Towards Understanding Biotic, Psychic and Semiotically Mediated Mechanisms of Anticipation

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Abstract. Anticipation is an inevitable characteristic of life. Instead of asking whether this or that organism reveals some form of anticipation as it is often done in biology and psychology today, it is more fruitful to ask, in which ways different organisms anticipate future. In this chapter Anokhin's Functional Systems Theory is taken as a starting point to proceed with the analysis of how psychic and cultural mechanisms of anticipation have evolved over the history of mind. Grounded also on Vygotsky's and Lotman's theories, it is concluded that there are nine different developmentally ordered mechanisms of thought and correspondingly nine different forms of anticipation. Knowing the basic mechanisms of thinking, it becomes possible to evaluate research in anticipation from a new perspective. Limitations of less developed forms of anticipation can be recognized and replaced with more efficient hierarchically higher-order forms of anticipatory thinking.

Keywords: biotic anticipation · functional systems theory · psychic anticipation · semiotically mediated anticipation

1 Introduction

Anticipation is one of the essential characteristics of life. All organisms are able to anticipate certain changes of their environment. Anticipation is everywhere – it is common in our everyday lives. When we plan (sic!) to take a bus, we predict that bus is going to be in a certain place at a certain time and after we sit in it, it travels to a predictable place. We put clothes on predicting that our body temperature is going to increase after that. And so on and so forth. Even though often not called in this way, all science is also a form of anticipation. Medicine, for instance, is constantly looking for better ways to diagnose different disorders. Every diagnosis is in essence a form of anticipation: the diagnosis predicts the forms of effective treatments and also the state of a patient in the future. Economy, political science, chemistry, physics – all areas of human knowledge from natural sciences to human involve predictions of future states as well. If not otherwise, every scientific experiment is conducted to learn whether expected event is going to take place as predicted or not.

Thus it is safe to conclude that human activities aimed at making sense of the world and adjust to it are essentially forms of anticipation studies. Most of the time the studies aim to discover how to anticipate certain events. Humans, especially scholars among them, are interested in finding more and more information about the phenomena under study in order to use it for predicting future events. What is not so often realized is that anticipation is a two-sided phenomenon. On the one hand, obviously, knowledge about the phenomenon to be predicted is relevant. On the other hand, however, there is a living and sense-making organism who learns the ways to predict future. In order to learn the most efficient ways to anticipate, we should know how we – humans who anticipate – do it. We need to know, how our mind works and what kinds of possible obstacles we may encounter while trying to see the future before it arrives. In short, we need a psychological theory of anticipation.

In this chapter I am going to outline this theory as I see it. This theory is rooted, among others, in the works of two outstanding Russian scientists, neurophysiologist Piotr Anokhin and psychologist Lev Vygotsky. We are going to see that theories of these two scholars allow not only to understand anticipation processes better but – what is even more important – they also suggest direction for the development of new theories. Before going to the theory, I would like to mention that the theory described is quite complex. In the limits of one chapter it is not possible to discuss all the relevant background in sufficient details. So several fundamental concepts, among them life and psyche, are defined but not discussed.

2 Anticipation as a Characteristic of Life

First we need to understand how, in principle, living organisms anticipate. This might seem a little out of place – why to bother us with biology, if the aim is to understand psychology of anticipation? Yet understanding life is not just useful, it is essential for developing a coherent theory of any mental activity, including anticipation. The problem is that there are different ways how anticipation is achieved; in order to understand psychic forms of anticipation we must be able to distinguish them from biotic forms.

Before describing the basic form of anticipation in living organisms, it is necessary to define life. Today hundreds of different definitions can be found (e.g., [1]). These are not interesting for us as we need a definition that can be coherently incorporated into our theoretical framework. So we do not need to bother ourselves with questions whether life is defined by metabolism, reproduction or several other characteristics of life forms. Our subject is anticipation – which is always about environment or, more exactly, about the change of the relationships between an organism and its environment. Thus our definition of life should define it not as a list of characteristics of an organism as if isolated from its environment but make the unity of organisms and their environments explicit. In the following I rely on Anokhin's works, which did not give to the very best of my knowledge the definition of life necessary for the comprehensive theory of anticipation but nevertheless provided all the ingredients for that (see also [2] for a short survey of Anokhin's ideas).

Anokhin suggested that the decisive and primary characteristic of life processes is stability on the basis of self-regulation principles [3]. Here 'self-regulation' refers to systems, which equilibrium is maintained by the internally generated goal-oriented activity of the system. All nonliving nature may preserve their stability over considerable length of time without any activity. So we need to ask, why goal-oriented activities are necessary for living organisms. I think the answer to this question leads to qualitative[1] distinction of life from nonliving matter: living organisms preserve their integrity not just in changing environments but in environments, which changes would be destructive to an organism unless organism does something purposefully. In principle, there are only two ways to adjust to an environment and its changes. Organisms can either change themselves or their environments. Trees is northern countries, for instance, would just explode in minutes if in summer temperature would fall in short time, say a minute, considerably below freezing point of water. Water in a tree would freeze and expansion of it would destroy the tree. Yet nothing like that happens in ordinary situations, where changes from warm to cold are relatively slow. In that case trees can anticipate the change of the temperature beyond critical level before that change takes place, and they would change themselves either by decreasing their water content or by binding water with chemical substances so that water will not freeze in winter temperatures. Making things short, we arrive at the following definition of life: *Life is a form of organization of matter, which, on the basis of the anticipatory reflection of the environment and corresponding goal-oriented activities leading either to change of itself or its environment, is able to sustain its integrity despite potentially destructive effects of its environment.*

This definition explains, among other things, why anticipation is absolutely essential to life – effects of potentially destructive changes of the environment can be prevented only before these changes take place. Another important component in this definition is that of environment; life is defined not as a set of characteristics of an isolated organism but rather as unity of an organism and its environment. Each and every organism is adapted to its environment, including the changes of it, in certain limits that characterize the organism. Thus in a certain sense every organism can be defined by characterizing the environment it is adapted to.

