Purposefulness as a Principle of Brain Activity

Evgenii E. Vityaev[1,2]

[1] Sobolev Institute of Mathematics, Novosibirsk, Russia
[2] Novosibirsk State University
vityaev@math.nsc.ru

Abstract. Two cognate notions are considered: that of task and goal. It was argued by K.Samokhvalov and Y.Ershov in their "Contemporary Philosophy of Mathematics" that existing problems in the foundations of mathematics follow from insufficient precision of the task notion. A mathematical task is set iff we have a criterion of verifying its proof. It was proven that only in "weak" formal systems, in which Gödel's incompleteness theorem does not hold, are we able to verify by means of the formal system itself whether the given text constitutes a proof of that task or not. This result produces a new approach to the D. Hilbert program of grounding mathematics. We present similar considerations on the notion of purpose (goal) in the framework of cognitive and physiological sciences. We cannot attain a goal without having a criterion of its attainment; otherwise we can assume that the goal has already been attained. From a definition of the goal, a definition of the result of attaining the goal follows – it is that, what is achieved by attaining the goal and satisfying the criteria of its attainment. The theory of functional systems (TFS) developed by P.K.Anokhin and many other distinguished scientists of his school is one of the few known theories in which the notions of goal (purpose), result, and goal-directed activity are the principal ones and in which the physiological mechanisms of their realization are carefully investigated. Hence, TFS is a physiological theory of brain activity, in which purposefulness is regarded as a principle of its activity. We will present TFS as a theory of purposeful activity.

Keywords: goal-directedness, purposeful activity, brain, cognitive model, the theory of functional systems, behavior

1 Introduction

Following [1-2] we will establish a relationship between two concepts: those of task and goal. In Section 2, the concept of task is analyzed in terms of the foundations of mathematics, and it is shown that existing problems in the foundations of mathematics follow from insufficient precision of the notion of task. A mathematical task is set only if there is a criterion for verifying that a proof offered for its solution really constitutes its solution. It was proven in K. Samohvalov's and Yu. Ershov's monograph on the foundations of mathematics [3] that only in "weak" formal systems, in which Gödel's incompleteness theorem does not hold, are we able to determine, by means of the formal system itself, whether some text constitutes a proof of the given task or not. This allows us to formulate a new approach to the foundations of mathematics and Hilbert's program of grounding mathematics: "mathematical theories can be only regarded as a reservoir for weak formal systems that are extracted from the whole theory for solving specific tasks" [4].

In section 3, we show that a similar situation characterizes the notion of goal in cognitive sciences and physiology. A goal cannot be attained without having a criterion of its attainment; otherwise we can always assume that the goal has been already attained. The definition of goal is paradoxical (produces a goal paradox), since it does not imply knowledge of how, by what means, and when can it be attained. Actions are always goal-directed. If an action does not have a goal, it is unclear when and how it should be terminated. The goal of an action is to change the current state and/or some external stimulus. Goal-directed activity consists in organizing the activities that will satisfy some of the organism's needs. A definition of the goal allows us to define the result, attained through the goal, as that which meets the criterion. We drink water to quench thirst, eat to ease hunger, etc.

The theory of functional systems (TFS) developed by P.K. Anokhin and many other distinguished scientists of his school is, at the moment, one of the few known theories in which the concepts of goal, purpose, result, and goal-directed activity are principal ones and which exposes the physiological mechanisms that implement these concepts. In TFS, it is studied in detail how the brain constantly solves the goal paradox during goal-directed activity, by defining by what means, when, and how can goals be attained. For solving the paradox we need an experience that is based on the «principle of anticipatory reflection of reality»[1] formulated by P.K. Anokhin [5]. Therefore, TFS is a physiological theory of the brain in which goal-directness based on anticipatory reflection is a principle of brain activity. In Sections 4 and 5, TFS is presented from this exact standpoint.

2 The Notion of Task and Foundations of Mathematics

Let us present an analysis of the concept of desire as given in [4]. Despite the generality of authors' account, their direct and accurate formalization produces the mentioned mathematical result and the revision of the foundations of mathematics, obtained in [4].

