QUANTAL TIMING AS A CONSEQUENCE OF THE ANTICIPATORY ACTIVITY OF THE NERVOUS SYSTEM

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Abstract

An experimental investigation of the quantal nature of the mental processes is complicated. The paper discusses the anticipatory activity in the nervous system as the most important feature of the living systems aiming to show that the very anticipation is a source of the quantal information processing. It is assumed that a discrete character of anticipation is conditioned by the mechanism of hypotheses generation and their verification. The model described may stimulate an experimental study of the quantal processes.

A problem of the sensation and perception continuity is being intensively discussed since beginning of the psychophysics (Weber, 1846; Fechner, 1860). In fact, a concept of the threshold already included some meaning of the discontinuity. As developed by Fechner (and other nineteenth century workers) the basic concept of the threshold was quite simple. One value of the stimulus produces just insufficient neural energy to trigger a critical event in the nervous system and detection or discrimination does not occur. The next increment of stimulation does trigger the event. Such definition of the threshold leads us to rectilinear psychophysical function. However, psychophysicists soon discovered that actual threshold data do not typically match to such form function. It is much more common to find that they are better fitted by a sigmoid function. The discrepancy between theory and practice led to some change of the classical concept of threshold to the theory of the neural quantum. The theory of the neural quantum was first formalized by Stevens, Morgan and Volkman (1941). The theory assumes that sensitivity in the nervous system is discontinuous and is mediated by neural "quanta". Various experimental data received by Stevens et al., Békésy, who measured the difference threshold for hearing, DeCillis for the detection of moving stimuli on the skin, and Jerome for the olfactory detection of certain smell were in good agreement with predictions of the neural quantum theory (Gordon, 1995).

Special attention should be devoted to temporal organization of the mental processes. Many research works (Geissler, 1985, 1987, 1990; Geissler et al.,1999; Kompass, 1999; Kristofferson, 1967, 1980; Stroud, 1955; Treisman, 1963; Treisman et al., 1990; Vanagas et al., 1976; Vanagas, 1991) demonstrates the existence of the substantial amount of the time discretization across different tasks and sensory modalities. The presence of any kind of the discrete intervals means that a perceptual process is not continuos but have some "perceptual intermittencies" (Allport,1968). It seems relevant that various time units differing in size and functional significance are involved in an information processing (Geissler, 1987, 1990).

The exceptional importance of the time in organization of the structure of mental processes allows us suppose, that a threshold detection of stimulus intensity, so deeply investigated in classical psychophysics, is determined by temporal intermittencies of the perception.

However, in spite of above mentioned interesting findings, the experimental verification of the quantal phenomena meets with serious methodological difficulties and is under permanent criticism, which is mainly determined by contemporary paradigm of the measurement. Firstly, in order to obtain reliable experimental results the whole set of data from observer must be gathered in a single continuous session involving many trials. On the other hand, the state of the observer in the long term experiment inevitably changes and, as a result of that, a possible discrete behavior of the parameter under measurement can be missed. Perhaps, that it is the main reason why the attempts to replicate the best-known findings in this area have not always been successful (Corso, 1970). Strongly speaking, the quantum theory can be tested only by quantum procedures. Unfortunately, at present time, we do not know how to realize that.

A theoretical understanding of the quanta origin could lead to formulation of the new testable experimental procedures. At beginning of the neurophysiology, the inspiration for the quantum approach to threshold was the well known behavior of neurons: propagation of a nerve impulse down an axon fibre obeys the all-or–non law. But the synaptic and dendritic processes which precede and follow the generation of impulses are essentially graded in nature. In fact, the all-or-none behavior of the axon is interpreted simply as a means of conveying graded messages from one part of the nervous system to another using a frequency code. Thus, the behavior of neurons does not necessarily imply that the sensitivity they mediate should also be discontinuous.

The different models, which rely on synchronization of mental processes by a "central clock" were proposed aiming to explain a discrete mental timing. The role of the clock is prescribed to rhythmic electrical oscillations in a brain (Stroud, 1955; Treisman, 1963; Treisman et al., 1990). Currently a functional role of the oscillatory activity of the frequency 30- 80 Hz in the responses of visual neurons is discussed very intensively (Eckhorn, 1991; Dehaene, 1993; Ghose & Freeman, 1992; Niebur et al., 1993). Mainly it is supposed that stimulus-induced synchronized oscillations serve as feature binding agent. A basis for the linking of the features might be: proximity in visual space, various local similarities, near simultaneity of events and so on (Eckhorn, 1991; Elliot & Müller, 1998). However, it seems, that the idea of the central clock is influenced by the construction of the discrete technical systems and there is doubtful it direct applying for brain mechanism. Besides of that, the oscillations of brain are harmonic. Thus, the applying of central clock idea for explanation of brain mechanisms looks insufficient for explaining of the discrete timing of the mental processes.