Now our question is, how living organisms anticipate future changes of their environments. Anokhin proposed the following idea [5][2]: in the beginning of the formation of living systems, every distinguishable event in the sequence of events in the environment became connected with a different chemical reaction in the system: environmental event *A* became connected with a chemical reaction *a* in the system; event *B* with a reaction *b*, *C* with *c*, etc. Chemical reactions *a*, *b*, and *c* begin to reflect the whole sequence of corresponding environmental changes when internal connections $a \rightarrow b \rightarrow c$ emerge. This sequence becomes anticipatory, if the chain of chemical reactions in the organism, triggered by the environmental event *A*, is faster than corresponding sequence of environmental events. It is noteworthy that recent studies seem to confirm Anokhin's theory – though not mentioning his contribution – and open ways to understand biotic anticipation at the molecular level (e.g., [7-9]).

[1] 'Quality' is one of the terms that must be explicitly and consistently defined, in order to understand the following discussion. Quality, as I have defined it, *is the potential of a structure to become into relationship with another structure* ([4], p. 283). Thus in this particular case, as an example, qualitative difference between nonliving and living forms of matter refers to special ways the living can relate to its environment, the kinds of relationships that do not exist in nonliving world at all.

[2] This idea was rediscovered by Robert Rosen (cf. [6]). Even though he was familiar with some of the Anokhin's works, he did not mention Anokhin's contribution in that particular context.

3 Anticipation in Living Systems: Far More Complex Than it Seems

At the moment it might seem that we have understood anticipation, at least in living organisms. Next we see that we are far from that yet. There is a fundamental issue we must take into account. Namely, Anokhin followed the way of scientific thinking, I have called structural-systemic (cf., e.g. [4, 10-12]). Shortly, according to this view, every distinguishable from others material object, including all forms of life, is a whole composed of distinguishable but not separable elements. It is important that the properties of elements, when they are included into a higher order whole, change. Anokhin, who also relied on this understanding, conjectured logically from this principle that no analytic study of the objects of studies can be conducted without exact identification of this object as a component of a big system [13]. This principle applies also to chemical chains of anticipatory reflection of reality that are not isolated from the organism as a whole – therefore understanding of anticipation requires understanding of the whole where this molecular chain-system is an element.

4 Anticipation in the Structure of Goal-oriented Behavior

According to Anokhin's theory, the living system must be able to answer four questions about the future result of its behavior ([13], p. 70): (1). What result must be achieved? (2). When exactly this result must be achieved? (3). With what mechanisms this result must be achieved? and (4). How the system ensures the sufficiency of the result? Every living organism, in order to be able to answer these four questions and execute on the basis of these answers actions with the expected results, must be organized in a certain way. This organization was defined by Anokhin in his Theory of Functional Systems (TFS; [13-17]). Functional system was defined as follows: Functional system as a unit of integration is a strictly delimited group of processes and structures that are united for realization of a certain qualitatively specific function or act of behavior of an organism ([14], p. 128).

Next I will outline very shortly the basic architecture of a Functional System, which is described in Figure 1.

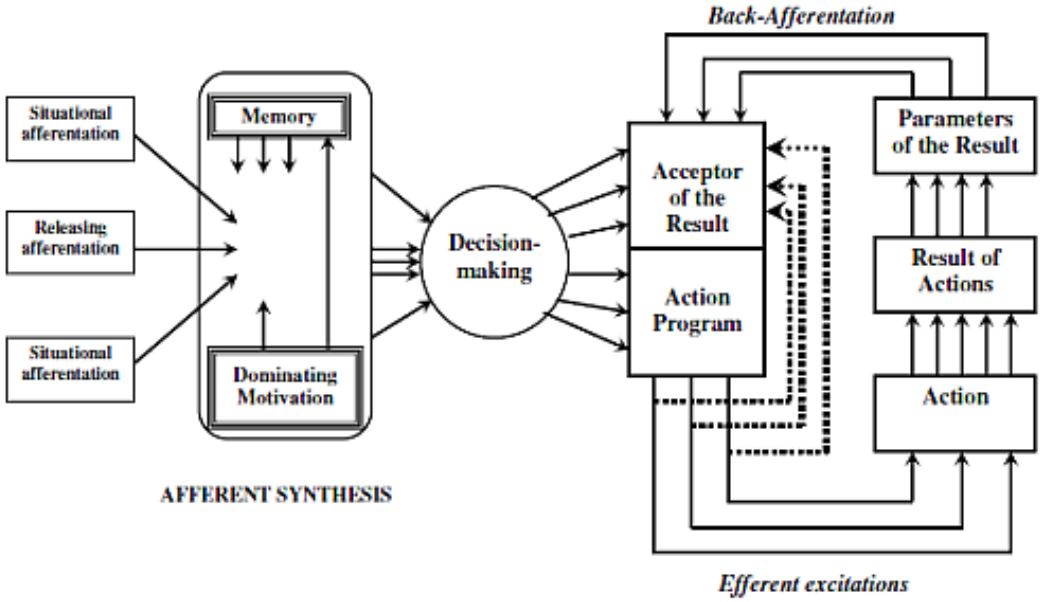

Fig. 1. The basic architecture of a functional system. Adapted from Anokhin ([13], p. 87; [16], p. 372).

Behavioral act begins with *afferent synthesis*. A behavior emerges on the basis of dominating at a given moment *motivation*. Motivational impulses activate in *memory* all information that has been connected to satisfying a given need in the previous experience of an organism. *Situational afferent* information is needed for further selection of memory information: this is information about what resources in the environment are available for an organism at a given moment as well as what environmental factors may hinder using the needed resources. In afferent synthesis all sources of information are integrated into a unitary whole on the basis of which *Decision* is made about what, how,

and when should be done. Decision-making involves formation of two complementary dynamic structures: *Acceptor of the Result* and *Action Program*. Acceptor of the result includes all information about the physiological parameters that characterize the expected result. When the *releasing afferentation* informs organism that it is time to release the action program, the *Actions* will be performed. Actions lead to some *results*, either in the organism itself or in the environment. Release of action program is also connected to the Acceptor of the Result which receives feedback from performed behaviors and therefore allows deciding whether behaviors correspond to the plan that is executed. Actions lead to changes either of the organism or its environment; these changes, sensed through sensory organs, comprise *back-afferentation*. Back-afferentation is compared with the expected pattern of inputs encoded by the acceptor of the result. If these two flows of information match, an organism is informed that expected result was achieved. In that case behavior is either stopped or, in case of a sequence of behaviors, a next behavior in the sequence is released until the final expected result is achieved. If there is a mismatch between the acceptor of the result and back-afferentation, new functional system is organized to achieve the motivated result.

