

Functional Constructivism: In Search of Formal Descriptors

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Abstract: *The Functional Constructivism (FC) paradigm is an alternative to behaviorism and considers behavior as being generated every time anew, based on an individual's capacities, environmental resources and demands. Walter Freeman's work provided us with evidence supporting the FC principles. In this paper we make parallels between gradual construction processes leading to the formation of individual behavior and habits, and evolutionary processes leading to the establishment of biological systems. Referencing evolutionary theory, several formal descriptors of such processes are proposed. These FC descriptors refer to the most universal aspects for constructing consistent structures: expansion of degrees of freedom, integration processes based on internal and external compatibility between systems and maintenance processes, all given in four different classes of systems: (a) Zone of Proximate Development (poorly defined) systems; (b) peer systems with emerging reproduction of multiple siblings; (c) systems with internalized integration of behavioral elements ("cruise controls"); and (d) systems capable of handling low-probability, not yet present events. The recursive dynamics within this set of descriptors acting on (traditional) downward, upward and horizontal directions of evolution, is conceptualized as diagonal evolution, or di-evolution. Two examples applying these FC descriptors to taxonomy are given: classification of the functionality of neuro-transmitters and temperament traits; classification of mental disorders. The paper is an early step towards finding a formal language describing universal tendencies in highly diverse, complex and multi-level transient systems known in ecology and biology as "contingency cycles."*

Key Words: functional constructivism, contingency cycles, ZPD, diagonal evolution, neurotransmitters

PICKING A PARADIGM: REACTION, ACTION, CONSTRUCTION

Ever since psychological science adopted behaviorism, it has been difficult for psychologists to let go of the assumption that our behavior is determined primarily by situational (trigger) Stimuli, with Culture and

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experience mediating the Response (S-C-R schemata). The classic picture of ligand-based synapses describes our brains as electrical networks conducting or inhibiting received stimuli in the S-R manner, and establishing their connectivity bias upon the history of neuronal firing. The fact that most information in the brain is being transferred not by ligand-based synapses but by G-protein coupled receptor synapses (that allow a range of degrees of freedom during the transfer) still stays in the shadows, both in psychology and in mathematical models of human behavior.

A growing objection to this S-C-R paradigm emerged in psychology almost at the same time as the operant conditioning language had been established. Evidence in neurophysiology showed that the brain and the human psyche, in general, are not reactive but rather are constructive. Most of the processes that the brain is capable of noticing and reacting to often go unnoticed in human perception. Many actions are produced without immediately present trigger stimuli and are driven by reinforcers of which an individual has only a rather vague idea. Only a small part of the human brain is comprised of systems that process sensory information. Most of the brain is made up of “associative” areas that integrate the behavioral regulation primarily “in-house.” Brain connectivity is constantly re-arranged *with or without* external stimulation. Walter Freeman’s work provided us with evidence that most neuronal firing does not produce a literal transmission of information. Instead, the image of “stimuli” is being created in stage-by-stage construction via iterations between the electrical activity of a large number of neurons and occasional “sampling” of current objects and events. “Sensation is computable, perception is not,” wrote Freeman and Barrie (2001, p. 46) describing the failed attempts to model the binding of stimuli to brain response in perception.

The choice of the paradigm describing “how does the brain work” affects our studies’ design, language and the interpretation of results, and therefore determines the efficacy of our science. As an alternative to the “reactivity” paradigm in psychology, the Soviet school of psychology proposed the Activity Theory (AT) in the 1930s to 1970s, especially in the works of Bernstein (1935, 1947, 1996), Anokhin (1964, 1975) and Leontiev (1978, 1981, 1983) which were adopted by a number of European scientists; see Bongaardt and Meijer, (2000) and Bedney and Meister (2014) for reviews. The Activity Theory (AT) is often presented as a theory suggesting that behavior is regulated not by external stimulation but rather by the goals or motives of behavior. This sounds almost theological and somewhat misrepresents the theory. More accurately, Leontiev (1983) and others have described in their experiments that it is the properties of the internal needs that generate a person’s interest to specific objects and events and determines the selectivity of attention, perception, memory and action itself. Very often people do not have a well-defined image of the target of their behavior. However, even when their motives are rather vague, they determine what stimuli should be suppressed and what should be attended to, which actions should be taken, and how they should be

sequenced. This means that the regulators of behavior, to a large degree, are internal, most of the time unconscious, and are not well-defined goals, contrary to how it may seem in some interpretations of the AT, including the one that is listed in Wikipedia. This “lost in translation” connotation was often overlooked in discussions of AT that mostly underlined the goal-oriented assumption of activity and its cybernetic interpretations (Bedney & Meister, 2014), rather than accentuating the regulatory power of internal needs in behavior as described in this theory.

While the main difference between Reactivity and Activity paradigms relates to the source of behavioral regulators (the “external-becoming internal” in behaviorism and the “internal-becoming external” in AT), less attention was paid to the fact that the authors of AT insisted on the constructive, generative nature of behavior. For example, Leontiev (1983, p. 169) discussed, in depth, the constructive nature of psychological processes which are determined by the needs of behavior. A focus on transient and generative features of psychological processes recently created a strong trend that could be called *functional constructivism* (FC). Even though a part of this trend was represented within AT, the FC can be viewed now as a stand-alone paradigm that considers behavior to be a generative process, constructing actions based on both available capacities and situational demands, as opposed to the S-R approach attributing it solely to situational demands. Earlier (Trofimova, 2016a) we suggested the use of a concept of performance to describe the FC principles and an analogy of this process to a performance of a play: even when the behavior follows the same script and is repetitive, “every act is constructed anew,” and, neuro-physiologically speaking, nothing is actually being repeated. The most prominent pioneering evidence that specifically has demonstrated the constructive principles of behavior, was reported in experiments in kinesiology by Nikolay Bernstein in mid-1930s (Bernstein, 1935, 1996). The FC phenomena were subsequently described and simplified in cybernetics (Amazeen, Amazeen, & Turvey, 1998; Bedney & Meister, 2014; Pickering, 2010), and received additional evidence in neurophysiology (Alexandrov, 2006, 2015; Anokhin, 1964, 1975; Hebb, 1961; Joel & Wiener, 2000; Pribram, 1971; Quartz & Sejnowski, 1997), neurochemistry (Tsein, 2006; Waldhoer, Bartlett, & Whistler, 2004), developmental and educational psychology (Bruner, 1973; Elkonin, 2005; Pearce, 1995; Vygotsky, 1998), ecological psychology (Bateson, 1972; Gibson, 1979), psychological modeling (Bar-Yam, 2000; Carbonaro & Serra, 2002; Guastello, Koopmans, & Pincus, 2009; Sulis, 1995, 2008; Trofimova, 2001a; Trofimova, Mitin, Potapov, & Malinetsky, 1997), psychology of cognition (Freeman, 2000, 2001; Kahneman, 1973; Norman, 2002; Treisman & Gelade, 1980; Trofimova, 1999, 2014) and psychology of emotions (Barrett, 2009; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Russell, 2003; Vuilleumier, 2005).

Walter Freeman summarized his contribution to functional constructivism in the statement that “*behavior is proactive, not reactive.*” He wrote these

words in the draft of a paper which he sent to me at the end of the 20th century during our email exchanges related to my psychosemantic studies¹ when we were discussing my weird concept of “projection through capacities.” I found his position to be very similar to that of Russian Activity Theory and was happy to see that his paper was eventually published (Freeman, 2003a). In his view perception was not only a proactive process but also a product of the gradual construction of an internal model of events being perceived, a construction based on back-and-forth iterations between the neurodynamics of large number of neurons and the context of activity. He concluded that, *what we know is the consequence of our own actions,*” a principle that may be useful to many fields of psychology. We were both enthusiastic and optimistic that at the end of the 2nd millennium psychology finally recognised the FC principles and could now start a new era. Now it is clear that the process of bringing this message to psychologists about the constructive nature of behavior, and even to model it – is a task associated with major challenges.

