Brain as Quantum-like Machine for Transferring Time into Mind

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Abstract

We propose a model of processing of information in the brain which has the following distinguishing features: a). It is quantum-like (QL). The brain uses the quantum rule (given by von Neumann trace formula) for calculation of averages for psychological functions. b). Those functions are considered as self-observations of the brain. c). The QL-representation has the temporal basis. The brain is a machine transferring time into cognition. d). Any cognitive process is based on (at least) two time scales: precognitive time scale (which is very fine) and cognitive time scale (which is essentially coarser).

To couple our model to physiology, behavioral science, and psychology, we consider a number of known fundamental time scales in the brain. Although the elaboration of those scales was based on advanced experimental research, there are still many controversial approaches and results. The temporal structure of the brain functioning is very complex.

1 Introduction

The idea that the description of brain functioning, cognition, and consciousness could not be reduced to the theory of neural networks and dynamical
systems (cf. Ashby (1952), Hopfield (1982), Amit (1989), Bechtel and Abrahamsen (1991), Strogatz (1994), van Gelder (1995), van Gelder and Port (1995), Eliasmith (1996)) and that quantum theory may play an important role in such a description has been discussed in a huge variety of forms, see e.g. Whitehead (1929, 1933, 1939), Orlov (1982), Healey (1984), Albert and Loewer (1988, 1992), Lockwood (1989, 1996), Penrose (1989, 1994), Donald (1990, 1995, 1996), Jibu and Yasue (1992, 1994), Bohm and Hiley (1993), Stapp (1993), Hameroff (1994, 1998), Loewer (1996), Hiley and Pylkkänen (1997), Deutsch (1997), Barrett (1999), Khrennikov (1999, 2000, 2002, 2003, 2004, 2006a), Hiley (2000), Vitiello (2001), Aerts, D. and Aerts S. (2007), Conte et al. (2007) and literature thereby.

This idea that quantum mechanics might have some consequences for cognitive science and psychology was discussed at many occasions already by fathers of quantum theory. We can mention, for example, attempts of Niels Bohr to apply the quantum principle of complementarity to psychology (see A. Plotnitsky 2001, 2002, 2007 for discussions). We can also mention the correspondence between Pauli and Young about analogy between quantum and mental processes.

During the last 30 years it was done a lot for the realization of the very ambitious program of quantum reductionism. There were various attempts to reduce mental processes to quantum physical processes in the brain. Here we point out to fundamental works Hameroff (1994, 1998) and Penrose (1989, 1994, 2005).

However, the quantum formalism provides essentially more possibilities for modeling of physical, biological, and social processes. One should distinguish quantum mechanics as physical theory and its formalism. In principle, there is nothing surprising that a formalism which was originally developed for serving to one special physical theory can be used in other domains of science. For example, we are not surprised that differential calculus which was developed to serve to classical Newtonian mechanics was later used in field theory, quantum mechanics, biology, economics. Nobody protests against applying the classical probability calculus (the Kolmogorov measure-theoretic model) to modeling of financial processes and so on. In the same way one might import into cognitive science and psychology the mathematical formalism of quantum mechanics, even without trying to perform a reduction of mental processes to quantum physical processes.

To escape misunderstanding, we shall reserve notations classical and quantum for physics. And in applications outside physics we shall use nota-
tions classical-like (CL) and quantum-like (QL).

By using non-reductionist QL-models one can escape some fundamental problems arising in the quantum reductionist approach, e.g., the presence of the huge gap between the quantum (physical) and neurophysiological scales. However, the problem of coupling with physical reality could not be just forgotten. Suppose that the quantum processes in the brain as a physical system are not responsible for mental phenomena. The natural question arises: "What is then the mechanism (physical, chemical, biological) inducing the QL-rules of mental processing?" In the present paper we shall show that the temporal structure of the brain functioning could be responsible for the QL-structure of processing of mental information.