"What do the words 'I want to drink' mean? There is certainly no mistake in believing that the words 'I want to drink' mean just that – a certain state of my consciousness, which I experience right now and which I refer to as thirst. But then a new question arises: how is the sensation of thirst (of desire) related to the actual act of drinking (of satisfying the desire)? Whence do I know that thirst can be satisfied by drinking? Does the experience of thirst itself contain the knowledge of how the thirst can be satisfied? ... To have a desire does not mean to know what you desire, but rather the ability to recognize it on some possible occasion. In other words, you understand your desire ... only if you associate with it a feeling of confidence that you can convincingly and faultlessly recognize any future state of your consciousness as either a state which satisfies or does not satisfy this desire... Although... I do not necessarily know how this quenching will be achieved. From past experience, I expect that it can be achieved using water, but perhaps some tablet will also quench my thirst" [4].

This argument allows us to specify the concept of task. We understand a *task* only when we associate with it "a reasonable feeling of confidence that we can convincingly and faultlessly recognize any state of our consciousness either as one in which a solution to the task is found, or as one in which it is not found" [4]. Note that if this condition is not fulfilled, then the task does not require a solution, since any state of consciousness can be considered as providing it.

Suppose we have some text. Does it represent a "convincing and faultless" solution of a given task? In mathematical theories, it is usually assumed that "reasonable confidence" that a proposed solution indeed solves a given task arises when the given account constitutes a proof of this task. The proof gives a formal criterion to evaluate if the task has been solved, to "recognize if a solution had been found or not". Thus, a mathematical task is set only when we have a reasonable feeling of confidence that we can convincingly and faultlessly recognize any state of our consciousness as either one in which a proof of solving the task has been found, or one where it has not been found. Suppose that our states of consciousness together with the proof can be formalized within some formal system S. Let us ask ourselves: does this formal system enable us to determine for any given text, using only the formal system S itself, whether this text comprises a proof of the given task's solution? If such a formal system does exist, then it can serve as a formal model for both setting and solving mathematical tasks. This question has been analyzed in [4], and it was proven that only in "weak" formal systems, in which Gödel's incompleteness theorem fails, are we always able to determine, by means of the formal system itself, whether some text comprises a proof of some task's solution or not.

This result allowed its authors to formulate a new approach to the foundations of mathematics, comprising a radical change in Hilbert's program for grounding mathematics. "As is known, Hilbert believed that, generally speaking, not all statements of a mathematical theory make sense. This being said, he implicitly assumed that the partitioning of the set of all statements of a theory under consideration into meaningful ones ("real") and meaningless ones ("ideal") is completely determined by the form of statements themselves and, therefore, this partitioning is the same for all theories which share both syntax and signature. According to the

[1] «One universal regularity was formed during the adaptation of the organisms to the environment, which is further was developed during the whole period of evolution of living organisms: the highest order of speed for the reflection of the low speed deployment of the events of the real world».

new paradigm, the partitioning into meaningful and meaningless statements depends not only on the syntax and signature of a theory, but also on the class of tasks which this theory is intended to deal with. From this point of view, a theory, as a mathematical calculus, will have different sets of meaningful statements if it is designed to handle different classes of tasks. In other words, a mathematical theory is regarded merely as a "reservoir" for "weaker" formal systems, which are separately "extracted" from the whole theory, depending on a given task. In itself, without regarding the set of potential tasks ... a theory has no practical meaning, and therefore the question whether it is inconsistent or not as a whole is not so interesting" [4].

However, our interest lies not only in mathematical tasks. Consider again the formulation of the task concept: "We understand a task only when we have a reasonable feeling of confidence that we can convincingly and faultlessly recognize any state of our consciousness as either one where a proof of solving the task has been found, or one where it has not been found". Let us reformulate the task concept so as not to appeal to states of consciousness. We say that the task is sensible if and only if there is a criterion to decide whether we possess a solution to the task or not, in the sense that we are always able to determine for each prospective solution whether it really is a solution or not. Tasks in this respect emerge not only in mathematics, but also in many other areas, and therefore in all these cases we should always keep in mind that a criterion for solving the task should be present. As it turns out, the concept of task is related to goal-directed activities.

3 Goal and Goal-directed Activity

Desire is not passive. It makes no sense to desire if there is no possibility to get closer to satisfying the desire by some actions or activity. There are some organisms – corals and plants – that have very limited possibilities to display their own activity, and thus to somehow actively approach the moment of satisfying desires. Do they have awareness of desires or needs, or they are just processing what occurs to them naturally?