CHALLENGES TO FORMAL DESCRIPTIONS OF TRANSIENCE IN NATURAL SYSTEMS

Two very distant groups of sciences – behavioral sciences (psychology, neurochemistry, neurophysiology, kinesiology) and evolutionary sciences – appear to describe similar generative principles of functional constructivism and “emergent fitness” in dealing with the process-like nature of emergent phenomena (Blitz, 1992; Eldredge & Greene, 1992; Goldstein, 2002, 2011, 2016; Gould, 2002; Grantham, 1995, 2007; Lewontin & Dunn, 1960; Lloyd & Gould, 1993; Stoltzfus, 2012; Trofimova, 1996, 2016a; Vrba, 1983, 1989; Vrba & Eldredge, 1984; Vrba & Gould, 1986). Multiple attempts were made to apply methods of nonlinear dynamics in the biological and behavioral sciences (Bar-Yam, 2000; Guastello, 1995; Guastello & Gregson, 2011; Guastello et al., 2009; Nation, Trofimova, Rand, & Sulis, 2003; Otto & Day, 2005; Prigogine, 1977; Sulis & Trofimova, 2001; and multiple papers in the journals on mathematical biology, evolutionary algorithms, and biophysics), to model transient behavioral phenomena (Carbonaro & Serra, 2002; Sulis, 1995, 2016; Trofimova, 2001a, 2003; Trofimova et al., 1997) and to offer various process algebras (Baeten & Weijland, 1990; Fokkink, 2000; Hennessy, 1988; Sulis, 2014, 2017a, 2017b). There are, however, features of generative processes that severely limit the application, not only of classical mathematics but also methods of nonlinear dynamics and computer modeling in behavioral sciences (Trofimova, 2001a, 2003; Whitehead, 1978). As Otto and Day (2005, p. 195) pointed out, “If a model exhibits chaotic dynamics, then you can rest assured that there is no general solution. For most nonlinear models ... it is hard to tell whether or not a general solution exists.” These are just some of the many challenges of emergent behavioral phenomena:

1. *Transience*. In emerging and developing systems the state space describing a system is far from being fixed, and, in fact is very “patchy.” As an

example, a seed that transforms to a full-grown plant illustrates the challenge of plotting a phase space of development of this (rather common biological) system with limited behavior. Similarly, many of our actions are just one-time try-outs, and cannot be the subject of time series or statistical analysis.

2. *Diversity, insufficient similarity.* Many statistical and modeling methods take similarity or a limited range of variation (means, SD, modes, probabilities, etc.) of the objects under study for granted, assuming a continuing existence of this range, as well as the continuing degree of similarity between objects that once did belong to the same class. Meanwhile FC observations point out that life systems, their parts and features are being constructed every time anew (Bernstein, 1935, 1996). It is amazing, therefore, that anything appears to be consistent at all, and that we can find several similar “products” of such constructions. Biologists are focused on what creates mutations (Lloyd & Gould, 1993) and psychologists are focused on deviations in behavior, whereas we have to ask a different question: *What principles make the behavior (or species) look similar from time-1 to time-2, so that we can identify them as something consistent?* If anyone has had the chance to go to an exhibition of orchids, one can appreciate the challenge of “calculation of the means” over the diversity of the “natural products” that belong to the same biological taxon: shapes, colors, sizes, growing cycles, demands for nutrition are all different for various types of orchids. This diversity of behavioral elements coupled with their fluid, dynamical nature presents an even bigger challenge with respect to the formal analysis of behavior as a constructive process.

3. *Multiple copies: an overproduction of similar systems and multiplicity* of their components was noted in many natural and social sciences (Lewontin & Dunn, 1960; Lloyd & Gould, 1993). Plants overproduce seeds, frogs overproduce eggs – and these products that are meant to be just carriers of reproductive material, are employed by the species for multiple other functions, such as to protect, to feed, to make temporary cushion structures surrounding these plant or animals, etc. The degree of this over-production and its multiple functionality are hard to model without a qualitative conceptual analysis.

4. *Interdependence of components.* Since in natural systems “everything depends on everything,” how can we partition our functions and variables? To apply mathematics we need to take special care in mapping the functions describing this interdependence, but this is a challenge if the defining sets for these functions constantly change.

5. *Global neutrality of emergence.* There is a consensus, in both evolutionary theory and behavioral sciences, that the emergence of features often “just appears,” and on these common occasions has little to do with adaptation to the environment, to stimuli or to the actions of some independent variables or factors (Dawkins, 1986; Gould, 2002; Kimura, 1982; Stoltzfus, 1999, 2012). There are indeed features of species that facilitate adaptation and promote better survival (speaking from evolutionary science) or a better adjustment in terms of behavior in situations (noted in behavioral sciences). Yet,

emergent phenomena, as well as changes (for example, mutations described in biology or deviant behavior described in psychology) often come without any action by these factors. They appear or disappear “just because” (Blitz, 1992; Blount, 2016; Gould, 2002; Kimura, 1982; Lewontin & Dunn, 1960; Mayer, 1976; Whitehead, 1978). The best that mathematics can do for this aspect of reality is to declare these phenomena as quantum-mechanical, probabilistic or akin to stochastic noise, blending their underlying complexity into non-specific probability distributions.

6. *Cross-association and overlap of components.* As we argued earlier (Trofimova, 2012, 2016a), the old Lego approach to modeling natural systems might not be very efficient. The *Lego approach* describes the objects of natural sciences as being built up from a collection of smaller, structurally-identifiable building blocks. This reductionist philosophy presumes that the behavior of natural systems can be derived from the properties of these blocks. For example, physiology is focused on the actions of organ systems within bodies; biology is focused on bio-molecules and their interactions, especially those forming genes; physicists are focused on elementary particles and the search for grand theories of everything based on their properties. Meanwhile all natural and social sciences report that the components of their systems have strong functional overlaps. For example, the same neuron can be involved in the regulation of several behavioral elements; the same organs can serve several functions; the same biological species can be involved in different ecological cycles and the same people can contribute drastically different impacts to the functioning of others or of different organisations. This means that, by the Lego analogy, if one is to imagine natural systems as towers built out of Lego blocks, the same blocks are somehow used in several towers.

Moreover, the components (blocks) of these “tower” systems constantly change, even though the shape of these “towers” remains the same (Trofimova, 2003). The division of our sciences into physics, chemistry, biology, geology, psychology, sociology etc. is a matter of convenience for human thinking, however, we should not limit the development of our analytic tools by using this division. Think of ecological cycles that maintain the life of a person – they include gravitational, chemical, biological, physiological, psychological, social and economic sub-cycles that strongly overlap. This functional overlap and cross-association between systems and their components makes our statistical and mathematical tools barely applicable in formal descriptions of the FC principles. It also challenges the “levels of organisation” concept that is common in complex systems research and models based on the Lego approach.

To address these challenges, perhaps we should step back and see what formal descriptors can be used to present conceptual knowledge gathered in behavioral sciences as well as in evolutionary theory. At this stage it might be hard to do specific calculations using these descriptors but calculations are not the only tool needed for scientific purposes. In this paper we give an example of how the FC descriptors could find be useful in psychological taxonomies and

classification of mental disorders. In this sense, these formal descriptors might have different actions than classical mathematical operators but can be complementary to the mathematical apparatus of nonlinear dynamics and complex systems research.

POSSIBLE DESCRIPTORS OF FUNCTIONAL CONSTRUCTIVISM

Let us start by denoting the most common features of functional constructivism.

O - cycle process, with the function to “keep,” to “replicate” that reflects the concept of “contingency cycles” (Blount, 2016; Oyama, Griffiths, & Gray, 2001). Let us consider a universe of non-associated elements $\{o_i\}$ and possible compatible sequences of these elements $[\{o_i\}]$.

A contingency cycle (denoted O) is a consistent (but not steady) structure maintained by a sequence of transformations. This cycle remains consistent even though it is contingent upon the environment and on the states of other parties participating in these cycles. A common example, described in applications of nonlinearity in biology, is the autocatalytic Lotka–Volterra model (known as the predator-prey model) describing the rates of growth of the populations of prey (x) and predators (y), with A-D representing interaction parameters:

$$dx/dt = Ax - Bxy, dy/dt = Cxy - Dy \tag{1}$$

After separation of variables and integration the solution can be expressed in terms of a consistent quantity O: $O = -Cx + D\ln(x) - By + A\ln(y)$. When we denote the x and y components of the cycle as o_i we can generalize this expression to a sum of these components (with individual interaction parameters) and their logarithms:

$$\begin{aligned} O &= \{A_1o_1 + A_2o_2 + \dots + A_n o_n + B_1\ln(o_1) + B_2\ln(o_2) + \dots + B_n\ln(o_n)\} \\ &= \{A_i o_i + B_i \ln(o_i)\}. \end{aligned} \tag{2}$$

Autocatalytic functions describing cyclical behavior were used in many models of mathematical biology (Bar-Yam, 2000; Guastello & Gregson, 2011; Nation et al., 2003; Otto & Day, 2005; Sulis & Trofimova, 2001) and the models of open and dissipative systems (Prigogine, 1977). Ecological cycles, sleep-wake cycles, seasons, and neuro-transmitter release cycles are common examples of contingency cycles.

As noted earlier, natural systems do not reproduce identical copies and are not built of identical components. To deal with that, we need descriptors that (a) reflect the range of diversity of o_i elements, and (b) reflect compatible associations that could be part of a working cycle (parameters A, B).