As far as I know, Anokhin did not locate anticipatory processes coherently into the architecture of the functional system. In his TFS he discussed the role of anticipation in the acceptor of the result. Indeed, purposeful result-aimed action is impossible without anticipation of the specific result. This, however, cannot be the only process of anticipation in the system for two reasons.

First, acceptor of the result anticipates consequences of actions of the organism. These actions, according to Anokhin, must have adaptive value – they are performed only when it is beneficial for the organism. The definition of life I proposed above, explains also, what kinds of actions are beneficial – these are action that, through changing either the environment or the organism itself, prevent potentially harmful effects of the changing environment to the organism or potentially harmful changes of an organism that limit the resistance to environmental conditions. In either case, it is the nature of the environment and its changes that determine the nature of actions. In the nonliving world, relationships between objects are determined by the physical-chemical principles alone. In the living world, the sequences of physical-chemical events affecting an organism can be modified by purposeful actions. Thus the result of an action – what is anticipated by the acceptor of the result – is different from the sequence of events that would take place in the environment and therefore in the environment-organism relationship without that action. Further, the action is adaptive only when the environment or organism is predictably changing – this change must be anticipated in order to act and achieve a result of action that is different from the anticipated change in environment-organism relationship. Therefore two different forms of anticipation are necessary for an action to be adaptive. One mechanism anticipates what and how is going to change in the environment and another – anticipation of the result of an action – anticipates essentially that this change is not going to affect the integrity of the organism.

This line of argument is in accordance with Anokhin's ideas. Particularly, he wrote:

> "[...] any structure of the organism and any form of reaction, regardless of its simplicity, must pass through a historic course of development in which the external factors stereotypically repeated their action on the protoplasm of the organism during a period of many millions years. [...] any inborn activity already has the properties to adapt the organism to forthcoming stages of sequentially developing events of the environment." ([18], p. 25).

Thus it is clear that actions of an organism emerge historically after experiencing sequences of environmental events over a long time, and adaptive reactions prevent the effects of potentially harmful conditions in those sequences.

The second reason as to why anticipation of the result can not be the only form of anticipation is that acceptor of the result must contain elements that are determined not by the environment but by the structure of the organism itself. Organisms are built so that, as a rule, the expected result that is related to the satisfaction of the need, can be achieved only in more than one step:[3]

> "In the life of an organism, and especially in human life, there are no actions not resulting from preceding actions and not evoking subsequent actions. Therefore, it is natural that appropriate distinctions must be introduced into the actual concepts of reverse afferentation, depending on what type of reverse afferentation we are dealing with: whether it involves information about the results of some intermediate action or whether it provides information about the final implementation of an initial intention. Thus, if a person who is at home resolves to make some purchase, a number of

[3] I am not aware of any result-oriented action that would need only one step to achieve the expected adaptive end-result. By "as a rule" I leave open a possibility that such actions may exist. In those cases, this argument does not suggest the need for more than one form of anticipation.

> individual actions occur after the appearance of this intention: the person gets dressed, checks for money, opens the door, goes downstairs, crosses the street, opens the door to the store, selects the needed item, etc. The intention of buying something includes a number of intermediate stages which, in their sequential order, are dynamically patterned in the action acceptor. These stages could not be carried out if the person did not receive reverse afferentation about the successful completion of each of them." ([18], p. 233).

Further, not one but two different forms of intermediate actions must be posited. One form was just described – it contains certain intermediate changes in the environment of an organism achieved through action.[4] In order to go shopping, we need to open some doors – the goal can be achieved only through a sequence of such steps. But there is another form of action, at another level of action-execution, which also must be anticipated:

> "For example, on the basis of a number of objective processes of interaction of the organism and the environment, a person may intend to drink a cup of tea. He extends his arm toward the cup of tea and picks it up. Then the tactile excitation of the palm by the surface of the cup, and the thermal, weight and, finally, visual stimulation from the contact of the hand with the cup supply the information that the result of the action corresponds to the original intention. In the implementation of this action, however, the actual approach of the hand to the cup is continuously regulated by proprioceptive signalization which attests to the correct and appropriate distribution of the contracted muscles, to the degree of effort exerted by the hand, to the height of its position in relation to the intended aim, etc. This form of afferentation is undoubtedly very important for the execution of the movement of the hand, but it cannot provide the central nervous system with any information about the results of the given action, since no position of the hand and, consequently, no proprioceptive afferentation may provide information on whether a cup or glass has been grasped. [...] Thus, the reverse afferentation arising during any motor act should be divided into two completely different categories: *movement-directing* and *resultative*. While the former afferentation is represented primarily by proprioceptive impulses from the muscles bringing about the movement, the latter is always complex and encompasses all the afferent signals indicating the actual result of the movement decided upon." ([18], p. 233).

I think the necessity for intermediate stages in actions is determined by the structure of organisms, which constrain possibilities to achieve adaptive goals. If there are three kinds of the results of action, two of intermediate stages of actions (movement-directing and resultative) and that of the end-result, three different forms of anticipation must also be involved – one for each form. Further, the first two of them are not directly determined either by the anticipated changes of the environment or by the needs that must be satisfied. Rather, they are determined by the structure of the organism and by the particular state of the organism-environment relationship, respectively. Yet both of them also must be anticipated by the acceptor of the result.

In sum, anticipation by the acceptor of the result must be partly based on information that is not directly related either to the anticipated changes of the environment *per se* or to the needs that must be satisfied through actions. Acceptor of the result is too specific – it is created as expectation of the result of very specific movements that comprise very specific actions in very specific environmental circumstances.[5]

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[4] Perhaps it is worth mentioning that the simplest form of changing the environment is movement in space, i.e., changing a position in space. Environment is not determined by some absolute, independent from organisms, characteristics. Rather, environment is always relative to the organism. So moving from one position to another leads to a change of the environment *for the moving organism*. In addition, I think exchange of matter between the organism and its environment – which is also absolutely necessary characteristic of life, because every action requires energy – is another most primitive form of changing environment. With every breath, for example, we inhale a certain amount of gas that was part of our environment and becomes part of us. By inhalation we have changed our environment – the gas we inhaled is not surrounding us any more. Exhalation, in turn, adds something to the environment.

