanding of the feedback from the sensory (real) level to the cognitive (p-adic) level is required. More precisely, how sensory (real physics) input is transformed to cognition.

p-Adic physics as physics of cognition is a fundamental key idea of TGD inspired theory of consciousness. For long time I believed that p-adic-to-real transformations of space-time sheets realized as quantum jumps could serve as correlates for the transformation of intentions to actions

allow deeper understanding of also psychological time as a front of p-adic-to-real transition propagating to the direction of the geometric future. It turned out that the mathematical realization of this idea might involve unsurmountable challenges and the natural vision is based on adeles: both reals and various p-adic number fields would be present and cognition would be present already at elementary particle level as also the p-adic mass calculations suggest.

The original belief was that the transformation of real space-time sheets to p-adic l ones in quantum jump would correspond to the generation of thoughts. It is now clear that this hypothesis is both un-necessary and difficult to realize mathematically.

Rather, TGD Universe is adele meaning that both imbedding space, space-time, and WCW are adelic structure containing real sector and various p-adic sectors as correlates of cognition. Real space-time sheets representing classical space-time correlates of physical events are automatically accompanied by p-adic space-time sheets defining what might be called cognitive representations. Intention in turn is part of the experience of self identified as a sequence of state function reductions at fixed boundary of CD and dying when the first state function reduction to opposite boundary occurs and gives rise to a volitional act of higher level self having self as a mental image.

2. How the dynamics of volition is realized?

The idea that negative energy MEs representing signals propagating to the geometric past represent volitional acts conforms with the ZEO based view about volitional action as state function reduction at opposite boundary of CD reversing the arrow of geometric time.

Zero energy ontology allows to formulate the notion of negative energy ME rigorously. They are space-time sheets associated with CDs for which time runs in non-standard direction. In ZEO volitional action would be in a formal sense time reversal of the sensory perception with signals initiating the action propagation in time reversed direction from magnetic body to brain and eventually to the level of motor neurons.

This idea has become rather precise after the formulation of quantum measurement theory in terms of ZEO [K10, **?**, K1]. In ZEO self corresponds to a sequence of state function reductions at fixed boundary of CD changing only the situation at the opposite boundary (in standard quantum measurement theory nothing would happen to the state). This sequence gives also rise to the development of intention. The volitional action begins with the first state function reduction to the opposite boundary of CD and means that the sub-self (mental) images dies and reincarnates at the opposite boundary of CD. This picture leads to a simple answer to most basic questions and seems to be the correct one.

3.2.4 A general view about the role of synchrony

The hypothesis that synchronization is due to the presence of MEs suggests the following general view about how conscious brain functions.

1. The basic states for the various areas of brain could represent more or less chaotic neuronal activity without synchrony. During sleep primordial neuronal chaos might be realized in the scale of the entire cortex.

2. Negative energy MEs would select from the sea of cortical chaos islands of order and generate objects of perceptive field or behavior (by sensory-motor analogy one might perhaps speak of "behavioral field") realized as sub-selves. MEs would obviously feed negentropy to the neuronal primordial chaos and generate macro-temporal quantum coherence and thus sharp sub-selves lasting for a sufficiently long time to contribute significantly to the contents of consciousness and behavior (note the analogy with a social group: very short-lived member does not contribute significantly to the development of the social group).

3. The question whether there exist non-neuronal correlates for consciousness is definitely settled in this framework: they do exist and correspond to both p-adic and real charged and neutral MEs both in the sense of electro-weak and color interactions and the synchronous firing of neurons provides a direct experimental evidence for these correlates visible already at the primary sensory areas.

4. The mesoscopic feature level visible in EEG and reflecting the synchrony MEs could represent a higher abstraction level in which memetic code words are compressed to the genetic code.

This view combined with the general vision about the realization of the various representations represents a reasonably coherent vision about how magnetic body controls brain. There remains of course challenges even at the level of principle.

3.3 40 Hz Synchrony And Negentropic Entanglement

If one accepts the vision about life as something in the intersection of real and p-adic worlds 40 Hz EEG synchrony can be interpreted as a correlate for the generation of negentropic entanglement (see **Fig.** `http://tgdtheory.fi/appfigures/cat.jpg` or **Fig. ??** in the appendix of this book) between cortical neurons. Before proposing this interpretation let us first describe the experimental findings of a finnish neuroscientist Antti Revonsuo [J2] challenging the simplest view about the role of 40 Hz synchrony in binding.

3.3.1 Findings

The interpretation for 40 Hz EEG frequency inspired by the binding hypothesis is as a synchronizing frequency necessary for the generation of unified percepts. This hypothesis has been studied using auto-stereograms [J2]. There was no detectable difference in the power spectrum at 36-44 Hz range in the situation when auto-stereogram was experienced as a set of random dots as compared to the situation when it was perceived as a coherent, symmetrical gestalt. The situation was same also in 8-13 Hz and 13-20 Hz beta bands. The finding is consistent with the place coding hypothesis.

On the other hand, when the conscious percept was transformed from a random set of points to a coherent gestalt, there was a detectable increase in 40 Hz power in the occipital and right posterior sites for EEG electrodes in a time window 500-300 ms before the unified percept was reported. There could be also some time lapse between the unified percept and the report about it but probably this cannot explain the entire lapse. No increase of power in beta bands was detected: this might be due to the fact that the widths of the measured bands are much wider than the widths of the narrow sub-bands reported masked by other EEG activity according to [J28]. Note that in the model for a hierarchy of EEGs based on dark matter hierarchy beta band correspond to data communicated to the magnetic body [K4].

That the change in activity is associated with the emergence of a new percept suggests that the temporary increase of the EEG power could be assigned to the communications of the forming percept to the magnetic body.

3.3.2 Interpretation in terms of generation of negentropic entanglement

A fresh view about what really happens during 40 Hz synchrony came with the realization that negentropic entanglement is possible in the intersection of real and p-adic worlds. The generation of negentropic entanglement between two sub-selves means that the corresponding mental images are fused [K19, K10]. The process is experienced by the fusing sub-selves as an expansion of consciousness whereas consciousness is lost when when bound state entanglement is generated. Also the meditative states begin with enchanged 40 Hz activity and the interpretation would be same. Quite generally, the generation of negentropically entangled neuron groups could be a correlate for the emergence of a new idea or a new holistic pattern emerging from a chaos. Synchronous firing would be a natural correlate for the synergic state resulting in this manner. The paradoxical looking reduction of the oxiditative metabolism associated with 40 Hz firing could be seen as a signature of reduced dissipation when dissipating ensemble of neurons forms a single quantum coherent system.

What could then be the interpretation of the 300-500 ms time scale and synchronous firing in TGD framework?

1. If one assumes that only brain is involved, one must answer whether the new percept emerges after such a long time period. One would naively expect that negentropic entanglement immediately gives rise to the percept. Negentropic entanglement however means that a quantum superposition of several alternative percepts is involved. In the beginning the new percept is present with only small probability so that one would only know that the moment of heureka is quite near (this is indeed the experience that one has) and in the final situation it dominates but not completely since it requires conscious effort to preserve the percept.

2. Also magnetic body should be involved in TGD framework. The natural question is "Why this synchronous neuronal firing?". The natural answer would be that it allows to communicate the new percept as a consequence of a generation of negentropic entanglement to the magnetic body. The frequency scale of 40 Hz corresponds to a time scale of 25 milliseconds and corresponds to a length scale involved is about $.75 \times 10^7$ m, a good candidate for the size of the part of the magnetic body involved. This time scale is much shorter than 300-500 seconds. If the layer of the magnetic body in question corresponds to the fundamental 100 millisecond time scale assignable to electron as is natural in case of sensory percepts, the time lapse could be essentially due to the communication. If one takes the time scale literally the value of Planck constant which is about 3 to 5 larger than its standard value would suggest itself. Of course, the development of the percept from a fuzzy inkling to the final heureka could involve several communication loops between brain and magnetic body so that the interpretation as a lapse due the slowness of communications need not be inconsistent with the first interpretation.

3. The time scale 300-500 ms could characterize the duration of negentropic entanglement but this is not necessarily the case since negentropic entanglement would be un-necessary after the percept has been represented symbolically so that one knows what is lurking behind the chaos.

4 Stochastic Resonance And Brain

This section begins with the review of the notion of the stochastic resonance. Also its applications to neuronal systems are reviewed. With motivations coming from conceptual difficulties of the proposed neuronal models, a reduction of the stochastic resonance to the quantum level, which is assumed to control the functioning of bio-systems, is developed by refining the quantum model for nerve pulse generation by specifying the interaction with MEs. Another key idea described in detail in [K3] is that bio-systems correspond to flow equilibria for ions in the many-sheeted space-time with atomic space-time sheets having the role of a controlled system and super-conducting space-time sheets taking the role of the controlling system. The possibility that MEs generate by stochastic resonance soliton sequences associated with Josephson currents, is discussed.

4.1 Stochastic Resonance

Background noise is usually seen as a mere nuisance in communications but under certain circumstances it can in fact improve, rather than hinder the performance. The notion of stochastic resonance [D4] was originally put forward by Benzi and collaborators [D2] in seminal papers where they study the problem of the periodically recurrent ice ages. The same suggestion was raised independently by C. Nicolis and G. Nicolis [D5]. The planetary glaciation sequence has a period of about 10^5 years which happens to be same as the period of the planetary gravitational perturbations with a typical time scale of 10^5 years inducing an extremely small (of about .1 per cent) periodic variation of the solar constant which as such cannot explain ice ages. The system is modelled by a bistable potential in which the two potential wells represent the ice-covered Earth and the normal climate. Short term climate fluctuations are modelled by white noise and if the intensity of the white noise is correct, the weak periodic variation of Earth's temperature is amplified to a synchronized hopping between cold and warm climates.

The notion of stochastic resonance has been considerably generalized to include a number of different mechanisms. The unifying features are the increased sensitivity to small perturbations and phase locking for an optimal noise level. Stochastic resonance like features have been reported also for autonomous systems. Also the quantum version of the stochastic resonance taking into account quantum tunnelling has been studied. Stochastic resonance has been also generalized to coupled (that is higher-dimensional) systems and to excitable systems allowing only single stable state and meta-stable states. The interested reader can find references to the rich literature about stochastic resonance in [D4].

Stochastic resonance has been verified for a wide variety of system such as Schmitt trigger, bistable ring laser, electron paramagnetic resonance, and super-conducting quantum interference devices (SQUIDs) [D4]. An especially important application is to neuronal systems [D6].

4.2 Basic Model For Stochastic Resonance

The archetypal model of stochastic resonance involves a one-dimensional system equivalent with a particle with mass m moving in a double potential well

$$V(x) = -ax^2/2 + bx^4/2$$

under a friction force $\gamma dx/dt$ proportional to velocity, a weak periodic external driving force $A(t) = A_0 sin(\Omega t)$, and a random force which can be modelled as a white noise $\xi(t)$ with vanishing mean and correlation function

$$\langle \xi(t_1)\xi(t_2) = 2D\delta(t_1 - t_2) \ .$$

Here the parameter D characterizes the noise level.

The noise could be also a more general colored Gaussian noise with ultraviolet frequency cutoff. The fluctuation forces cause transitions between the potential wells with a rate given by the Kramers rate [D3]:

$$r_K \ = \ \frac{\omega_0\omega_b}{2\pi\gamma} exp\left[-\frac{\Delta V}{D}\right] \ . \tag{4.1}$$

Here $\omega_0^2 = V''(\pm x_m)/m$ is square of the frequency of small oscillations at the bottom of well and $\omega_b^2 = -V''(x_b)/m$ is an analogous quantity estimated at origin which correspond to the maximum of the potential. ΔV denotes the height of the potential barrier separating the two minima.

If a periodic spatially constant force is applied to the particle, it induces a periodic variation in the shape of potential. At a given well the minimum of the potential barrier occurs periodically with frequency Ω and if the particle hops to second well when barrier height is minimum it experiences minimum height barrier in the second well after a half period. If the white noise is such that the rate r_K is twice the frequency Ω:

$$r_K \ = \ 2\Omega \ , \tag{4.2}$$

the rate for the jumps between potential wells is synchronized with the periodic variation of the external force. One can understand this relationship intuitively on basis of the previous simple observations.

Stochastic resonance is manifested as a phase locking of $x(t)$ to the external force and as maximum of the average amplitude as function of the parameter D characterizing the noise level when the resonance condition is satisfied. In linear response theory, which is appropriate when the condition $A_0 x_m << D$ is satisfied, the approximate expressions for the average amplitude and phase shift read as

$$\begin{aligned} \overline{x} &= \frac{1}{m\gamma\omega\omega_b}\frac{A_0\langle x^2\rangle_0}{D}\frac{2r_K}{\sqrt{4r_K^2+\Omega^2}} \ , \\ \overline{\Phi}(D) &= arctan(\tfrac{\Omega}{2r_K}) \ . \end{aligned} \tag{4.3}$$

$\langle x^2\rangle_0$ denotes the variance for the unperturbed noisy system. The distribution of time intervals between hoppings has characteristic peaks at $T = 2\pi/\Omega$ and its integer multiples.

The phase averaged power spectral density $S(\omega)$ defined as the Fourier transform of the correlation function $\langle x(t+\tau)x(t)\rangle$

$$S(\omega) \ = \ \int_{-\infty}^{\infty} exp(-i\omega\tau)\langle x(t+\tau)x(t)\rangle d\tau \ , \tag{4.4}$$

exhibits delta peaks at frequencies $(2n+1)\Omega$ superposed to a noise background $S_N(\omega)$ whereas even multiples of Ω correspond to dips. This reflects the reflection symmetry of the double potential well. The heights of the spectral spikes behave as A_0^{2n} and since the periodic perturbation is

assumed to be weak, it is possible to restrict the consideration to the first spike ($n = 1$). In the linear response theory one obtains following expressions for the noise density $S_N^0(\omega)$, total spectral density $S(\omega)$, and signal-to-noise ratio:

$$\begin{aligned} S_N^0(\omega) &= 4r_K \frac{\langle x^2 \rangle_0}{\sqrt{4r_K^2+\Omega^2}} \quad , \\ S(\omega) &= \frac{\pi}{2}\overline{x}(D)^2 \left[\delta(\omega-\Omega)+\delta(\omega+\Omega)\right] + S_N(\omega) \quad , \\ SMR &\equiv 2\left[lim_{\Delta\omega\to 0}\int_{\Omega-\Delta\omega}^{\Omega+\Delta\omega} d\omega\right]/S_N(\Omega) = \pi(\frac{A_0 x_m}{D})^2 r_K \quad . \end{aligned} \tag{4.5}$$

4.3 Stochastic Resonance And Neuronal Systems

During the last decade stochastic resonance has become a well accepted paradigm in the biological and neurophysiological sciences [D6]. This despite the fact that neuronal systems are excitable systems with only single stable ground state and a short-lived excited state with lifetime of order millisecond which can be short as compared to the typical driving frequency. The simplest models effectively assume that neuron is a bistable system. The most obvious functions of the stochastic resonance in neuronal systems are the amplification of weak periodic signals (such as the noise produced by a predator) and temporal coding (say in auditory nerve).

In TGD framework the natural question is whether the stochastic resonance really occurs at the neuronal level or at a deeper control level. If the latter option is correct, the simplest paradigm of bistable system might be enough to model the system.

4.3.1 Empirical evidence for stochastic resonance in neuronal systems

The encoding of acoustic information on the primary auditory nerve of mammals has been studied for a half century. It has been known that, in contrast to the conventional theory, the information about the frequency of the stimulus is coded also to the inter-spike distribution of the spike sequence. This correlation between neuronal input and output is known as phase locking in neurophysiology and presents one particular form of temporal coding [J26]. It is needless to emphasize that various forms of temporal coding and its reverse process are absolutely crucial in TGD based model of qualia.