Λ - “diversity” process, that expands degrees of freedom (d.f.). Λ denotes a shape of distributions (means and variance) of established systems when such statistics can be gathered, however, let us use this descriptor for the more general case, and include *all* emerging d.f., even the most transient and

unique. Since the work of geneticists such as Dobzhansky (1937) it has been known that recessive genes maintain the genetic variability of populations, and that the production of sets with diverse siblings, instead of sets with copies of dominant configurations, improves a species' survival (Lloyd & Gould, 1993; Mayer, 1976). Modern research in evolutionary biology suggests that mutations appear more often and spontaneous than it was previously thought (Blitz, 1992; Blount, 2016; Gould, 2002; Kimura, 1982; Lewontin & Dunn, 1960; Lloyd & Gould, 1993; Mayer, 1976; Oyama et al., 2001). The phenomenon of "convergent evolution" describes the trend in which similar features of species come from different evolutionary lines (Gould, 2002; Morris, 2010). Despite the different origins of these features, they are employed similarly by a super-system as a functional component in its contingency cycle. In fact, mathematical modeling in biology showed that a significant multiplicity of components produces more consistent patterns and results than do models using small populations (Otto & Day, 2005).

\square - *selector process*, (denoted by two square brackets \square) expresses a ranking function acting on the diversity of emerging configurations $\wedge\{\}$ and integrates their associations based on their compatibility. Most compatible associations have higher chances to be repeated (and therefore to survive). Indeed, in evolution theory it has been recognised that components that have no leading adaptive value for organisms also survive as long as there is no specific factor targeting their extinction (Blitz, 1992; Blount, 2016; Dobzhansky, 1937; Lloyd & Gould, 1993; Kimura, 1982; Vrba & Gould, 1986). Still, following the natural selection principle, those configurations that had both sufficient O (consistency) and \wedge (diversity) have better chances for eventually joining those cycles that are most compatible and supportive of their configurations than those with less consistency or diversity. After all, diversity, multiplicity and overproduction of components of natural systems, as noted in the previous section of this paper mean that a long time is required for natural selection to achieve a good-enough match when possible "offers" are randomly compared for employment as parts for possible cycles.

While the \wedge process refers to the degree of dissimilarity and expansion of d.f. within sets, the O process refers to the degree of consistency (repetitions, similarity) of occasional integrations \square . The processes \wedge and \square are similar to the two-step evolutionary dynamics described by Cairns-Smith (1982). He suggested that something as sophisticated as living systems could not evolve just by a random "compatibility" search, but by having "add a little, remove a little," a collector-remover pair working on the gradual perfection of a developing complex system. The O process is similar to "replicator" concepts, such as genes, memes (Dawkins, 1989), clay molecules (Cairns-Smith, 1982), habits or solitons.

We will need four additional subtypes for processes of functional constructivism: $\{\}$ that means "any" set; $\{+\}$ that means sets with overlapping components that can be (but not always) shared and exchanged between members of the set; $\{\square\}$ means internalizing control over part of a cycle; $\wedge\backslash$

means differential treatment of specific parts of a distribution (outliers, means and standard deviations).

Both the evolution and construction of behavior (as a selection process acting on multiple alternatives) are presented here as trends in transformations of expansion, selection and replication processes.

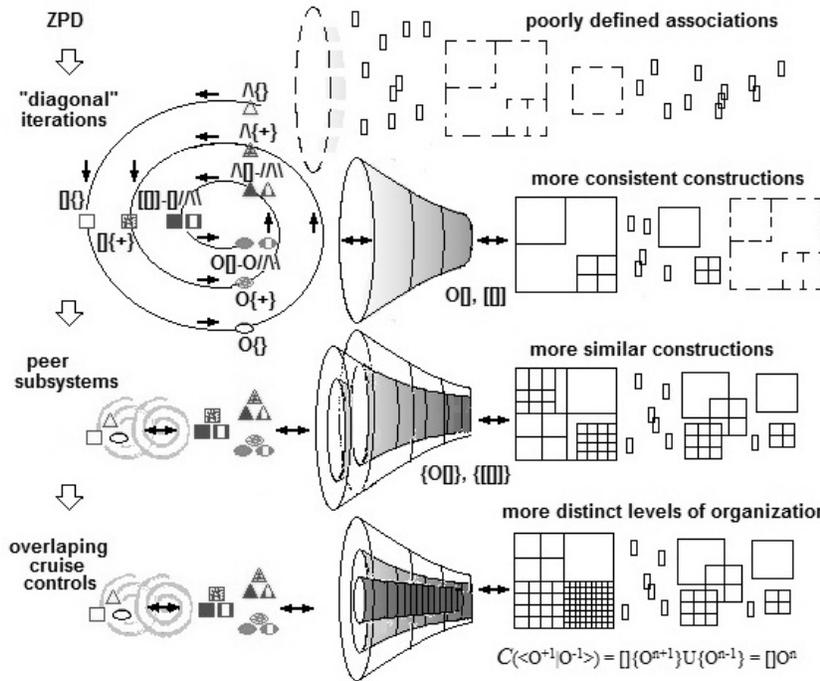


Fig. 1. Schemata of the recursive dynamics between 12 processes of functional constructivism leading to emergence of consistent natural systems (including consistent behavioural elements).

FUNCTIONAL CONSTRUCTIVISM TRENDS

The next step is to attempt to find similarities between dynamical trends describing functional constructivism. It is hard to resist the temptation to examine the detailed architecture of specific systems and the relationships between their components. It is useful, however, to stay focused on finding universal dynamical features that are common between both transient and established systems. Identifying such features might look very general but it might help in classifying natural systems and assessing their variability.

Considering the contingency of natural systems based upon many factors, a question arises – what principles make a system consistent, enduring

Table 1. Notations for the Processes of Functional Constructivism Based on Evolutionary Theory and Dynamics of Construction of an Action.

<i>“Expand”, “diversify” processes</i> \wedge	<i>“Select”, “integrate”, “rank” processes</i> \square	<i>“Maintain”, “replicate” processes</i> \circ
Dealing with poorly defined or structured components during the ZPD		
$\wedge\{\}$ Dispositions for expansion of “whatever”	$\square\{\}$ An integration, association of “whatever” elements	$\circ\{\}$ Dispositions for approval/replication of “whatever”
Dynamics <u>horizontally</u> allows sharing resources		
$\wedge\{+}$ Sharing/borrowing additional d.f. from same- level “peer” systems	$\square\{+}$ Selections based on collective modes, simulations of peer systems	$\circ\{+}$ Reproduction of peer system’s components
Dynamics <u>down the diagonal</u> creates Cruise Controls provides stability of a system		
$\wedge[]$ Internalization of control voluntary d.f., self- regulation	$\square[]$ Integration of structured sequences of transformations	$\circ[]$ Replication of single [] and sequences $\square[]$
Dynamics <u>upper the diagonal</u> dealing with not immediately present elements of potential larger cycles and probabilistic features		
\wedge/\backslash Expansion of d.f. using upper lobbies-levels for selection of components	\square/\backslash Selection of associations compatible with elements of a upper lobbies even when they are not explicitly present	\circ/\backslash Maintenance associations compatible with a wide range of cycles

and observable for some period of time? Here insights from evolution theory and the behavioral sciences can be represented as formal trends of functional constructivism. These trends appear to have a semi-recursive dynamics between \wedge , \square and \circ processes, each having a subtype of $\{\}$, $\{+ \}$, $\{[] \}$ or $\{/\backslash \}$, resulting, therefore, in a set of 12 descriptors, as listed in Table 1. Their dynamics is summarized in Fig. 1. Let us briefly review these trends.

Structuring Trend Starts From the ZPD

The multi-level *structuring trend* was noticed in evolutionary theory (Buss, 1987; Cairns-Smith, 1982; Frank, 2013; Gardner & Grafen, 2009;

Grantham, 2007; Keller, 1999; Lewontin & Dunn, 1960; Marshall, 2011; Price, 1995; Vrba, 1983, 1989) and also in psychology and neurophysiology. Here we borrow the concept of the *Zone of Proximate Development (ZPD)* offered by Vygotsky (1998) in developmental psychology. ZPD is observed when children are orienting their behavior to adult activities even though they are too young to produce such acts properly (such as driving, providing medical treatment, cooking, teaching, etc.). Yet, in trying elements of future adult activities they set up a “map,” an overall range of actions related to such adult tasks, and then learn the details and skills needed for these activities. In neuropsychology it had been noticed that during the construction of an action, a selection of neuronal ensembles involved in its regulation is determined by the context of the task. Then a neuronal and behavioral integration proceeds with constant feedback adjustments between the neuronal ensembles and the structure of the task itself. In line with Gould’s (2002) idea of “trending characters,” the evolution (not development) of natural systems might not come as the gradual growth of a state space; instead it maps distant future limits ahead of time and fills out the intermediate states in a non-sequential manner.

Walter Freeman’s (2000, 2001) idea of *circular causality* in perceptive processes is also in line with the ZPD concept. He shared the view that the brain processes and makes sense of information, not by encoding signals in a mechanical way via the transmission of a “signal” through synapses, but instead through *circles of perception*, as a construction of meaning of the perceived object. He described such construction not by selected “grandmother cells” but instead by a large number of cortical neurons whose dynamics possesses a large collection of basins of chaotic attractors that provide a generalisation over the infinite varieties of incoming stimulation. According to Freeman, the re-entry of sensory flow modifies the landscape of sensory cortices, and the limbic system enhances a few particular attractors in this valley which are relevant for a current action. This emerges as an enhanced sensitivity to specific features of behavior. In Freeman’s view the stochastic firing of a large number of neurons is eventually organised into chaotic attractors around the specifics of behavioral context that subsequently evolves into limit cycle attractors and then possibly to a point state.