[5] Several phylogenetically old vegetative functions, such as respiration, are, according to Anokhin, also built as functional systems containing all universal components I shortly described above. Such functions, as was pointed out by an anonymous reviewer, may seem to have acceptor of the result component that is also built into the system of respiration and not constructed specifically for achieving specific results. Also it may seem that such systems are not specific but function similarly across individuals, often in widely different species and environments. I argue, however, that acceptor of the result is created as expectation of the result of very specific movements that comprise very specific actions in very specific environmental circumstances. First it is important to understand that such old functions may be universally present but still specific. Namely, such functions are specific not in respect

So we actually need another kind of anticipation – that, which allows to anticipate the changes of the environment independent of the organism and its actions. No purposeful action can be planned unless it is known, what kind of effect of environmental change needs to be prevented. If this other kind of anticipation is not located in the acceptor of the result, it must be connected to the functioning of some other component of the functional system. If the question is put in this way, the answer becomes, I believe, obvious: another form of anticipation we are looking for must be located in the afferent synthesis; more specifically it must be located in the *motivation*. It is so indeed; dominating motivation, according to Anokhin, informs the organism about the *need* that must be satisfied. 'Need', however, refers to emerging mismatch between integrity of the organism and environmental conditions. So need is essentially the result of anticipation. Now we can be even more specific in locating this kind of anticipation in the structure of the functional system – the chemical chain-reaction that corresponds to certain chain of environmental events must be one element in the structure of a need. Thus we have distinguished two kinds of anticipation, one about the results of goal-oriented activity (this, in turn, is further distinguished into movement-directing and resultative forms of anticipation), and the other about the possible mismatch between the changing conditions of the environment and the condition of the organism. Let us call them for sake of brevity action anticipation and mismatch anticipation, respectively.

5 Beyond Biotic Forms of Anticipation

Survival of living organisms depends directly on their ability to anticipate potentially harmful events and act in ways that prevent the effects of them. Biotic forms of anticipation are, however, strongly constrained. Anokhin mentioned that emergence of an ability to anticipate novel environmental sequences emerges over many generations, sometimes it can take even millions of years. It is important that the nature of sequences of environmental events is different. Organisms experience stereotypically repeated environmental sequences,

> "[S]ome of these physical factors (light, temperature, gravity, circadian and seasonal variation, etc.) have scarcely changed the nature of their influence from the beginning of life to the present. On the other hand, others (supply of oxygen, atmospheric pressure, specific effects of the aqueous medium, etc.) arose de novo and had a prolonged but temporary action on the organism, appearing in connection with a change in the conditions of life." ([18], p. 25).

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of other organisms but in respect of other functional systems built for achieving other adaptive goals of the same organism. Second, *every* adaptive function of an organism needs at least to some degree flexible acceptor of the result. Anokhin was clear here: "The universality of decision making in the functions of the organism can be seen not only from the behavioral acts, but also from purely vegetative functions. For example, the amount of inhaled air at a given moment corresponds to the organism's needs for oxygen supply and carbon dioxide elimination. Any change in these needs is immediately met by a decrease or an increase in the air take." ([18], pp. 225-226).

Thus respiration must change flexibly to meet changing needs of the organism. These needs, in turn, are determined both by the state of the organism, level of oxygen in the blood, for example, and by the conditions of the environment. In higher altitudes it is necessary to breath more frequently in order to achieve the same level of oxygen in the blood. It is important to realize here that functional systems are not isolated entities in the organism with their own goals and adaptive reactions. Functional systems do not have needs themselves – needs characterize the organism as a whole. As the needs of the organism change when its state or environment changes, all functional systems, even the vegetative, must allow flexibility in their functioning to meet specific needs of the organism that correspond to organism's specific state and specific environmental conditions at any given time. It does not follow, however, that all functional systems must have the same degree of flexibility. Some environmental conditions are relatively stable and functional systems for adapting to those conditions can be less flexible than others, which ground adaptation to relatively variable environmental conditions.

And perhaps one point more. I am not suggesting that creation of the acceptor of the result requires every time establishing completely new structural relationships between the elements of the functional system. Obviously, in case of organisms with a CNS, there is no need to create new synapses to connect neurons every time an acceptor of the result – or actually the whole functional system – is dynamically created. Rather, the functional system must be plastic; it must be possible to modify it according to the state of the organism and the state of the environment – which both are constantly changing. There is evidence to suggest that this principle applies indeed, even in case of relatively simple organisms. In *Drosophila*, for example, four GABAergic interneurons were recently identified, which control the amount and quality of the intake of water and nutritients [19]. In terms of Anokhin's TFS, these neurons belong to the acceptor of the result. It is noteworthy that the system is plastic, its state can be modulated. Depending on the activity level of the interneurons: intake of all compounds can become indiscriminate and excessive in case of inactivation; acute activation of the same interneurons, conversely, suppresses consumption of water and nutritients.

Anokhin, thus, draws attention to the fact that some environmental sequences have not changed over periods of very long time whereas others emerge in some time of earth history and therefore the time available for organisms to adapt to such changes is shorter. It is known that even unicellular organisms can acquire new anticipatory abilities in a relatively short time, in a few months or even weeks [20, 21]. It is still important that "short time" is also a relative term; in the mentioned studies, new adaptations emerged in novel environmental conditions after a few hundreds of generations. If humans would rely only on qualitatively similar to unicellular organisms mechanisms of adaptation, "short time", i.e. a few hundreds of generations, would still cover a few thousand years.

Any adaptive action is possible only on the basis of anticipation. We just distinguished two kinds of anticipation, action and mismatch, respectively. This distinction becomes relevant here. Namely, mismatch anticipation must emerge before it becomes possible to develop functional systems for actions that support adaptation to anticipated environmental changes. So action anticipation can emerge only after relevant mismatch anticipation is available for the organism. Together with new actions, however, the environment of the organism changes. These changes are never limited to adaptation but extend beyond them. But acceptor of the result does not provide feedback about such unexpected side-effects. There is no guarantee, however, that novel changes introduced to the environment with new forms of actions will not be nonadaptive.[6] Thus some short-term adaptations may turn out to be nonadaptive in the long run. As acceptor of the result would not inform about such side-effects, new mismatch anticipation must develop. Biotic mismatch anticipation would take, again, many generations before ways to cope with nonadaptive consequences of organism's own actions would emerge.