Our starting point is a series of works Khrennikov (2005a, b, 2006b-d) on a new interpretation of quantum mechanics as a special representation of classical statistical mechanics. In such an approach the quantum formalism is merely a way of representation of information about systems (physical as well as biological). Suppose that we are not able to collect the complete set of information about a system (e.g., because of some restrictions for measurement procedures and technologies). In such a situation we may, nevertheless, try to create a model of phenomena which is based on ignorance of a part of information. By our interpretation the quantum formalism provides the consistent rules for such a modeling.

In this paper we shall apply methods developed in Khrennikov (2005a, b, 2006b-d) to cognitive science and psychology. We are especially interested in the following fundamental question: How can such a QL-projection of information be realized in biological systems?

We propose a model of processing of information in the brain which has the following distinguishing features:

a). It is quantum-like (QL). The brain uses the quantum rule (given by von Neumann trace formula) for calculation of averages for psychological functions.

b). Those functions are considered as self-observations of the brain.

c). The QL-representation has the temporal basis. The brain is a machine transferring time into cognition.

d). Any cognitive process is based on (at least) two time scales: pre-cognitive time scale (which is very fine) and cognitive time scale (which is essentially coarser).

To couple our model to physiology, behavioral science, and psychology,
we consider a number of known fundamental time scales in the brain. Although the elaboration of those scales was based on advanced experimental research, there are still many controversial approaches and results. The temporal structure of the brain functioning is very complex. As the physiological and psychological experimental basis of our QL-model we chosen results of investigations on one special quantal temporal model of mental processes in the brain, namely, Taxonomic Quantum Model –TQM, see Geissler et al (1978), Geissler and Puffe (1982), Geissler (1983, 85, 87,92), Geissler and Kompass (1999, 2001), Geissler, Schebera, and Kompass (1999). The TQM is closely related with various experimental studies on the temporal structure of mental processes, see also Klix and van der Meer (1978), Kristofferson (1972, 80, 90), Bredenkamp (1993), Teghtsoonian (1971). We also couple our QL-model with well known experimental studies, see, e.g., Brazier (1970), which demonstrated that there are well established time scales corresponding to the alpha, beta, gamma, delta, and theta waves; especially important for us are results of Aftanas and Golosheykin (2005), Buzsaki (2005).

The presence of fine scale structure of firing patterns which was found in Luczak et al (2007) in experiments which demonstrated self-activation of neuronal patterns in the brain is extremely supporting for our QL-model. Of course, not yet everything is clear in neurophysiological experimental research, see Luczak et al (2007): "The way spontaneous activity propagates through cortical populations is currently unclear: while in vivo optical imaging results suggest a random and unstructured process Kerr et al (2005), in vitro models suggest a more complex picture involving local sequential organization and/or traveling waves, Cossart et al (2003), Mao (2001), Ikegaya (2004), Sanchez-Vives and McCormick (2000), Shu, Hasenstaub, and McCormick (2003), MacLean (2005)."

In any event our QL-model for brain functioning operates on time scales which are used in neurophysiology, psychology and behavioral science. This

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1"Even in the absence of sensory stimulation, cortex shows complex spontaneous activity patterns, often consisting of alternating "DOWN" states of generalized neural silence and "UP" states of massive, persistent network activity. To investigate how this spontaneous activity propagates through neuronal assemblies in vivo, we recorded simultaneously from populations of 50-200 cells in neocortical layer V of anesthetized and awake rats. Each neuron displayed a virtually unique spike pattern during UP states, with diversity seen amongst both putative pyramidal cells and interneurons, reflecting a complex but stereotypically organized sequential spread of activation through local cortical networks. The timescale of this spread was 100ms, with spike timing precision decaying as UP states progressed," see Luczak et al (2007).
provides an interesting opportunity to connect the mathematical formalism of quantum mechanics with theoretical and experimental research in mentioned domains of biology. We hope that our approach could attract the attention of neurophysiologists, psychologists and people working in behavioral science to quantum modeling of the brain functioning. On the other hand, our QL-model might stimulate theoretical and experimental research on temporal structures of the brain functioning.