Longtin, Bulsa and Moss [J16] observed that inter-spike interval histograms of periodically stimulated neurons of a cat exhibit a remarkable resemblance to the return time distributions of a periodically driven noisy bistable system with Gaussian noise for which correlation function decays exponentially:

$$\langle \xi(t)\xi(t')\rangle = \frac{D}{\tau_c} exp\left(-\frac{|t-t'|}{\tau_c}\right) \quad . \tag{4.6}$$

Return time is defined as the time for the system to be kicked from one well to another and back again. With only one fitting parameter it was possible to achieve an excellent agreement. Neuron is definitely not a bistable system and this forces to ask whether the assumption about the underlying bistable system might make sense at some deeper, controlling level.

Moss and collaborators studied also the behavior of the mechanoreceptor cell of a crayfish [J9] by stimulating it with an input consisting of a sum of single tone and noise. The spectral properties of the action potentials were analyzed, yielding a power spectrum typified by a background noise plus sharp peaks at multiples of the frequency of the stimulus. Also signal-to-noise ratio was studied and was found to resemble the shape of the corresponding curve for a bistable system although the resonance peak as function of the noise intensity does not decrease so fast as for stochastic resonance in a bistable system.

Stochastic resonance has been demonstrated to occur also in the hair cell of cricket [J24]. In this case the function of the stochastic resonance is to help the detection of a weak periodic signal (a coherent motion of air created by say predator) from a huge noisy background.

4.3.2 Models of stochastic resonance based on standard neuroscience

Several phenomenological models reproducing the stochastic resonance for inter-spike interval distributions have been proposed.

1. Neuron firing and Poissonian spike trains

The simplest model is based on the idea that neuron emits uncorrelated sharp spikes at random times [J17] The spiking rate $r(t)$ is however sinusoidally modulated and the specification of $r(t)$ defines the model. One can express the phase averaged spectral density $S(\omega)$ for the spike train as a sum of frequency independent white noise term $\overline{r}$ and sum of delta peaks at frequencies $\omega = n\Omega$:

$$\begin{aligned} S(\omega) &= \overline{r} + 2\pi \textstyle\sum_{n=1}^{\infty} |r_n|^2 \delta(\omega - n\Omega) \ , \\ r_n &= \tfrac{1}{T} \textstyle\int_0^T r(t) exp(-in\Omega t) dt \ . \end{aligned} \tag{4.7}$$

The rate theory for noise-induced barrier crossing in the presence of a periodic external force suggest the generalization of the Kramers rate formula for the hopping rate r_D between potential wells to

$$r(t) = \nu \times exp\left[-\tfrac{\Delta V}{D} - \tfrac{A_0 x_m}{D} cos(\Omega t)\right] \ . \tag{4.8}$$

Here ΔV is the barrier height in absence of forcing, D is noise strength, A_0 is the amplitude of the periodic driving force, and the scale factor x_m characterizes the position of the potential well. The pre-factor ν depends on the details of the process. This formula should make sense for sufficiently low frequencies Ω (adiabatic approximation).

By calculating the Fourier transform of $r(t)$ one obtains for the signal to noise ratio defined as the ratio

$$SNR = \tfrac{2\pi r_1^2}{\overline{r}} \simeq \tfrac{\pi x_m^2 A_0^2}{D^2} exp\left(-\tfrac{\Delta V}{D}\right) \ . \tag{4.9}$$

Signal-to-noise ratio shows a behavior characteristic for stochastic resonance. The comparison with the data from the mechanically modulated mechanoreceptors of a crayfish shows qualitative agreement with this prediction although the decrease of SNR for large noise levels is overestimated by this model. The parameterization of $r(t)$ is based on the assumption that system is effectively bistable: this is of course not true at the neuronal level.

3. Integrate and fire model

Integrate and fire model assumes that the input of the neuron consists of a spike train $i(t)$ (cortical neurons) or a continuous signal (sensory neurons) [D4], [J8]. The membrane voltage $u(t)$ is obtained by integrating the input $i(t)$ represented as a current through the membrane. By representing cell membrane as a capacitance C and resistance R the equation of motion for the membrane potential reads as

$$\frac{d}{dt}u = -\frac{1}{\tau_{RC}}u + \frac{i(t)}{C} + \frac{\xi(t)}{C} \ . \tag{4.10}$$

Here one has $\tau_{RC} = RC$. Gaussian white noise with a zero mean is assumed. In the case of a perfect integrator ($1/RC = 0$) the Fokker Planck equation for the probability distribution for the potential values as a function of time reads as

$$\frac{\partial P(u,t)}{\partial t} = -\left[i_0 + A_0 cos(\Omega t)\right] \frac{\partial P(u,t)}{\partial u} + D\frac{\partial^2 P(u,t)}{\partial u^2} \ . \tag{4.11}$$

The equation states that probability is conserved for the flow in the phase space defined by u and velocity variable $\partial_t u$. Initial values are $P(u = b, t) = 0$ at threshold stating that particle is absorbed at $u = b$. The rate for crossing is given by $r(t) = dP(u = b, t)/dt$.

The distribution function for the inter-spike intervals is given by the mean-first-passage time distribution ρ which is essentially the probability $P(b \to b)$ that the random walk in the external driving force leads from the point $u = b$ representing the threshold for nerve pulse generation ends up for the first time back to $u = b$. This probability can be calculated using Wiener integral for a particle performing random walk in the external force field defined by the periodic perturbation at the half-line $u \geq b$. The first passage distribution shows a multi-peaked structure with higher peaks suppressed exponentially. For a sufficiently large stimulus the peaks are located at $t_n = nT$, $T = 2\pi/\Omega$. The heights of the peaks decay exponentially. The peaks heights run through a maximum as a function of the noise strength D.

This model is unrealistic for several reasons. For instance, the phase of the sinusoidal stimulus is reset after every spike so that the coherence of the stimulus is eliminated.

4. Neuron firing and threshold crossing

One can improve the integrate and fire model by allowing the resistance to be finite and modify it by assuming that the phase, rather than being reset, does not change at all in the emission of a nerve pulse [D4], [J27]. One can solve $u(t)$ from the previous equation in absence of the noise explicitly by assuming that the amplitude of the driving force is so small that the threshold is not crossed in the absence of the noise. This gives at large values of time

$$u_\infty(t) = i_0 R + \frac{A_0 R}{1 + \Omega^2 \tau_{RC}^2} sin(\Omega t - \phi_{RC}) \quad . \tag{4.12}$$

Here one has $tan(\phi_{RC}) = \Omega/t_{RC}$. The presence of the ohmic current induces the reduction of the threshold to $b - i_0 R$. Gaussian colored noise is assumed to cause the crossing and the generation of the nerve pulse, which is for simplicity idealized with a delta peak.

The problem of calculating the rate for the threshold crossing can be formulated mathematically as a random walk on half line $u \geq b$ in presence of an external force using a semiclassical approximation for the Wiener integral over all paths. This means a functional integration over small perturbations of an unperturbed solution to give the probability $P(t)$ that an arbitrary path of the particle leads to the threshold $u = b$ during time interval t. The rate $r(t)$ for the threshold crossing is given as $r(t) = dP(t)/dt$. In [J27] $r(t)$ the threshold crossing rate is estimated for a colored Gaussian noise and one finds stochastic resonance also now. The formulas are not reproduced here: the interested reader can find them in [D4].

This model effectively assumes that the membrane potential is driven by an external driving force and that the phase of the membrane potential is not appreciably affected by the emission of the spikes. This is consistent with the idea that there is some deeper control mechanism giving rise to the stochastic resonance and that neural level is only the controlled level.

4.4 How Neuronal Stochastic Resonance Could Be Realized At Quantum Level?

There is no doubt that neuronal systems exhibit stochastic resonance. The excellent fit of the inter-spike interval distribution by a return time distribution for a bistable system in the case of the auditory nerve of a cat suggests that genuine bistable system might be somehow involved. It is however not at all clear whether it is possible to understand the emergence of the stochastic resonance without leaving the framework of the standard Hodgkin-Huxley theory.

1. Neuronal systems are excitable media rather than bistable systems and it is not at all obvious whether excitable media allow stochastic resonance.

2. The time scale for the return of a neuron to the resting state is of order milliseconds and can be much shorter than the period of the driving external force. Thus the intuitive picture behind stochastic resonance need not make sense at neuronal level. Perhaps one should turn the attention to a more fundamental level, and interpret nerve pulse activity as a result of quantum control with the bistable system to be identified acting as a control system.

The previous model for sensory receptor applied to hearing suggests that perhaps a plausible model of stochastic resonance could be obtained by including besides neurons also a system able

to represent sensory input as evoked potentials giving rise to cognitive and/or emotional representations in the manner discussed. This system could be sensory receptor such has hair cell or an aggregate of glial cells (the possible role of astrocytes for brain functioning has been discussed earlier in [K8]).

As found, periodic signal and white noise affecting bistable system are the key factors in the stochastic resonance. Astrocytes would induce the spiking of nearby neurons whereas spike activity and/or microtubular input would generate perturbations of the astrocyte membrane potential which might perhaps allow idealization as white noise. In the case of sensory receptor the source of white noise could be neuronal and/or microtubular back projection.

The basic prediction is that the frequency of the stochastic resonance has an exponential sensitivity to $1/D$, where D characterizes the intensity of the white noise assumed to be generated by the neural activity. The noise level should correlate with the average firing rate if neurons are responsible for the white noise. Also microtubular white noise could be induced by the neuronal firing. The intensity of the white noise should be under automatic or conscious control so that important frequencies could be spotted out from the sensory input by "tuning to the correct wavelength" by varying the level of (possibly neural) noise. The reduction of the resting potential generates higher level of spontaneous firing so that the level of alertness would correlate directly with the value of the spotted frequency for neural noise option.

In the case of sensory organ the oscillatory signal would be contained in the sensory input represented as an evoked potential. In the case of astrocytes the oscillatory signal would be contained to the sensory signal mediated by microtubuli inducing oscillating evoked membrane potentials V. For hearing V could represent electric counterpart of a sound wave with a well-defined frequency. V would modulate Josephson frequency since it would appear as an additive component in membrane potential besides membrane voltage.

Stochastic resonance should transform a frequency associated with the sensory input V to a peak frequency in the autocorrelation function for spikes so that spike interval distribution would reflect the frequency of the sensory input and its harmonics. For sound frequencies sufficiently below kHz this is easy to understand since the membrane potential oscillates in the same rhythm as the sound wave. Above kHz frequency rate coding does not make sense.

If neuron is Josephson junction it could serve as a system allowing bistability and stochastic resonance. Josephson junctions are indeed known to allow stochastic resonance [D1] but this situation applies to small oscillations of the phase difference Φ over the junction with regions $\Phi > 0$ and $\Phi < 0$ identified as the analogs of the two potential wells. The two state should correspond to firing and non-firing states of the neuron and the model for nerve pulse and EEG identifies the resting state as a state in which Josephson junction is mathematically analogous to a rotating pendulum but with so low a rotation velocity that small reduction of the rotation velocity leads to an oscillation mode. The reduction of membrane potential below the critical value for nerve pulse generation would reduce the rotation velocity and would reduce the rotation to oscillation and induce nerve pulse. The return to the original state would be automatic. The transition between the two states (no firing induced or firing induced) would be induced by the neuronal noise with Kramer rate equal to two times the frequency of the periodic stimulation.

Astrocyte system could control the level of the neural noise acting like a listener of the radio turning the knob to find the station. The position of knob would be replaced with the level of the neural noise. A feedback loop between the two systems would make possible to find the optimal noise level. Glutamine-glutamate cycle for astrocyte-neuron interaction could make this system possible.

5 Temporal Codings

An impressive evidence exists for the temporal coding [J26] despite the fact that the dominant view has for long time been that rate coding is all that is involved. The vision about MEs as quantum holograms suggests that nerve pulse patterns are coded to the pulse patterns of the light-like current along ME. The hierarchy of Planck constants and the model of EEG in terms of Josephson radiation suggests a quite precise realization for the brain as orchestra metaphor with frequency modulation used as the basic tool to represent information.

5.1 Basic Structure Of EEG In TGD Framework

It is known that EEG decomposes to sum of two parts: the part consisting of relatively few fundamental frequencies and their harmonics and the quasi-continuous part, "noise". Both the amplitudes of harmonics and fundamental frequencies fluctuate.

Josephson current of particular ion is proportional to $sin(Q_{eff}\int(V_0+V_1+V_{noise})dt)$, V represents fundamental frequency, V_1 to spike contribution, and V_{noise} to the neural noise. The current and thus also Josephson radiation can be decomposed by basic trigonometric formula to the sum

$$sin[Q_{eff}\int(V_0+V_1)dt]\times cos[Q_{eff}\int V_{noise}dt]+cos[Q_{eff}\int(V_0+V_1)dt]\times sin[Q_{eff}\int V_{noise})dt] \ .$$

The integral over the noise is small so that one has $cos[Q_{eff}\int V_{noise}dt]\simeq 1$ and $sin[Q_{eff}\int V_{noise}dt]\simeq Q_{eff}\int V_{noise}dt$ giving a representation which might be consistent with the observations.

What is new that the noise level is amplitude modulated. If the frequency of the stimulus is high as compared to the Josephson frequency, the neuron automatically performs variation of the noise level in order to find ideal noise level for stochastic resonance during the period. This is like automaticized periodic turning of the knob back and forth to identify the correct wave length.

The fluctuation of the frequencies would be due to the fluctuation of the membrane potentials and the fluctuation of the amplitudes due to the intensity of Josephson currents.

Due to the fact that the neuronal membrane is near to the threshold for firing the treatment of the noise as something small is justified only if the amplitude of the noise remains low enough. Indeed, stochastic resonance becomes possible and leads to neuronal firing in the rhythm defined by external perturbation.

5.2 TGD Based Overall View About Temporal Codings

The following is a summary about TGD inspired attempt to build an overall view about temporal codings.

5.2.1 Brain as orchestra metaphor

1. The prevailing neuro-scientific view is that the resonance frequencies of EEG can be assigned to resonances in neural circuits. In TGD inspired picture nerve circuits are not necessary and there are reasons to believe that this kind of resonances are too wide to explain kHz resonances frequency or even sharp EEG resonances. Rather, EEG frequencies are reduced to Josephson frequencies assignable to the effective cell membrane potential and are proportional to the membrane potential. The energies of corresponding dark photons are in visible and UV range and their decay gives rise to either EEG photons or bio-photons. The spectrum of frequencies is dictated by the spectrum of the preferred Planck constants and the scale of spectrum depends on ion and value of membrane potential.

   Singing whale provides a good metaphor for how EEG codes for the information carried by neuronal activity since the small perturbations of the membrane potential and even nerve pulse induce frequency modulation of the fundamental frequency. Depending on the character of perturbation the situation corresponds to singing or speech (when recorded speech is represented slowly it becomes clear that also now frequency modulation is involved). If preferred Planck constants come as powers of to dictated by Mersenne hypothesis then also brain as orchestra metaphor becomes surprisingly precise.

2. The interference of perturbations of the membrane potential from presynaptic cells means that membrane potentials are summed up so that rate coding is only partial description and it is indeed known that emotional aspects of speech cannot be produced using only this information. At the level of brain an attractive hypothesis is that the signals from neurons are transferred to glial cells as small perturbations and communicated to the magnetic body therefrom.