In sum, biotic emergence of novel forms of anticipation is slow and supports the survival of the species but not necessarily the survival of individuals of that species. We know very well, however, that humans do learn to adapt to novel environmental conditions – such as internet or iPod – within one generation. And not only humans, there are many other species, who develop novel forms of anticipation during their individual lifetime. This form is based on a qualitatively novel form of adaptation.

6 Psychic Forms of Anticipation

Among living organisms there is a subgroup that is able to anticipate in two ways, biotic and psychic. The main difference between the two, was just introduced. Thus we are ready to define mind or psyche.[7] We know that all living organisms anticipate on the basis of the experiences of the *species*; this is biotic form of anticipation. Some of them anticipate also on the basis of *individual* experiences – this is where psyche is born. I define psyche as follows: *Psyche is a form of organization of living matter that is characterized by active, purposeful aimed at self-preservation relation to its changing environment on the basis of individual experiences* (see for earlier versions of the definition, [24], pp. 10-11; [25]).

The mechanism of the emergence of novel psychic forms of anticipation must be different from biotic forms. This fact is suggested already a difference between biotic and psychic anticipations: psychically emerging forms of anticipation are not passed over to next generations by biological-genetic mechanisms. Further, psyche requires presence of a system that is suitable for encoding, storage and recall of the chains of processes that correspond to individually experienced sequences of environmental events. Psyche exists only in organisms with central nervous system (CNS), the organ, which functions ground individual memory.

Further, CNS does not encode and store patterns of all kinds of receptors, organs that stand in the beginning of all forms of anticipation. It is noteworthy here that receptors, which mediate the physical-chemical events in the environment to the CNS are relatively complex organs whereas receptors that ground biotic anticipation can also be

[6] Numerous examples of such actions can be found in the recent human history. Among them, for instance, use of insecticide DDT, which eventually turned out to have several unexpected dangerous for nature side effects, and use of Thalidomide, which relieved some uncomfortable effects of pregnancy but also caused phocomelia (malformation of the limbs) in thousands of children.

[7] I prefer to use the term 'psyche', because the term 'mind' is in modern mainstream psychology usually used as an attribute of an organism as if isolated from the environment. Historically the term 'psyche' is also contaminated – by questionable theories of psychoanalysis. Yet the term 'psyche', psychoanalytic speculations left aside, is free of fragmented and both ontologically and epistemologically problematic meanings that characterize modern mainstream psychology (see, e.g., [11-12], [22-23], for the discussion of these fundamental problems). So I stick to 'psyche', even though 'mind' can be taken as synonym of it.

specific molecules inside or on the surface of a single cell. Thus psychic forms of anticipation are based on only those experiences that are sensed by sensory organs. Psychic forms of anticipation are therefore all based on patterns of sensory experiences stored in the CNS. What is organized in psychic learning, is not chains of chemical reactions beginning from molecular receptors but rather sensory attributes, such as color and contour in vision or frequency and intensity in the auditory system.

Even though psychic anticipation is qualitatively different from biotic, there are also important similarities. The basic architecture of the functional systems remains the same. The differences lie in the processes and structures that ground mismatch anticipation in the afferent synthesis and action anticipation in the acceptor of the result. These differences, however, change the nature of a functional system as a whole – entirely novel possibilities to organize the structure of actions emerge. First, and most obviously, it becomes possible to learn to anticipate new sequences of environmental events fast and, on the basis of that, to search for ways to adapt individually to discovered mismatches between changing environmental conditions and integrity of the organism. So a dog, for example, can learn to associate ringing of a bell with a certain source of food and find it more efficiently.

Second, resultative form of action anticipation becomes flexible too. Through experiencing consequences of one's own actions, it becomes eventually possible to modify the structure of the resultative acceptor of the result. In this way actions can be programmed in increasingly specific ways to achieve more and more specific adaptive forms of actions. This possibility is, I suppose, especially important for increasing the number of different kinds of intermediate actions between a state of unsatisfied need and achieving the adaptive end-result, which satisfies the need. A dog, again, in order to achieve a goal – to go out for a walk, for instance – may learn to introduce intermediate actions into the whole program, for example to take a leash and bring it to the owner.

Flexibility of action planning increases also through the emergence of psychic forms of movement-directing acceptors of the result. Let us remind a quote from Anokhin's work, I provided above. Anokhin distinguished movement-directing and resultative forms of anticipation on the basis of the fact that the former cannot provide the CNS with any information about the results of a given action, grasping a cup or a glass, in his example. Psyche, however, allows to experience and learn relationships between one's own actions and changes of the environment. This includes a possibility to discover – if such repeated regularities actually exist – relationships between movements of the body and unpredicted by the acceptor of the result changes in the environment. This is why it is possible to teach a dog or a bear to "dance" – to perform certain patterns of movements as results in themselves. In that case movement-directing acceptor of the result is transformed into a resultative acceptor of the result.

There is one major qualitative step in the development of anticipatory mechanisms more to discuss. Before doing that, I think, it is important to realize that psychic sensory-based form of learning should be distinguished into qualitatively different stages of development. Without going into details, three developmentally ordered ways of forming associations between sensory attributes can be distinguished (see for background, [26]). First just relevant for the organism *associations between sensory attributes* can be learned. Classical example of that kind of learning is Pavlovian conditioning, where an animal learns an association between some sensory attributes of food and regularly co-occurring to them events in the physical world; ring of a bell, for instance. In this way an organism learns to react on novel anticipatory events of the environment. Yet no novel ways of action can develop at that stage. In other words, action anticipation cannot be modified yet. The reasons for this limit become clear with the next stage.

At the second stage of psychic development, the learned associations of sensory attributes differentiate; certain learned structures form higher order wholes that correspond to *things* in the organism's environment. Now an organism can also change the structure of its actions – novel actions can be created and executed. At the first stage, associated attributes could belong to many different things in the environment and there is no way to act towards all of them in one act. If things are distinguished, the organism changes qualitatively; now it can act towards them. Entirely novel patterns of actions become available in this process. Most primitive forms of tool-use emerge at this stage.