The bottom line is that natural systems, before being established as contingency cycles, likely have early stages consisting of “try-outs” (denoted as $O\{\}$) forming from the sets of possible integrations of such try-outs (denoted as $\square\{\}$) where $\wedge\{\}$ can be presented as a universe of components that could be used for such integrations.

During their emergence natural cycles have “approximation” stages (denoted as $O\{\}$). Using the example of a play, before its actual performance in front of an audience there are multiple rehearsals and many failures. These rehearsals are not observed by the public and therefore are difficult to measure. Similarly, natural cycles undergo rehearsals, and these partial sub-cycles form an essential part of establishing a consistent cycle. Formal descriptors with

empty set notations sets refer to the earlier (ZPD) stage of evolution (and construction of behavior) and going along the structuring trend:

$$\Lambda\{\} \supseteq \Pi\{\} \supseteq O\{ \} \quad (3)$$

This trend goes from unspecific expansion of d.f. $\Lambda\{\}$ to occasional integrations $\Pi\{\}$, among which the most stable are represented by cycles $O\{\}$.

Two Trends for Maximizing Compatibility

Earlier we proposed a compatibility algorithm (Trofimova Potapov, & Sulis, 1998; Trofimova, 2001a, 2003), similar to a natural selection algorithm: The inclusion of an element $\{o_i\}$ to an association O is based on its ranking for fitness to join such an association O in variable unstructured media which consist of stochastically emerging parties. Let us denote this algorithm as C .

As noted above, there is a set of “projects” $\Pi\{\}$ associating emergent elements $\{o_i\}$ into potential $O\{\}$ cycles in the universe $\Lambda\{\}$ of these emergent elements. The $\Pi\{\}$ sets are often transient and are not all established cycles (or emerged structures). For a cycle O to be established it is not enough to have a set of o_i elements needed for this cycle. It is important that there are multiple “offers” similar to o , which are on “stand-by,” eventually to be employed by the cycle and which can survive independently from the given cycle. Without such multiplicity of components of similar functionality, a cycle might die when one of the elements contributing to that cycle calls in a “sick day” and does not do its part. In line with our comment in the second section of this paper in regards to diversity of composing elements, for a cycle to be consistent, there should be not one but a set of similar o_i elements that a given cycle O can employ. An expansion of the range of this set that is still “employable” by a given cycle can be denoted as $\Lambda\{o_i\}$. The brackets of the $\{o_i\}$ events denote not a single event but a (equivalence) class of events similar to the $\{o_i\}$ set. The C algorithm ranks the existing “offers” $\{o_i\}$ to join the future $O\{\}$ in terms of their compatibility to the needs of this emerging cycle, and a use (final selection) of specific “offers” that is proportional to their C -ranks.

The associations $O\{\}$ are not stable, have variable survival rates and sizes, and undergo constant upgrades based on multiple offers for continuing the “compatibility check.” During the emergence of a cycle that includes two or more such associations, there is, therefore, a gradual improvement of choices of participating components based on salient features A, B governing their participation in the cycle. Then, similar to speed dating or to employee recruitment, the greater the compatibility, the longer the relationship between components will be maintained leading to sustainable cycles $O\{\}$. In other words, the survival of these integrations is a function of the compatibility between components of the emerging cycles: $C_{max}(\Pi\{\}) = O\{\}$, where C_{max} denotes a trend to maximize compatibility between these transformations.

There are two compatibility trends that eventually start conflicting with each other leading to future evolution. When $\{o_i\}$ is “joining the club” within an establishing cycle of transformations O , this joining puts limitations on its variability, since interactive factors (such as A and B in our example of the predator-prey model) limit the range of the diversity of the elements in this class o_i . We can denote such *internal compatibility* of the fitness of the o_i elements to the team of other elements in the cycle as C^{int} . So a class $\{o_i\}$ of initially non-associated elements has a subset $\{o_i\}([\]_i)$ of elements that were compatible for integration $[\]_j$ leading to O_j , and within this subset the class of o_i is being “stripped” of the variability even further by internal compatibility to the members of the cycle in which this class “was invited,” leading to the subset $C^{int}\{o_i\} \quad \{o_i\}$.

We can imagine that in the universe $\wedge\{\}$ several integrations $[\]\{\}$ are possible that lead to $O\{\}$, and each of the $O\{\}$ has a Compatibility trending of their components. Staying with the example of predator-prey model,

$$\begin{aligned}
 O_1 &= \{A_{11}o_{11}+A_{12}o_{12}+\dots+A_{1n}o_{1n}+B_{11}ln(o_{11})+ B_{12}ln(o_{12})+\dots + B_{1n}ln(o_{1n})\} \\
 &= \{A_{1i}o_{1i} + B_{1i}ln(o_{1i})\}, C^{int}((A_{1i}, B_{1i})\{o_{1i}\}) \quad \{o_{1i}\} \\
 O_2 &= \{A_{21}o_{21}+A_{22}o_{22}+\dots+A_{2n}o_{2n}+B_{21}ln(o_{21})+ B_{22}ln(o_{22})+\dots + B_{2n}ln(o_{2n})\} \\
 &= \{A_{2i}o_{2i} + B_{2i}ln(o_{2i})\}, C^{int}((A_{2i}, B_{2i})\{o_{2i}\}) \quad \{o_{2i}\} \\
 O_m &= \{A_{m1}o_{m1}+A_{m2}o_{m2}+\dots+A_{mn}o_{mn}+B_{m1}ln(o_{m1})+ B_{m2}ln(o_{m2})+\dots + \\
 &\quad B_{mn}ln(o_{mn})\} \\
 &= \{A_{mi}o_{mi} + B_{mi}ln(o_{mi})\}, C^{int}((A_{mi}, B_{mi})\{o_{mi}\}) \quad \{o_{mi}\}. \tag{4}
 \end{aligned}$$

As noted in the second section of this paper in regards to overlapping constructions, natural systems have a multiplicity of associations of components o_i with different cycles O , i.e. the same components of a cycle can be parts of other cycles: $o_i \in C\{O\}$, where $\{O\}$ is a set of cycles converging on the element o_i . The overlap of the cycles $\{O\}$ on class o_i components is driven therefore by their common compatibility with such components, which we can call external compatibility, C^{ext} .

This C^{ext} compatibility, however, doesn't completely converge with the C^{int} since it is driven by different sets of interaction terms C and D , even if they include parts of the interaction terms associated with the contributing cycles (A and B). For example, if two established cycles O_1 and O_2 converge on the same class of elements o_i , then:

$$\begin{aligned}
 O_1 \cap O_2 &= \{A_{1i}o_{1i} + B_{1i}ln(o_{1i})\} \cap \{A_{2i}o_{2i} + B_{2i}ln(o_{2i})\} \\
 &= C^{ext}((A_{1i}, B_{1i}) \cap (A_{2i}, B_{2i}))\{o_i\} \\
 &= C_{12}^{ext}(C_i, D_i)\{o_i\}, \tag{5}
 \end{aligned}$$

putting its own limitations on the variance of the o_i elements.

A Horizontal Replications Trend

Two compatibility trends act on the diversity of the same class of elements o_i , and only those configurations of this class that are compatible with both trends stay at the intersection of these compatibilities:

$$\{C^{int}\}(\{o_i\}) * C^{ext}(\{o_i\})(\{O\}) \quad \{o_i\}. \quad (6)$$

When O systems overlap on some elements, most often there are still elements that belong only to one particular O cycle and do not belong to the overlapped subset. Since these elements most often differ for different cycles, their interaction terms also differ, and so, in addition, it is reasonable to expect that when both compatibility trends are acting on the same class of elements o_i , their interaction terms (A , B) will not be in synch and instead will generate their own dynamics leading to either an increase or a decrease of the diversity sets of $\{o_i\}$. There is no space here to expand the discussion of such interactions. However, out of all possibilities let us consider the case in which two types of compatibility work in synch: $C^{int} \sim C^{ext}$. Such converging compatibility improves the consistency of their associated cycles but also means stronger limits on the variance of the elements of these cycles. This leads to more similarity and homogeneity between emerging products. Moreover, the more components that are involved in the cycle, the more strict the selection of the integrating elements, the less diversity of these elements. With the diversity of compositions decreased and similarity increased more “siblings” are being reproduced that have similar components.

“Siblings,” or *peers* (denoted with the specifier $\{+\}$) are defined as systems that can interchange, exchange or share their building components without loss of integrity, and therefore have compatibility with respect to these building components: $\wedge_{ij}\{+\} = \{\wedge_i \cap \wedge_j\}$ as sharing and/or exchange of diversifying elements; $\sqcap_{ij}\{+\} = \{\sqcap_i \cap \sqcap_j\}$ as sharing and/or exchange of selection and integration mechanisms; $O_{ij}\{+\} = \{O_i \cap O_j\}$ as sharing and/or exchange of replicating mechanisms. $O\{+\}$ represent most alike “siblings” among the $\sqcap\{+\}$ sets (which include very transient and diverse communities), most similar emergences that have appeared either in different space (i.e. “peers”) or time (i.e. “predecessors or offspring”) partially replicating this cycle.