   "Note" and "phoneme" representations (song and speech) defining emotional and cognitive representations would be realized as temporal patterns of evoked potentials at the level of

sensory receptors and glial cells. Genetic or even memetic code could be realized in case of speech like representations. The hierarchy of Planck constants allows very complex hierarchy of frequency modulations induced by the interaction of nearby neurons and glial cells and by spike activity. The aggregates of glial cells could be in the role of highest level in the representational hierarchy. Orchestras have soloists and one can wonder whether soloists are now analogs of Grandma neurons or groups of neurons or glial cells producing especially intricate frequency modulation patterns. Features include also spatial modulation patterns.

4. That neural transmitters and modulators control resonance frequencies in neural circuits is also a natural hypothesis in neuroscience context. In TGD framework neural transmitters and modulators can affect average firing rates and also the intensity of neural activity by controlling the resting value of the membrane potential and sensitivity for the firing. Glial cells might also participate on this control in accordance with idea that they take the role of conductor.

5.2.2 Codings

Several kinds of codings reducing basically to frequency modulation can be considered and also here orchestra metaphor helps to imagine various options. First kind of could would rely on nerve pulse patterns and the perturbations induced by these.

1. The cortical representation of audible frequencies above 1 kHz requires representations using evoked potentials of glial cells and the transfer of sensory input as Josephson radiation along sensory pathway and/or as acoustic/electric oscillations of microtubuli to the glial cells is a necessary prerequisite of this representation. The cortical feedback via outer hair cells expands the audible frequencies above 1 kHz in the case of mammals and makes possible the representations of EEG frequencies as frequency modulations of the Josephson frequencies for the aggregates of glial cells. This representation would emerge in frontal lobes.

2. Also the coding of (say sound) frequencies based on spike interval statistics is supported by experimental findings and is possible for frequencies below 1 kHz. This representation might be induced from the above discussed representation at the level of glial aggregates and sensory receptors via stochastic resonance. Periodic signal and white noise affecting bistable system are basic elements of stochastic resonance. Astrocytes induce the spiking of nearby neurons whereas neuronal noise affects astrocytes. Suppose that astrocytes receive also sensory signals mediated by microtubuli inducing oscillating evoked membrane potentials V of astrocytes.

   Stochastic resonance would transform V to a peak frequency in the autocorrelation function for spikes. Glutamine-glutamate cycle for astrocyte-neuron interaction could define the neuron-astrocyte interaction with astrocytes taking the role of radio listener tuning the neurons to a specified wavelength by using the level of noise as a knob.

3. Rate coding defines the roughest coding and would relate to the perturbations of resting potentials of glial cells induced by spike patterns. For the rate conding the temporal pattern of spikes does not matter.

4. The proposal that nerve pulse patterns could realize genetic or even memetic code is one of the earliest TGD inspired conjectures. The time scales of CDs assignable to electron and d quark provide additional support for this idea. In the proposed framework the realization would be in terms of frequency modulation patterns induced by spikes and in principle could realize genetic code by allowing maximum flexibility. 10 Hz alpha rhythm would specify uniquely the time intervals containing the genetic codons. The discrete value of the firing rate expressed as the number of spikes per period of 10 Hz alpha wave would realize genetic codon as an integer $n \leq 63$. One can however argue that memetic code looks somewhat too rigid a representation to be used by a musician.

   The hint about what might be involved comes from the fact that music is also recorded and nowadays the recordings are digital. Millisecond and 100 ms time scales characterizing nerve pulse activity and features correspond to the standard value of $\hbar_0$. Maybe genetic and memetic code representations result via the interaction between large $\hbar$ space-time sheets

with space-time sheets with the same time scale of CD but different Planck constant and p-adic prime. $\hbar_0$ space-time sheets would represent the lowest level of this interaction hierarchy. Mersenne hypothesis indeed relies on this interaction transforming dark weak bosons to their lighter counterparts with a lower value of Planck constant. This interaction would produce something analogous to a binary representation of music piece as a CD able to regenerate to the original experience to some degree and might be of special relevance for long term memory and cognition. The model for the sensory receptor provides a concrete representation for how this transformation could take place [K4].

5.2.3 Objections against temporal coding can be circumvented in TGD framework

There are several objections against temporal coding which all involve in an essential manner the relationship between subjective and geometric time. If t=constant snapshot represents the reality, as believed in standard quantum physics, the inclusion of frequencies and temporal patterns does not make sense except phenomenologically. In TGD approach the problem disappears since quantum states are quantum histories. The quantum jump sequence represented by a nerve pulse pattern corresponds to subjective time development as hopping between geometric time developments characterized by EEG patterns. Each nerve pulse affects slightly the EEG pattern.

This raises the question whether EEG record represents the EEG spectrum associated with the space-time surface generated in the last quantum jump or whether it is some kind of an average over the EEG spectra over quantum jumps. If the recording of EEG is completely automatic process, it is updated in every quantum jump and represents EEG at the space-time surface generated in the last quantum jump and, rather paradoxically, is therefore changing all the subjective time. The experiments of Radin and Bierman support this view [J4]. Also the experiments related to the timing in active aspects of consciousness suggest that the EEG of the past changes in the interval which is a considerable fraction of second [J3] and long time scale compared to the millisecond time scale of nerve pulse patterns.

5.3 As If Time Really Mattered

Not only physics, but also neuroscience is plagued by the tensions caused by the erratic identification of the subjective time with the geometric time. There are two views about how nerve pulses patterns code for the sensory data. The first, and still dominating, view is that firing frequency codes for the intensity of the sensory experience. Competing view is that temporal patterns of nerve pulses code for the sensory information (fore a review see [J26]).

In TGD framework first approach can be seen as emphasizing the dynamics with respect to subjective time whereas temporal patterns with respect to geometric time are neglected. Both memetic code and spectroscopy of consciousness rely crucially on temporal patterns with respect to geometric time. Hence these approaches are in conflict with the standard view about time. The approach based on temporal coding in the framework of the classical field theory forgets the dynamics with respect to subjective time and concentrates on the dynamics with respect to the geometric time. One however ends up with philosophical paradoxes circulating around time-frequency uncertainty relation: it is difficult to understand how communication is possible at all in deterministic classical world.

Quantum jumps between quantum histories view fuses both of these approaches to a more general unified description. The excellent review article "As if time really mattered: Temporal strategies for neural coding of sensory information" by Peter Cariani about temporal coding will be referred to several times in the following discussion. This article also reviews the difficult problems of frequency coding approach [J26].

5.4 Rate Coding Contra Temporal Coding

Rate coding is the dominating view about the representation of the sensory data in neuroscience and most neural net models rely on this approach. The approach is based on three assumptions.

1. Rate coding is the whole story: the average rate of firing defined by an interval with duration of ten to few hundred milliseconds codes the intensity of the sensory input.

2. Everything is ultimately coded into spatial patterns and spatial rate differences somehow code all relevant sensory information. The standard coding relies on rate-place scheme: average firing rate increases along one-dimensional axis. In TGD this hypothesis is generalized in the sense that brain is assumed to build miniature virtual world model of the space-time and that magnetic transition frequencies code for the values of the spatial and temporal coordinates.

3. A further element is connectionism: in some manner the architecture of the neural pathways gives rise to qualia associated with it.

Geometric time is completely absent from rate-coding based model of brain. This is what mere quantum statistical determinism neglecting the notion of quantum history and the physics of the classical em fields associated with them would leads to. In particular, EEG is mere epiphenomenon in this approach. What makes the situation so problematic is that neural net models describing information as purely spatial patterns can always reproduce the observed behavioral patterns by brute force by introducing a sufficiently complex neural network. From modelling perspective this might be nice but need not have anything to do with how Nature does it. The situation has been however changing during the last decade. The observations about the correlations of EEG patterns with conscious experience, the successes of neurofeedback [J25], the realization of the potential importance of 40 Hz coherent oscillations in binding, and a rigorous experimental proof for the temporal coding of odors [J22], are forcing the view about brain as a system in which classical em fields are important.

Temporal coding provides alternative and much more general approach but, as already noticed, has also its problems which relate to the fundamental confusions about the relationship between geometric and subjective time. There is empirical evidence for the occurrence of temporal coding in virtually every sensory system [J26] . One can imagine many temporal coding mechanisms but the most important ones rely on spike interval statistics and latency-place representations.

Temporal coding provides solutions to the three basic difficulties of the rate coding paradigm: contrast degradation problem, pattern recognition problem and multiple object problem or "superposition catastrophe". Contrast degradation implied by the saturation of the firing rates at high stimulus intensities. Good example of pattern recognition problem is related to the perception of pitch. Same pitch can be generated in very many manners: by monochromatic sound; by a sequence of clicks; or even by a superposition of multiples of fundamental frequency not involving the fundamental frequency itself as in the case of periodic pitch phenomenon. It is very difficult to understand how the stimulus coded to a spatial representation based on mere firing rates could even contain the information needed to decode the pitch. For temporal coding these problems are almost trivial [J26]. Superposition catastrophe is identity problem for different objects of perceptive field. For instance, how it is possible to identify the sound of a familiar person in large crowd of people or distinguish transparent object from a nontransparent one, and how it is possible to group sensory inputs to form objects of perceptive field? In temporal coding approach common temporal structures allow to define objects of perceptive field: for instance, points of perceptive field moving in the same direction or behaving synchronously belong to the same object.

5.5 Spike-Statistics Coding In TGD Framework

The idea about temporal coding by spike-interval distributions or by some other distribution of time scales associated with the nerve pulse patterns (say intervals between spike bursts) resonates strongly with the spectroscopy of consciousness idea.

5.5.1 Spike-interval statistics and EEG

Spike interval statistics is rather successful. For instance, the information provided by single nerve fiber is enough to reproduce recognizable speech. The correlation of EEG with contents of consciousness experience could be understood by the effect of spike sequences on EEG waves. In the standard framework EEG waves are assumed to be excited by neuronal loops at subcortical level.

Several experiments described in [J26] however suggest that spike-interval coding could occur also at subcortical level which supports the view that the necessary information is present already at the level of sensory receptors as indeed assumed in TGD inspired model. In TGD framework nerve

pulse patterns would stimulate frequency modulations of EEG waves with frequencies identified as Josephson frequencies and since EEG waves transfer information about sensory data to the magnetic body, the success of the spike interval statistics can be understood.

5.5.2 Multiplexing and broadcasting

Multiplexing means the possibility of transmitting several messages simultaneously as superpositions of different harmonics. In TGD context this means frequency modulations coming as superpositions of this kind and are coded to the EEG waves directly. In the case of small oscillatory perturbations one can apply the product formula to the Josephson current to obtain an approximate linear superposition at the level of Josephson current.

Josephson radiation should affect also neurons and glial cells - in particular regeneration of sensory quale could be possible [K4] - and the attractive possibility is that resonance like situation occurs when the period of the oscillatory perturbation co-incides with the average Josephson frequency of the receiving cell and leads to a selection of only this particular contribution from the signal.

This mechanism makes also possible broadcasting is possible: the same message or superposition of messages can be send as Josephson radiation propagating along axonal flux tubes or larger flux quanta at which axonal flux tubes are topologically condensed. This allows mass communications and depending on Josephson frequency of receiving cell, only part of the message is received.

This kind of communication mechanism -if it involves radiation at larger space-time sheets- would provide a mass media type communication mechanism depending only weakly on the connectivity of the neural circuitry. Brain as a neuron society metaphor indeed supports the view that besides neural chatting also mass communications are important. In particular, mass communications might be involved with the synchronous firing of the neuron groups. Combined with the possibility of simultaneous superposition of various data in EEG pattern, broadcasting mechanism replaces the rather poorly defined problem of computing the representation of the external world from spatial firing rate patterns by direct experiencing. The computational problem is transformed to understanding how experience of, say, motion is represented by magnetic quantum phase transitions. Of course, the very assumption that computation gives rise to conscious experience is completely ad-hoc hypothesis.

5.5.3 The role of transmitters and modulators in generating correct EEG frequencies?

The recovery periods for neurons vary from milliseconds to seconds. Recovery time can be affected by neurotransmitters as well as neuro-modulators. Many axons [J26] show triphasic recovery period consisting of refractory period, super-excitable phase and depression phase. Clearly, neuron favors inter-spike intervals for which the next spike arrives in neuron during super-excitable phase. Many-levelled hierarchy of neuronal pathways could thus serve as a sequence of sieves selecting preferred frequencies. Emotions are known to affect strongly the information processing in brain but not to alter the information content and peptides as molecules of emotion expresses the importance of these molecules as correlates of the emotional state.

Josephson radiation is absent during recovery period. During the refractory period the Josephson frequency would be higher, during refractory period low, and depression phase presumably higher again. This would allow to code information about the state of the neuron in terms of the pitch of the neuronal song.

Neurotransmitters and neuro-modulators control among other things the value of the resting potential. Besides small scalings of the resting potential also phase transitions changing the value of Planck constant and leading to a new octave could take place. Neither of these changes afffects the information but could code for the emotional state. For instance, alpha and 40 Hz bands could relate by this kind of scaling and the TGD inspired model for EEG during sleep assumes that a phase transition increasing the value of Planck constant by a factor of two occurs twice [K4]. It is known that "hippocampal theta frequency" varies in wide limits [J5] and that its value correlates with the state of arousal [J29]. This could be due to both $\hbar$ changing phase transitions and smooth change of the resting potential.

5.5.4 Resonant generation of complex motor activities?

There is also the fascinating possibility that a characteristic EEG pattern induces complex self-organization patterns giving rise to the basic building blocks of motor actions or even patterns of them. If this is really the case, then characteristic EEG patterns could serve as names for self-organization processes. This idea is of course not new and is expressed eloquently already by Ernst Mach [J26] .

Multiplexing and mass communications based on the selective receival by resonance mechanism indeed makes possible for single temporal pattern to carry very complex superposition of EEG frequencies with each frequency coding for a particular spatiotemporal position in the virtual world of brain and exciting neuron in that particular position and leading to to a generation of a complex spatiotemporal pattern amplified to motor action by puppet in string mechanism.

5.6 Applications Of Spike Interval Coding

Spike interval statistics codes information in the temporal pattern. This information can be information about the temporal or spatial pattern of the sensory stimulus (audition, vibratory sense) or about the non-geometric quale (this might be the case in the case of color vision, tastes and odors).

Empirical data support following type of spike-interval coding. The dominating time interval ΔT in the spike sequence codes for the heard frequency below kHz: $f = 1/\Delta T$ in the case of audition. The intensity of experience is measured by the ratio of the power in dominant interval to the power in non-dominant intervals [J26]. This relationship holds true generally. This code gives frequency coding by averaging.

The nice feature of temporal coding mechanism is the possibility of multiplex coding: same nerve pulse pattern can contain simultaneously several messages represented by spike patterns which are mutually orthogonal with respect to the inner product defined by Fourier transform. For instance, information about color, shape and temporal pattern of illumination might be coded as a superposition of nerve pulse patterns. In the following some well established examples about this mechanism [J26] are discussed.

5.6.1 Hearing

Hearing involves both spatial coding of frequencies in the sense that special points of cochlea are especially sensitive to frequencies around the center frequency. This is not however the whole story. Rather, it would seem that this frequency serves only as a carrier frequency for amplitude modulated messages generated by the pattern of nerve pulses. The spike sequences for nerve fibers specialized to a given center frequency contain spike intervals which code for various qualities of sound like pitch, timbre and phonemic identity. Rather remarkably, the spike distribution of single nerve fiber contains enough information about speech to make possible speech recognition [J26] .

One problem related to the pitch quale is that nerve pulse rates are able to code only for the frequencies considerably below kHz and one must understand the coding of frequencies above kHz. Coding of the frequency by the modulation frequency of Josephson radiation provides a solution to the problem. One could even assume that there is a resonance in the sense that the modulation frequency of the frequency equals to the frequency itself [K12] so that the Josephson current decomposes into harmonics of the fundamental frequency. This would mean that EEG patterns would be analogous to harmonics sounds produced by music instruments. Of course, also non-harmonic sounds can be considered.