Desire is active but meaningless without purposefulness – which causes the organism to be active and display some behavior in order to satisfy the purpose. Thus the concept of goal emerges. Activity and actions are always goal-directed. If there is no goal for an action, it is unclear when (and by what means) it should be terminated. The goal of both activity and behavior is to change the current state and/or some external influences in order to attain something. Goal-directed activity aims to satisfy certain organismic needs (desires).

The goal cannot be attained without having a criterion of its attainment; otherwise we can always assume that it has already been attained. The notion of goal is more general than that of task – the solution of a task constitutes its goal, and the criterion of attaining this goal is whether we have a solution to the task or not.

Let us define the *goal* as such an activity/behavior that is aimed at satisfying certain criteria. Setting a goal is meaningless without having a criterion of its attainment, since we have to make sure that this criterion is not already fulfilled. Hence, it only makes sense to set as a goal something that is not already attained and that we wish to attain. Such a definition of goal allows us to define the *result of attaining the goal* as that, what we obtain by meeting the criterion and attaining the goal (fulfilling the desire). We drink water to quench thirst, eat food to ease hunger, breathe when there is not enough oxygen, etc. Between the concepts of goal and result, the following relationship holds: the result is obtained when the goal is attained and the criterion of its availability is "triggered". But when the goal is being set, we have the goal but not the result.

The definition of goal is paradoxical since the activity/behavior of satisfying some criteria does not essentially presuppose knowledge of how to attain the goal; you can set a goal without defining either how it can be attained, or by what means, or when. This paradoxicality of the goal concept we call the goal paradox. For the resolution of the paradox we need an experience, based on the «principle of anticipatory reflection of reality» formulated by P.K. Anokhin [5]. This principle is a more general category than different phenomena of anticipation: «From our point of view, we ought to consider as the most encompassing and insightful category with respect to different phenomena of anticipation the category of «anticipatory reflection» introduced by P.K. Anokhin» [6, p.19].

As will be seen latter on, in the framework of the theory of functional systems, brain activity during goal-directed behavior is seen as being constantly occupied by solving the goal paradox, and determining by what means, when, and how to attain goals.

Let us proceed to outline the theory of functional systems, in which the concepts of goal, result, and goal-directed activity are principal ones, and which analyzes the physiological mechanisms of these concepts.

4 The Theory of Functional Systems of Brain Function

The theory of functional systems (TFS) is a theory of systems, whose function is to attain goals (satisfy needs) by solving the goal paradox. Therefore, we will outline the theory of functional systems as a theory of solving goal paradoxes, and describe how the brain determines by what means, when, and how goals can be attained.

On the concept of task, P.K. Anokhin writes the following: "If a person has solved a task, on what grounds is he convinced that the solution is sound? Conditions of soundness for a solution have to be determined in advance, since his colleagues' failures gave him an experience of "unsolved tasks", and allowed him to determine what exactly could be considered a solution. Consequently, he did not foresee the result, but he did foresee the conditions a solution must satisfy" [7. p.13, 6]. This definition is similar to the formulation of the task concept presented in [4]. Such definitions of task and result are the fundamental achievements of TFS, which distinguish it from other known theories. "#[2]Perhaps one of the most dramatic moments in the history of research on the brain as an integrative formation involves the focus of attention on the action itself, but not on action results ... we can consider that the result of a "grasp reflex" is not the action of grasping itself, but rather the totality of afferent impulses corresponding to features of the "grasped" object (the action result)#" [8-10].

"In our opinion, the most important milestone (in the history of the development of the concept of functional systems – E.V.) is the formulation of the "action result" concept (in 1966). P.K. Anokhin now considers action results as an independent physiological category" [10]. Understood this way, the action result itself reflects if the criterion of attaining the goal (of grabbing an object) has been satisfied, as signaled in the "totality of afferent impulses corresponding to features of the "grasped" object" [10]. Thus, the notion of action results establishes in physiological terms the criterion for assessing goal attainment. The dramatic moment in brain research on which P.K. Anokhin writes is still pertinent, as no other theory explores the mechanisms of attaining results in the given sense.