2 Quantum-like processing of incomplete information

As was pointed out, in this paper we consider not the quantum mechanics – a special physical theory which is applicable for a special class of physical systems (so called quantum systems), – but its formalism – a special mathematical formalism for representation of information. The quantum formalism is a special way of processing of incomplete information. However, if information cut off were done occasionally, one would have a chaotic information picture. The quantum formalism provides a possibility to create a consistent processing through the information projection. Such a formalism was first time found in physics at the beginning of 20th century.

Of course, our interpretation of quantum mechanics – as an incomplete description of quantum systems – contradicts to the original views of Bohr, Heisenberg, Pauli, von Neumann, Dirac and many others who postulated that quantum mechanics is a complete theory: the wave function provides the complete representation of statistical information about a system, e.g., electron. However, our “incomplete information processing interpretation” might be sympathetic for Einstein, Schrödinger, De Broglie, Bohm, Margenau, Popper, and nowadays Marshal, Ballentine, De Baere, De Muynck, Santos, Khrennikov and many others; cf. also with Svozil, 2006.

Even if the first application of processing of incomplete information on the basis of the quantum formalism was found in physics, there are no fundamental reasons to restrict its applications only to physics. We are interested in applications to cognitive sciences.

One might guess that the ability for the quantum-like (QL) processing of information was developed by biological organisms. From the very beginning of evolution biological organisms operated with huge information flows.
They could create a representation of external world which was based on an information-projection such that cuts of information flows were done in a consistent way. In the process of evolution there could be developed the ability to work with information by using the QL-representation.

We start with physics and we consider two time scales Khrennikov (2006d). One scale, we call it prequantum, is a fine time scale, another, we call it quantum, is a coarser time scale. Oscillations at the prequantum time scale are averaged and used for probabilistic reasoning at the quantum scale. The latter time scale is considered as an observational time scale.

It is important to mention that it was shown mathematically that one can really derive quantum averages as approximations of classical averages at the prequantum time scale, Khrennikov (2006d).

In the conventional quantum mechanics for physical systems the two time scale representation has a “semi-subjective character.” On the one hand, the quantum time scale – the atom time scale in Khrennikov (2006d):

\[ t_q \approx 10^{-21}\text{sec}, \]

and the prequantum time scale – the Planck time scale in Khrennikov (2006d):

\[ s_{pq} \approx 10^{-44}\text{sec}, \]

are scales of real physical processes.

On the other hand, the choice of the quantum (observational) scale and, hence, the concrete application of the quantum representation of information is a consequence of the presence of a special class of observers – human beings – and the special level of development of measurement technologies.

We now suppose that a biological system might create the QL-representation and QL-processing of information which are based on operating at two time scales.\(^2\) There is an analogue of the prequantum time scale. Information which is processed at that time scale is considered as non-cognitive. Thus this is a time scale of subconsciousness. We call this time scale precognitive and denote the precognitive time by \(s\) and its scale unit by \(s_{pc}\). There is also an analogue of the quantum time scale. One can say that it is the observational time scale. However, the crucial difference from the conventional quantum mechanics (for physical systems) is that there are no external

\(^2\)Thus discovery of quantum mechanics for physical systems was simply a rediscovery of the basic representation of information in the human brain!
observers. The brain performs observations on itself. It is better to speak about self-observational time scale. It is assumed that this is the time scale of cognition. We call it the cognitive time scale and denote the cognitive time by \( t \) and its scale unit by \( t_c \). Of course, we have the inequality:

\[ s_{pc} < t_c. \]

The crucial parameter that determines the measure of quantumness (or better to say QL-ness) of cognition is the parameter:

\[ \kappa = \frac{s_{pc}}{t_c}. \]

(1)

It provides a numerical measure of deviation of the QL (fuzzy, unsharp) representation of information from the “classical” (complete, sharp) one.

Under the assumption that the precognitive time scale \( s_{pc} \) is fixed, we find that for small periods of fluctuations \( t_c \) the parameter \( \kappa \) is very large. Thus higher frequencies (at the cognitive time scale) induce larger deviations from the (complete) CL-processing of information.