Cooperation in sharing resources gives advantage to systems that have $\{+\}$ elements and facilitates their reproduction. Dynamics within the $\{+\}$ sets improves the replication of peers and represents “horizontal” emergence phenomena, which are observed in communities that belong to the same level of complexity. Examples of such dynamics are predator-prey and host-parasite relationships, symbiosis, sex, kin and group selection (Frank, 2013; Gardner & Grafen, 2009; Grantham, 2007; Keller, 1999; Lewontin & Dunn, 1960; Marshall, 2011; Price, 1995; Vrba, 1983, 1989; Wilson & Wilson, 2007), collective mode phenomena (Sulis, 2008), collective intelligence (Sulis, 2009), functional differentiation between cells or organisms (Trofimova, 2000), and the impact of a spectrum of sociabilities of agents on behaviour of a population (Trofimova, 2001a; Trofimova et al., 1998). Since Darwin, it had been noticed that living systems often co-evolved resulting in correlated changes among their features. Co-evolution was mostly described as applying to systems at the same level of organization (e.g. co-evolution of organisms (Thompson, 1994), or even co-evolution of galaxies (Heckman & Kauffmann, 2011), but not across all levels.

Cruise Control Production and Downward Self-regulation Trend

During the early stages of the ZPD these distributions are not established as it is impossible to “count heads” when occasional integrations could be described as random emergences of “apples and oranges.” The structuring of a system is a process of moving from wide distributions of possible d.f. (“Zoned” system) to more narrow distributions of successful integrations, with fewer outliers and smaller variance associated with the diversity of these systems, and with more stable modes and means. Having {+}-types systems of similar siblings speeds up the compatibility search and try-outs of novel integrations, giving way to new processes denoted as $\wedge[]$, with the most stable of them denoted as $O[]$.

Moreover, out of the sets of all integrations $[]$ some of them are more consistent than others, creating, when repeated, sub-cycle elements named here as cruise controls, and denoted as $[][]$. *Cruse controls* are the most stable integrations that are established within developing system and arising from repeated iterations between its components. Cruise controls have very limited variability and very high consistency, and their low variability doesn’t let them survive as independent small cycles. Their consistency might be just a lucky configuration, but more often it is a result of them being part of multiple cycles. As noted above, a convergence of several cycles onto one class of o_i decreases their variability with an external compatibility C^{ext} factor. The variability of these elements is controlled by other components of the given cycle acting as selection mechanisms, promoting specific $[][]$ configurations and suppressing outliers among the siblings of these configurations (internal compatibility C^{int}).

Similar to the use of cruise controls for cars, the structured nature of $[][]$ -s allows a super-cycle to use them as ready modules of regulation for constructing states of the system, as a pack of ready integrating processes. The $[][]$ processes compound several more transient $[]$ -integrations into a chain of transformations, and a supercycle O uses ready integrations $[][]$ -s as components of more complex and more transient integrations. For example, a $[][]$ block might consist of two elements:

$$[][]_{m12} = []\{A_{m1}, A_{m2}, B_{m1}, B_{m2}\} \tag{7}$$

and so a cycle O_m that represents the most consistent integrations of this class would be:

$$\begin{aligned} O_m &= \{O_{12}([][]_{m12}) \dots + \dots A_{mn}O_{mn} + B_{mn}ln(O_{mn})\} \\ &= \{A_{mi}O_{mi} + B_{mi}ln(O_{mi})\} \end{aligned} \tag{8}$$

Having several such cruise controls, or ready integration units within the same cycles is likely what led to the development of voluntary motion and a wide range of self-regulation mechanisms. The development of $[][]$ allows systems to internalise control over parts of the cycle that previously belonged to the environment (such as maintenance of constant body temperature, storage of nutrition, or a voluntary change a position in space and time). For example,

considering Eq. 8, having at least two cruise controls $[\]_{m12}$ and $[\]_{m34}$ within one cycle O_m gives this cycle two possible trajectories which could be coupled with two different external compatibilities. This means that the cycle can respond to contingencies of the environment by constructing two different behaviors, such as approach or withdrawal, which is even observed in amoeba (Egbert, Barandiaran, & Di Paolo, 2010).

The structuring trend, therefore, that was described above at the beginning of the section on trends, can have a more general form:

$$\wedge \beta \rightarrow \] \beta \rightarrow \] \] \beta \rightarrow O \quad (9)$$

This trend starts from poorly associated media and progresses to well-established cycles (structures). The $[\]$ term is almost non-existent in Zoned systems ($\wedge\{$ and $\wedge\{+$) but is a leading term in well-established systems ($O[\]$ and O/\wedge). The processes at the ZPD differ, therefore, from the processes in well-structured systems, and this difference can be described by the presence of the $[\]$ term. The use of common $[\]$ modules in the construction of O-cycles make them more similar and creates $O\{+$ sets of peers, and these cruise-controls $[\]$ carry functional specificity of the multi-level factors that contributed to their consistent emergence. As depicted in Fig. 1, the production of cruise controls (i.e. least variable sub-integrations that are used as modules during constructive processes) can be viewed as an evolution of modules (i.e. downward evolution) whereas the consistent production of “siblings” that is facilitated by the development of “cruise controls” can be viewed as the evolution of “horizontal” productions. Vertical emergence phenomena are often described in the modeling literature as assimilations of lower-level modules into some superordinate-system. Fundamental particles form atoms which, in turn, form molecules – and so on, with organelles, cells, organs, organisms, families, societies - this causation is described as acting from the bottom up and from the top down.

There is also a trend that can be viewed as evolution going up the ladder in terms of levels of organisation. As noted above, this paper shares the view that the concept of such levels over-simplifies the complexity of evolutionary processes, and so it is used here only for comparison to a traditional level-oriented presentation of complex systems.

Saving Outliers in Upward Trends

If cycles were reproduced identically, replicating their predecessors, then they would risk death should a change in the environment challenge their capacities. This is a tough choice for nature: (a) to excel in the consistency of structures, multiplying extensively in a stable environment but with high odds of dying in an unstable environment, or (b) to sacrifice the consistency of systems by allowing deviations from the means, settling for less than perfect, “good enough” compositions that improve survival in changing, uncertain environ-

ments. Nature partly solved this problem through sex differentiation, which uses gene recombination. Such recombination is one example of diagonal subordination, as the parts of the DNA molecules (configurations of “cruise controls”) are exposed to selection by different environmental conditions in the production of the phenotypes. What is rarely discussed in regards to sex differentiation is that it provides two partitions of a biological species: one that stores beneficial features of the species (i.e. cruise controls), and another that allows the species to experiment with outliers (Geodakyan, 1985, 2012; West, 2009). The Evolutionary Theory of Sex (ETS) that analysed sex differences in the shapes of phenotypic distributions described sexual dimorphism as a functional specialization of a species into two partitions, (a) conservational (female sex) and (b) variational (male sex). Trofimova (2015) analysed sex differences in communicative and exploratory abilities and mental disabilities from the perspective of the ETS and suggested that male superiority in risk- and sensation seeking, physical abilities, higher rates of psychopathy, dyslexia, autism, higher birth and accidental death rates reflected the systemic, variational function of the male sex. Female superiority in verbal abilities, lawfulness, socialization, empathy and agreeableness reflected the systemic, conservational function of the female sex. Trofimova also suggested that the male sex (variable partition) plays an evolutionary role in pruning the redundant excesses in a species’ bank of beneficial characteristics, in spite of resistance from the conservational partition.

Constructive Neutral Evolution (CNE) theory also describes a two-step origin-fixation process (Stoltzfus, 1999, 2012). Similar to the ETS, it suggests that the first stage of evolution is the origin of mutations (the ETS describes these emerging in males more often than in females) during which selection processes reinforce and fixate beneficial characteristics (by passing these to female genes). The CNE treats these two processes as consecutive stages of evolution whereas the ETS considers them as two partitions in a species, with sex dimorphism existing simultaneously.

Outliers emerge within the $\{o_i\}$ classes and become integrated within the most stable associations, such as $[[[]]$ and O as their C^{ext} is too low (they are not compatible with many systems due to their exceptionality). Still, there is a mechanism to produce them. Both compatibility trends C^{int} and C^{ext} are based on the dynamics between the components of the sub-cycle elements that compose the cycles which these trends are acting upon (i.e. A, B, C, D terms). Let us suppose that one of these elements, say o_2 , is unavailable in the universe of elements $\wedge\{\}$ when the state of the cycle reaches a specific point. Then the cycle either dies or uses those values of its remaining $\{o_i\}$ components that could at least temporarily compensate for the deficiency of the o_2 (after all, the $\{o_i\}$ sets refer to a spectrum of elements of this class, and not only to a single configuration):

$$O-o_2 = \wedge(o_2^*)\{A_1o_1+A_2o_2^*+A_3o_3... A_no_n+ B_1ln(o_1)+B_2ln(o_2^*) +... +B_nln(o_n)\} \tag{10}$$

where o_2^* denotes the deficiency of o_2 elements and $\wedge_{o_2^*}$ denotes the extreme values in the spectrum of employed elements o_1, o_3, \dots, o_n and adjusted (for o_2^*) states of their interaction terms.

