SYSTEM QUANTA AS DISCRETE UNITS OF BEHAVIOR

ABSTRACT: System quanta are specific operators in the dynamic activity of the organism’s functional systems discovered by P. K. Anokhin. By the term “system quantum” of life activities we propose to understand discrete system processes proceeding from any arising need up to its satisfactions.

Every system quantum of behavior presents a self-regulating organization including the initial need, motivation, system architectonics as described above, intermediate and final results and continuous evaluation of the achieved results by dynamic reconstruction of acceptor of action’s result. System quanta may be organized at different levels of life activity. These levels extend in their hierarchy from genes and functional systems of metabolic and autonomic level to zoo-social populations of animals and human communities.

Every system quantum is also characterized by information properties. Information properties of every system quantum are closely related to the initial need and its satisfaction.

KEY WORDS: system quantum, functional systems

INTRODUCTION AND GENERAL DEFINITION OF SYSTEM QUANTA

In 1979 I suggested a hypothesis about systemic quantification of the behavior. In order to make a distinction with the commonly accepted term “quantum” in physics, we entitled the proposed unit of behavior as “system quantum”. System quanta are specific operators in the dynamic activity of the organism’s functional systems discovered by P. K. Anokhin (3, 19, 21).

By the term “system quantum” of life activities we propose to understand discrete system processes proceeding from any arising need up to its satisfactions.

System quanta are disclosed externally behaviorally and by the results of satisfaction of organisms needs. Inside the organism (internally) the system quanta — their structure and dynamic — are realized through physic-chemical and information processes of system architecture of functional systems. The
brain mechanisms of the functional systems include the following successively changing each other stage: afferent synthesis, decision-making, prediction and estimation of required results-acceptor of action’s result, metabolic and autonomic behavioral reactions of an organism (3).

According to our concept all continuum of behavioral and psychic activity in humans and animals is split into separate resulting system quanta, which provide the satisfaction of leading requirements of living beings.

Every system quantum of behavior presents a self-regulating organization including the initial need, motivation, system architectonics as described above, intermediate and final results and continuous evaluation of the achieved results by dynamic reconstruction of acceptor of action’s result (Fig. 1).

In development of central architectonics of system quanta of behavior and psychic activity under influence of reverse afferentation from parameters of the achieved results and signals from the acceptor of action’s result to afferent synthesis, a dynamic reconstruction of system architectonics of a behavioral act takes place, which in the long run provides the achievement by a subject of the adaptive result — satisfaction of the initial need.
System quanta may be organized at different levels of life activity. These levels extend in their hierarchy from genes and functional systems of metabolic and autonomic level to zoo-social populations of animals and human communities.

Needs of organisms also arise at different levels of life activity. They include metabolic (biological) needs of the required nutrients, oxygen, optimal temperature, osmotic pressure, pH etc. Zoo-social needs determine the formation of system quanta of behavior of groups of animals. Social needs of people form system quanta of their social activity. With these system quanta biological and social needs are satisfied after the achievement of biologically or socially significant results. A detailed classification of needs is given in (10).

One can consider as examples the internal system quanta satisfying an optimal level of nutrients in an organism, of osmotic pressure, of a level of products of a metabolism, of body temperature, etc.

System quanta of behavioral level have an external active link of self-control due to interaction with the environment. Functional systems and corresponding biological motivations compose such system quanta and determine purposeful behavioral activity.

At a zoo-social population level, system quanta and functional systems composing them differ to some extent. Separate individuals with a set of their own homeostatic and behavioral functional systems represent components of these system quanta. Cumulative activity of individuals united in system quanta produce the end results of activity of functional systems at this level. Some of these individuals perform specific functions (leaders, executors, watchmen, etc.).

In human populations system quanta are built by social needs of people and are directed to their satisfaction. At that every social organization performs its specific functions.

System quanta of behavior can be formed sometimes entirely based on genetically determined mechanisms. The so-called instinctive behavior is produced in that case. In the organization of system quanta of individually acquired behavior the mechanisms of learning and memory play an important role.