Anticipatory information processing in a nervous system

The study of the information processing in human beings and animals, the investigation systems of the artificial intelligence in the last decades show that perception of the world has "active" or "constructive" nature. It means, that perception is a dynamic interplay between current stimulation and expectations based upon previous dealings with the world. Early models of this kind were known as "analysis by synthesis" systems (Stevens, 1960; Norman & Lindsey, 1972) or "nested analysis" systems (Arbib, 1972). Often they are named as the active perception or recognition systems (Kirvelis, 1999; Vanagas, 1991) or an active vision systems (Bajcsy, 1988).

The structure of the system capable analyses environment in active way, is presented in Fig.1. An information processing in the system includes the following operations:

- ♦ detection of the features and preliminary analysis of the current situation;
- ♦ formation of the hypothesis “what is present in the world and where it is”;
- ♦ verification of the hypothesis i.e. comparison of the current situation with the assumed one extracted from the memory.

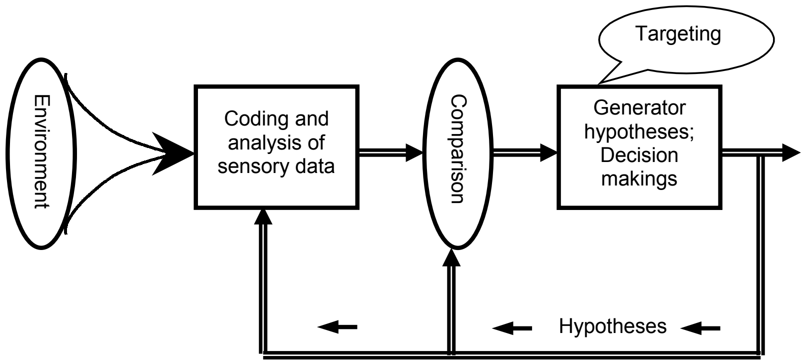

Figure 1. Functional structure of the active (anticipatory) system.

It is important to emphasize a deductive part of the operations i.e. generation of some kind of the expectations-hypotheses. The system gets considerable amount of the information on the possible contents of hypotheses from the results of comparison of implied and real situation. Yet, other sources of the information must be used by the system for the generation of hypotheses. A preliminary analysis of the environment can be one of such sources. Other reasons restricting the amount of possible expectations lie in motivational influences of an organism, awareness of the whole situation under recognition both in space and time (Crick &Koch, 1990). The functioning of the active (anticipatory) system could be described by the next representation (Vanagas, 1994):

$$S_a : X(t) * Y(t - \Delta t) * Q(t - \Delta t) \rightarrow Y(t),$$

where X(t) – the set of the input events at the moment t; Y(t) and Y(t-Δt) – the sets of output decisions at the moments t and t-Δt; Q(t-Δt) – the set of the targeting of the higher levels of the information processing or the whole organism. A member Y(t-Δt) of the equation represents a content of the expected hypothesis.

According to the standpoint of discussed approach, of special interest is a model of MacKay (1963) devoted to psychophysics of intensity perception. With aim to explain the existing disagreement between Weber-Fechner’s and Steven’s laws, he proposed functional closed-loop scheme in which decision about presented intensity of stimulus is accepted by the special “coordinating element”. The coordinating element compares frequency of the nervous impulses (proportional to stimulus intensity according with law of the Weber-Fechner) evoked by presented stimulus with the frequency of the impulses (proportional to a logarithm of the sensation) generated by the some inner structure, changing the last one until coincidence between them is achieved. In this case "inner frequency" reflect expected stimulus intensity i.e. have a content of the hypothesis. From our point of view, two issues are of great importance: (i) an intensity of the stimulus is perceived by matching presented value with expected one; (ii) a matching process takes some time. Thus, MacKay model indicates that in relatively simple mental function such as a perceiving of stimulus intensity anticipation process should be already involved.

In more general terms, the systems capable to generate the expectations are named as anticipatory systems (Dubois, 1998; Rosen, 1985). Rosen defined anticipatory system as a "system containing a predictive model of itself and/or it's environment, which allows it to state at an instant in accord with the model's pertaining to a later instant". Rosen emphasizes an importance of predictive activity saying that "what differentiates living systems and inorganic systems is anticipation".

Discrete character of the information processing in an anticipatory system

A great amount of operations in a nervous system is performed in parallel neural nets simultaneously, e.g. detection of the features in vision. However the sequence of events related to hypothesis formations with consequent its verification should be consequent process in nature. Thus, information processing in anticipatory system is going temporally.