If indeed such compensatory cycle O- o_2 is possible due to the presence of extreme d.f. that the cycle can take without losing its integrity, then it generates a deviating configuration O- o_2 that still can belong to the class of the given cycle O. This creates the possibility of a downward lobbying of specific parts of variance of existing classes of elements and also the generation of new elements (“farming”), increasing d.f. in the universe $\wedge\{\}$.

Another line of expansion of $\wedge\{\}$ comes from less consistent integrations. Establishment of associations with best fitness is the result of a trend of increasing compatibility between associating parties, but associations with imperfect, good-enough compatibility are also possible, merely producing less consistent cycles. We can imagine a scenario in which many components of o_i type are not included into the O-cycle (due to the overproduction of o_i components) and therefore are not supported by the feedback of this cycle. Survival of the “unemployed” o_i components improves if they are involved in at least some cycles, even if these other cycles are not the most compatible or beneficial for these components. For example, a talented pianist might not be included in a top-orchestra performance but can still find employment playing in small restaurants.

Saving outliers comes with a cost to the cycle but, as Lloyd and Gould (1993) pointed out, there is a natural selection trend for preferences of variability. Therefore, the more advanced systems can afford to keep more diverse phenotypes and save their outliers, even though it requires an integration of special care around outliers (denoted here as O// \wedge) and a readiness to respond to low-probable events (denoted as \square // \wedge). When such integration is achieved, however, the presence of outliers adds degrees of freedom to a system that involves not only explicitly present, established components of cycles but also not immediately present components (denoted as // \wedge) that can only be formed on the developing ZPD.

AUTOCATALYTIC RELATIONSHIPS BETWEEN \wedge AND O PROCESSES AND COUPLING OF \square AND O PROCESSES

The two-way arrows in Eq. 9 indicate an autocatalytic relationship between these processes in the following way:

$\wedge \uparrow$ - High diversity of states leads to an increase of possible associations between them \square ;

$\square \uparrow$ - High number of integrations leads to an increase of possible overlaps on the same elements o_i , increasing their consistency and chances to be integrated within formed cycles O. This leads to the emergence of a number of O-systems.

O \uparrow - High number of stable cycles induces the production of specific configurations o_i which are non-associated (staying in \wedge) or associated to

establish O. This leads to the production of more similar systems having similar sub-integrations [], and therefore to a decrease of diversity \wedge .

$\wedge\downarrow$ - A decrease of diversity of o_i leads to a decrease in compatibility between those elements needed for novel integrations [].

$[\downarrow]$ - A decrease of novel integrations leads to a decrease of established cycles O.

$O\downarrow$ - A decrease in existence of established cycles reduces the demand for similar elements and leads to the production of more diverse elements \wedge

$\wedge\uparrow$ - and the cycle runs again...

However, having a media with established [] units might create a cycle of relationships between \wedge -[]-O running in an opposite direction. Space does not permit further discussion of this dynamics.

The one-way arrows running along the spiral in Fig. 1 indicate an overall direction of evolution, however, within this dynamics there are likely more subtle two-directional trends between the described processes. The \wedge -O relationships seems likely to be following an autocatalytic trend, and []-O relationships work more in unison. Stochastic modeling with ensembles of variable structures (EVS; Trofimova, 2001a) indeed showed a “small town effect” and “big cities effect:” In small populations low diversity leads to low numbers of clusters and homogeneity of these clusters, whereas in super-large populations high diversity prevents systems from converging to established clusters and from forming consistent systems.

DIEVOLUTION PROGRESSES AT SEVERAL LEVELS OF ORGANIZATION SIMULTANEOUSLY

Previously, we described formal processes leading to *horizontal emergence*, denoting the production of peer systems that are capable of exchanging their components, and *vertical emergence*, in which more stable sub-integrations [] serve as building blocks of more transient multi-level integrations []. Gould (2002) emphasized that the “units of selection must be defined as interactors, not as replicators” (p. 622).

In earlier work (Trofimova, 2016b) we proposed the idea of diagonal evolution, or *Dievolution*, suggesting that evolution and emergence of living phenomena are a result of recursive processes happening *on a diagonal of a vertical hierarchy and horizontal diversity of living systems*. Processes from the up-down direction of the diagonal emerge as “cruise controls,” or elements with the highest stability at the lower level of organization, and processes from the bottom-up direction of the diagonal emerge in the shaping of the ZPD of upper-level systems (Fig. 1). The dievolution concept also suggests that specific features of the structures at some level of organization are the result of natural selection occurring reciprocally at several levels of organization.

Evolution progresses as the lower level of organisation becomes more specialized and partitioned while the top level is being sketched out and developing. In dievolution theory, “same level of organization” means the

ability of systems at this level to use similar resources, exchange parts and overlap in the use of sub-cycles of similar complexity. “Sameness” is never fully achieved, but the more that sub-cycle are inter-changeable between systems, the more they belong to the same level of horizontal emergence. A similar idea about multi-level selection was independently expressed in the Multilevel Selection Theory, MLS and the group selection theory (Buss, 1987; Damuth & Heisler, 1988; Eldredge & Green, 1992; Frank, 2013; Gardner & Grafen, 2009; Grantham, 2007; Keller, 1999; Lewontin, 1970; Marshall, 2011; Price, 1995; Salthe, 1985; Vrba, 1983, 1989; Wilson & Wilson, 2007). These theories also suggested that same-level and higher-level selection can be a significant evolutionary force for lower-level selection. The difference between MLS and dievolution theory is that dievolution asserts that the middle level of organisation is being produced simultaneously with the formation of upper and lower levels. The evolution is gradual and iterative between emerging cycles.

The difference between our formal descriptors from Price’s (1995) equation of multi-level selection is that we do not assume that “parents,” “offsprings” or their traits are well-formed and accountable. We assume that these elements of evolution are emerging on the overlap of multiple media, and only some of these media can be identified; most of them – not. Our universe of evolving and emerging entities is therefore significantly less structured than classical mathematical equations of covariance (like that offered by Price about 40 years ago) would require. Instead of focusing on the transitions between the amount and characteristics of these discrete products we suggest focusing on the universal dynamical features of their construction, assuming their transience.

If we must use “levels of organisation” language, then we say that recursive processes between several levels of organisation form cycles at the intermediate levels: This can be denoted as $C(\langle O^{+1}|O^{-1}\rangle) = \{O^{n+1}\}U\{O^{n-1}\} = \{O^n\}$ where the upper indices indicate levels of organisation. The action of the upper level reinforces specific lower-level elements (by “lobbying”) but the action of the lower level emerges as offers of only those configurations that this level currently has, regardless of what the upper level wants (i.e. capacities-dependent process). Performance capacities of the lower level work serve, therefore, as a selective factor in an integration.

Freeman’s ideas were also in line with the concept of dievolution acting at several levels of organisation and forming its products at the middle level. He suggested that large-scale environmental systems contribute to the organization of chaotic activity of rather low-level systems (neurodynamics), creating products on the *meso-level* brain systems (Freeman, 2000, 2001, 2003b).

Diagonal recursive processes and contingency cycles are two solutions to the problem of *saving outliers vs. maintaining the mean* by making “cruise controls” down the diagonal and shaping the ZPD up the diagonal are two closely integrated processes, even though they happen in different time frames. These processes allow *two simultaneous directions of evolution working on a diagonal across a vertical hierarchy and horizontal diversity of living systems*. It

is suggested here that cycles on multiple levels, and not just one level, determine the shape of the ZPD, i.e. the properties of the emerging upper levels of organization.

Table 2. Application of Functional Constructivism Descriptors to Classification of Biologically-based Individual Differences (Temperament) and Analysis of Functionality of Neurotransmitters.