Huge amounts of information which are processed at the precognitive time scale are neglected, but not arbitrary (randomly). There is the QL-consistency in the information processing. Consequently, for low frequencies (oscillations with long periods) this coefficient is small. Therefore the QL-processing does not imply large deviations from the CL-computational regime.

The crucial problem is to find those biological time scales which induce the QL-representation of information. There are many ways to create such time scales. We split the problem into the two parts:

1) to find the precognitive time scale;
2) to find the cognitive time scale.

It seems that (as in physics) the first problem is more complicated. First we consider the second one. We start the discussion on the choice of the cognitive time scale in by considering experimental evidences, see, e.g., Khrennikov (2006a) for discussion and references, that a moment in psychological time correlates with \( \approx 100 \) ms of physical time for neural activity. In such a model the basic assumption is that the physical time required for the transmission of information over synapses is somehow neglected in the psychological time. The time (\( \approx 100 \) ms) required for the transmission of information from retina
to the inferiortemporal cortex (IT) through the primary visual cortex (V1) is mapped to a moment of psychological time. It might be that by using $t_c = 100\text{ms}$, we shall get the right cognitive time scale.

However, the situation is not so simple even for the second problem. There are experimental evidences that the temporal structure of neural functioning is not homogeneous. The time required for completion of color information in V4 ($\approx 60\text{ ms}$) is shorter than the time for the completion of shape analysis in IT ($\approx 100\text{ ms}$). In particular it is predicted that there will be under certain conditions a rivalry between color and form perception. This rivalry in time is one of manifestations of complex level temporal structure of brain.

Our fundamental assumption is that there exist various pairs of scales inducing various QL-representations of information. In the next section we shall discuss such a temporal QL-model of cognition in more detail.

We shall come back to the “difficult problem, namely, determination of the precognitive time scale, in section 5. But at the moment we forget about physiological and psychological time scales in the brain and we present in more detail our QL-approach for processing of information.

### 3 Quantum-like approximation of temporal statistical averages in brain

There are two time scales, a precognitive time scale $s_{pc}$ and a cognitive time scale $t_c$. There is a cognitive process $\pi$ (e.g., a cognitive task) which is performed at the $t_c$-scale. It integrates a number of processes which are performed at the $s_{pc}$-scale. Here ”integrate” has the meaning to produce averages with respect to oscillations at the $s_{pc}$-scale. Such averages are considered as cognitive quantities at the level of the $\pi$-process.

In our model ”self-observation” is nothing else than the calculation of an average. However, this is only a part of the story. If the brain were compute averages by the CL-algorithm – as statistical sums (with respect to huge ensembles of oscillations at the precognitive time scale) – then it would be simply an analogue of the ordinary computer. This would be a kind of ”statistical physics thinking.”

In our approach the QL-story of processing of information is in fact the purely computation story. To calculate averages as statistical sums (over

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$^3$No quantum mysteries at all. The basic point is evolution for optimization of com-
huge neuronal ensembles), the brain should consume too much computational and, hence, physical resources. My guess is that the brain has the ability to perform calculations of averages by using the rules of quantum mathematical formalism. Instead of a huge statistical sum, the brain calculates its QL-approximation given by the von Neumann formula for the quantum average given by the operator trace, see von Neumann (1955).

A classical mental quantity (psychological function) is given by a function \( f(\omega) \) depending on the vector of parameters \( \omega \) which are produced at the precognitive time scale. In the QL-algorithm \( f \) is approximated by its second derivative, Khrennikov (2005a,b, 2006b-d). In this way the brain obtains a symmetric operator \( A \), Hessian of the map \( f \). This is a QL-observable. A statistical distribution of random oscillations at the precognitive time scale is represented by its covariance operator. In this way the brain produces a symmetric positively defined operator. By scaling there is obtained the operator \( \rho \) which has all properties of the von Neumann density operator, i.e., it also has the unit trace. This is the QL density operator. After this the brain is ready to find the QL-approximation of the classical statistical average \( <f> \):

\[
<f> \approx \text{Tr} \rho A.
\]