We distinguish successive and hierarchic quantization of behavior. Under successive quantization the satisfaction of one need is followed in time by the appearance of the other need and so on. Under hierarchic quantization the result of the action (satisfaction of the need) of one system quantum is delayed in time to the future and in order to achieve the result it is necessary to perform a number of successive system quanta and hierarchically changing each other.

GENERAL SYSTEM QUANTA CHARACTERISTICS

Specific physical and chemical processes determine metabolic need and its satisfaction and in this way form energy basis of any system quantum of a living organism. Besides, every system quantum is also characterized by information properties.
Information properties of every system quantum are closely related to the initial need and its satisfaction.

It is possible to postulate information equivalent of the need and its satisfaction. Information equivalent of need is formed in all cases when a deviation occurs of the result from its value that is optimal for life maintenance. The information of the need is preserved at all levels of system quanta regardless of the change of physical and chemical processes representing the need. Different nervous and humoral processes, excitation of special nervous centers and formation of behavior are processes that also include all significant information for the need. Two specific main processes — the information on need and its satisfaction — are compared on special brain structures, which constitute an information screen. These screens are based on processes of imprinting and corresponding structures of acceptor of action results and include outstripping replication of information on the need on the structures of acceptor of action results.

The subjective core of any system quanta is reflected in these information screens. Estimation of the information on the need and its satisfaction is intrinsic to all life activities from information molecules to integrative processes: irritability, emotional sensations and verbal language in human mental activity. They also take part in different stages of evolutionary development of living beings.

A leading information signal in behavioral system quanta is emotion. Negative emotions accompany the needs, positive emotions accompany the satisfaction.

Under repeated and sometimes single satisfaction of the need positive emotions begin to be foreseen in advance even when the need arises.

Fig. 2 — Trigger mechanism of excitation of neuron in the motivation center of hypothalamus. It is shown, that previously silent hypothalamic neuron starts to generate pulses only when its excitability achieves a critical level (K) under the influence of an increasing humoral need. Neuron pulses stop when its excitability decreases to an initial level when the need is satisfied. Pulse activity of neuron arises again at the subsequent formation of need and increasing of excitability of neuron up to a critical level.
Trigger mechanisms. The activity of system quantum originates after excitability of elements forming it achieves certain critical level (Fig. 2). Activity of system quanta proceeds until the initial need is satisfied.

The most investigated are the trigger mechanisms of system quanta of behavior. Biological motivations originating on the basis of these system quanta are built on the trigger principle (20).

The wave and particle properties of system quantum. Any system quantum may be characterized by the properties of a particle or a wave. Thus system quantum can be considered as a discrete unit (“particle”) of a continuum of a life span. On the other hand, the trigger mechanism determines wave properties of any system quantum.

Torsion mechanism in system quanta activity. The torsion mechanisms are known to be produced by the rotator spin moments of interacting particles. Spin moment corresponds to the direction of the spin, which can change its direction when new information influences molecular environment of the particles.

Two opposite tendencies continually operate in every system quantum. One is revealed at the increase of the value of the result, the other one — at its decrease. The first acts to decrease the value of the result to a normal level, the other — to increase it.

When initial need is formed all components of the organism, united by a dominating motivation, start to organize behavioral system quantum, directed to the search of the substances, satisfying the need. At the achievement of the required result the reinforcement occurs, the motivation disappears, the activity is reduced and subjects quite often get relaxed and may fall asleep.

Holographic principle in organization of system quanta. As is well known, in optics, a holographic principle was discovered by Dennis Gabor. Creating a hologram, a light wave is normally split by a special prism into two waves. One is a supporting wave, and the other, a subject wave, reflected from the object to be photographed. To reconstruct a hologram, only a supporting beam is sufficient.

Taking into consideration the analogy with a physical hologram one can consider the need as an information reference (supportive) wave. On the basis of motivation that wave forms an acceptor of action results performing the prediction of required result. Multi channel reverse afferentation from achieved results may be represented as a signal (subject) wave (22) (Fig. 3).

Dominating motivation is a basic factor for brain hologram retrieval (23). Dominating motivation retrieves memory traces (engrams) from acceptor of action’s result containing the properties of the needed result and specific conditional stimuli and pathways previously contributing or inhibiting the achievement of adaptive results useful for the organism and satisfying the organism’s vital needs.