Acting towards things also grounds the next stage in psychic development. While manipulating things, an organism can learn relationships between them; it can develop representation of *situations*, i.e. structured patterns of relationships between things, at this stage. Actions also change; an organism becomes able to plan actions that relate things into novel structures. Now more complex tools can be created by synthesizing several things into one tool with novel qualities.

Psychic anticipation, as we saw, is related to qualitative changes of the organism – entirely novel ways to relate to the environment emerge in psychic development. Yet there is a very fundamental limit to even the most developed forms of anticipation; all anticipation is limited to environmental events that can be sensed. The senses, however, are activated only in the interaction with very limited number of physical events of the far more complex environment. Things too large, too small, too distant, too close cannot be sensed as well as many other physical phenomena for which there are no senses at all. We know that humans are able to represent this world that goes beyond senses and

also anticipate events in this extrasensory world. Entirely new kind of psychic operations must emerge for experiencing extrasensory world.

7 Specifically Human Forms of Anticipation: Semiotically Mediated Thought

Theory to explain the mechanisms by which humans have acquired an ability to represent the world beyond senses is quite complex (see [27-30], for elaboration). In principle, following Yuri Lotman's theory (e.g., [31-34]), for creation of a novel kind of information, at least two different mechanisms of information processing must interact. If these two mechanisms process the same initially given information – a pattern of sensory attributes, for instance – then by their different nature, each of the mechanisms achieves a different understanding of the same phenomenon. This is not enough for entirely novel information to emerge, though. If a third mechanism is introduced into a system, which "translates", as Lotman termed it, the results of one system to another, novelty emerges that transcends the results of information processing achieved by each of the mechanisms separately.

I have shown that one of these two mechanisms in humans is sensory based thinking just described above and the other is language. Language is not just for reflecting or mirroring sensory-based experiences. In language information is processed according to another set of principles – those of social interaction. As the rules of connecting language units are qualitatively different from the rules by which sensory experiences are connected, the same experiences are processed in two different ways and therefore also with two different results. Novelty, including representation of the world beyond senses, emerges when these two results are synthesized into a higher order psychic whole.

Let us take just one example to understand this. When we are looking some numbers on a display, we can just see the light emanating from the display. In sensory-based thinking we can associate these numbers – if they regularly co-vary with other observable events – with other sensory experiences. But a scientist, who has formulated a scientific theory – which is always with no exceptions in some form of language – the same numbers on a display can be interpreted as concordant or discordant with the theoretically expected numbers. Thus sensorily the "same" numbers can acquire very different meanings depending on whether they are or are not interpreted in the context of some theory formulated in language. In scientific interpretation, these numbers may reliably and validly refer to extrasensory world, to the existence of the Higgs boson, for example.

8 How Anticipation and Functional System Change with the Emergence of Semiotically Mediated Thought

Semiotic mediation grounds possibilities for anticipating entirely novel kinds of events. Anticipation extends in time, space and quality. I will give just a few examples for each of the three kinds of anticipation, distinguished above. I suppose all these examples seem to be trivial, and in a certain sense they are. But the question here is not so much in whether or what humans can anticipate. The main point is rather that we should take into consideration that there is more than one kind of anticipation and each of the kinds is supported by a different subsystem of a whole functional system.

In mismatch anticipation, examples of extension in time, space, and quality beyond that, available for nonhuman species, are numerous. Anticipation is always about time, about events that are predicted to take place in the future. But only humans can predict future in time-frames that go far beyond their own life-time and scales of space far beyond their reach. So it is only humans, who know that sun will turn into a red giant in about 5.4 billions years and in that process it might engulf earth. In this anticipation not only time and space are interesting. It is also interesting that this kind of prediction is possible at all – humans have no direct and repeated experiences of suns turning into red giants but yet they can anticipate such events. Mismatch anticipation extends also qualitatively into realms of experience that are not available for senses. So, for example, radioactivity can be measured and used for finding potentially dangerous places. And this is possible despite the fact that humans have no receptors for radioactivity.

Resultative action anticipation also changes so that novel aspects of the consequences of actions can be introduced into the acceptor of the result. Medical doctors, for instance, may measure concentration of an antibiotic in the blood of a patient and prescribe medicines so that their concentrations remains in predicted limits during the whole course of the treatment. An ability to take into account oversensory information allows also introduction of novel intermediate steps into sequences of actions and anticipate both when the expected results of these intermediate steps are achieved and how introduction of such steps allows to achieve entirely new goals. I think

methodology of science is one example of this form of anticipation: in science specific procedures are used to achieve novel knowledge; many of the intermediate steps in scientific research are based on anticipating oversensory events.

Finally, movement-directing anticipation changes qualitatively too. For instance, it becomes possible to model theoretically the best movement trajectories for achieving best results in different sports and create teaching methods for learning how to perform theoretically the best movement patterns.

Altogether, emergence of semiotically mediated thought leads to fundamental reorganization of all anticipatory systems. Yet, depending on the kind of the anticipation – mismatch anticipation, resultative action anticipation, or movement directing anticipation – the mechanisms by which one or the other form of anticipation is learned, are different.

9 Stages of Word Meaning Development

Psychic forms of anticipation can be distinguished into developmentally different kinds. The same principle applies to semiotically mediated forms of anticipation. The full potential to use language as a tool for organizing thought is achieved over several stages. It was Lev Vygotsky, who not only put language in the center of human cognition – that was done by many long before him (see, e.g., [35, 36]) – but also grounded a developmental theory of language that could explain qualitative differences in cognition. Vygotsky distinguished three stages in word[8] meaning development – syncretic concepts,[9] complexes or everyday concepts, and scientific concepts (e.g., [37, 38]). This most innovative theory of the time had some fundamental deficiencies. First, there was no understanding how language evolves from nonlinguistic processes and how every next stage of word meaning structure develops from the previous stage. Second, Vygotsky did not provide arguments as to why the stages evolve in that particular order. And third, he also did not describe in sufficient details what exactly distinguishes word meanings at different stages. I have tried to answer these questions. Answers to these questions forced to look at word meaning structure development in novel ways. Among other things it turned out that not three but five stages in word meaning development should be distinguished [30, 39]. Next I describe these five stages shortly.[10] I also add short remarks as to the forms of anticipation available at each of the stages of word meaning development. So the stages, as I see them, are characterized as follows.