We have shown in Khrennikov (2006d) that the classical average, the statistical sum with respect to the random oscillations at the time scale \( s_{pc} \), is approximated by the trace QL-average and the precision of the QL-approximation is of the magnitude \( \kappa \) which is given by (3). Thus if the parameter \( \kappa \) is very small the brain does not lose too much information. This is practically the CL-computation. But if \( \kappa \) is rather large, then the brain works in a nonclassical regime. One may say (as von Neumann would like) that in such a regime the brain uses nonclassical logic. Huge amounts of information are permanently neglected. But this does not generate a kind of chaos. Information is neglected in a consistent way.

As was pointed out a few times, such a QL-processing of information save a lot of computational resources. It might be an important factor of the computational abilities. The QL-computation is quicker, because it is an approximative and because it does not need so much resources as the CL-computation.

4We have a simple picture of arising nonclassical, in particular, quantum logical structures. These are systems for processing of incomplete information. The classical logic would not be violated if we were able to collect and process complete sets of information. However, sometimes we are not able. Therefore we develop special systems for processing of incomplete sets of information.
natural selection of biological organisms.

4 Multiplicity of time scales in brain and quantum-like cognitive representations

The main lesson from the experimental and theoretical investigations on the temporal structure of processes in brain is that there are various time scales. They correspond to (or least they are coupled with) various aspects of cognition. Therefore we are not able to determine once and for ever the cognitive time scale $t_c$ ("psychological time"). There are few such scales. We shall discuss some evident possibilities.

Before to go deeper in the temporal structure of mental processes, we shall analyze in more detail the multi-scale temporal aspects of quantum mechanics. Such aspects have never been discussed, because, on the one hand, it was commonly assumed that quantum mechanics is complete (this is the Copenhagen interpretation), and, on the other hand, the quantum formalism is used by only one class of observers – human beings. The latter generates the unique observational (quantum) time scale. However, we can consider a possibility that there exits a class of observers ("super-clocks civilization") which use a time scale $t'_q$ which is essentially finer than our time scale $t_q$:

$$t'_q << t_q$$

Suppose that the super-clocks civilization has also created the quantum representation of information. Of course, their time scale should not be extremely fine comparing with the prequantum time scale $s_{pq}$:

$$s_{pq} << t'_q$$

(we assume that both civilizations – our and super-clocks – are interested in processes at the same prequantum time scale). The super-clocks civilization would discover the same mathematical formalism of quantum mechanics. But the presence of deviation from prequantum reality would be more evident with respect to their time scale (since $s_{pq}$ is the same, but $t'_q$ is smaller than $t_q$, the coefficient $\kappa'$ for the super-clocks civilization is larger than the coefficient $\kappa$ for our civilization). On the one hand, the super-clocks civilization has a better possibility to find deviations of the incomplete quantum description from the complete classical description. However, there might be
chosen a strategy to ignore such deviations and still use the quantum picture of the world. Even if it does not match precisely with the complete set of information about external world, it might be, nevertheless, convenient (by computational and consistency reasons) to proceed with the quantum pictures of reality.

Similar functioning with a few time scales of observation (in fact, self-observation) can be present in the brain. How can we find those scales?

It is well known, see, e.g., Brazier (1970), that there are well established time scales corresponding to the alpha, beta, gamma, delta, and theta waves. Let us consider these time scales as different cognitive scales. There is one technical deviation from the QL-scheme which was discussed above. We cannot determine precisely definite cognitive times corresponding to these scales. The scales are defined by ranges of frequencies and hence ranges of scaling times.

For the alpha waves we choose its upper limit frequency, 12 Hz, and hence the \( t_{c,\alpha} \approx 0.083 \) sec. For the beta waves we consider (by taking upper bounds of frequency ranges) three different time scales: 15 Hz, \( t_{c,\beta,\text{low}} \approx 0.067 \) sec. – low beta waves, 18Hz, \( t_{c,\beta} \approx 0.056 \) sec. – beta waves, 23 Hz \( t_{c,\beta,\text{high}} \approx 0.043 \) sec. – high beta waves. For gamma waves we take the characteristic frequency 40 Hz and hence the time scale \( t_{c,\gamma} \approx 0.025 \) sec.