Various indicators of general herd needs operate as a reference (supportive) wave in zoo populations. The signal (subject) wave in this case is determined by signals from the achieved results of activity important to the herd.

Social environment play a decisive role in development of social needs of humans. These needs include absent in animals human motivations, such as
aspiration for the general or special education, working activity, creativity and even self-sacrifice in the name of public interests etc. Social needs of individuals substantially change their biological needs, socially tinting them and play the role of a supportive wave.

A signal (subject) wave is provided by the information from receptors signaling the parameters of events in social environment.

The accumulated individual and public knowledge, laws, morals, ethics forms a reference wave in social populations of people. A signal wave arises from individual and public work of institutes, governmental organs, industrial and agricultural production establishments, etc.

Information waves corresponding to the need and its satisfaction are distributed to structures of the brain in the certain time sequence. The conditions for their interference on brain structures and for construction of holograms are created in such a way. Thus a brain holographic screen of the information is formed.

These brain holographic screens are constructed on the structures of the acceptor of action results of different functional systems. Molecular engrams are built on the acceptor of action results with the properties of reinforcing events. The information from the parameters of basic needs and the results achieved comes exactly to these engrams.

The holographic information screens in the brain structures are presented by plasmatic membranes and liquid crystals — molecules of DNA and RNA of glial and neural cells. They compose acceptors of action results of various functional systems. Information models of the reality are continually built with
the structures and functions of the brain in advance of overt behavior, due to information signals about needs and their satisfaction.

**Prediction of the required results and their assessment in system quanta of behavior.** Prediction of properties of the required results is realized on information screens at all mentioned levels of system quanta. Prediction reactions in the brain are related to the corresponding activities of the acceptors of action results of different functional systems. Processes of afferent synthesis activate the engrams of an acceptor of action results, outstripping the real events, at brain holographic screens. These brain holographic screens predict future results and continually control both various needs of the organism, and their satisfaction. The inherited neuron structures and mechanisms as well as the acquired mechanisms of learning and memory underlie the prediction of metabolic, homeostatic and behavioral results.

Programming of the properties of the required results can be carried out rigidly, for example, in system quanta of instinctive and autonomic activity, or flexibly in cases of the skills acquired in the individual life. The acceptor of action results is continually enriched with information from parameters of the achieved results and ways of their achievement.

System quanta of human and animal behavior are organized through interaction of a dominating motivation with reinforcement, satisfying or, on the contrary, not satisfying initial needs of the organism. An acceptor of action results is the main point of interaction of motivation and reinforcement in central organization of system quanta. It programs the properties of required results. The continued estimation of parameters of results achieved by the organism is performed by acceptor of action results with the reverse afferentation.

**NEUROPHYSIOLOGICAL AND NEUROCHEMICAL MECHANISMS OF LEADING MOTIVATION**

The experiments (12, 22) testify to the fact that biological motivations in animals, caused by various metabolic needs such as hunger, thirst, fear, aggression, sex and so on are formed on the background of ascending activating influences of hypothalamic centers on other brain structures: limbic ones, thalamus, brain stem reticular formation including brain cortex and its frontal structures, in particular. Those influences are distinctly seen on animals’ electroencephalograms under urethane anesthesia.

In a complicated cortical-subcortical architectonics of biological motivations a leading, pacemaker role belongs to motivation-genic centers of hypothalamus. Destruction of these structures completely eliminates their activating influence on other brain structures and corresponding biological motivations (16, 12).

Social motivations in humans are built by pacemakers localized not in hypothalamus but in other brain structures including frontal brain cortex (5).

It was found that in the process of forming dominating biological motivations cortical neurons in their turn influence the pacemaker center of hypothalamus (specific descending activating and inhibitory influences). As a result
ascending and descending influences under dominating motivations develop into
dynamic cortico-subcortical reverberating interactions that define the energy of
dominating motivations. On that ground a retrieval of memory traces by domi-
nating motivation occurs. In mechanisms of ascending activating influences of
hypothalamic structures on other brain regions different neurotransmitters and
neuropeptides participate in various integrative correlations. Dynamic integra-
tion of chemical mechanisms of various brain structures on different stages of
animals’ resultant activity was revealed as well (1, 14, 15).