<i>Function. aspects:</i>	<i>Behavioral orientation to reinforcers: NE+... Λ</i>	<i>Dynamical aspects Speed of integration of actions: DA+... []</i>	<i>Energetic maintenance of prolonged activities: ACh, 5-HT+... O</i>
Regulation by the opioid receptors systems, amplification/appraisal of: orientational, dynamical and energetic aspects			
<i>Emotional amplifier</i>	Λ{ } Neuroticism KOPr→NE-HPA KOPr > MOPr	[] { } Impulsivity DOPr→(DA, MOPr)	O { } Self-confidence MOPr→(5-HT, DA) KOPr < MOPr
Regulation by monoamine and hormone systems tuned to socialization			
<i>Social-verbal</i>	Λ { + } Empathy/-autism NE+OXY, VSP	[] { + } Social-verbal Tempo DA+ PRL, OXY	O { + } Verbal Endurance 5-HT+NP, OXY
Regulation by neuropeptide and basal ganglia monoamine systems as tuning between bodies' capacities and physical aspects of behavior			
<i>Physical-motor aspects</i>	Λ [] Sensation-seeking NE+AdrR, Cortisol?	[] [] Motor Tempo DA+PRL, NP	O [] Motor Endurance 5-HT, GH, NP
Regulation by cortical monoamine systems as a tuning to implicit, more probabilistic aspects of situations			
<i>Mental aspects</i>	// Sensit. to probabilities NE+DA+ACh	[]// Plasticity vs. rigidity DA+5-HT	O// Mental Endurance (attention) ACh, NE

Note: 5-HT: serotonin; DA: dopamine; NE: noradrenalin; ACh: acetylcholine; Glu: glutamate; GH: Growth Hormone; SOM: Somatostatin; PRL: prolactin; OXY: oxytocin; SubP: Substance P; NPY: Neuropeptide Y; AdrR, KOPr, MOPr, DOPr: adrenergic, kappa-, mu-, delta-opioid receptors.

**APPLICATION OF FUNCTIONAL DESCRIPTORS IN
DIFFERENTIAL PSYCHOLOGY**

Differential psychology is a branch of psychology that is concerned with the classification (taxonomies) of psychological individual differences. Neurochemically-based individual differences (referred to as temperament) are considered to be the most consistent, universally affecting the behavior of an individual across situations. The call for a “functional” instead of a “structural” approach to the psychology of “consistent traits” probably started several centuries ago, and has certainly continued within the 20th century (Rusalov, 1979, Simonov, 1986; Trofimova, 1996). It has been suggested that the classification of human traits should follow the architecture (stages) of construction of human actions (Rusalov, 1989; Trofimova, 2016b; Trofimova & Robbins, 2016), including probabilistic and motivational aspects of human actions (Simonov, 1986). Rusalov (1989; Rusalov & Trofimova, 2007) proposed a 12-component model of temperament that was later upgraded by Trofimova in an alternative 12-component model that is more in tune with Luria’s (1966) theory of functional partitioning of neuroanatomic systems regulating human behaviour (Rusalov & Trofimova, 2007; Trofimova, 2010; Trofimova & Sulis, 2011).

Functional constructivism was applied to the neurochemical analysis of temperament traits, and suggested that the main neuro-transmitter systems (NT) regulating our behavior were reinforced through evolution by everyday animal or human activities. A universal architecture of these activities, therefore, could shed a light onto the functionality of the main NT systems. Indeed, a review of the most commonly reported NT functionality and existing temperament theories gave rise to the neurochemical model for the *functional ensemble of temperament* (FET; Trofimova, 2016b, in press; Trofimova & Robbins, 2016). The FET summarizes 12 biologically-based components of behavioral regulation in a 3 x 4 ensemble, in which components regulate each other’s performance. None of the components (temperament traits) are proposed to be regulated by a single neuro-transmitter system. Instead, each component of the FET is linked to an interplay between specific neuro-transmitter (NT) systems, similar to the team compositions of elementary particles made of quarks. Whenever the functionality of monoamine transmitter (MA) systems is discussed here we have to keep in mind that there are several stages in the release of each of these NT that involves a cascade of transformations between GABA/Glutamate, enzymes and metabolites, G-protein coupled receptors, BDNF, CREB, calcium and other chemical systems, including partner monoamines. Moreover, the diversity of MA receptors and their different actions in different brain structures create another serious challenge for understanding the functionality of MA systems. Still, when we look at the most consistent effects of these NT in an animal’s behaviour (including humans), a pattern of functional differentiation emerges in their ensemble action, with one of these NT playing a leading role in a class of temperament traits that match the

class of evolutionary processes described above (Table 2). The three columns of the FET model include: (a) expansion, orientational aspects (preferred choice of reinforcers) - these traits resemble the \wedge -class of FC processes; (b) dynamic aspects (the speed of integration of actions), traits which resemble the \square -class of FC processes; and (c) energetic aspects of behavior (endurance, or for how long an activity can be performed) these traits resemble the O-class of FC processes.

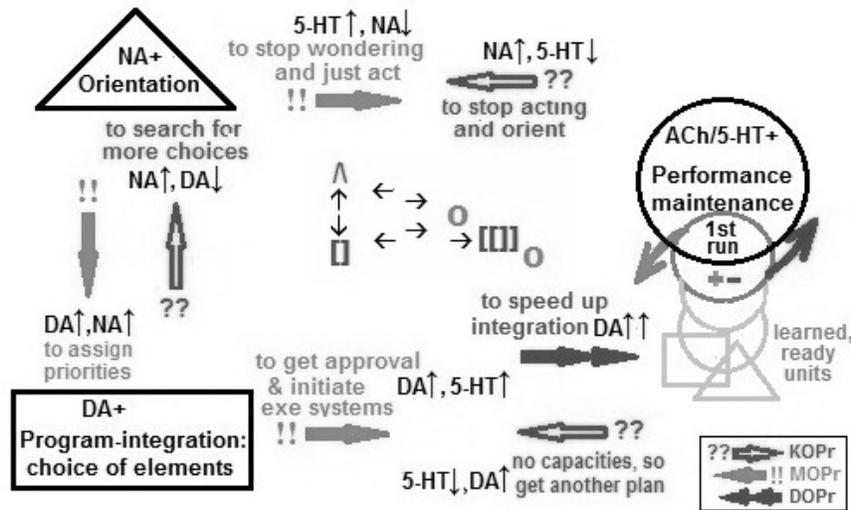


Fig. 2. Regulatory relationships between G-protein coupled opioid receptors (OR - KOPr, MOPr, DOPr) systems and monoamines, MA (NE, DA, 5-HT). Colors of arrows correspond to OR systems action, with reference to the action on the MA neurotransmitters. Arrows facing downward (\downarrow) indicate a suppression of the release of MA, and arrows facing upwards (\uparrow) indicate an activation of such a release. The dynamics of this neurotransmitter ensemble is consistent with the dynamics between FC descriptors, as discussed in text.

The FET suggests a more significant role for neuro-peptide systems in deterministic, rather than in probabilistic, aspects of behavior, which are mainly regulated by monoamines. Emotionality is presented in this model as an interplay between three types of opioid receptor systems acting as amplifiers of the dynamical aspects, i.e., of sensitivity, energetic and dynamic characteristics (Trofimova, 2016b, in press). The specific functionality of MA and acetylcholine (ACh) appeared to be in line with features of the three FC descriptors. As discussed in previous publications, noradrenaline (NE) systems appeared to be regulating aspects of behavior that relate to orientation and expansion of degrees of freedom (\wedge -process); dopamine (DA), which regulates the assignment of priorities and salience to stimuli and actions that are necessary for plasticity and programming of behavior (\square -processes), and serotonin (5-HT) is entangled with endocrinal regulation of energetic maintenance of behavior,

whereas ACh regulates sustained attention (O-processes) (McClure, Gilzenrat, & Cohen, 2005; Netter, 1991; Robbins & Everitt, 1996; Trofimova, 2016; Trofimova & Robbins, 2016, Table 2).

The mutual regulation between these NT follows the pattern of the \wedge -[]-O relationships described above; see Fig. 2, Trofimova (2016b), and Trofimova and Robbins, (2016) for further details. Studies in neurochemistry showed that the NE system is capable of dual regulation of 5-HT release; in turn, some types of 5-HT receptors activate or inhibit NE release, using other neurotransmitters (such as GABA and glutamate) as mediators (Adell et al., 2010; Fink & Göthert, 2008). Such mutual regulation between the NE and 5-HT follows the \wedge -O autocatalytic pattern described two section above. Mutual regulation of DA-5-HT systems also has bi-directional mechanisms (Di Matteo et al., 2008, Fink & Göthert, 2008) but these work more in unison, in line with the []-O dynamics. Reports within neurochemistry also describe reciprocal suppression or mutual activation and co-release of DA and NE (Devoto & Flore, 2007; McClure et al., 2005; Moron et al., 2002; Pozzi, Invernizzi, Cervo, Vallebuona, & Samanin, 1994; Yamamoto & Novotney, 1998), i.e. between [] and \wedge -processes. These two NT work in tandem in situations of moderate levels of arousal; however, in high-arousal situations, both insufficient or excessive DA (D1) receptor stimulation leads to an increase in NE synthesis and symptoms of stress, i.e., reacting to an imbalance within the DA system by busting the \wedge -orientation component. Complementarily, the central NE system appears to have mechanisms for suppressing DA release (Grenhoff, Nisell, Ferre, Aston-Jones, & Svensson, 1993; Paladini & Williams, 2004; Rey, Lew, & Zanutto, 2007), in line with the idea that the orientational component of behavioral regulation should have a way to suppress existing programs of actions (Fig. 2).