Let us briefly outline the theory of functional systems following the monograph of K.V. Sudakov [10], one of the leading disciples of P.K. Anokhin. This book summarizes not only the works of P.K. Anokhin himself, but of his entire school. First of all, let us consider what physiological mechanisms are used by the organism to set goals. There is an interesting analogy here between these physiological mechanisms and the mathematical results obtained in [4]. As noted in [4], "to solve any meaningful task, we have no right to extract from the theory a fragment so large that it fails to be a weak system". In the theory of functional systems, such "fragments" are the functional systems of the organism, which are formed to solve tasks the organism is facing.

"#By a *functional system* we refer to a system of neural components with their corresponding peripheral working organs, combined on the grounds of performing some well delineated and specific organismic functions. Such delineated functions include, for instance, locomotion, breathing, swallowing, swimming, etc#". And further: "#The composition of a functional system cannot be determined by any anatomical principle. On the contrary, a variety of "anatomical systems" can participate and can be banded together on the basis of simultaneous excitation while performing a particular organismic function#" [8-10].

Thus, the units of an organism's activity are not separate organs, but rather different functions of the organism. Performing these functions is exactly the task of the organism's activity.

As we know, the goal (task) makes sense only if there is a criterion of attaining it. Organism's functions should also lead to attaining particular goals, which are registered by corresponding results. "The main postulate of the theory of functional systems consists in a provision stating that the *result* that is useful for the

[2] Among quotations from [8] we will distinguish those of P.K. Anokhin with the # symbol.

organism and adaptive for the whole system acts as the leading system-defining factor for organizing functional systems at any level of the organism. It is namely the result which, due to constant reverse afferentation of its state, produces a kind of "mobilization" of the central and executive components to form a functional system" [10]. Thus, the units of organism's activity – functional systems – are dynamic assemblies of various organs, combined in order to attain particular useful results.

As achieving results consists in satisfying some criteria, this achievement should be registered in some way. In the physiological sense, what constitutes a criterion for registering the attainment of a result? According to P.K. Anokhin, this is physiologically realized by a "special receptor apparatus". "Every *need* is immediately perceived by a special *receptor apparatus,* even if there is a slight deviation of a vital function from the optimal level of metabolism" [10]. "The existence of these receptors, which "stand on guard" for the final adaptive result, is the starting point for the mechanism of self-regulation in each functional system. Smaller deviations from the optimal level of metabolism lead to a lesser excitation of receptors and, consequently, to a lower level of signaling in the nervous system" [10].

Thus, the result consists in attaining the optimal level of some physiological constant, as registered by a special receptor apparatus. The signaling of this receptor apparatus about obtaining a result (i.e., on the lack of deviation from the optimal level of metabolism) and attaining the goal is called *reverse afferentation*.

"...The signaling about a need has a dual function. On the one hand, it plays the role of a trigger, stimulating a special self-regulation mechanism, and on the other hand, it constantly informs these same centers about the results of actions performed by a functional system. This was called the *reverse afferentation*, since this signaling contains information on the final result – and on whether there is a deviation from the optimal level of metabolism, or whether this level has been restored…" [10].

Now we can explain, within the framework of TFS, how tasks and goals are being physiologically set by the organism. An organism need constitutes a goal in TFS. "The dual function of needs" means, firstly, that a goal is set in the organism to restore disturbed metabolism and, secondly, that an energy supply is provided for goal attainment. The criterion of goal attainment consists in obtaining reverse afferentation about the fact that a normal level of some physiological constant is restored. If, on the other hand, the normal level is disturbed and reverse afferentation indicates the criterion is not satisfied at the moment, then a need emerges, which sets the goal for the organism to satisfy the corresponding need. In this case, the goal (and its attainment criterion): firstly, signals by means of reverse afferentation that there is a lack (that some constant is not on the normal level), which essentially means there is a need; secondly, it sets a goal to wait for a signal, indicating that the normal levels of variables have been restored and that the results have been attained; and thirdly, it provides energy and actually forces the organism to attain the goal. Thus, the physiological mechanism of goal-setting in fact consists of the emergence of a need. Consequently, it is precisely the need that constitutes the goal that is being set to the organism. In TFS, the concepts of need and result are related to each other. In our definition, the notions of need and result are connected by the notion of the goal, where the result consists simply of registering that the goal has been attained and the need has been satisfied.

The interaction of different goals and results is organized in several ways according to TFS: by the "principle of the dominant", by the "hierarchy of results" and by "result models".