In the phenomenon of periodic pitch superposition of the harmonics of fundamental frequency, which is not itself present in the superposition, generates experience of pitch at the fundamental frequency. Periodic pitch has also visual counterpart which can be understood as coding of the visual textures along lines to temporal patterns by scanning. Periodic pitch can be understood if one assumes coding of the temporal patterns to spike patterns. The point is that any superposition of Fourier components not containing constant term is periodic function with a period determined by the fundamental frequency and must have at least one zero in the period since the integral of this function vanishes and must therefore change its sign at least once in the period. Thus sensory stimulus vanishes at least once during the period which means that threshold crossing occurs

periodically and generates spike train. This periodicity in turn implies that also EEG contains the fundamental frequency.

In TGD framework also the feedback from cortex via outer hair cells to the inner hair cells is needed to generate fundamental frequency as an artificial auditory input.

Two visual/auditory/tactile stimuli are experienced as separate if the time interval between them is longer than 25 ms/.01 ms/5 ms. For hearing the time interval is by a factor 1/100 shorter than the millisecond time scale of nerve pulse which suggests that nerve pulse patterns cannot code for the high frequency part of the auditory stimulus. The representations of the auditory stimulus as evoked potentials at hair cells and glial cells inducing frequency modulations of Josephson frequencies would resolve the problem.

One cannot avoid the temptation to understand these time scales in the framework provided by Mersenne hypothesis involving the Planck constants $r = 2^{k_d}$ with preferred values of k_d and the time scale hierarchy assignable to CDs. 25 ms corresponds to the CD time scale (secondary p-adic time scale) $T(125)$, 6.25 ms corresponds to $T(123)$ and to the time scale of CD assignable to u quark and .012 ms to $T(112)$. The values of k_d for these scales come from $T(k_d) = 2^{k_2}1/f(2\ eV)$ are $k_d \in \{45, 43, 35\}$. They are all odd whereas the allowed values of k_d are even for the most stringent form of the Mersenne hypothesis. The corresponding p-adic length scales are 5.12 m, 2.56 m, and 32 cm, which corresponds to the size scale of head.

5.6.2 Tactile senses

Humans can perceive vibrations applied to skin in the range $5 - 1000$ Hz. The so called rapidly adapting receptors code for 5-100 Hz frequency range whereas Pacinian corpuscle receptors code for 30-1000 Hz. There is evidence that this ability relies on or at least involves spike statistics coding. The temporal patterns of the vibratory stimulus are evident in the temporal discharge patterns of all units at all stations in the ascending somatosensory pathway. In TGD framework the spike patterns would reflect the deeper coding in terms of glial evoked potential patterns.

It is known that the ordering of the inter-spike intervals is disrupted by jitter along neural pathway to cortex. Note that the loss of information about temporal ordering is not important for our sensory experience which is temporal average over quantum jumps over time interval of at least .1 seconds as suggested by the fact that temporal resolution of sensory experience is about .1 seconds. If the time separation between visual, auditory, or tactile stimuli is above 20 ms, their temporal ordering can be perceived correctly. It could be however that the reaction to the sensory input is associated with some lower level self and that at our level averaging over longer time scale occurs.

Spike interval codes has also been reported for pain, touch, temperature and nociception (for more details and references see [J26]). These modalities are highly emotional which suggests that the temporal interference patterns of Josephson radiation code for the emotional content.

5.6.3 Chemical senses

Odor discrimination relies on spatiotemporal coding of odors [J22]. The facts about olfaction and gustation does not fit well with the hypothesis that connection structure of the neural pathway somehow codes for the quale. This hypothesis requires that the connection structure should be more or less static. Both taste buds and olfactory neurons have limited lifespans. Cells of taste bud move from center to boundary during the life cycles and are innervated by different axons during their life cycle. In TGD framework these problems disappear.

Taste discrimination experiments [J26] have demonstrated that electrical stimulation using the spike patterns stimulated by odorant reproduce the emotional expressions following the perception of the real odor. When temporal pattern is changed by keeping the firing rate same, emotional response disappears. This is consistent with the assumption that "emotional" representations experienced by us are realized at the level of glial cells and that neuronal spike patterns are enough to excite the frequencies involve with these representations. Second type experiments demonstrate that electrical stimulation of an individual taste bud generates taste experience. This would suggest that the frequency giving rise to taste quale is excited automatically by the sensory stimulus and that each cell of taste bud generates it own primary taste.

5.6.4 Vision

In the case of vision there is psychophysical evidence for the temporal coding of color, texture and form. Color sensations can be produced using achromatic temporal patterns. Any color can be induced by the appropriate pattern of luminal changes. Benham's top is a famous device used to achieve this [J1]. Also electric stimulation of retina can directly induce color sensations. In TGD framework the color sensation in the case of Benham's top should result from the back projection from glial cells to the sensory receptors induced by the achromatic temporal pattern communicated to glial cells and would involve genuine generation of photons which could be also dark photons. The stimulation would take place by dark photons with energies in visible region but frequencies much lower than those of ordinary visible photons: 80 Hz frequency associated with retina is a good candidate for this frequency (this frequency corresponds to a dark p-adic length scale of 1.8 m).

Also ordinary visible photons could be transformed to dark photons before the arrival to the photoreceptors. It is known that photoreceptors are obscured by three or four coats of neurons. This has been traditionally represented as an example of not so intelligent design. One should be however rather cautious before making this kind of statements. It has turned out that these cells act as optical fibres [J12]. One can however still wonder why this complex manouvre is needed. The possible answer is that in this manner communications from both brain and external world to retina are optimized. Optic fibres could also induce the leakage of these photons to dark space-time sheets.

In TGD framework color qualia could be seen as coding spatial gradients of the illumination at a particular wavelength (in consistency with the color constancy phenomenon) to subjective experience. The saccadic motion of the eye would code a spatial change in the illumination to a subjecto-temporal gradient represented by the increments of appropriate color quantum numbers in quantum jump. This phenomenon is related to the color sensations stimulated by suitable frequency patterns of achromatic illumination [J26]. What would happen that some colors present in the achromatic illumination would be amplified more than others. How precisely the coding of spatial illumination gradients to color qualia occurs is a challenge for TGD approach but it seems obvious that classical color gauge fields accompanying always classical electromagnetic fields must be an essential element of this coding.

Scanning and saccadic motion suggests itself as a fundamental mechanism generating at neuronal level temporal maps of the surface texture. Each line of the perceptive field scanned by the saccadic motion could give rise to spikes at those moments when the line is crossed by the saccadic line. Neighboring neurons would in turn code the direction of the line to the direction of a line in space-time-plane: line would be like space-time orbit of particle. There is empirical evidence for multiplex coding of information about visual form and color (for more detail and references see [J26]). Also information about changing illumination seems to be coded into spike-statistics.

5.7 Latency-Place Representations

Latency-place representations use relative time-of-arrival differences to code information about the intensity of the sensory stimulus. Since latency typically decreases with intensity, the contrast degradation problem is circumvented. As absolute latencies decrease, so do the variances of latency distributions. Latency differences can be amplified more centrally by lateral inhibition since the impulses can excite inhibitory units which can inhibit regions surrounding the region with the shortest latency. This mechanism might be involved with the generation of space-time sheets representing objects of perceptive field. Variants of the latency-place representation can be involved with vision (motion perception), electroception, auditory, somatosensory, olfactory and gustatory systems.

Co-incidence detection is basic mechanism related with the formation of latency-place representations for position or direction. There is evidence that pyramidal neurons in cortex apply co-incidence detection [J26]. In the case of hearing, which is the most studied case, co-incidence detection occurs in brain stem. In many vertebrates, inter-aural time differences are used to deduce the azimuthal direction of the sound source at frequencies above kHz whereas at lower frequencies phase differences between waves entering into separate ears are used for this purpose. The general mechanism uses pathways from corresponding positions of right and left ear to an array

of co-incidence detectors in brain stem such that the length difference for the pathways varies linearly with the array coordinate. Only that part of array fires for co-incidence for which the delay caused by the length difference between right and left pathways compensates the time lapse between signals to separate ears. The time difference for the arrival times of the signal to two ears is thus coded to spatial coordinate and this coordinate represents information about azimuthal angle characterizing the direction of the sound source.

It is interesting to notice that music metaphor reflects itself also at the level of brain anatomy [J26]. Brain resembles piano in that distances along axes coding different temporal or spatial frequencies depend logarithmically on frequency ratios: this guarantees the invariance of the sensation with respect to the scaling of frequencies. It might have also something to do with the hallucinatory states in which objects of the external world are perceived as gigantic or miniature sized: perhaps hallucinatory state leads to anomalous frequency-scales for some objects of the perceptive field.

In TGD the comparison of parallel supra-currents representing sensory inputs to be compared makes possible co-incidence detection at quantum level. When two identical supra currents flowing in parallel super conductors and forming Josephson junctions enter at same time they are in the same phase, resonant Josephson current is generated and wakes up sub-self giving rise to mental image about co-incidence and also generates nerve pulse activity giving rise to further experiences.

5.8 Do Brain Areas Correspond To Particular EEG Resonance Frequencies?

The scaling law of homeopathy inspires the guess that the information processing hierarchy, which starts from the primary sensory organs and contains besides sub-cortical nuclei also primary, secondary, etc... sensory areas, corresponds to a hierarchy of increasing EEG resonance wavelengths. This is consistent with the idea that primary, secondary and higher sensory areas of the cortex correspond to the periods of the periodic table in increasing order such that gamma band corresponds to the primary areas. Similar hierarchy should be realized at the motor areas.

This hierarchy should be realized dynamically by resonantly amplifying the EEG MEs with fundamental frequencies near the resonance frequency associated with a particular brain area. Neural circuits generating nerve pulse patterns, whose autocorrelation function contains the resonance frequency, could form a part of the mechanism. Alfven resonance could be even more important. If the magnetic flux loops associated with the magnetic body of a given brain area have a particular length L, one expects that the ELF MEs passign around the magnetic loop acting as a wave guide are amplified, when the fundamental frequency of the ELF ME satisfies certain resonance condition. This passage might involve several reflections but one might hope that only single curvilinear ME parallel to the magnetic flux loop acting as an Alfven wave guide is needed. In this case the length L of the magnetic flux tube would correspond to the resonance frequency $f = c/L$.

The generalization of this argument to the case of super-symplectic resonance frequencies would suggest the following scenario.

1. Primary sensory areas correspond to tertiary excitations of $k = 5_2^3$ algebra with the fundamental frequency of 40 Hz to primary excitations of $k = 251$ with fundamental frequency of 28 Hz. It is also possible that $k = 83_3$ excitations with frequency 56 Hz are associated with primary sensory areas and subcortical areas.

2. Secondary sensory areas correspond to secondary excitations of $k = 127$ with fundamental frequency of 10 Hz, average frequency in alpha and fundamental frequency associated with memory.

3. Tertiary association areas turn correspond to $k = 2^8 = 256$ with fundamental frequency 5 Hz belonging to theta band.

4. Unimodal association areas correspond to $k = 257$ with fundamental frequency of 3.5 Hz, the upper end of delta band.

5. Multimodal association areas would correspond to secondary excitations of $k = 131$ with fundamental frequency .63 Hz.

Of course, one could shift the positions of p-adic length scales along cortex but the assignment of 40 Hz to primary sensory cortex suggests that the identification could be correct. The mirror mechanism of long term memories suggests that an analogous hierarchy is realized at much lower frequency scales in terms of MEs and magnetic flux loops.

6 Scaling Law

Scaling law provides bird's eye view about transitions which can represent conscious-to-us qualia at given level of the p-adic self hierarchy. I ended up with the scaling law much before the realization that sensory representations could reside outside the brain and have same sizes as EEG MEs. The hypothesis that scaling law relates the sizes of the magnetic flux tube structures outside the body serving as a magnetic canvas to the sizes of the sensory representations inside brain implies that the view about hierarchy of magnetic body becomes rather quantitative. The scaling law has several forms and the latest of them is based on the hierarchy of Planck constants.

6.1 Various Forms Of Scaling Law

Scaling law relates two levels of self hierarchy corresponding to mental images associated with magnetic bodies of possibly astrophysical size and with physical bodies, the latter with size not much larger than brain size. Scaling law assumes that self sizes L at given p-adic level k are between the p-adic length scales $L_e(k)$ and $L_e(k(next))$. Scaling law is of form

$$L = \frac{v}{f} = \frac{v}{c}\lambda \ , \tag{6.1}$$

and relates ELF self size characterized by ELF frequency f (wave length λ) to the self size L and to the effective phase velocity v of the EEG wave.

With the discovery how non-episodal/declarative long term memories could be realized, came the realization that the scaling law could also relate the sizes of magnetic loops involved with positive frequency MEs propagating with sub-luminal effective phase velocity v along magnetic flux tubes and negative frequency MEs propagating with light velocity along much larger flux loops. Quite generally, it would seem that it is magnetic structures associated with positive and negative energy MEs, whose sizes are related by the scaling law.

The input from the work of Cyril Smith [I1] led to a variant of the scaling law stating the existence of imprinted frequency pairs (f_h, f_l) such that the presence of f_h implicates the presence of f_l and vice versa and satisfying

$$\frac{f_h}{f_l} \simeq 2 \times 10^{11} \ . \tag{6.2}$$

Also other values for the ratio can be considered. Scaling law in this form is discussed in the chapters [K7] and [K8]. One can interpret this scaling law in terms of $L = v/f_l$ law if one identifies the ratio of frequencies as velocity $v = f_l/f_h$.

The hierarchy of Planck constants leads to a further development in the understanding of the scaling law. For dark matter hierarchy the scaling law relates the time scale defined by Josephson frequency f expressible as

$$\begin{aligned} f &= r f_0 \ , \ L = \frac{\sqrt{r}}{f_0} = \sqrt{r}\lambda \ , \\ r &\equiv \frac{\hbar}{\hbar_0} \ . \end{aligned} \tag{6.3}$$

The second form of the scaling law corresponds to

$$\frac{f_h}{f_l} = \sqrt{r} \tag{6.4}$$

with $r = 4 \times 10^{22} \simeq 5 \times 2^{75} = .944 \times 2 \times 10^{11}$. The error is 6 per cent. Note that the value of Planck constant would correspond to a ruler and compass integer but would be more general than allowed by Mersenne hypothesis. The imprinting process associated with the water memory would correspond to phase transitions changing the value of Planck constant. One of them transforms large $\hbar$ dark photons to ordinary photons with same energy having interpretation as bio-photons and also the reversal of this transformation is possible. Second one transforms large $\hbar$ photons to bunches of photons of generalized EEG photons with the same frequency and probably does not have reversal.

If one assumes also the first form of the scaling law, one can conclude that there is a velocity parameter given by the expression

$$\frac{v}{c} = \sqrt{\frac{1}{r}} \ . \tag{6.5}$$

This velocity could have several interpretations. It could correspond to the velocity of nerve pulse conduction, of propagating EEG wave, or of Ca^{++} wave. The velocities of the latter waves vary in extremely wide range. If EEG corresponds to Josephson radiation then the effective velocity of EEG wave could correspond to the disturbance of the propagating soliton sequence induced by the resting potential, which is most naturally at rest in the rest system of the soliton sequence. Hence the propagation of EEG wave could be interpreted as the conduction velocity of the solitons sequence or equivalently that of the nerve pulse.