Let us discuss information timing in the system in detail. An interval of time needed for the generation and verification of the hypothesis we shall mark as δ. Let us say that the fixed interval of time T is given for investigation of presented situation. In the case of the formation of successful hypothesis, it will be tested after period not less than δ and system will get some quantity of information about object which is under investigation. If the hypothesis was not correct a new one will be generated and tested only through additional period of time δ. This means that time not less then $T=2\delta$ will be taken for the increasing information quantity about the object. It become obvious that during some intervals of time the quantity of information will not change. Therefore, an increasing amount of information (knowledge) as a function of time analysis of the object in anticipatory system is determined by step-like function (Fig.2).

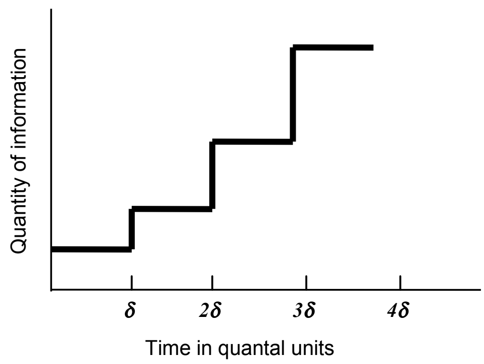

Figure 2. Increment of the information quantity in an anticipatory system as a function of the time analysis of the object.

A time interval δ reflects a shortest period of time, which enables system to get some information about interested object and, for this reason, it could be named as perceptive quantum. Thus, we incline to suppose that the very anticipatory activity of the nervous system is main reason of the quantal timing in psychological experiment.

A length of the quantum, beyond of the other factors, depends on complexity of the hypotheses. By that reason an experimental investigation of the quantal phenomena is complicated. Therefore, experimental conditions might be chosen in the way, which stimulates a developing discrete nature of the perception. For example, in the visual recognition task, we have used the special geometrical figures, constructed as much as possible equally complex (Vanagas et al., 1976). The number of the correct pattern identification as a function of its time analysis was studied. Step-like function of the recognition process, similar to presented in Fig.2, was obtained. A coincidence of the experimental and theoretical functions was examined with help of the chi-square criterion and turned out to be quite satisfactory for approximately fifty percent of experimental data. It was found that the length of the step δ varied insignificantly for all subjects and lasted for $8 \div 10$ ms. However, the duration of the perceptive quantum could be various for different tasks and for different levels of perception (Geissler, 1987,1990).

A study of the correlation of anticipatory process with neuronal activity of the brain could be important. We are inclined to think that the clustered (oscillatory) responses of the neurons might be interesting for an investigation of the discrete nature of the perception on the neuronal level. Such activity is described as excitatory discharges, which are interrupted by inhibitory intervals. The significance of the clustered activity for encoding and processing of the information were shown at different levels of the visual system (Cattaneo et al., 1981; Vanagas et al., 1987). According to suggested model, the clustered activity may be caused by feed-back links coming from the decision-making block to the feature analysis and comparison blocks (see Fig.1) and, therefore reflect process of the hypotheses verification. Who knows, but it may happen that future development in neurophysiology will make possible a direct verification of quantal theory at neuronal level.

References

Allport, D. A. (1968). Phenomenal simultaneity and the perceptual moment hypothesis. *British Journal of Psychology*, **59**, 395-406.

Arbib, M. (1972). The Metaphorical Brain. Wiley-Interscience, a Division of John Wiley and Sons, Inc. New York-London-Sydney Toronto.

Bajcsy, R. (1988). Active Perception. *Proceedings of the IEEE*, **76**, 8, 996-1005.

Cattaneo, A., Maffei, L. and Morrone, C. (1981). Patterns in the Discharge of Simple and Complex Visual Cortical Cells. *Proceedings of the Royal Society of London,* **B212**, 1176, 279-297.

Crick F. and Koch C. (1990). Some Reflections on Visual Awareness.Cold Spring Harbor Symposiums in Quantitative Biology, LV, 953-963.

Corso, J. F. (1970). The Experimental Psychology of Sensory Behavior. London: Holt, Rinhart & Winston.

Dehaene, S. (1993). Temporal oscillations in human perception. *Psychological Science*, **4/4**, 264-269.

Dubois, D. M. (1998). Introduction to Computing Anticipatory Systems. *International Journal of Computing Anticipatory Systems*, ed. by D. M. Dubois, published by CHAOS, **2**, 3-14.

Eckhorn, R. (1991). Stimulus - Specific Synchronizations in the Visual Cortex: Linking of Local Features Into Global Figures? In J. Krüger (Ed.): Springer Series in Synergetics. Neuronal cooperativity, 184-224.