Let us consider the "principle of the dominant". This principle states that two goals that are satisfied by some behavioral acts cannot be attained simultaneously. "Since the organism's metabolism is always multifaceted, the organism's total metabolic need is often multi-parametric, reflecting various aspects of metabolism ... But there is always the leading parameter of the total metabolic need – i.e. the dominant need which is the most important one for the survival of the individual, its genus or species. It stimulates the dominant functional system and builds a behavioral act aimed at satisfying it. When the main need is satisfied, than another need, important for the survival of the species or its genus, becomes dominant" [10].

Thus, the behavioral goals of the organism – i.e. the dominant needs – are always linearly ordered in time. Let us consider now how functional systems interact with each other at some moment of time. With respect to the dominant functional system, the remaining systems are arranged in a hierarchy by the principle of the "*hierarchy of results*". "In relation to each dominant functional system, all other functional systems are arranged in a certain hierarchical order, beginning with the molecular level and leading up to the organismic, social and public levels. The hierarchy of functional systems ... includes primarily hierarchical interaction of their action results – i.e., results of activity of one functional system are included as components in the result of another one" [10]. "Thus, the dominant functional system of a hungry rabbit is the one which involves searching for food. At that moment, all other functional systems that regulate, for example, blood pressure, respiration and excretion, are assigned to provide the best support for the dominant functional system" [10].

Let us consider in more detail how the hierarchy of results is formed. If searching for food forms the dominant functional system in a hungry rabbit, then during its activity oxygen consumption increases, the amount of nutrients in the blood decreases, the amount of harmful substances produced during metabolism and requiring removal from the organism increases, etc. All this leads to a shift from the normal level of a number of organism's physiological constants, and this fact is registered by the receptors of a number of other functional systems. This automatically "triggers" functional systems, whose goal is to ensure the normal levels of these physiological constants, and the results of these systems consist in reaching the corresponding normal level. Thus, the dominant need activates a hierarchy of functional systems whose goals are mutually coordinated (and subordinated) to ensure the normal level of physiological constants involved in satisfying the dominant need.

5 Goal-Directed Activity in The Theory of Functional Systems andthe Goal Paradox

Functional systems can be conveniently divided into two groups: those that require appealing to the environment to attain their results and those that do not. The former group includes the functional systems of obtaining food and satisfying thirst, the reproductive functional system, etc. The latter includes functional systems of digestion, excretion, blood pressure, etc. It is clear that "the results of behavioral activity aimed at satisfying internal organismic needs can be regarded as "sub-results" of those functional systems which support main internal metabolic parameters" [10]. Thus, goal-directed activity can be regarded as an integral part of functional systems of the second type. With respect to the goal, the principal difference between the two types of functional systems is that for functional systems of the second type (breathing, blood pressure, and excretion) we can assume the existence of some genetic mechanisms for attaining their goals and results, while for those of the first type we cannot assume this. For functional systems of the second type, the way of solving the goal paradox and determining by what means, how, and when the goal can be attained is genetically determined and there is nothing to add to the explanation of how such functional systems operate, apart from what has already been said in the previous section. As for the first type of functional systems, which are dealing with complex environment and require learning, it is still necessary to answer the main question: how does the brain solve the goal paradox and determine by what means, when, and how can the goal be attained? To this end, a number of new concepts for describing goal-directed behavior are introduced by TFS.

The difference between functional systems of the first and second type is well illustrated by the following example: "The behavior of a newborn animal, stemming from some biological need, is constructed fully by way of "trial and error" ... A newborn's directed search for certain environmental stimuli it has never met before is striking. Therefore, they must possess some innate models containing properties of those stimuli that can satisfy these needs, and all the attained results are being constantly compared to these stimuli" [10]. "... Immediately after birth, a calf's first goal-directed activities involve developing an upright posture, then moving toward the mother, finding a nipple, sucking on it and, finally, the reaction of imprinting" [10]. Therefore, immediately after birth, goal-directed behavior is constructed drawing also on genetically inherent patterns of "searching for specific environmental stimuli". But it is only the required succession of results, as well as some rather general types of behavior like "trial and error", that are genetically determined. An improvement and development of these activities takes place in the individual learning process.