Oligopeptides stimulating and inhibiting biological motivations were also
discovered.

It was shown that oxytocin microinjection into lateral hypothalamus in
fed rabbits stimulated an additional food intake. β-lipotropin injection into lat-
eral ventricles in fed animals caused activation of instrumental food-searching
behavior and additional food intake. The same effect was observed under
ACTH_{10—14} and MSH_{4—7} intracerebroventricular injections.

Pentagastrin intra-abdominal injection activated feeding behavior in fed
rabbits while microiontophoresic application to neurons of lateral hypothala-
mus in fed rabbits caused a pattern of pulse-to-pulse activity typical for hunger
state; ACTH_{5—8} application activated self-stimulation in rabbits. Bradykinin
injection into cerebral lateral ventricles facilitated defense reactions in rabbits
under electrical stimulation of ventromedial hypothalamus.

Additional intra-cerebral lateral ventricular injection of angiotensin II,
arginine-vasopressin, delta-sleep-inducing peptide, substance P, lei- and met-
enkephalins, β-endorphin suppressed defense and feeding reactions and self-
stimulation caused by electrical stimulation of ventromedial and lateral hypo-
thalamus.

It was shown that under cerebral lateral ventricular injection of anti-se-
rum to β-endorphin, angiotensin II and delta-sleep-inducing peptide double-
stage effects were observed: for the first hours — a suppression of biological
motivations and their facilitation on the next day (11, 23).

Motivations are formed by the principle of dominant (25). In every given
moment of time a dominating social or biological motivation, caused by the
need, the most significant for survival or adaptation, governs the brain. The
rest subdominant motivations support or inhibit the dominant one. When the
leading motivation is satisfied, sub-dominant motivations become dominating
hierarchically.

Special experiments showed that dominating motivation significantly chan-
ged convergent and discriminating properties of brain neurons increased their
sensibility to neurotransmitters, neuropeptides and other biologically active
substances. Neuron sensitivity to reinforcing factors satisfying the initial needs
significantly widens. Besides, dominating motivation increases sensitivity of
the corresponding peripheral receptors (4, 7).

Different dominating biological motivations (hunger, thirst and fear) are
distinctly reflected in the character of distribution of dominating inter-spike in-
tervals of single unit activity in various brain structures. Most of the neurons
of various brain structures in rabbits that are in need of food, water or avoi-
dance of danger generate a burst like impulse activity. Typical inter-spike in-
tervals can be registered in these neurons. After a 24-hours food deprivation, for example, neurons with burst activity in sensomotor, visual, insular cortex, n. caudatus, dorsal hippocampus, lateral hypothalamus and reticular formation of midbrain have a dominating bimodal distribution of inter-spike intervals within 1—20 and 150 ms. After a 24-hours water deprivation in structures of dorsal hippocampus, septum, n. caudatus, lateral and supraoptical nuclei of hypothalamus on the background of neurons activity also two modes of inter-spike intervals dominate, but within 25 and 150 ms.

Under electrical stimulation of “fear center” of ventromedial hypothalamus in immobilized animals neurons of sensomotor and visual cortex show domination of inter-spike intervals within 45 and 150 ms (26).

Under the influence of dominating motivations the activation of c-fos and c-jun early gene expression in brain structures was revealed (2).

It is significant that neurons involved into dominating biological motivation despite their generalized localization in brain structures make up only a certain number of common neuron populations of brain structures. The part of neurons involved in dominating biological motivation is significantly higher in brain stem and gradually decreases in direction to the cerebral cortex. Cortical neurons in their adaptive behavior fulfill other not less significant functions: they react on conditioned stimuli, location and migration of reinforcing external agents and so on (9). Unlike the structures involved in architecture of genetically determinate biological motivation the most of the brain cortical neurons fulfill plastic adaptive functions of learning and estimation of the factors of the environment by subjects.

The experiments mentioned above testify to the fact that dominating motivations change the properties of brain structures and respective peripheral receptors making them selectively perceive and interact with factors that satisfy the needs underlying these motivations. As a result under the effect of a dominating motivation a peculiar informational constellation of neurons of different brain structures is formed able to perceive reinforcing influences.