Elliott, M. A. & Müller, H. J. (1998). Synchronous information presented in 40 Hz flicker enhances visual feature binding. *Psychological Science*, **9**, 277-283.

Fechner, G. T. (1860). Elemente der Psychophysik, Vol. 2. Leipzig: Breitkopf und Haertel.

Geissler, H.-G. (1985). Sources of seeming redundancy in temporally quantized information processing. In: G. d'Ydewalle (Ed.), Cognitive information processing and motivation. Selected/revised papers of the 23rd International Congress of Psychology, Vol. **3**, 119-228. Amsterdam: North-Holland.

Geissler, H.-G. (1987). The Temporal Architecture of Central Information Processing: Evidence for a Tentative Time-Quantum Model. *Psychological Research*, **49**, 99-106.

Geissler, H.-G. (1990). Foundations of quantized processing. In H.-G. Geissler (Ed.), Psychophysical Explorations of Mental Structures. Göttingen a.o.: Hogrefe, 193-210.

Geissler, H.-G., Schebera, F.-U., & Kompass, R. (1999). Ultra-precise Quantal Timing: Evidence from Simultaneity Thresholds in Long-Range Apparent Movement. *Perception & Psychophysics*, **61**, 707-726.

Ghose, G. and Freeman R. (1992). Oscillatory Discharge in the Visual System: Does it Have a Functional Role. *Journal of Neurophysiology*, **68**, 5, 1558-1574.

Gordon, I. E. (1995). Theories of Visual Perception. John Wiley & Sons.

Kirvelis, D. (1999). Visual Analyzer as Anticipatory System (Functional Organization). In AIP Conference Proceedings 517, Computing Anticipatory Systems: CASYS'99 Third International Conference, ed. by D. M. Dubois, 277-286.

Kompass, R. (1999). Analysis of discrete temporal structures of cognitive processes (in German): Analyse diskreter zeitlicher Strukturen perzeptiver Prozesse. Dissertation University Leipzig.

Kristofferson, A. B. (1967). Successiveness discrimination as a two-state, quantal process. *Science*, **158**, 1337-1339.

Kristofferson, A. B. (1980). A quantal step function in duration discrimination. *Perception & Psychophysics*, **27**, 300-306.

Lindsay, P.H., Norman D.A. (1972). Human Information Processing N.Y., Lnd.

MacKay, D. M. (1963). Psychophysics of Perceived Intensity: A Theoretical Basis for Fechner's and Steven's Laws. *Science*, **139 (3560)**, 1213-1216.

Niebur, E., Koch, C., Rosin, C. (1993). An Oscillation-Based Model for the Neuronal Basis of Attention. *Vision Research* **33**, 18, 2789-2802.

Rosen, R. (1985). Anticipatory Systems. Pergamon Press.

Stevens, K. N. (1960). Towards a model for speech recognition . *J. Acoust. Soc. America*, **32**.

Stevens, S. S., Morgan, C. T., and Volkman, J. (1941). Theory of the neural quantum in the discrimination of loudness and pith. *American Journal of Psychology*, **54**, 315-335.

Stroud, J. M. (1955). The fine structure of psychological time. In Quastler, H. (Ed.), Information Theory in Psychology, 174-207. Glencoe, Ill., The Free Press.

Treisman, M. (1963). Temporal discrimination and the indifference interval: Implications for a model of the internal clock. *Psychological Monographs*, **77 (13)** Whole No. 576.

Treisman, M., Faulkner, A., Naish, P. L. N. & Brogan, D. (1990). The internal clock: evidence for a temporal oscillator underlying time perception with some estimates of its characteristic frequency. *Perception*, **19**, 705-743.

Vanagas, V., Balkelytë, O., Bartusyavitchus, E., Kirvelis, D. (1976). The Quantum Character of Recognition Process in Human Visual System (in Russian). In V. D. Glezer (Ed.). Information processing in the visual system, Leningrad, Academy of Science of the USSR: 26 - 30.

Vanagas, V., Rukshënas, O., Ketleris, I., Shatinskas, R., Purtulytë, A. (1987). Bursting Activity in Visual Neurons of the Cat Cortex During Pattern Detection. *Neurophysiology*, **19**, 247-254.

Vanagas, V. (1991) Activeness of the Recognition Process: Possible Methods of Investigation. *Experimental Biology,* Vilnius **2(6),** 3-18.

Vanagas, V. (1994). Active , Hierarchical Visual System Organisation and Attentional Information Processing. In: 39. Internationales Wissenschaftliches Kolloquium, Tehnische Universitat Ilmenau, Thüringen, Band 2, 91-94

Weber, E. (1846). Der Tastsinn und das Gemeingefühl. In E. Wagner (ed.), *Handwőrterbuch der Physiologie*, **3**, 481-588.