If this interpretation is correct, the value of the Planck constant assignable to a given neural pathway are glial cell cluster could be measured. Nerve pulse velocities vary in the range 1-100 m/s and increase with the radius of axon. One would have $r \in \{2^{43}, 3 \times 2^{55}\}$ and $r \simeq 10^{14}$ would correspond to 5 Hz EEG frequency. The corresponding frequency range would be 80 Hz-.032 Hz. The latter scale corresponds to.51 minute period for the generalized EEG. These bounds look realistic.

If v corresponds to a velocity of EEG wave (it is not clear whether they indeed propagate), one can deduce the corresponding value of Planck constant and frequency from v as well as the size scale of the body part involved. This gives the consistency condition

$$\frac{f}{f_0} = r = (\frac{c}{v})^2 \tag{6.6}$$

allowing to test the hypothesis. Here f_0 is the photon frequency (around 2 eV for -50 mV resting potential: see the tables of [K4]) defined by the energy of the dark Josephson photon and is proportional to the membrane potential and thus varies with certain limits. The right-hand side is constant so that the Josephson frequency must be proportional to EEG and different ions must correspond to different brances of generalized EEG. If EEG waves are assumed to propagate with the same velocity as EEG waves the hypothesis reduces to the above case, which seems to be consistent with what is known about the range of EEG frequencies.

The phase velocity of the soliton sequence can be either $v < c$ or $v = c^2/V > c$, $V < c$ and this suggests that these velocities correspond to two kinds of EEG waves. $v = c^2/V > c$ gives standing solitons at the limit $V \to 0$: in practice even $v = c$ gives effectively standing waves. The phase velocities larger than light velocity would formally correspond to the values of Planck constant smaller than the standard value. Physically these waves would correspond to the firing of the entire axon simultaneously and are excluded.

If one accepts the identification of velocity in terms of Planck constant completely generally and allows only sub-luminal velocities, then only integer valued Planck constants are possible because otherwise the velocities could exceed light velocity. Hence only singular coverings of CD and CP_2 would be allowed. Once the value r of Planck constant is known the coverings of CD and CP_2 correspond to different decompositions of r to a product of integers for this option. If singular factors spaces are allowed, an infinite number of decompositions are possible.

6.2 Scaling Law For The Qualia About Brain Structure Of Given Size Scale

The classical fields associated with MEs are expected to code information about the contents of conscious experience at various levels of self hierarchy. EEG represents one level in this hierarchy. This coding is crucial for the realization of declarative memory as classical communications from the geometric past. p-Adic length scale hypothesis to estimate how wide the range of frequencies responsible for coding information about conscious experience at given level of self hierarchy is. The model makes a prediction for the number of EEG harmonics representing information about conscious experience at a given level of self hierarchy, and suggests a general law telling what transition frequencies correlate with experiences conscious-to-us.

6.2.1 Relationship between self size and EEG frequency

Scaling law in its basic form reads as

$$\begin{aligned} v &= \lambda f \ , \\ L &= \lambda \ . \end{aligned} \tag{6.7}$$

Here v denotes the effective phase velocity associated with the EEG wave, λ corresponding wavelength, and f EEG frequency. L denotes the size of the sub-self and is assumed to be multiple of the effective wavelength associated with the EEG wave. The sub-self in question can give rise to a sensory mental image at the level of primary sensory organs or to a symbolic or cognitive representation at the level of brain.

In TGD Universe effective EEG phase velocities correspond basically to the effective phase velocity for MEs drifting along the relevant brain structure or a closed magnetic loop. The sub-luminal phase velocity results because positive energy ME tends to hop towards geometric future in quantum jump with some average rate while the space-time sheet representing environment is stationary. This velocity can be super-luminal for negative energy MEs if they dissipate since dissipation in this case would mean gradual shifting of ME backwards in the geometric time. Whether the dissipation really occurs significantly is not at all clear. If the frequency of the negative energy ME corresponds to an energy above thermal energies, the probability that negative energy can be absorbed is very low. This makes negative energy MEs ideal for generating time-like quantum entanglement, which is the prerequisite for the sharing of mental images. This process is the key element of long term memory, and even of the ordinary sensory experience and motor activity.

TGD based model for nerve pulse and EEG relates effective EEG phase velocities to the effective phase velocities of MEs moving along axon and generating the nerve pulse and also cell membrane oscillations [K13]. The dropping of ions to the magnetic flux tubes of the Earth's magnetic field during the process generates positive energy EEG MEs propagating along magnetic flux tubes of the personal magnetic body with sub-luminal phase velocity and representing in their modulation pattern information about the contents of sensory experience presumably crucial for declarative long term memories.

In many-sheeted space-time particles topologically condense at all space-time sheets having projection to given region of space-time so that this option makes sense only near the boundaries of space-time sheet of a given system. Also p-adic phase transition increasing the size of the space-time sheet could take place and the liberated energy would correspond to the reduction of zero point kinetic energy. In this case the process would occur coherently for all particles. Particles could be transferred from a portion of magnetic flux tube portion to another one with different value of magnetic field and possibly also of Planck constant h_{eff} so that cyclotron energy would be liberated.

1. Ordinary states of consciousness and scaling law

One can argue that for the states of consciousness deriving only from ordinary sensory data by information processing in CNS, L cannot be larger than brain or body size for normal states of consciousness. The reason is that ELF self gains the sensory information from nerve circuits when

it scans the relevant brain region and it does not make sense to scan regions much larger than brain size. This obviously implies $v < c$.

A stronger hypothesis making sense for ordinary states of consciousness encouraged by the empirical data [J28] is that apparent phase velocity is actually equal to the conduction propagation velocity of the nerve pulses in the neural pathway involved:

$$v = v_{cond} \ . \tag{6.8}$$

2. Transpersonal states of consciousness and scaling law

One could argue that transpersonal levels of consciousness (during sleep perhaps) provide sensory information from several brains simultaneously. Also states of transpersonal consciousness and even cosmic consciousness are difficult unless one allows self sizes much larger than brain size. That this kind of experiences might be possible is suggested by out-of-body experiences in which person sees her own body in eyes of outsider.

1. The first guess was that transpersonal states of consciousness correspond by $L = v/f$ law super-luminal effective phase velocities $v = c^2/V > c$ associated with the Lorentz boosts of time-like soliton sequences. The soliton sequences can be assigned with the possible existing Josephson junction structures connecting parallel super-conducting magnetic flux tubes. The potential differences associated with the junctions are extremely weak and correspond to the EEG frequencies via the formula $\omega = Q_{eff}eV/\hbar$.

2. The second guess is that they correspond to negative energy MEs for which EEG frequencies predict length of the order of the Earth's circumference. Negative energy MEs are indeed natural correlates for the generation of the bound state entanglement and the generation of macrotemporal quantum coherence accompanied by experiences of "one-ness". Negative energy MEs make also possible telepathic sharing of mental images. Episodal (sensory) long term memories would involve negative energy MEs with ultra low frequency scale. The generation of negative energy MEs could also provide metabolic energy by buy now-let others pay mechanism and might explain the claims about the ability of yogis and meditators to survive with minimum nutrition.

It might be that negative energy MEs associated with semitrance mechanism (semitrance mechanism is described in chapters [K16] and [K17] and possibly also with the initiation of motor actions. Positive energy MEs would in turn be involved with long term declarative memories involving classical communication with a sub-luminal phase velocity along closed magnetic loops of size $L = v/f$. These communications could be more or less automatic and the active memory recall could only mean a decision to receive the signal. Hippocampus and amygdala are good candidates for the parts of brain responsible for generating the positive energy MEs responsible for inducing the non-episodal memories.

Memory circuits could be also indirectly responsible for the generation of long term episodal memories. It is indeed known that removal of these structures leads to a loss of, say, hallucinations induced by say LSD [J29]. In [K14] the mechanism of synesthesia is discussed with the cautious conclusion that the activity in the hippocampal region indirectly induces the generation of long term episodal memories. The over-activity in the memory circuits would induce a "starvation" in certain cortical regions. In order to get metabolic energy these starving regions would apply buy now-let others pay mechanism and generate negative energy MEs inducing a time-like entanglement with the geometric past and a sharing of mental images resulting in episodal memories.

6.2.2 Maximal number of harmonics at given level of p-adic hierarchy

The general vision is that we can have experiences mediating information about several levels of the p-adic length scale hierarchy associated with body. Both primary and secondary and even higher p-adic length scales are allowed in this hierarchy. The sharing of mental images made possible by negative energy MEs and classical communications made possible by positive energy MEs are the main mechanisms involved. Classical communications involve some code translating information

to the shape of the classical fields and/or vacuum currents associated with positive energy ME propagating with sub-luminal phase velocity.

To build a model one can make more detailed technical assumptions.

1. For a given p-adic length scale $L_e(k)$ the self sizes between $L_e(k)$ and $L_e(k_{next})$ contribute to the experiences about that level. $v = Lf$ law in turn allows to estimate for a given fundamental transition frequency f how many harmonics contribute to the classical field of ME in question at level k. The number of harmonics determines the maximum information content of the experience generated by the classical signal carried by ME at that level.

2. For a given transition frequency and nerve pulse velocity v_{cond}, which could be for definiteness assumed to be equal to EEG phase velocity, there is some minimal p-adic prime $k(min)$ nearest to the length scale v_{cond}/f:

$$L_e(k_{min}) \leq \frac{v_{cond}}{f} \quad . \tag{6.9}$$

   The minimal p-adic length scale does not in general allow maximal sensory acuity since v/f is not in general infinitely near to $L_e(k_{min})$.

   The next k: s can however give maximal number of transition frequencies corresponding to $[k_{next} - k]/2$ octaves if the spectrum of self sizes is maximal. The frequency band for a given k is filled by starting from the frequency corresponding to the lowest possible "bodily self" size $L_e(k)$, which is the largest possible frequency for that k, and proceeding to smaller frequencies corresponding to larger values of self size. This means that the hierarchy of p-adic length scales coming as octaves of the basic scale very precisely corresponds to the hierarchy of conscious experiences about various length scales. Every p-adic length scale is like music instrument producing $[k_{next} - k]/2$ octaves of musical notes.

Scaling law leads to rather strong predictions when combined with the formula identifying self size as the apparent wave length associated with EEG waves.

For instance in the case of $k = 199$ characterizing the size of brain, there are 6 octaves of frequencies between $L_e(199)$ and next primary p-adic length scale $L_e(211)$. Rather interestingly, the range $1.5 - 90$ Hz of EEG frequencies spans also 6 octaves. ELF self can have also experiences about what it is to be brain hemisphere ($k = 197$): this is possible for suitably tuned drift velocity range of ELF self, in this case the maximal frequency range would be 2 octaves. Amygdala would presumably correspond to $k = 193$ and in this case three octaves of EEG frequencies are possible. One must also consider the possibility that secondary and higher p-adic length scales are involved. In this case $L_3(67) = 32$ cm corresponds the p-adic length scale next to $L_e(199) = 16$ cm.

6.2.3 Communication between different levels of the self hierarchy and fractal scalings

Communication between different levels of p-adic hierarchy means mapping of various functions representing sensory information from a given level p to another level p_1. The obvious manner to realize this mapping is simply to scale by the ratio $p_1/p = 2^{(k_1-k)/2}$. Music piece is transposed to $(k_1 - k)/2$ octaves higher. For instance, actual EEG pattern corresponding to virtual motor activity would be simply its fractally scaled version containing virtual nerve pulse pattern as a repeated command (*"Do this- do this-..."*). It is known that motor neurons indeed serve as low pass filters [B2] noticing only low frequencies and this might correspond to this kind of fractality. Unconscious fine structure of motion could result from unconscious-to-us processing by this kind of fractal scaling. This kind of temporal scaling fits nicely with the paradigm of 4-dimensional brain.

Super Virasoro frequency scales $f(n_1, k_1)$ and $f(n_2, k_2)$ discussed in [K5] differ from each other by power of 2 when both n_1 and n_2 are even or odd. This means that for a given prime supersymplectic transition frequency spectrum is fractal and contains the frequency spectra associated with shorter p-adic length scales as sub-spectra and thus can generate resonantly Super Canonical transitions in shorter p-adic length scales. Similar fractality might be realized for magnetic frequencies. The scaling law $B \propto 1/L^2(k)$ for magnetic field strengths suggested by p-adic fractality would imply that magnetic transition frequency scale scales as $f(k) \propto 1/L^2(k)$.

6.2.4 Is there a correlation between brain size and apparent EEG phase velocity?

A natural assumption is that self sizes at level k are in the range $[L_e(k), L_e(k_{next})]$. $L_e(k_{next})$ can be also secondary or even higher p-adic length scale such that brain size is in the range $[L_e(k), L_e(k_{next})]$. This would give

$$\frac{v}{f} \quad \in \quad [L_e(k), L_e(k_{next})] \ . \tag{6.10}$$

An interesting possibility is that there is correlation between brain size and nerve pulse conduction velocity in the neural pathways contributing to consciousness:

$$\frac{v_1}{v_2} = \frac{L_e(k_1)}{L_e(k_2)} \ , \tag{6.11}$$

where $L_e(k_i)$ are the p-adic length scales associated with the brains of the organisms 1 and 2 and v_i are velocities in corresponding neural pathways. If this assumption holds true then the maximal information content of the field pattern of ME depends only weakly on the size of the brain since the frequency ranges are more or less the same. That velocity of conduction should increase with the size of organism sounds rather natural since axons get thicker.

It is possible to make definite estimates about conscious qualia for given species using information about nerve pulse velocities involved and about brain size. There is indeed some evidence for the correlation between brain size and inverse of the peak frequency of EEG [J28]. For instance, it is known that in the case of dog intracranial phase velocities of alpha waves are in the range $.3 - 1.2$ m/s [J28]. These data suggests that the sizes of alpha wave selves for dog are in the range $3 - 12$ cm so that dog's alpha consciousness would correspond to $L_e(197) = 8$ cm, which is the length scale associated with single brain hemisphere for humans. The result supports the view that the sizes of self correlate with brain size. Large animals like whales could have in ordinary wake-up state sensory input from p-adic length scales above $L_e(199)$ [$L_3(67) = 32$ cm, $L_2(101) = 45$ cm, $L_2(103) = 180$ cm].

If the phase velocity of the alpha waves is same along the entire magnetic flux loops associated with the magnetic body, the values $.3 - 1.2$ m/s *resp.* 14 m/s for the phase velocities of dog *resp.* human would mean that the time span for the long term non-episodal memories would be at least by a factor 1.2/14 shorter for dogs than for humans. This would roughly conform with the dog/human life time ratio.

Consider some examples illustrating what this hypothesis predicts assuming that the velocity range $(v_l, v_u) = (3, 7)$ m/s applies to EEG waves associated with the entire brain and that the doubled velocity range $6 - 14$ m/s applies to single brain hemisphere. **Table 1** helps to get overall view about the important p-adic lengths scales.

1. For $k = 199$ corresponding to entire brain the maximal self size L_m, when identified as the next p-adic scale, is $L_3(67) = 32$ cm if tertiary p-adic length scales are allowed. Otherwise L_m is $L_2(101) \simeq .45$ meters. By $v = L/f$ law the ratio $L_m/L_e(199)$ should be smaller than the ratio $v_u/v_d = 7/3 \simeq 2.3$. $L_2(101)/L_e(199) = 2\sqrt{2} \simeq 2.8$ is larger than the ratio $7/3 \simeq 2.3$ whereas $L_3(67)/L_e(199) = 2$ satisfies the constraint so that $k = 67$, which corresponds to rather closely to the length scale of head, is favored.

2. The EEG frequency ranges correlating with qualia conscious-to-us are predicted to be $9.4 - 21.9$ Hz for $k = 67$ and $6.7 - 15.6$ Hz for $k = 101$. The frequency range associated with $L_e(199)$ is $19.0 - 43.8$ Hz.