SYSTEM MECHANISMS OF REINFORCEMENT: INTERACTION OF MOTIVATION AND REINFORCEMENT OF BRAIN STRUCTURES

From functional system theory position the processes of reinforcement include: the impact of different parameters of behavioral results on the receptors of the organism, which experiences a definite need and their comparison by reverse afferentation with the acceptor of action’s result.

Acceptor of action’s result of every functional system presents a mosaic architectonics, widely spread along different cortical and subcortical brain structures.

In line with the hypothesis, proposed by P. K. Anokhin, a structural basis of acceptor of action’s result in functional systems defining various behavioral acts in humans and animals consists of interneurons of different brain structures on which copies of effector excitations of cortical pyramidal neurons are spread along pyramidal tract collaterals (Fig. 4).
Due to cyclic interactions between interneurons associated into acceptor of action’s result, excitations in these neurons by reverberation are able to remain for a long time and to continuously evaluate the reverse afferentation coming to them from different parameters of the results achieved by the subjects. The confirmation of the spread of pyramidal tract stimuli on interneurons was found in special experiments where reactions of interneurons of different brain structures which are cyclically interacted.

1. Under the influence of a dominant motivation (M) effector stimuli of pyramidal neurons are spread on axons of a pyramidal tract. At the same time copies of these stimulations through collaterals of a pyramidal tract are spread on intercalary neurons of different brain structures which are cyclically interacted.

2. Stimulations from the parameters of the achieved results are “imprinted” on intercalary neurons which constitute the acceptor of action’s result.

3. Motivation in advance stimulates structures of acceptor of action’s results earlier formed by afferentation from different parameters of the achieved results.

Due to cyclic interactions between interneurons associated into acceptor of action’s result, excitations in these neurons by reverberation are able to remain for a long time and to continuously evaluate the reverse afferentation coming to them from different parameters of the results achieved by the subjects. The confirmation of the spread of pyramidal tract stimuli on interneurons was found in special experiments where reactions of interneurons of different brain structures in response to antidromic stimulation of the central end of pyramidal tract cut in the olive of medulla were investigated.

Under antidromic stimulation of the pyramidal tract responses of neurons were registered in somato-sensory, visual cortex and dorsal hippocampus. The same neurons vividly reacted on stimuli of different sensory and biological modality and on stimulation of motivation-genic centers of hypothalamus. All that shows that on the brain inter-neurons that constitute the acceptor of action’s result activated by a dominant motivation, sensory information coming from various organism’s receptors excited by relevant parameters of reinforcing influences, can be “imprinted”.
In the processes of successive change of system quanta a dynamic architectonics of acceptor of action’s result is formed, reflecting on informational grounds the chain of actions and results leading to the satisfaction of the relevant need.

Every parameter of the reinforcing effect leaves its own specific information trace in the corresponding visual, taste, auditory, tactile etc. projection brain zones, determining in this way a generalized in various brain structures architectonics of acceptor of action’s result. At that if genetic components of acceptors of action’s result of different functional systems are conservative the architectonics of the acceptors of action’s results dynamically changes during individual’s life span according to the changes in the parameters of the reinforcing influences. Every reinforcement, as a part of a many-sided activity leaves its own information imprint on the acceptor of action’s result structures of a corresponding functional system.

Under stable conditions and the same types of reinforcement the “imprints of reality” on the structures of relevant acceptors of actions result from stereotypes able to maintain for a long time and sometimes the whole individual’s life. In changing life conditions “imprints of reality” are unstable and quickly change each other. “Imprints of reality” on the structures of acceptors of action result in different functional systems direct human or animal behavior to the optimal satisfaction of the vital needs playing the role of a certain vector of behavior.

As the central units of many functional systems of homeostatic and behavioral level converge on the brain structures, a generalized acceptor of action’s result is formed on which every given moment anticipatory (forthcoming) reactions of a dominating functional system are revealed.

Reinforcing stimuli are addressed just to the brain neurons which initially are involved into dominating motivation and in their discharge activity reflect a specific for the given motivation character of inter-spike intervals distribution.