"According to P.K. Anokhin, the central mechanisms of functional systems that support goal-directed behavioral acts have a similar structure" [10]. Let us examine in detail the architecture of goal-directed activity, as well as the physiological mechanisms of solving the goal paradox.

5.1 Afferent synthesis

The afferent synthesis, which includes the synthesis of motivational excitation, memory, contextual and triggering afferentation, constitutes the initial stage of a behavioral act of any complexity.

5.1.1 Motivational Excitation

As we know, the goal is set by an emerging need. But in case of goal-directed behavior, it transforms into a motivational excitation. “The leading stimulus… which determines goal-directed activity even for animals is the *motivational excitation*, which is formed on the basis of the leading internal need” [10]. “The dominant need is always perceived by a complex of specific receptors which are located both in the periphery and directly in the central nervous system. With their participation, a crucial moment arises in forming goal-directed behavior – the process of transforming internal needs into corresponding stimuli in the brain. Thus the dominant motivation emerges. The latter is always accompanied by a certain emotional sensation. In other words, during the process of forming a motivational stimulus, the material metabolic need is transformed into an excitation process of brain structures” [10]. But a motivational stimulus does not consist in the excitation of receptors which stand ‘on guard’ for some physiological constant – it is rather an excitation of ‘central brain structures’ initiated by the arising need. It is the motivational stimulus that constitutes the goal set in the organism in case of goal-directed behavior. As in the case of needs, the motivational stimulus not only sets a goal but also energetically supports its attainment. “Negative emotions accompanying motivation have essential biological significance. They mobilize the animal’s effort to satisfy the emerging need. Negative emotional sensations that accompany the motivational stimulus facilitate an animal’s search for a supporting agent” [10].

The attainment of the result and the activity of the reinforcing stimulus are subjectively perceived in goal-directed activity as positive emotions (elimination of negative emotions). As goal-directed behavior must be learned, it’s necessary to memorize the sequences of stimuli which have led to the attainment of a result. Therefore, positive emotions (elimination of negative ones) also have a reinforcing (authorizing) role, which retains in memory the entire sequence of actions that led to goal attainment.

5.1.2 Memory

Memory constitutes the second component of afferent synthesis. The whole sequence of stimuli that has led to goal attainment is recorded during reinforcement, starting with the motivational stimulus. “...Extracting past experience from memory follows the same neurochemical path on which it was recorded at the time of acquiring this experience” [10]. Extraction of past experience from memory is based on the “principle of anticipatory reflection of reality” [5]. Thus, the emergence of a motivational stimulus is enough to “extract from memory” all previous sequences of actions which have led to attaining the respective result and reinforcement. Moreover, motivational stimuli possess chemical specificity, allowing them to “extract from memory” all ways of attaining a particular goal set by a given motivational stimulus. “Each motivation is built by a chemical metabolism specific to it, and ascending activating stimuli of the corresponding subcortical centers to the cerebral cortex. This leads to the fact that animals, with the help of motivational stimuli, perform active selection of only specific environmental stimuli to satisfy their dominant needs” [10].

5.1.3 Situational Afferentation

While recording a memory trace, the situation in which the result is attained is also being recorded. This situation is registered, along with the motivation, as a necessary precondition for attaining the result. Thus, the motivational stimulus in this situation “extracts from memory” only those ways of attaining the goal that are possible in the given situation. Therefore, while interacting with experience extracted from memory, situational afferentation determines how and what can be done in the given situation to attain the goal.

5.1.4 Triggering Afferentation

The fourth component of afferent synthesis is the triggering afferentation. It is essentially the same as the situational afferentation, with the difference that it involves the time and place of attaining the result, rather than the stimuli of a situation. "...Special stimuli reveal the so-called pre-triggering motivation, which is formed on the basis of interaction between motivational and situational excitation and memory mechanisms. These triggering stimuli, therefore, attribute certain time and place to the goal-directed activity" [10]. Thus the triggering afferentation answers the questions when and where can the result be attained.

Consequently, the goal paradox is solved for the most part during afferent synthesis, as it's here that the what, how, and when of goal attainment are determined. "Thus at the stage of afferent synthesis, a number of points are determined: what to do (based on the comparison of internal and external stimuli), how to do it (based on memory), and when to do it (based on the effect of triggering stimuli)" [10].