Word meaning development begins with *syncrets* or *syncretic concepts*. Their relation to referent is not fixed in any way; the same word form, depending on the context, can be used to refer to different aspects of the situation. The basis of extension of the word meaning can change also; different sensory and functional qualities of the situation are selected for extending word meaning. Therefore semiotically mediated thought, i.e. thought, which structure involves a word as one element, is not focused as yet. Nevertheless, words can be used for anticipation at that stage in ways not possible in biotic or sensory-based psychic anticipation. Perhaps the most important qualitative change that takes place with the emergence of syncretic words in comparison to earlier sensory based forms of thinking is that words, due to their flexibility, allow to expand the ways different events are connected in anticipatory thought. Word meaning connects together things and phenomena in novel ways, determined not by the environmental circumstances but by the principles of social communication. Thus entirely novel ways to relate experiences emerge with syncretic signs. One interesting example of such emerging abilities is emergence of verbal reference to the past as a kind of explanation of the current state of affairs in early child development (cf., e.g., [40]). Past cannot be directly experienced, but an ability to refer to the past with words allows to analyze observed event sequences differently and develop novel ways of anticipation on that ground.

Next *object concepts* develop. These words are distinguished into two classes by their reference. One class of object words refer to objects and another class to object-specific attributes, both sensory and functional. At this stage, it is not possible yet to express relationships between things in language; situations are thought in not mediated semiotically sensory-based units. Categories of objects referred to by objects concepts do not have clear boundaries; object-words refer to prototypical categories (see on prototypes, [41, 42]). Object concepts allow to anticipate new properties and functions of objects not obvious from direct encounters with them in the environment. Every time a

[8] Vygotsky usually used the term 'word' in a wide sense referring to all kinds of linguistic signs, not only oral speech. I am using the term 'word' in this chapter in the same wide sense.

[9] 'Concept' is another term, which Vygotsky often used as synonymous to 'word' or linguistic sign. I am also going to use the term 'concept' as referring to linguistic signs exclusively.

[10] It should be noted that I am going to use terms to name every of the stages, which only partly overlap with those I proposed earlier. These older terms just feel a little clumsy to me now.

different word referring to some novel attribute is associated with the word referring to an object, the object in the environment is thought in a novel way. Children, for instance, discover a possibility to attribute objects with novel properties with the help of the words – new actions can be performed with the same things and also novel changes in the environment can be anticipated when objects are used in novel ways.

Third stage of word meaning development is that of so-called *everyday concepts*. At this stage it becomes possible to describe situations, i.e. structured patterns of relationships between objects, in the sensory world. Words that refer to objects can distinguish, differently from the previous stage, exemplars from one another. Both within-object and between-object attributes of situations can be referred to. As combining of the words is not constrained by directly observable situations, imaginary worlds not available for senses – such as fairy-tales or religion – can be created. Yet there is no cognitive mechanism by which to distinguish imaginary extrasensory worlds from realistic ones. This mechanism develops only with the next stage.

As to anticipation, concepts at this stage open entirely new possibilities. Words allow to extend anticipation quantitatively both in time and space; predictions can be made over life-time and further as well as over distances not personally experienced. I think agriculture is one of the activities that emerged on the basis of everyday conceptual thinking.[11] Here we see anticipation over considerable amount of time: seeds to be used in spring are preserved from the crop collected in autumn; the same seeds sowed in spring are anticipated to give crop in the next autumn. Planning of sowing requires purposefully "throwing" food away in order to get more of it many months later. Humans have done it in many occasions even when very hungry. Complexity of planning goes further; the soil is prepared, fertilizers are used, etc. All this requires planning where things are purposefully organized beyond what can be experienced in spontaneous natural environment.

In the next stage, I call *logical concepts*, the main limitation of the previous stage is overcome: it becomes possible to distinguish intralinguistically created imaginary extrasensory worlds from potentially realistic representations of the world beyond senses. Two parallel changes in the word meaning structure underlie that potential. First, categories referred to by logical concepts are organized intralinguistically; this allows to create categories of referred aspects of the world with sharp yes-or-no boundaries. Verbal thought becomes precise at this stage. Second, logical concepts are used as a system where description of the external world is combined with metacognition. In addition to describing the world, it is thought how the thoughts about that external world are organized. This is most obvious in all sciences, where theories of the world are always checked in terms of thought itself – it is asked, whether the conclusions follow from premises logically or not. Illogical conclusions are rejected independently of their subjective appeal. In this way it becomes in principle possible to distinguish between myths, fairy-tales, religion, etc. on the one hand and rational empirically based sense-making of the (extrasensory) world on the other.

Anticipation acquires now qualitatively novel dimensions; foresight can be rationally based on knowledge about extrasensory attributes of the world. In addition, as logical concepts rely on metacognition, it becomes possible to formalize predictions; forms of mathematical anticipation become possible, for instance. Another formal form of anticipation is based on creation of lists of individually necessary and collectively sufficient attributes of phenomena. If all the attributes are present, predictions can be made. This kind of prediction is common in modern medicine, for instance. In medicine diagnoses are made. Diagnosis is a form of prediction: it predicts the effects of possible treatments and also the future states of a patient.

Here we can also distinguish predictions based on logical concepts from predictions based on everyday concepts. In everyday concepts also lists of predictive attributes can be made. But everyday conceptual thought does not have possibilities to select the attributes rationally. Health and future states of it can be predicted on the basis of many "signs", such as the color of the skin, patterns of pulse, presence of pain, difficulties in breathing, etc. But such predictions may occasionally turn out to be useless if not harmful. One problem is related to the theories of the causes of the sicknesses. Modern medicine creates and constantly revises attributes necessary for a diagnosis on the basis of increasing understanding of the mechanisms of the sickness. In traditional cultures, where thought is based on everyday conceptual thinking, causes of some diseases can be attributed to supernatural forces. "Cure" in that case is supposed to be found in communication with that supernatural world through dances, offerings, etc.