3. For $k = 197$ corresponding to brain hemisphere one has $L_e(k_{next}) = L_e(199)$ and frequency range corresponding to the velocity range $7 - 14$ m/s is $43.8 - 102$ Hz and for $L_e(197)$ the range is $87.6 - 204$ Hz.

Table 1: p-Adic length scales $L_e(k,n)$ possibly relevant to consciousness and life at length scales relevant to human brain and body. k characterizes p-adic prime via $p \simeq 2^k$ and $n = 1, 2, 3$ tells whether primary, secondary, or higher p-adic length scale is in question. $n > 3$ n-ary scales are assumed to be un-important.

k	191	193	97_2	197	199	67_3	101_2	103_2
L_p/m	.01	.02	2.8	.08	.16	.32	.45	1.8

Table 2: Table gives the length scales below which electron, proton and ionic consciousness is possible assuming that the nerve pulse velocities vary in the ranges associated with somatosensory system.

$v/(m/s)$	$.5-2$	$5-30$	$35-75$	$80-120$
$L_e(1,e)/\mu m$	.8-3.2	8-48	58-125	133-200
$L_e(1,p)/mm$	$.27-1.0$	$2.7-5.9$	$19-41$	$44-66$
$L_e(1,Li_+)/cm$	$.1-.5$	$1.2-7.1$	$8.3-17.9$	$19.0-28.6$
$L_e(1,Ca^{++})/dm$	$.3-1.2$	$2.9-17.1$	$20-43$	$46-69$
$L_e(1,Co_+)/m$	$.1-5$	$1.2-7.0$	$8-17$	$18-28$

6.2.5 Lower bounds for "bodily" self sizes from the range of nerve pulse conduction velocities

The range for nerve pulse conduction velocities associated with EEG waves does not correspond to the entire range of nerve pulse velocities in somatosensory system ranging from .5 m/s to 120 m/s [B2]. Thus our brain anatomy could allow much wider spectrum of sizes for mental images than allowed by the rather narrow range $3-14$ m/s of propagation velocities for alpha waves.

Nerve pulse conduction velocity as a function of the axon thickness obeys the approximate law [B2]

$$v = kv_0 \times \frac{d}{d_0} \quad , \quad v_0 = 1 \ \ m/s \quad , \quad d_0 = 1 \ \ \mu m \quad .$$

The value of k is about 6 for thickly myelinated axons and between 1.5 and 5 for thinly myelinated axons. The variation ranges of conduction velocities in somatosensory (!) system are in ranges $80-120$ m/s, $35-75$ m/s, $5-30$ m/s and $.5-2$ m/s for unmyelinated axons. Conduction velocity varies in rather wide range $(.5-120)$ m/s: "quale key" can vary in a range of almost 8 octaves. The lowering the conduction velocity of nerve pulses by reducing myelinization or thickness could make it possible for us to have qualia about length scales of brain nuclei.

It is interesting to look for the lower bound $L_e(min)$ of self sizes assuming that 90 Hz is upper bound for transition frequencies representing experiences possibly conscious to us. The values of L_{min} are.89 m for $80-120$ m/s range;.39 cm for $35-75$ m/s range; 5 cm for the range $5-30$ m/s and.5 mm for the range $.5-2$ m/s associated with the unmyelinated axons.

Table 2 gives the length scales below which electron, proton and ionic cyclotron consciousness is possible assuming that the nerve pulse velocities vary in the range described above. These ranges of nerve pulse conduction velocities are associated with somatosensory system and actual "phase velocities" of EEG waves seem to vary in much narrower ranges.

From **Table 2** one finds that electronic cyclotron consciousness is possible in p-adic length scales $L_e(173) = 20$ μm and $L_e(179) = 160$ μm but not above this length scale. Also the length scale $L_e(169)$ might be possible. Protonic cyclotron consciousness is possible at all length scale above $k = 169$ up to $k = 193$.

6.3 Scaling Law And Evolution

Scaling law, when combined with general ideas about consciousness, allows to build speculative models for the evolution of consciousness at both biological and cultural level. What would be new and nontrivial would be the strong correlation between cultural and electromagnetic evolution (strictly speaking, also the evolution field bodies is involved). Cultural evolution could be perhaps seen as evolution of memes with memetic code playing the role of genetic code. There are good reasons to believe that the intronic portion of DNA codes for memes represented dynamically as field patterns associated with MEs [K6]. The portion of the introns in genome is indeed large for humans (99 per cent).

6.3.1 Scaling law contra biological, cultural, and spiritual evolution

One can distinguish between two kinds of developments of individual: the neural development of child in the p-adic length scales relevant to body and the evolution of magnetic body and of communications between magnetic body and biological body. Besides the personal magnetic bodies also the magnetic body of Earth, magnetosphere, is expected to carry sensory, cognitive and symbolic representations resulting through entanglement with various organisms. Negative energy MEs in EEG range are natural in this respect. These representations would give rise to multi-brained magnetospheric selves [K9]. The development at ELF frequency range corresponds by *ontogeny recapitulates phylogeny principle* to the evolution of civilization.

There are good reasons to believe that brain anatomy has remained more or less the same in time scales much longer than the evolution of civilization from bicamerality to modern man. This would mean that the evolution of our consciousness and civilization is basically electromagnetic rather than genetic evolution and corresponds to the evolution of EEG and ZEG during ontogeny. The evolution of magnetospheric consciousness might be a crucial factor in this development. These evolutions are not completely independent since $L = v/f$ ($v < c$) relationship correlates these developments to each other.

1. Scaling law and the relationship between cultural and biological evolution

A fascinating challenge would be to understand the detailed relationship between cultural evolution and the evolution of field body. In particular, there are many interesting questions related to the relationship between self-hierarchy and Freud's ideas. Is super ego above EEG length scales or above the body length scale? Could one regard the counterpart of Id as a species consciousness, some kind of biological superego, in length scales larger than body size but considerably below ELF length scales representing cultural aspects of consciousness? Can one speak of cultural superego? Is the time scale of the phenomenon direct measure for the p-adic length scale of the corresponding self?

It is important to notice that $v = Lf$ relationship defines mapping $k \to f(k)$ between the biological and electromagnetic length scale hierarchies such that ELF self at particular p-adic level has sensory experiences about experiences of particular self at bodily level? Very roughly this mapping would correspond to the scaling

$$L_e(k) \to [\frac{c}{v} L_e(k)] \equiv L_e(f(k)) \ ,$$

where $[L]$ is shorthand for the nearest p-adic length scale below length scale L. More explicit manner to define this mapping would be as

$$k \to [k + log_2(c/v)] \ ,$$

where $[k]$ now denotes the nearest power of prime below k. If this kind of mapping is involved then the evolutions at these two widely different length scales might correspond to each other rather closely.

6.3.2 Evolution at the level central nervous system

The natural implication of the proposed picture is that the biological (as also electromagnetic) evolution of the central nervous system (CNS) proceeds from shorter to longer p-adic scales. Jump

in the evolution correspond to emergence of new p-adic length scale when the size of self becomes equal to next p-adic length scale.

This vision about evolution of central nervous system can be tested immediately. Magnetic spectroscopy of consciousness predicts that there are seven levels between $k = 169$ level of neuron and brain and they correspond to the primary p-adic length scales associated with $k = 173, 179, 181, 191, 193, 197, 199$. Central nervous system indeed has 7-levelled hierarchy corresponding to spinal chord, medulla, pons, midbrain, diencephalon, brain hemisphere, brain and higher levels of this hierarchy have indeed emerged one-by-one during evolution. The eight levels of the hierarchy (perhaps it is worth to notice the amusing connection with the eight-fold way of Buddhism and the idea of Lily about eight levels of consciousness) would correspond to the next level of bio-consciousness $k = 211$ which might be already present at delta and theta frequencies.

Geometric consciousness at the level of spinal chord geometric consciousness should at least correspond to multiples of electron cyclotron frequencies. Electronic consciousness is not possible at higher levels. This picture explains why the activities of autonomous nervous system is more or less unconscious to us. Hypothalamus and thalamus and presumably also many other brain nuclei would correspond to the level $k = 193$ in the hierarchy. Their sizes are indeed above 2 cm and below 8 centimeters. Thus autonomous nervous system should correspond to lower level of the p-adic hierarchy of selves so that the contribution to our consciousness would involve several averageings. Note that protonic cyclotron consciousness is still possible at at this level but not at higher levels for typical conduction velocities of nerve pulses.

6.3.3 Scaling law and ontogeny

During the early development neural pathways myelinize gradually [J28] and this means gradual increase of the conduction velocities $v = Lf$. This suggest that various versions of quale about given p-adic length scale $L_e(k)$ labelled by the harmonics of the fundamental frequency emerge gradually one by one as nerve pulse propagation velocities in neural pathway increase. First pops up $n = 1$ version of quale, then $n = 3$ version, etc.. One could visualize this as drift of various versions of quale from shorter to longer p-adic length scales.

This predicts that the sensory acuity of infant increases in stepwise manner at critical values of the nerve pulse propagation velocity making possible new harmonic of EEG pattern representing particular quale. The critical values of the nerve pulse propagation velocity for secondary experiences about events at level k are given by

$$v(n) \quad = \quad nf \times L_e(k) \quad . \tag{6.12}$$

This applies also to motor expression which in TGD framework is very much like virtual sensory experiencing amplified to macroscopic motor activity by puppet-in-string mechanism. For instance, coordination and control of motor activities improves and emotional expression in speech becomes more refined.

This option is not the only one that one can imagine. Also EEG develops during the development of individual. The fact that the peak frequency of EEG moves gradually from delta band to alpha during the first ten years allows to consider the possibility that the sizes L of mental images, stay more or less constant during maturation. This requires that both that nerve pulse velocity and the harmonic of the fundamental frequency giving the dominating contribution to the quale gradually increase. An interesting possibility is that the sizes of selves correlate with body size or with the size of relevant body part during development of individual.

$$L = \frac{v}{f} = k \times L_e(\textit{body part}) \quad .$$

This would mean that all ions correspond to the same self size for given value of nerve pulse conduction velocity.

6.3.4 Transition from bicamerality to modern consciousness

TGD based vision about the evolution of civilization relies on *ontogeny recapitulates phylogeny principle* stating that the development of child's electromagnetic body is fractally scaled version

of the development from bicamerality to modern consciousness. In particular, the hypothesis has been that this development meant the emergence of higher level emotion and cognition and of the semitrance mechanism in which collective self gave commands and advices to the bicameral.

The proposed model for the evolution of qualia concretizes this general vision considerably. The picture about what might have happened in the transition might perhaps look like follows.

1. Semitrance mechanism

Semitrance mechanism made possible for the collective higher level ELF self to communicate commands and advices to the bicamerals. This higher level ELF self presumably had also higher level sensory experiences about entire social group in some p-adic length scale larger than body size. $L_e(211) = 10$ meters and $L_e(223) = 640$ meters are the most obvious length scales involved. The emergence of new ELF frequencies to EEG meant also that the sensory and emotional acuity of bicameral man improved. It is not absolutely clear whether semitrance is communication of higher level selves to us or sensory experiencing of transpersonal levels of consciousness or both. The predicted lifetimes of transpersonal selves are however measured in years which suggests that they are closely involved with long term memories.

2. Development of speech

The emergence of modern man involved the development of speech faculty. This evolution must have been proceeding in two directions. We have self-narrative in rather long time scales and someone must tell it to us: this implies that ELF MEs corresponding to $k = 127_2, 2^8$, $257, 131_2, 263$, $89_3, 269, 271$, $137_2, 277, 139_2, ...$ should have emerged gradually. This could have also meant development of amplitude modulation hierarchy and increasingly complicated linguistic structures. Note that the time scale starting from .1 seconds ($k = 127_2$) and ending up to 6.1 seconds ($k = 139_2$) contains especially many primary, secondary and tertiary p-adic time scales. This also meant development of increasingly refined linguistic structures in short time scales: words decomposed to syllables and syllables to phonemes presumably identifiable as memetic codewords at $k = 127_2$ level and this made possible development of written language.

In conflict with the standard beliefs about our position in the hierarchy of consciousness, this picture suggests that to some extend both speech and internal speech are speech of higher level self. It is indeed well-known that it is almost impossible to speak fluently if one tries to control what one is saying: one must simply let it go. Also body unconscious-to-us language can be interpreted as talk of higher level self using limbic brain as instrument of expression: this would explain why we express emotional reaction before becoming conscious about the emotion.

3. Emergence of long term memory

What Jaynes believes could be translated to the statement that the transition from bicamerality to modernity involved the emergence of the long term memory and its evolution from a direct sensory memory to declarative memory [J19]. Sensory memory means direct re-experiencing by the sharing of mental images made possible by time-like entanglement. Declarative memory would be based on a symbolic representation of the data, and would be communicated classically (communication would be ultra-slow!) from the geometric past as a response to the shared mental image representing the desire to remember.

A possible model for long term declarative memories is based on the generalization of the frequency representation of the memetic code. What is presumably coded, are perhaps not details of particular experience but sequence for names of "program modules" realizing particular kind of experience. Thus very high level coding would be in question. In this model long term memories could perhaps be represented as a modulation of the carrier frequency of "hippocampal theta frequency" varying in the range $4-12$ Hz [A1] by multiples of some lower ELF frequency representing higher level of self hierarchy.

The large range of variation for hippocampal frequencies suggest that they could correspond to magnetic transition frequencies of various ions subject to homeostatic regulation. It is indeed known that the state of arousal correlates with the hippocampal frequency. The modulating level would correspond naturally to the ELF self associated with multimodal association regions which project via entorhinal cortex to hippocampus. If the tertiary time scale associated with $k = 251$ (28 Hz) corresponds to primary sensory areas, this region must correspond to $k = 131$ and frequency of .63 Hz and cycle of 1.6 seconds which sounds sensible. If this is the case, long term memories

should have natural time unit of 1.6 seconds.

The motion of the peak frequency of child's EEG from delta band to alpha band during the first ten years looks paradoxal against the idea that lower frequencies correspond to higher levels of consciousness. One interpretation for the presence of low frequencies is that the child is in a semitrance state and that the presence of the low frequencies reflects control from the higher levels of self hierarchy. A second interpretation allowing to get rid of the paradox is that the carrier frequency evolves gradually from delta to alpha band while fundamental modulation frequencies stay constant. This would mean that the number of multiples fundamental frequency which can appear in the modulation increases and information storage capacity increases.

This kind of coding is not the only possibility and it is quite possible that entire fractal hierarchy of codings are involved such that single codeword at higher level corresponds to an equivalence class of codewords at lower level. For instance, hippocampal theta period could define the duration for the codeword of a lower level code realized by modulation using gamma frequencies. There is evidence for temporal coding in the sense that the relative temporal shift of the spike sequence with respect to the "hippocampal theta frequency" codes for the position of moving rat [J21]. This would mean the coding of rat's position to the overall phase of the complex Fourier components representing $n > 1$ harmonics of the memetic codeword ($n = 1$ would correspond to "hippocampal theta frequency") and can be understood if the motion of rat is coded to periodically occurring nerve pulse patterns inducing reset of theta oscillator.

4. Schizophrenic as a modern bicameral?

Schizophrenic is regarded by Jaynes as a modern bicameral. According to Jaynes, schizophrenics seem to have amazing ability to tolerate pain and to work hardly for long times without experiencing fatigue. For instance, catatonics can stay in same bodily posture for hours. Perhaps this is due to the fact that they do not experience pain in same sense as normal persons do. Jaynes also explains by this the architectural feats of ancient civilizations impossible for modern man using the primitive tools available for bicamerals.