Therefore, taking experience and environment into account, the motivational excitation as a goal automatically solves the goal paradox and determines by what means, how, and when can the goal be attained. By "extracting" from memory all relevant experience, the motivational excitation – when regarded as a goal – transforms into a *particular goal*, which determines the way of attaining the result. This particular goal is called the "*higher motivation*" in TFS.

5.2 Decision-making

At the stage of afferent synthesis, motivational excitation can extract from memory several ways of attaining the goal. At the stage of decision making, only one of them is selected – thus forming the *program of actions*. "At the stage of decision making, in accordance with the initial need, only one particular line of behavior is selected" [10].

Decision making is a delicate process that should take into account [11-12]:

– The likelihood of attaining the goal in a given situation;

– The total energy consumption of a particular method of attaining the goal, taking into account the informational certainty of whether the goal can be really attained;

– The amount of experience extracted from memory, including dominant (genetically defined) forms of behavior in case current experience is insufficient for decision making.

5.3 Acceptor of Action Results

Suppose a program of action is chosen. At that point, there is no guarantee yet that the final result will necessarily be attained, nor even intermediate ones. The goal can only be attained if each of the intermediate results of the current program of actions will be attained. Motivational excitation "extracts from memory" the entire sequence and the hierarchy of results that should be attained during the action program. This sequence and hierarchy of results are defined in TFS as the *acceptor of action results*. "It is exactly the dominant motivation that "extracts" into the acceptor of action results all available experience to determine the final result. This will satisfy the underlying need by creating a particular *model* or program of behavior. From this standpoint, the acceptor of action results is a transformation of the organism's dominant need into anticipatory neural excitation, into a complex "receptor" of corresponding reinforcement" [10]. "...It should be noted that in the acceptor of action results, not only the continuum of behavioral results is programmed, but also the whole mosaic of actions aimed at attaining every result" [10].

Therefore, while being transformed into a particular goal, the motivational excitation extracts from memory the *particular criteria* of attaining this goal. This consists of the whole sequence and the hierarchy of criteria of results which must be attained in the process of attaining the goal and performing the program of actions, i.e. the acceptor of action results. Thus, the acceptor of action results anticipates the particular criteria of attaining a particular goal and the attainment of a *particular result*. "The formation of a "goal" in the central architecture of a behavioral act involves constructing the next stage in the systemic organization of a behavioral act. This relies on a mechanism for predicting the future result (of the entire sequence and hierarchy of results) that satisfies the dominant need, i.e., on the mechanism of the acceptor of action results" [10]. "Thus, forming prognosis of future results in functional systems – i.e., in the acceptor of action results – constitutes the physiological mechanism of setting a goal" [10], or setting a "particular goal", in the terms employed here.

The definitions of a "goal" by P.K. Anokhin and our definition of a "particular goal" differ: firstly, motivational excitation according to P.K. Anokhin is not involved in the process of determining the goal; secondly, by a goal P.K. Anokhin understands not only the result and the "entire mosaic of actions", but also its prognosis. Prognosis is understood by him in two senses: firstly, as the expectation of attaining the result (corresponding to reverse afferentation), based on the "principle of anticipatory reflection of reality" [5], and secondly, as a prediction of attaining the final result. In our definition of the acceptor of action results as a particular goal, the second meaning of prognosis as a prediction is not necessary.

Transforming motivational excitation as a goal into a particular goal, the criteria of the result attainment into the acceptor of action results, and the program of actions into the model of a particular result also transforms the original paradoxical goal – for which it is not determined by what means, how, and when it can be attained – into a non-paradoxical particular goal, for which the final goal (and result) is divided into sub-goals (and sub-results), so that for each sub-goal it is already known by what means, how, and when it can be attained.

5.4 Efferent Mechanisms of Functional Systems

How is the action program executed? "The stage where the acceptor of action results is formed is dynamically and gradually replaced by the formation of goal-directed action itself. However, this is preceded by a stage where the action, while not being externally realized yet, has already been formed as a central process ... It seems that the name "stage of efferent synthesis" reflects the semantic meaning of this stage most successfully. The dynamic association of somatic and vegetative functions into a holistic behavioral act is performed at this stage with the help of central nervous excitations" [10].