Another problem is related to the selection of treatments. Some problems of the lungs, for instance, could be "cured" in Europe just a few centuries ago with a "Lohock", a certain form of a linctus, a drug "to be licked up" ([43], p. 135), made of the fox lungs (*ibid.*, p. 137). And how was use of such drugs justified? It is not hard to guess

[11] I am switching here from examples of child development to examples of the evolution of the humanity. Theoretically, semiotically mediated thought develops through the same stages in both phylogenesis and ontogenesis. So both child development and history of the human kind provide examples of anticipations that emerge together with a new stage of development of the semiotically mediated thought.

by just reading the title page of the book, where we find that the author Nich. Culpeper was "Gent. Student in Physick and Astrology" – yes, Astrology. The reasons for using substances with quite questionable today health effects was justified then by astrological considerations. No wonder that these drugs are mostly gone from modern pharmacopoeias.

Logical concepts, however, are still constrained. Formal logic is a powerful tool – illogical chains of thought can be rejected without any further analysis. Yet, logically correct conclusion is not necessarily correct about the world. Logical conclusion about the world is correct, when the premises of it are correct. Thought in logical concepts does not question the sources of premises; these are just accepted. Modern mainstream psychology,[12] for instance, relies almost exclusively on statistical data analysis methods in interpreting the data. On the basis of such analyses conclusions are made about the mental processes that supposedly underlie observable behaviors. One fundamental question, however, is not even asked – why to assume that quantitative methods are actually appropriate for achieving such conclusions? Here we see that certain premises of scientific thought are not questioned; they are accepted with no ground. As a matter of fact, after asking the question, one would find that it is impossible to infer hidden from direct observation psychic processes on the basis of observed behaviors by any kind of mathematical data interpretation procedure [10, 44-47].

This limitation can be overcome at the next stage of development, that of *systemic concepts*. In this form of semiotically mediated thought, the whole process of sense-making is made conscious; in addition to the chain of conclusions, the premises of the chain are explicitly analyzed and their sources studied. Systemic semiotically mediated thought can be characterized from another perspective as well.

Here it becomes crucial to define what 'system' is. It is important to realize that 'system' has been defined in several different ways. So the definition that characterizes systemic thought must be rationally chosen – I have done it elsewhere [4, 10-12]. On the basis of theoretical considerations – I already mentioned above that this theory I have called structural-systemic – I suggest that system must be defined as a qualitatively novel whole that emerges in the synthesis of elements in specific relationships. This definition is not original; in psychology, for example, it was adopted already by Wilhelm Wundt [48] and followed by many scholars, among them Anokhin, Vygotsky, and Luria.

When element is incorporated into a higher-order whole, its qualities change according to which exactly whole it belongs to. These principles apply to thought as much as to the rest of the material world. Thus in systemic conceptual thought it is explicitly understood that every act of thought – including every act of anticipation – is part of the more complex whole of psyche. It follows that results of thinking depend on the context where the act of thought is situated – this context contains, among other components, the premises. Thought becomes systemic only when the context of it is explicitly defined. In addition to its premises, several other aspects need to be taken into account. First of all, a systemic thinker must – not should or would! – be able to understand the principles of his or her own thought.

Anticipation as a special form of thought also changes qualitatively at this stage of development of word meaning structure. All of the changes cannot be described here. First and foremost not because of space limitations – which are obviously important – but because I am not able to analyze them in sufficient details (yet?). But I think one important aspect of systemic anticipation must be stressed. In systemic thought all kinds of anticipation, including those based on lower levels of thought organization, can be accepted – if this acceptance is based on a theoretically grounded justification. For example, quantitative mathematical prediction can be accepted if it is understood that systemic prediction is not yet available because of the lack of relevant knowledge (see [46]). But what is unacceptable is to believe that mathematics is the best possible form of prediction. According the structural-systemic approach, the best possible anticipation is achieved with explaining the thing or phenomenon under study. Explanation is here defined unequivocally as knowledge about what elements in which specific relationships form the qualitatively novel whole that is studied. Prediction in that case is not quantitative-probabilistic but rather qualitative: knowing which elements are available and into which relationships they can enter in a particular context, it is possible to anticipate exactly which kind of a higher-order whole emerges.

I add here a last remark. I am not saying that systemic thought allows to predict systemically every possible state of affairs in the universe. This is impossible for several reasons. Among them the most important limitation lies in the impossibility to understand unique aspects of events; only repeated aspects of them can be understood in principle [45]. Another reason lies in the fact that qualities of a whole that emerges first time, cannot be predicted. As novel wholes with unique qualities emerge constantly, it is not possible in principle to anticipate consequences of

[12] Mainstream psychology is, as I have defined it, "an approach to the science of mind accepted by majority of psychologists and defined by ontological and epistemological qualities questioned by representatives of non-mainstream psychology." See for a justification of this definition, [12].

such emergence. So anticipatory thought will always be limited. And yet there are ways to improve our anticipation qualitatively and through this to become able to know possible futures in far more details than it can be done today.

9 Summary and Conclusions

In this chapter I followed the path grounded by Piotr Anokhin, Lev Vygotsky and Yuri Lotman, among others. Following their theories, I concluded that anticipation characterizes all forms of life. What is often not taken into account is that more than one mechanism of anticipation can be distinguished on two grounds. On the one hand, following Anokhin's theory of functional systems, different kinds of anticipation must be posited: mismatch anticipation should be distinguished from two forms of action anticipation, that of the resultative and that of movement-directing. On the other hand, all these three mechanisms change in the course of the development of organisms. In order to formulate a coherent theory of thinking development in general and anticipation in particular, some fundamental phenomena were defined – life and psyche in the first place. Three qualitatively different basic mechanisms of thought were distinguished: biotic, psychic, and semiotically mediated. I suggested next that psychic anticipation can take three developmentally ordered qualitatively different forms and semiotically mediated thought, in turn, exists in five hierarchically ordered forms.

Anticipation is always a two-sided phenomenon. On the one hand, efficient anticipation requires information about the anticipated phenomena. On the other hand, however, efficiency of anticipation is bounded by the mechanism of thought that underlies anticipation. Theoretically, the more developed is the mechanism of thought, the more efficient anticipation can be achieved. Every time we aim to find better ways for anticipation, we should explicitly take into account the form of anticipatory thought we are relying on. This allows us to search for the most informative kinds of information available and construct the best models for anticipation. Perhaps one of the most radical in today's context of science conclusions that emerge from the theory, concerns the use of mathematical tools for anticipation. It turns out that mathematical prediction is not and can not in principle be the most efficient way for anticipation. Theoretically the most efficient anticipation is qualitative or, as I have called it, structural-systemic.

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