The gamma scale is the finest and hence processes represented at this scale has the highest degree of QL-ness. On the other hand, we know that gamma waves patterns in the brain are associated with perception and consciousness. The beta scale is coarser than the gamma scale and it has less degree of QL-ness in processing of information. We know that beta states are associated with normal waking of consciousness.

The theta waves are even less QL than the alpha waves. They are commonly found to originate from occipital lobe during periods of relaxation, with eyes closed but still awake. They are involved into a representation of information with a high degree of classicality. And these rhythms are observed during some sleep states, and in states of quiet focus, for example, meditation, Aftanas and Golosheykin (2005). However, there are also experimental evidences that the theta rhythms are very strong in rodent hippocampi and entorhinal cortex during learning and memory retrieval. We can just speculate that learning needs using of an essentially more detailed information representation. Thus learning (or at least a part of it) is less QL and hence more CL. The same we can say about memory retrieval. It
also needs more complete, CL-representation of information. Large body of evidence, Buzsaki (2005), indicates that theta-rhythms are used in spatial learning and navigation. Here we present the same reasons: such tasks are based on CL-representation of information.

Finally, we consider delta waves. Comparing with the highest scale – the gamma scale, the delta time scale is extremely rough. This induces a low degree of QL-ness. This is the state of deep sleep.

Although we still did not come to the difficult problem, namely, determination of the precognitive time scale, we can, nevertheless, compare the degree of QL-ness of various time scales.

Our choice of the precognitive time scale will be motivated by so called Taxonomic Quantum Model, see Geissler et al (1978), Geissler and Puffe (1982), Geissler (1983, 85, 87,92), Geissler and Kompass (1999, 2001), Geissler, Schebera, and Kompass (1999), for representation of cognitive processes in the brain (which was developed on the basis of the huge experimental research on time-mind relation, see also Klix and van der Meer (1978), Kristofferson (1972, 80, 90), Bredenkamp (1993), Teghtsoonian (1971). In the following section we recall briefly the main features of this model.

5 Taxonomic quantum model

There could be presented a portion of good criticism against starting from EEG bands. Indeed, this band structure is one of the few indications that directly point to behaviorally relevant physiological properties. Physiologists suggesting the definitions had a good intuition. However, that these definitions depend on behavioral information is shown by enormous individual differences in the band structures that can be defined only on a behavioral basis. To some degree this concerns also the general band structure. Because of individual differences, alpha is often restricted to the common range which is too short to be theoretically fully relevant. Definitions often go only from 9 to 12 Hz. Most careful investigators (earliest Livanov) defined the band by the range 7.5 to 13.5 Hz.

Therefore we propose to start with Taxonomic Quantum Model (TQM), Geissler et al (1978), Geissler and Puffe (1982), Geissler (1983, 85, 87,92), Geissler and Kompass (1999, 2001), Geissler, Schebera, and Kompass (1999).

5The phenomena of sleep and dreaming are extremely complicated. We do not plan to study them in this paper.
Why do we propose to use TQM for start of theory instead of, say, some characteristic physiological parameters such as neuronal refractoriness, transmission times, coupling strength etc.? In my view, the reason is that *the only basis for interpreting physiological facts of brain processes are psychophysical (behavioral) observations, either based on motor reactions of conscious beings or verbal reports on conscious events.* This was the main way of thinking of von Bekesy (1936). Of course, many of the functional statements of psychologist have the same basis. For our purpose, this statement is absolutely essential, because a coherent account of temporal properties of brain activity must not only be related to behavioral observations, but it must be based on temporal invariants extracted by a coherent theoretical account of behavioral observations, and only these can provide the guideline to find the proper physiological correspondences.