Our emotions are partially generated by the feedback loop in which the lower level emotions expressed by the limbic brain are perceived by the cortical levels and amplified and in turn affect limbic brain. If this loop is not working properly (say due to the inhibited emotional expression), nociception is not accompanied by the experience of pain. If the transition to modernity meant also evolution of emotions and their expression, the emotional expression of bicamerals must have been primitive so that this loop cannot have been so effective as it is in the case of modern man. One can also consider the possibility that bicamerals spent a considerable fraction of time in semitrance in which regions of the emotional right brain were entangled with higher level selves or with large selves and were thus unconscious and unable to feel pain. The myth about exile from paradise would reflect that the newly developed ability to experience strong emotional pain.

Schizophrenics have often also unusually high sensory acuity: this is probably due to the weakened sensory censorship eliminating from sensory landscape unessential features. The fact that the attention of schizophrenic is more easily distractable is also consistent with this.

5. Child as a small bicameral?

Scaling law suggests that child is during the first years of her life more or less the modern counterpart of the bicameral man of Jaynes [J19] receiving commands and advices of the higher level selves as sensory, in particular auditory hallucinations as suggested in the chapters [K16] and [K17]. Semitrance hypothesis is consistent with the fact that REM occur during wakefulness and sleep. REM is also found to occur few moments after an infant begins to engage in nutritional sucking. Even modern man has day dreams with the same 90-120 minute period as he has REM period during sleep. That small children comment their activities from third person view (*"Now John is going to do this"*) is consistent with semitrance hypothesis.

Delta wave dominance of EEG (see below) is indeed consistent with the hypothesis that child spends long times at transpersonal levels of consciousness seeing her body with eyes of outsider. The fact that the speech of child however lacks much of the emotional component present in the speech of adult is consistent with the idea that emotional expression develops gradually more refined when also generalized sensory experience about state of body becomes more refined. It has been indeed noticed already by Rousseau that child's speech lacks much of the emotional color involved with the speech of adults.

It is known delta band dominates during childhood and that the EEG intensity in delta band is reduced during ageing. A possible interpretation is that the attention is during childhood more directed to transpersonal levels and gradually shifts to more bodily level (perhaps for the simple reason that the unpleasant side effects of ageing require more and more attention to the state of body!). This would suggest that ageing could but need not mean spiritual degeneration. The shift to higher frequencies could mean that higher harmonics of the cyclotron frequency in delta band begin to dominate. On the other hand, sensory acuity gets poorer when individual gets older. This could have purely anatomical reasons but could also involve gradual increase of the average cyclotron frequency associated with the quale so that also harmonics of low cyclotron frequencies responsible for high sensory acuity tend to disappear from EEG. Also the timing accuracy of the temporal patterns of nerve pulses could become worse during ageing. As a consequence, the frequencies of EEG waves would not be sufficiently near to the harmonics of low cyclotron frequencies anymore.

6. The role of Earth's magnetic field in the evolution of civilization?

The fundamental frequencies associated with exotic super-symplectic representations are constants of Nature. As far as the proposed role of these frequencies is considered, this is very satisfying feature. Many basic frequencies associated with exotic super-symplectic representations in EEG range are however very near to Schumann frequencies (inversely proportional to the circumference of Earth) and to important cyclotron frequencies proportional to Earth's magnetic field. This suggests the possibility of a resonant interaction so that the value of Earth's magnetic field could have played important role in the evolution.

During last thousand years Earth's magnetic field has reduced by a factor of one half. For instance, the cyclotron frequency of Co^{++} ion (probably closely involved with 10 Hz bio-clock in pineal gland), which is 10 Hz for present value of about $.5 \times 10^{-4}$ Tesla of Earth's magnetic field, has reduced by a factor two during this period. The considerations of the chapter [K9] raise the question whether the reduction of the magnetic field might have something to do with the exponential evolution of the civilization during this period.

6.4 Scaling Law And Sensory Maps

The vision about sensory maps realized using magnetic canvas outside the body inspires the hypothesis about a hierarchy formed by the primary and secondary sensory organs inside brain with levels labelled by the p-adic length scales. The radius of the approximately spherical structures from which the radial magnetic flux tubes serving as magnetic canvas emanate should be roughly given by the relevant p-adic length scale L. ELF MEs define the projection of the sensory image from the (possibly secondary) sensory organ to the magnetic canvas by place-frequency coding. This requires that the thickness of the magnetic flux tube depends weakly on the distance from the projecting sensory organ. A stronger assumption is that the magnetic structure serving as a sensory canvas has the same size as EEG MEs: $L_e(magn) \sim L_e(EEG)$. Hence sensory images would be magnetic giants in TGD framework whereas in standard neuroscience they would be miniatures defined by the cortical neural activity patterns.

By scaling law the sizes $L_e(EEG)$ of ELF selves relate to the sizes L of brain structures: $L_e(EEG) = (c/v)L$. Here v is the velocity of motion of EEG ME along axon, or equivalently nerve pulse conduction velocity, and f is the EEG frequency. The consistency with the scaling law is achieved if secondary sensory organs, which could be approximately spherical structures analogous to eyeball, have radii $L \sim v/f$ approximately given by various p-adic length scales $L = L_p$. As will be found later, the resulting sensory hierarchy correlates nicely with the brain anatomy, with the band structure of EEG and with the structure of the periodic table.

It is of interest to apply the scaling law at the level of eye. Amazingly, the sizes of the lense (about $L_e(191) \simeq 1$ cm) and retina (about $L_e(193) \simeq 2$ cm) are just at the lower bound of the p-adic length scale range allowing the EEG frequency to be in the range of cyclotron frequencies in Earth's magnetic field. For $v = 3$ m/s, which is the lower bound for the velocities of alpha waves, $f = v/L$ gives proton cyclotron frequency $f_c = 300$ Hz for lense size $L \sim 1$ cm and deuterium cyclotron frequency $f_c = 150$ Hz for retina size $L \sim 2$ cm or more naturally proton cyclotron frequency for a two times larger value of Planck constant. Note that higher harmonics cyclotron frequency are possible even if the lowest one is not and could thus allow deuteronic cyclotron consciousness. For

retina $v = 6$ m/s gives proton cyclotron frequency for retina. He_4 consciousness would require $v \sim 1.5$ m/s, which is possible only for unmyelinated axons: the axons from retina are myelinated.

Thus it seems that the lowest level or perhaps even two lowest levels of visual consciousness could be possible at the level of lense and retina. The size of the pupil correlates with the state of consciousness. An interesting question is whether these two levels of retinal consciousness could correlate with the size of pupil. For instance, the velocity of nerve pulse conduction in the axons from retina could correlate with the size of the pupil. Contracted pupils might correspond to the most primitive form of retinal consciousness and dilated pupils to consciousness with the value of Planck constant which is two times larger. The projection to the exterior world would be determined by the input from the next level of the visual hierarchy and would be directed backwards rather than to the visual field of the retina. Retinal visual selves could thus represent the lowest level of the visual self hierarchy above EEG and would be unconscious to us as also 40 Hz visual consciousness at the primary sensory areas seems to be. What is encouraging is that the size of retina fits nicely with the general vision about hierarchy of visual selves starting already at the level of the primary sensory organ.

The lowest level in the hierarchy of the sensory consciousness would correspond to electron with cyclotron frequency $f_c \simeq 6 \times 10^5$ Hz in Earth's magnetic field. The size of the the projecting organ would be about 5 micro–ns for the minimal value of $v = 3$ m/s of alpha wave velocity. This would suggest that even neurons can represent sensory input on the magnetic canvas and have senses just as we do. TGD neurons would be considerably more complex creatures than the fire-doesn't fire neurons of computationalist. This is of course what fractal self hierarchy predicts on completely general grounds. From the scaling law the size of the neuronal sensory image represented by electronic magnetic transitions would be of order 10^4 meters. A possible test for this view is whether radiation at electron's cyclotron frequency or its multiples has direct effects at neuronal level.

6.5 Does The Structure Of Neocortex Correlate With TheHierarchy Of P-Adic Frequencies?

p-Adic frequencies differing by appropriate scalings by a power of square root two would correspond naturally to the brain structures and organizational hierarchy of brain and CNS. The nice aspect of this hypothesis would be universality and prediction of the cognitive codes.

The $v = Lf$ scaling law described earlier implies the existence of a mapping

$$L_e(k(bio)) \to L_e(k(ELF))$$

between biological length scales $L_e(k(bio))$ and cultural length scales $L_e(k(ELF))$. The mapping means that ELF self characterized by $k(ELF)$ receives sensory input from corresponding biological length scale $L_e(k(bio))$ and presumably has corresponding biological selves as sub-selves. This mapping is illustrated in the table below. For instance, the selves at length range 8-16 cm corresponding to the size of brain hemisphere and to tertiary sensory areas are scanned by ELF selves at theta frequencies.

By $L = v/f$ correspondence the structures of neocortex correspond to definite ELF selves containing at least the p-adic length scales $L_2(2^5)$, $L_e(251)$, $L_2(127)$, $L_e(2^8)$, $L_e(257)$, $L_2(131)$, ... with fundamental Super Virasoro frequencies $f(k,n)$ equal to 40 Hz, 28.2 Hz, 10 Hz, 5.0 Hz, 3.5 Hz, .63 Hz, ... Note that the fundamental frequencies correspond to gamma, beta, alpha, theta and delta bands. The table below provides a concise summary of the proposed correspondences. The length scale $L_3(83)$ corresponds to $f(1,0) = 56$ Hz contained also in the EEG range and is not given in the table.

7 Consciousness As A Phenomenon In The Operational Architectonics Of Brain Organization: Criticality And Self-Organization Considerations

I received an interesting article by brothers Fingelkurts (Andrew and Alexander) and Carlos Neves to be published in Chaos, Solitons & Fractals [J11]. The title of the article is *Consciousness*

Table 3: Table gives the correspondence between biological and ELF length scales suggested by $v = L_e(k)f$ relationship assigning to the "biological" length scale $L_e(k(bio))$ (not larger than body size) ELF frequency $f(k,n)$ and corresponding "cultural" p-adic length scale, which is of order of Earth circumference for 8 Hz EEG frequency. Also the proposed assignments of the sensory areas of neocortex to these length scales are given. The lower index associated with the exponent k tells whether the scale is secondary or tertiary in the case that it is not primary (one has $p \simeq 2^k$ by p-adic length scale hypothesis).

k(bio)	191	193	97_2	197	199	101_2 (67_3)
$L_e(k(bio))/cm$	1	2	2.8	8	16	45 (32)
$k(ELF)$	2_2^5	251	127_2	$2^8 = 256$	257	131_2
$f(k,n)/Hz$	40.0	28.2	10.0	5.0	3.5	.63
sensory area	I	I	II	III	IV	V
EEG band	gamma	beta	alpha	theta	delta	delta
period	He	He	Ne	Ar	Kr	Xe

as a phenomenon in the operational architectonics of brain organization: Criticality and self-organization considerations.

Already on basis of the title it is clear that article is interesting also from the point of view of Topological Geometrodynamics (TGD) (for overview see Topological Geometrodynamics: an Overview [K21], especially the part II), where quantum criticality replaces thermodynamical criticality as a basic characteristic of the Universe dictating uniquely the dynamics fixing the geometry of the world of classical worlds (WCW [K20]) consisting of 3- surfaces in certain 8-dimensional space-time. Quantum criticality is also central in TGD inspired theory of consciousness and the basic picture is roughly the same as in OA model. The chapter Comparison of TGD Inspired Theory of Consciousness with Some Other Theories of Consciousness [K22] might help to get an overview about TGD inspired theory of consciousness.

Quantum self-organization [K2] is second key element of TGD inspired theory of consciousness and corresponds to a cascade of quantum jumps proceeding from level of given causal diamond (CD) defined as intersection of future and past directed light-cones of 4-D Minkowski space to shorter scales (sub-CDs, their sub-CDs, etc..). Quantum jump corresponds to a state function reduction at either boundary of CD and have interpretation as sensory perception and motor action (time reversed sensory perception). CD is identified as geometric correlate for "spotlight of consciousness".

In the following I summarize the basic concepts and ideas of the article and compare them with TGD approach to consciousness. There is also a section devoted to quantum criticality in TGD Universe. The approach is certainly TGD centred and I can only apologize this.

7.1 The Model For Operational Architecture Of Brain (OA)

In the following I summarize my understanding of OA model by comparing in with TGD approach to consciousness.

7.1.1 Basic philosophy

Concerning physics, the proposed model is necessarily conservative. Non-physicist - and I am afraid that also physicist - proposing theory of consciousness hardly has any other option. The model is basically thermodynamical: no quantum effects are considered although the general structure of the model can be considered also in quantum framework by allowing macroscopic quantum effects and replacing criticality and self-organization with their quantum counterparts. The vision is roughly the following.

1. *Spatiotemporal separability stating that two regions with space-like separation are un-correlated.* This assumption is natural if one believes that classical physics is all that is needed. In quantum field theory (QFT) this corresponds to micro-causality and assumption of point-like

particles. In quantum theory entanglement challenges this assumption. This assumption does not make easy to understand the unity of consciousness and the coherent behaviour of living organisms.

TGD approach differs here from the proposed one. Point like particle is generalized to 3-surface and the notion of topological field quantization brings in the notions of field body and magnetic body. Magnetic body becomes the intentional agent using biological body to its purposes. Magnetic flux tubes serve as correlates for directed attention and for negentropic entanglement (see **Fig.** `http://tgdtheory.fi/appfigures/cat.jpg` or **Fig. ??** in the appendix of this book) and bind disjoint systems to single quantum system in some degrees of freedom.

2. *The neuro-physiological state of brain (extracellular electric fields reflecting themselves via EEG)* is in 1-1 correspondence with the contents of phenomenal consciousness. Therefore the approach is materialistic. Phenomenal consciousness is not however doomed to be illusion (whatever this could mean) and is even allowed to have causal powers. Strong emergence (system has qualities not directly traceable to those of component systems) seems to be the philosophical characterization of their approach. Therefore the main criticism that can be made against the theory of Fingelkurts et al is that both phenomenal consciousness and causal powers emerge in miraculous manner as Revonsuo puts it. In TGD Universe the space-time sheet containing the smaller space-time sheet is something which does not reduce to the properties of the smaller space-time sheets.

   Macroscopic quantum effects are not considered, which I take to mean that quantum statistical determinism holds true. In this framework it is difficult to understand the non-determinism accompanying the causal powers of consciousness. The proposal seems to be that thermodynamical phase transitions are the source of causal powers.

   Even classical thermodynamics assigns to thermodynamical fluctuations at thermodynamical criticality certain kind of non-determinism: the motivation is the simple fact that experimentally this seems to be the case. Theoreticians must be in this kind of situation slightly illogical! Quantum non-determinism in microscopic scales might explain the non-deterministic features of critical systems extremely sensitive to fluctuations, even quantum fluctuations. If hidden macroscopic quantum coherence assignable to dark matter is present, the reduction to quantum level looks even more plausible. In TGD Universe dark matter identified as a hierarchy of phases with arbitrarily large effective value of Planck constant might be therefore also behind the long range fluctuations at thermodynamical criticality. Certainly these phase are crucial for biology in TGD Universe.