Since the real situation always differs somewhat from situations that have been extracted from memory and have been accounted for in the acceptor of action results, some "disagreements" will inevitably occur between the expected results and the actual reverse afferentation about the results of performed actions. "Action results are evaluated with the help of *orienting/search activity* [13] and emotional sensations. Orienting/search reaction occurs and is intensified in all cases when the result of a performed action unexpectedly does not agree with the properties generated based on efferent synthesis of the acceptor of action results, i.e., when "disagreements" occur in the behavioral activities. When such a reaction happens, the efferent synthesis is immediately rearranged, a new decision is made, and a new program of actions created" [10].

Note that when a disagreement occurs between the "reverse afferentation" and the afferentation expected by the acceptor of action results, a rearrangement of efferent synthesis is carried out and a new decision is made – which means setting a new particular goal and acceptor of action results, although both the motivational excitation and the corresponding final result remain the same.

"The goal-directed behavioral act is completed therefore by the last authorizing stage. At this stage, while influence of the stimuli satisfying the leading need – the reinforcement in the conventional sense – the parameters of the attained result ... cause, through excitation of the corresponding receptors, the flow of reverse afferentation, which has all the previously programmed properties of supporting stimulus in the acceptor of action results" [10].

During reinforcement, a "trace" is recorded of all stimuli which have led to the attainment of the result, and thus the realized action program is registered in memory.

6 Discussion

The key notions that were used in the analysis of the foundations of mathematics and TFS are the following:

1. Task and goal;
2. criterion of task solution or purpose attainment;
3. paradoxical gap between the task (goal) setting and its solution (attainment), as fixed in the criterion;
4. paradox solution by finding a proof of task solution or by formulating a plan of action in the course of decision making on the basis of anticipatory reflection of reality (anticipation).

These notions allow us to build a conceptual bridge between these theories by establishing a correspondence between their key notions and derivative ones (result, plan, paradox solution, etc). This bridge enables to mutually enriches both theories, and, in particular, to achieve a mathematical formalization of TFS. An approach to formalization where the main principle of the theory is formalized is the most accurate one. Thus, for the formalization of TFS a hierarchy of weak formal systems can be used.

In mathematical theories and weak formal systems the mentioned paradox is solved by finding proof of task solution. Then, following the established conceptual bridge, the principle of anticipatory reflection of reality and decision making in TFS must be formalized by logical inference of goal attainment. From the informational and philosophical point of view, anticipatory reflection of reality is a prediction. Prediction, in the frame of the hypothetical-deductive method in the philosophy of science, and in the works of K. Popper, is considered as the logical inference of a predicted (explained) fact from the theory and given facts. Thus, the principle of anticipatory reflection of reality in the frame of our conceptual bridge is formalized by the logical inference of prediction of goal attainment in the given conditions (facts). Moreover, this conceptual bridge connects us with the problems of epistemology, as they are presented in the works of K. Popper.

Hypothetical-deductive model of prediction presupposes the reliability of the used theory to draw conclusions. From neurophysiological investigations [8-12] it follows that the rules of actions that are revealed during learning have inductive, and moreover probabilistic character. Predictions based on inductive or probabilistic rules are described by inductive-statistical models [14]. For such predictions the following two problems arise: statistical ambiguity [15], when contradictory predictions are derived from inductive knowledge, and the problem of synthesizing probability and logic [16], when we obtain very low (or zero) estimation of probability of prediction while infering predictions from probabilistic knowledge. These problems were investigated in a series of Projic (Probability + Logic) workshops on «Combining Probability and Logic» in 2002-2013. However, these investigations were not connected with cognitive science.

The proposed conceptual bridge gives us an opportunity to consider these problems in the framework of cognitive science. We suggested the solution of both problems in the context of cognitive science, providing a new formalization of anticipation as prediction with the following properties:

1. it solves the problem of synthesizing probability and logic by introducing a special Semantic Probabilistic Inference (SPI). In the process of SPI probability values are highly increased [17-18];
2. it solves the problem of statistical ambiguity. We prove that SPI discovers maximally specific rules that are consistent with and satisfy the Hempel's requirement of maximal specificity [19-20];
3. at the same time SPI satisfies the Hebb's rule, so SPI may be considered as a formal model of a neuron potentially able to predict without contradictions [21];
4. the proposed conceptual bridge and the formal model of a neuron allowed us to develop a model of TFS that was used for creating a rather effective computer model of some animats [22-23];
5. the formal model of a neuron was successfully used for modeling expert knowledge [24].

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