The best short cut to the approach is through the history of its emergence: The first impulse towards a taxonomic turn arose in the early 1970s from the discontent of Geissler, see, e.g., Geissler et al (1978), with the fact that in simple psychophysical tasks data could indistinguishably be fitted to models resorting to widely differing, often enough even contradicting, assumptions. In his research in visual recognition, to circumvent this difficulty, Geissler introduced a technique of chronometric cross-task comparison. The main idea was to disambiguate models by temporal parametrization, thereby postulating invariance of time parameters under variation of stimulus parameters and task constraints (see e.g. Geissler et al. (1978) and Geissler and Puffe (1982)). At that time another research group at the same institute did something similar by fitting latencies in standardized reasoning tasks to predicted numbers of operations, e.g., Klix and van der Meer (1978). The estimates from the two lines of studies yielded a surprising picture: There seemed to exist small bands of operation times centering at around 55, 110 and 220 ms, thus exhibiting near-doubling relations. As a datum from the literature which fitted into this regularity the asymptotic value of 36.5 ms determined by Kristofferson (1972), see also Kristofferson (1980, 90), came to mind which up to the first decimal is 1/3 of 110 ms. Taken together, these four values suggested a system of magic numbers. Herein a period of 110 ms represents something like a prototype duration from which the rest of periods derives by either integer division or multiplication. From various fit procedures for step lengths, Buffart and Geissler came up with an largest common denominator (l.c.d.) of 9.13 ms (see Geissler, 1985) showing a standard deviation of 0.86 ms across individuals. It turned out that the four
above-mentioned periods, although partly many times larger than this small period, can be represented as integer multiples of it, with nearly absolute precision: $4 \times 9.13 = 36.5; 6 \times 9.13 = 54.8; 12 \times 9.13 = 109.6; 24 \times 9.13 = 219.1$. Of course, this might have been some strange coincidence. Yet, later, chronometric analysis seemed to support a modular unit of some 9 ms (see Geissler (1985); Puffe (1990); Bredenkamp (1993). Further investigations justify a modified assumption about quantal graining:

Regression yields the largest common denominator (l.c.d.) 4.6 ms, which is nearly exactly one half of 9.13 ms.

Note that, in terms of hypothetical quanta, a period of such duration represents the next smaller candidate of a true elementary time quantum which is compatible with the recognition data. In the following, let us adopt provisionally the (ideal) value of

$$Q_0 = 4.565 \text{ms}$$

for this time quantum hypothesis.

The solution TQM offers to these seeming contradictions, see Geissler (1987, 92, 85) can be considered as a generalization or at least an analogue of the psychophysical principle of relative-range constancy. According to Teghtsoonian (1971), this principle expresses itself in the fact that for all sensory continua, in terms of output magnitudes, the ratio of the largest to the smallest quantity is a constant of around 30. About the same value is obtained from the so-called Subjective Weber Law.

The generalization of the principle in the realm of quantal timing is the quantal-range constraint. To see how this analogue reads, consider first the assumed smallest period $Q_0$. For integer multiples $n \times Q_0$, consistency with the relative range constraint implies $n \leq M$, with $M$ being a constant of the hypothetical value 30. It follows that periods of durations in excess of $30 \times Q_0 \approx 137 \text{ ms}$ cannot be represented within this smallest possible range. To account for such periods, we have to assume larger ranges with correspondingly larger admissible smallest quantal periods to be operative. To retain consistency with the time quantum assumption, these periods must be integer multiples of $Q_0$ or, formally,

$$Q_q = q \times Q_0$$

(2)

with integer $q$ must hold. Thus, in general, the maximum extension of any quantal of periods $T_i$ belonging to it is given by $q \times Q_0 \leq T_i \leq M \times q \times$
Note that the lower bound $q \times Q_0$ also defines the smallest possible distance between admissible periods within a range. For this reason we will speak of it as the quantal resolution within a given range. Of course, in the actual development, this abstract definition resulted from a variety of empirical relationships suggesting a range ordering of quantal periods with upper bounds maximally at 30 times the value of quantal resolution.