3. *Consciousness is localized to brain.* This includes also sensory qualia. This identification has well-known problems. First, the term "consciousness" is problematic since strictly speaking "-ness" implies that "consciousness" refers to a property of system: this leads to problems unless one is ready to accept materialism (in TGD approach consciousness is in quantum jump, between two worlds rather than in the world or a property of the world). Secondly, the localization of conscious experience in space-time is a problematic assumption: a weaker assumption is that the contents of conscious experience *is about* some region of space-time (causal diamond in TGD approach). Thirdly, even the localization of contents of conscious experience to brain only is problematic (sensory qualia). A weaker assumption is that only reflective consciousness consisting of recognition of objects of perceptive field and naming them and producing a representation of the external world and self in this manner is *performed* by brain (and by magnetic body in TGD context). Brain could be seen as a manufacturer of standardized mental images - representations - and phenomenal consciousness would correspond to sensory qualia. In TGD framework it is also possible to assume that sensory receptors are the seats of sensory qualia: neurons could serve as seats of qualia not conscious-to-us since selves form a hierarchy.

   One can consider even the possibility that sensory organs generate quantum entanglement with the target of attention by reconnection of flux tubes of the magnetic bodies so that perceiver and perceived form a single quantum coherent system. This would explain among other things the 3-D character of sensory perception requiring complicated neural computation if

strictly 2-D data at retina is used to build the perception as a virtual world representation of the external world.

4. *Consciousness consists of a discrete series of mental images assignable to sharp phase transitions between thermodynamical far from equilibrium states.* There is a neuro-scientific support for this belief and the pleasant news is that it is just what TGD predicts via the identification of quantum jump as a moment of consciousness.

7.1.2 Basic ingredients of the model

Consider now the basic ingredients of the model.

1. *Living matter as open self-organizing thermodynamical system.* Energy flows through the system and gives rise to self-organization patterns with dissipation serving as a Darwinian selector taking care that very many initial states lead to the same final self-organization patterns. Second law translating to minimization of free energy is the essential element of the model.

   In TGD framework self-organization is replaced by 4-D self-organization for quantum superpositions of space-time sheets leading to asymptotic spatio-temporal rather than only spatial patterns accompanied by standardized mental images. EEG pattern would be one example of this. The 4-D self-organization has also 3-D counterpart since space-time evolution represents space-time correlate for dissipation. The new prediction is that the arrow of imbedding space geometric time of the resulting zero energy state is opposite in subsequent state function reductions at opposite boundaries of given CD.

   Negentropy Maximization Principle (NMP) [K10] states that the information contents of conscious experience is maximal. This requires a more detailed explanation.

   (a) In TGD framework state function reduction taking place in quantum jump means a measurement of subsystem density matrix leading to an eigen-space of density matrix. Hence the final state density matrix is $N \times N$ unit matrix with a degenerate eigenvalue $P = 1/N$ giving entanglement probabilities. These probabilities are rational numbers belonging to the intersection of reals and p-adic number fields Q_p. One can therefore assign to the resulting entangled state information measure that I call number theoretic entanglement entropy obtained from Shannon entropy by replacing logarithms of probabilities with p-based logarithms of the p-adic norms of probabilities. If the p-adic prime p divides N, the entropy is negative and maximum for the largest prime power factor of N: this assigns a unique p-adic prime to the final state.

   (b) The proposal is that quantum jumps between real and p-adic states creating cognitive representations correspond to transitions transforming real state to p-adic one with this particular p-adic prime to satisfy NMP [K10]. The interpretation is that the state pairs in the superposition of state pairs represent instances of a rule. This negative entropy should not be confused with thermodynamical entropy which characterizes the lack of information about a member of ensemble.

   (c) The systems with degenerate density matrix are clearly very special systems - quantum critical in well-defined sense- and the proposal is that the hierarchy of effective values $\hbar_{eff}/\hbar = N$ of Planck constants corresponds to this kind of systems. This hierarchy would be identifiable in terms of N-furcations of space-time surface made possible by the failure of the strict determinism of Kähler action serving as the variational principle dictating the dynamics of space-time surfaces.

   (d) Clearly, several ideas are unified: quantum criticality as a presence of N degenerate states realized by space-time sheets of N-furcation, negentropic entanglement with N-fold degeneracy, hierarchy of Planck constants $\hbar_{eff}/\hbar = N$, and the idea about life as something in the intersection of real and p-adic worlds ($p = 1/N$ is rational number). Furthermore, the measurement of density matrix automatically leads to exact criticality.

In dynamics without state function reduction criticality is approached only asymptotically. Note that in self-organized criticality [B1] the criticality corresponds to a minimum of potential with some flat directions in which the situation is non-deterministic at criticality.

Second law holds true also in TGD framework for (ordinary) matter, which is not negentropically entangled and is implied by the non-determinism of state function reduction at the level of thermodynamical ensemble. NMP however governs the quantal behaviour of dark matter crucial for the generation of negentropically entangled systems responsible for various representations as approximate invariants under quantum jumps (by NMP) and here negentropic entanglement enters the game. For some years ago I considered the pessimistic scenario [**?**] in which the negentropy assignable to negentropic entanglement is compensated by thermodynamical ensemble entropy. Experimentally the situation remains open since we do not have yet experimental methods to detect dark matter - and certainly not dark matter in the sense of TGD. At this moment only the evolution of intelligence and science itself could be seen as a support for optimistic scenario saving the Universe from eventual heat death.

2. *Renormalization group principle.* Thinning of degrees of freedom means reducing the measurement resolution and forgetting the un-necessary details. This gives rise to abstraction at the level of cognitive and sensory representations characterized by cognitive resolution. The higher the abstraction level, the more un-necessary details are dropped from the representation. This means that reflective consciousness has a hierarchical structure.

   In TGD framework causal diamonds (CDs) within CDs define this kind of hierarchy characterized by spatial and temporal scales defining imbedding space correlate for the self hierarchy. Many-sheeted space-time serves as a geometric correlate for the hierarchical structure of consciousness.

   p-Adic length scale hypothesis makes the hypothesis quantitative and means that continuous renormalization group evolution is replaced with a discrete p-adic coupling constant evolution. Finite measurement resolution implies effective discretization at space-time and imbedding space level.

   Discretization is also forced by the notion of p-adic manifold [K23], whose definition forces the introduction of finite length scale and angle resolutions having number theoretic interpretations. The common rational (or even some algebraic) points of real and p-adic space-time surfaces define the discrete cognitive representations at space-time level. One can say that life resides in the intersection of reality and various p-adicities.

3. *Self-organized criticality (SOC).* The sensitivity of sandpile to avalanches serves as an illustration for self- organized criticality (SOC [B1])). A very elegant characterization of SOC is as a critical point which is an attractor but such that the matrix defined by the second order partial derivatives of potential function has non-maximal rank being thus non-invertible.

   SOC inspires the notion of neuronal avalanche. Neuron groups form synchronically firing structures which end up to criticality. At criticality a fast increase of entropy takes place (the reduction of free energy per time is maximal: eat the food as fast as possible so that others do not steal it!). After this the system uploads the entropy to environment and generates negentropy for a while later compensated by entropy. There is evidence that a sequence of neural avalanches self-organize to avalanches in longer time scale. Temporal sequences of associations representing memories and predictions would be possible interpretation.

   In TGD framework this picture has interpretation in terms of the basic fractal structure of quantum jump. In quantum jump negentropic entanglement is generated: NMP dictates this. After this follows a cascade of quantum jumps (state function reductions for sub-CDs unless they are mutually negentropically entangled) and this generates ensemble entropy because the outcome of state function reduction for ordinary entanglement is random and takes entanglement entropy to zero. The process continues and certainly ceases when all sub-CDs have internal negentropic entanglement so that nothing can happen. At least after this the state function reduction to the opposite boundary of CD occurs. Whether second law is satisfied remains an open question as already noticed.

7.1.3 Operational architectonics of brain

This picture combined with the decomposition of local EEG to quasi-stationary segments leads to the notion of Operational architectonics of brain.

1. *Operational architectonics of brain (OA).* The hypothesis is that neuronal avalanches represent the primary building bricks of more complex brain activities. These more complex activities are constructed as operational modules (OM) from the elementary neuronal self organization patterns. This however requires synchronous firing of neurons and the challenge is to understand how this is physically possible if one assumes that disjoint regions of 3-space do not have any correlations.

   The spatiotemporal patterns of extracellular electric fields are assumed to be in 1-1 correspondence with phenomenal experiences. Authors introduce also the notion of operational space-time (OST) assumed to exist within internal physical space-time (IPST). These notions remain somewhat fuzzy in the framework of classical physics.

   The proposed architectonics is 4- rather than 3-dimensional. The notions of 4-D brain and causal diamond (CD) as 4-D spotlight of consciousness define the counterpart for OA in TGD framework. In TGD framework OST and IPST bring in mind p-adic and real variants magnetic body and the topological light rays parallel to them.

   Braiding of the short portions of flux tubes connecting bio-molecules (say tubulins and axonal membrane) serve as a geometric correlate for negentropic entanglement and negentropically entanglement subsystems give rise to various representations as "Akashic records", which are experienced consciously.

   The original view, which is *not* consistent with the recent view formulation of TGD inspired theory of consciousness, was that "Akashic records" could be read by interaction free measurement modified so that one obtains holographic representation of the data readable by using reference beam [K22] (see `http://tgdtheory.com/public_html/tgdlian/tgdlian.html#consccomparison`).

   The recent view is that only bit representations of memories can be read by interaction free measurements. The detectors in interaction free measurement correspond to the hologram substrate analogous to excitable lasers. The cyclotron Bose-Einstein condensates of dark matter with large value of $\hbar_{eff}/\hbar$ at the "long" portions of flux tubes and large flux sheets (with size scales exceeding even the Earth's radius) carry sensory and other representation as analogous of lasers excited in the reading of the representations.

2. *The decomposition of local EEG to quasi-stationary segments.* The proposal is that the sequences correspond to self-organization patterns for neuronal assemblies and serve as correlates simple qualia. The transitions between the quasi-stationary segments are sharp and the interpretation is as correlates for the above described phase transitions: they care referred to as rapid transitional processes (RTPs).

   In TGD framework EEG [K18] serves as a control and communication tool for magnetic body using biological body as sensory receptor and motor instrument. There is a strong temptation to assign the quasi stationary segments of EEG to self-organization patterns assignable CDs with frequency scale in 1-1 correspondence with the scale of CD (discrete). The amplitude- and frequency modulation of the Josephson radiation emitted by cell membrane acting as Josephson junction would map neural activity to temporal patterns of EEG.

3. *Neuronal synchrony binding neuron groups to operational modules.* Authors have introduced the notion of operational synchrony (OS) to describe the needed synchrony. This synchrony should be visible in EEG channels as correlations of the quasi-stationary segments.

   In TGD context OMs would be formed and destroyed by the reconnection of magnetic flux tubes building different quantum coherent structures formed from neurons. For instance, patterns defining objects of the visual field could correspond to this kind of quantum coherent units. This process would take place in all living matter and ATP-ADP transformation could generate standardized reconnection and negentropic entanglement between distant biomolecules. The basic function of metabolism would be production and modification of negentropic entanglement

7.2 About The Notion Of Criticality In TGD Framework

Criticality is one of the basic notions in Finglekurts et al's model and has quantum criticality as TGD counterpart. As a matter of fact, quantum criticality is a fundamental physical principle of TGD dictating the classical and also quantum dynamics so that it deserves a separate discussion. The value of Kähler coupling strength - the only parameter of theory - is fixed as the analog of critical temperature. In order to characterize the critical degrees of freedom one must say something about the K} ahler metric of "world of classical worlds" (WCW) [K20].

Very roughly, WCW can be seen as a generalization of the loop space of string models or of the super-space of Wheeler consisting of 3-geometries. WCW consists of all 3-surfaces in the 8-D imbedding space $M^4 \times CP_2$. Holography due to 4-D general coordinate invariance implies that one can speak about WCW also as a space of 4-D space-time surfaces with space-time surface being analogous to Bohr orbit. The challenge is to generalize Einstein's geometrization of physics program and geometrize quantum physics by providing WCW with so called Kähler geometry for which the metric is characterized by single function, so called Kähler function. There are excellent hopes that this geometry is unique since already for loop spaces this is the case. The mere mathematical existence of this geometry requires infinite-D symmetries and for 4-D space-time one can indeed generalized the conformal symmetries of super string model and achieve these symmetries. WCW becomes a union of infinite-dimensional symmetric spaces for which all points are geometrically equivalent. The zero modes labelling the symmetric spaces have interpretation as non-quantum fluctuating classical variables needed in quantum measurement theory.

Consider now what criticality means in this framework.

1. The matrix defined by the second order derivatives of Kähler function with respect to WCW coordinates is degenerate as is also the WCW Kähler metric defined by a subset of these derivatives ($G_{K\overline{L}} = \partial_K \partial_{\overline{L}} K$ is the defining formula of Kähler metric in complex coordinates in terms of Kähler function K).

   The reason for the degeneracy is that WCW metric depends on real zero mode coordinates, which do not appear as differentials in the line-element. These coordinate directions of WCW correspond to non-quantum fluctuating classical degrees of freedom not contributing to WCW Kähler metric. The proposed generalization of quantum measurement theory assumes that zero modes are analogous to classical variables defining say the position of a pointer of a measurement instrument and that they are in 1-1 correspondence with the outcomes of quantum measurements in quantum fluctuating degrees of freedom and give rise to quantum classical correspondence.

2. Quantum criticality would corresponds to a situation in which maximum of Kähler function (defining most probable space-time surface in their quantum superpososition) corresponds to a Kähler metric for which some elements of Kähler metric approach zero so that the rank for the matrix defined by the non-vanishing components of the Kähler metric is reduced. The resulting degrees of freedom would be effectively zero modes inside the critical manifold but not elsewhere. The criticalities would define an infinite hierarchy analogous to the finite hierarchy of criticalities for finite dimensional catastrophes Thom's catastrophe theory [A2]: cusp catastrophe is the simplest non-trivial example.

3. At the level of conformal symmetry algebras [K15] defining the infinite-dimensional symmetries of TGD Universe - call them with generic name A - this hierarchy could have very elegant representation. The elements of conformal algebra are labeled by integer plus other quantum numbers so that one can write the element of algebra $a_{n,\alpha}$. Critical sub-manifolds woud correspond to sub-spaces of WCW for which the elements $a_{nk,\alpha}$ of sub-algebra A_n (k is integer) annihilate the states or creates zero norm f states from them. Here n is a non-negative integer characterizing the critical manifold. Critical manifolds would be in 1-1 correspondence with non-negative integers n. If n_1 divides n_2, the critical manifold Cr_{n_2} belongs to Cr_{n_1}.

4. In the phase transitions between different critical manifolds some quantum fluctuating degrees of freedom become local zero modes in the sense that their contribution to WCW metric at a given point of WCW vanishes at criticality. Also the reverse transformation can take place.

There are some interesting questions to be answered.

1. Criticalities form a number theoretic hierarchy and primes define "prime criticalities". Does this mean that the primes dividing integer n define the possible p-adic topologies assignable to criticality defined by n?

2. The hierarchy of effective Planck constants is labelled by integers and giving integer n corresponds to n-furcation made possible by the failure of strict determinism for Kähler action. Could this integer correspond to the integer defining the criticality? Criticality is indeed accompanied by non-determinism realized as long range fluctuations.

3. Causal diamonds have size scales coming as integer multiples of CP_2 scale. Does this integer relate to the integer defining criticality?

4. The condition that the n characterizes finite measurement resolution in the sense A_n annihilates the physical states everywhere would de-localize the critical states outside the critical manifold. Does this mean that also finite measurement resolution is characterized by integer.

5. How the 4-D spin glass degeneracy due to the huge vacuum degeneracy of Kähler action implying breaking of strict determinism relates to quantum criticality?

These connections together with those suggested by NMP suggest that integer arithmetics is coded directly to the hierarchy of criticalities and is also basic characteristic of consciousness. This would give additional piece of support for the vision about physics as a generalized number theory [**?**]

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