Reinforcement (food and water intake, danger avoidance) significantly changes brain neuron activity involved into the initial motivation. At that, neuron burst-like activity changes into a regular one with domination of only one inter-spike interval (13, 17, 26) (Fig. 5).

It has been found that under reinforcement an increased $c\text{-}fos$ and $c\text{-}jun$ early genes expression, observed in motivations and accompanying them searching activity, decreases, and expression of late genes determining processes of cell differentiation, adherence and memory, appears (2).

A series of experiments shows that the animals’ behavior conditioned by early gene expression under electrical stimulation of hypothalamus motivation-genic centers is not blocked by protein synthesis inhibitors such as cycloheximide, puromycin, actinomycin D and others. However, under training when behavior initiated by motivation ends with the achievement of the needed results that is the formation of functional systems, the mentioned protein synthesis inhibitors block this behavior.

Pentagastrin on the background of protein synthesis inhibitors restores a feeding behavior, bradykinin — a defensive one, ACTG$_{4\text{-}10}$ — a self-stimula-
The moment of food intake is shown by bold line. 3 peaks of interspike intervals in pattern of a neuron activity of a hungry rabbit distribution of interspike intervals of a neuron after a rabbit’s feeding. On X—line — the value of interspike intervals (ms). On Y-line — percentage of the intervals from the general number of the examined intervals.

Imprinting phenomenon has got a new understanding from the theory of functional systems point of view.

In 1978 we proposed an imprinting hypothesis of constructing acceptor of action’s result.

According to the imprinting hypothesis of forming acceptor of action’s result under the influence of the results of behavior their different parameters by reverse afferentation are imprinted as molecular engrams on the respective structures of acceptor of action’s result. In that way acceptor of action’s result in every functional system is formed and becomes enriched during the whole
individual’s life by previous reinforcements and imprints of properties of parameters of the reinforcing effects on the structure of a dominating motivation.

The experiments of V. A. Pravdivtzev (8) confirmed the statement. While registering the impulse activity of inter-neurons in brain visual cortex the author elaborated in cat’s conditioned-reflex reaction on combination of electrical stimulation of central end of cut pyramidal tract with electro-skin stimulation. These experiments showed that after 8—10 such tests the neurons began to respond to the conditioned stimulus of electrical stimulation of pyramidal tract by reaction typical for electro-skin stimulation.

As shown above the interaction of reverse afferentation from the parameters of the achieved behavioral results with the initial dominating motivation takes place.

The reinforcement forms significant memory traces — engrams of properties of parameters of reinforcing results. Every time at the next occurrence of similar need these engrams are exited in anticipation of future end results and act as a directing component of the corresponding behavior. The parameters of the achieved results are compared with the predicted features of future results — by acceptor of action’s result and are evaluated by reverse afferentation. The estimation of parameters of intermediate and end results by the acceptor of action’s result allows the correction of the future behavior when necessary.

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REFERENCES


СИСТЕМ КВАНТУМИ КАО ДИСКРЕТНЕ ЈЕДИНИЦЕ ПОНАШАЊА

Константин Викторович Судаков

Истраживачки институт нормалне физиологије им. П. К. Анохина
Руска Академија медицинских наука, Москва, Руска Федерација

Резиме

Систем квантуми су специфични оператори у динамичној активности функционалних система организма, које је открио П. К. Анохин. Под појмом „систем квантум” животне активности подразумевамо дискретне системске процесе који потичу од растуће потребе и трају до задовољења те потребе.

Сваки систем квантум понашања представља саморегулативну организацију која у себи садржи иницијалну потребу, мотивацију, архитектонику система, међурезултате и финалне резултате, као и континуирану евалуацију постигнутих резултата динамичког реконструкуцијом акцептора резултата дејства. Систем квантуми могу да се организују на различитим нивоима животних активности. Ови нивои, у зависности од њихове хијерархије, протежу се од гена и функционалних система метаболичког и аутономног нивоа, све до зоо-социјалних популација животиња и људских заједница.

Сваки систем квантум такође се карактерише информацијама. Информације сваког систем квантума у тесној су вези са иницијалном потребом и задовољењем те потребе.