TQM does not exclude the possibility that there can be found smaller characteristic time scales, e.g., $Q_0/30$.

## 6 Precognitive time scale

We choose $Q_0$ as the unit of the precognitive time:

$$s_{pc} = Q_0 = 4.6ms$$

(3)

This corresponds to frequencies $\approx 220$ Hz. Under such an assumption about the precognitive scale we can find the measure of QL-ness for different EEG bands. For the alpha scale, we have

$$\kappa_\alpha = \frac{Q_0}{t_{c,\alpha}} \approx 0.055.$$

For the beta scales, we have:

$$\kappa_{c,\beta,low} = \frac{Q_0}{t_{c,\beta,low}} \approx 0.069; \kappa_{c,\beta} = \frac{Q_0}{t_{c,\beta}} \approx 0.082; \kappa_{c,\beta,high} = \frac{Q_0}{t_{c,\beta,high}} \approx 0.107.$$

For the gamma scale we have:

$$\kappa_\gamma = \frac{Q_0}{t_{c,\gamma}} \approx 1.84.$$

Thus QL-ness of processing of information increases. “Thinking through the alpha waves” is more likely processing of information by ordinary computer. Not so much information is neglected. Therefore the information processing is not so tricky: there is no need to manipulate with extremely incomplete information in the consistent way. “Thinking through the gamma waves” is similar to processing of information by an analogue of quantum computer – QL-computer, see Khrennikov (2006a). Such an information processing is very tricky: permanent informational cuts, but in the consistent QL-way.
Finally, we come to the theta and delta scales. For the theta scale $t_{c,\theta} = 0.125$ sec. Thus

$$\kappa_{\theta} = \frac{Q_0}{t_{c,\theta}} \approx 0.037.$$ 

And for the delta scale $t_{c,\delta} = 0.5$ sec and hence:

$$\kappa_{\delta} = \frac{Q_0}{t_{c,\delta}} \approx 0.009.$$ 

Here the difference between the biological QL-processing of information in the brain and the CL-processing (as in models of artificial intelligence) is practically negligible.

We now compare our QL-scales of time with the "quantum scales" which were chosen in Khrennikov (2006d):

$$s_{pc} \approx 10^{-3} \text{ sec}, \quad s_{pq} \approx 10^{-44} \text{ sec}. \quad (4)$$

$$t_c = 30Q_0 \approx 10^{-1} \text{ sec}, \quad t_q \approx 10^{-21} \text{ sec}. \quad (5)$$

Thus our model is based on macroscopic time scales, in the opposition to really quantum reductionist models.

If we follow TQM in more detail then we should consider a possibility that in the brain there exist a hierarchy of precognitive times, i.e., the above model with one fixed precognitive time given by (3) was oversimplified. From the point of view of TQM each $Q_q$ given by (2) could serve as the basis of a precognitive time scale. We obtain a picture of extremely complex QL-processing of information in the brain which is based of the huge multiplicity of various precognitive/cognitive scales.

In this framework the notion “precognitive” loses its absolute meaning. The notions “precognitive”/“cognitive” become relative with respect to a concrete psychological function (cognitive task). Moreover, a time scale which is precognitive for one psychological function can be at the same time cognitive for another.

But the crucial point is that the same cognitive time scale, say $t_c$, can have a number of different precognitive scales:

$$Q_{q_1} \leq \ldots \leq Q_{q_m}.$$ 

Each pair of scales

$$(Q_{q_1}, t_c), \ldots, (Q_{q_m}, t_c)$$
induces its own QL-representation of information. Therefore the same $t_c$-rhythm can be involved in the performance of a few different psychological functions.

The final message from TQM is that the cognitive time $t_c$ scale should be based on an integer multiplier of the time quant $Q_0$:

$$t_c = NQ_0.$$  \hspace{1cm} (6)

In such a model we can totally escape coupling with directly defined different EEG bands, alpha, beta, gamma,... We shall use only behaviorally defined time scales. The Weber law gives us the restriction to the value of the multiplier: $N \leq 30$.

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