The three functional aspects of behavior appear to have differential regulatory systems at three levels (rows 2-4 in Table 2): (a) the level of peer interactions; (b) the level of voluntary physical integration of behavior, and (c) the more probabilistic (not explicit) elements of behavior, common in novel, uncertain and complex situations. Neuroanatomic branching within each MA (i.e. NE, DA, 5-HT) and ACh systems into cortical and basal ganglia levels, supports the idea of such a separation. This neuroanatomic branching was linked to the process of habit formation (similar to the production of “cruise controls” [[]] described in the section on Trends), a process of gradual transfer of regulation of behavior by frontal cortical areas, dealing with novelty and probabilistic features, to basal ganglia levels that secure well-learned elements of actions) (Joel & Weiner, 2000; Robbins, 2010; Yin & Knowlton, 2006; Trofimova, 2016b; Trofimova & Robbins, 2016). The systems regulating more probabilistic (such as {}- or \wedge -type) and more deterministic aspects of behavior (such as {}+ and {}-)-types) complement each other, covering the whole spectrum of contextual complexity of behavior. Automatic acts use either pre-formed habits ([[]]-cruise-controls) or explicit reinforcers (\wedge [] – such as currently present sense-objects, other people’s motivations), whereas novel,

uncertain, or fast changing situations require analytical abilities (Alexander, Crutcher, & DeLong, 1990; Cools, Clark, & Robbins, 2004; Joel & Weiner, 2000; Reason, 1979; Robbins, 2010; Yin & Knowlton, 2006). This is in line with Bernstein's (1935, 1996) idea of a transfer of control of an action's construction between several levels of control depending on how novel, learned, or automatic an action was (Bongaardt & Meijer, 2000). It is important to note, however, that in the nervous systems of non-human animals there is no clear separation between the involvement of the cortex and the basal ganglia in any one specific action; it is more accurate to talk about the degree of cortical control rather than absolute cortical or non-cortical control of behavioral elements contrasted by contextual complexity.

Emotionality characteristics (the first row of Table 2) are viewed in the FET as first approximations of behavioral response, when more detailed tuning to the situation has not formed yet, resembling the \wedge {}, \square {}, and \circ processes. In fact, the Neuroticism trait (\wedge {-class}) is described in the temperament literature as a non-specific sensitivity to novelty. Impulsivity (\square {-class}) is a raw behavioral integration that is not well-regulated by established norms and plans. Self-Confidence (\circ {-class of processes}) is associated with a dispositional emotionality to sustain current behavior, even when such behavior might consist of the passive spending of time.

APPLICATION OF FUNCTIONAL PROCESSES IN CLASSIFICATIONS OF MENTAL DISORDERS

Earlier we suggested that the classification of mental disorders should be structured around the same dimensions that are used to describe temperament in healthy people (Trofimova & Sulis, 2010, 2016a, 2016b, in press). After all, temperament and mental illness lie along one continuum of neuro-chemical imbalances, where temperament represents weak degrees and mental disorders represent strong degrees of such imbalances. The FET structure of temperament helps us to classify symptoms of mental disorders as described by the DSM-5/ICD-10 by using sub-groups of physical, mental and social and emotionality-related aspects of behavior.

The FET framework and the categorization of FC processes allows us to map mental disorders and even possible approaches to treatment, in a compact and formal manner (Table 3). Studies using FET-related tests of temperament in patients suffering from Major Depression, Generalized Anxiety Disorder, Comorbid depression and anxiety (Trofimova & Sulis, 2010, 2016a, 2016b, in press) and other mental illnesses (Trofimova & Christiansen, 2016) indeed demonstrated benefits of the FET framework for such structuring. In the presence of mental illness, temperament profiles matched well to examples of classic symptoms related to this illness and also showed additional symptoms not included in the DSM.

SUMMARY

In summary, we gave examples of convergence between functional constructivism principles and the work of Walter Freeman III. This paper has offered basic descriptors of FC that can be used, at the very least, for classification purposes in assessing the variability of human behavior. These descriptors refer to the most universal aspects of construction of consistent structures – expansion of degrees of freedom (\wedge), selection (\square) and maintenance (O) of structures, given in four different classes of systems: (a) early ZPD, poorly defined, sketched systems ($\{\}$); (b) systems with emerging reproduction of multiple siblings (peers) at a horizontal level of organisation ($\{+\}$); (c) systems with internalized integration of behavioral elements and therefore more defined levels of organization using low-variable “cruise controls” (facilitating the reproduction of similar “siblings”), ($\square\square$); and (d) systems that are capable of handling low-probable and not immediately present events, and especially outliers ($\wedge\backslash$). The recursive dynamics within this set of descriptors acting on what was traditionally viewed as downward, upward and horizontal directions of evolution can be summarized by the concept of diagonal evolution, or dievolution.

We also briefly described two examples of how these FC descriptors can help us in the challenging task of classifying the functionality of neurotransmitters, temperament traits and mental disorders. Space did not permit more details of these examples, but we hope to expand on these in future publications.

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ENDNOTE

¹Later I learned that “projection through capacities” concept (Trofimova, 1999) was published same year a similar concept of “embodiment in cognition” (Lakoff, 1999). Once I heard about embodiment, I instantly converted to the use of this concept, appreciating its elegance and economy of

words. We were on the same footing with Walter believing that a state of the body is an important factor contributing to cognition.

REFERENCES

- Adell, A., Bortolozzi, A., Díaz-Mataix, L., Santana, N., Celada, P., & Artigas, F. (2010). Serotonin interaction with other transmitter systems. In C. Muller, C. & B. Jacobs, (Eds.), *Handbook of behavioral neurobiology of serotonin* (pp. 259-276). New York, NY: Elsevier Academic Press.
- Aleksandrov, Y. I. (2006). Learning and memory: traditional and systems approaches. *Neuroscience and Behavioral Physiology*, 36, 969-985.
- Alexander, G. E., Crutcher, M. D., & DeLong, M. R. (1990). Basal ganglia-thalamocortical circuits—parallel substrates for motor, oculomotor, prefrontal and limbic functions. *Progress in Brain Research*, 85, 119-146.
- Alexandrov, Y. I. (2015). Cognition as systemogenesis. In M. Nadin, (Ed.), *Anticipation: Learning from the Past: The Russian/Soviet Contributions to the Science of Anticipation* (vol. 25, pp. 193-220). New York, NY: Springer.
- Amazeen, P. G., Amazeen, E. L., & Turvey, M. T. (1998). Dynamics of human intersegmental coordination: Theory and research. In D. A. Rosenbaum, D. A. & C. E. Collyer (Eds.), *Timing of behavior: Neural, psychological, and computational perspectives* (pp. 237-259). Cambridge, MA: MIT Press.
- Anokhin, P. K. (1964). Systemogenesis as a general regulator of brain development. In W. A. Himwich & H. E. Himwich (Eds.). *The developing brain* (pp. 54-86). Amsterdam, The Netherlands: Elsevier.
- Anokhin, P. K. (1975). *Biology and neurology of the conditioned reflex*. Oxford, UK: Oxford University Press.
- Baeten, J. C. M., & Weijland, W. P. (1990). *Process algebra*. New York, NY: Cambridge University Press.
- Barrett, L. F. (2009). Variety is the spice of life: A psychological construction approach to understanding variability in emotion. *Cognition and Emotion*, 23, 1284-1306.
- Bar-Yam Y. (Ed.) (2000). *Unifying themes in complex systems*. New York, NY: Perseus Press.
- Bateson, G. (1972). *Steps to an ecology of mind: Collected essays in anthropology, psychiatry, evolution, and epistemology*. San Francisco: Chandler.
- Bedney, G., & Meister, D. (2014). *The Russian theory of activity: Current applications to design and learning*. New York, NY: Psychology Press.
- Bernstein, N. A. (1935). Problema vsaimootnosheniy koordinatsii i lokalizatsii [Problem of relationships between coordination and localization]. In *Arhiv biologicheskikh nauk [Archiv of biological sciences.]*, 38, 1-34.
- Bernstein, N. A. (1947). *O postroenii dvizheniy [On the construction of motions]*. Moscow, Russia: Gosizdat, Medic-State Publishing House.
- Bernstein, N. A. (1996). Dexterity and its development. In M. L. Latash & M.T. Turvey, (Eds.), *Dexterity and its development* (pp. 3-244). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Blitz, D. (1992). *Emergent evolution: Qualitative novelty and the levels of reality*. Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Blount, Z. D. (2016). History's windings in a flask: Microbial experiments into evolutionary contingency. In G. Ramsey & C. H. Pence (Eds.), *Chance in evolution*. Chicago, IL: University of Chicago Press.

- Bongaardt, R. & Meijer, O. (2000) Bernstein's theory of movement and behavior: historical development and contemporary relevance. *Journal of Motor Behaviour*, 32, 57-71.
- Bruner, J. (1973). *Going beyond the information given*. New York: Norton.
- Buss, L. (1987) *Evolution of individuality*. Princeton, NJ: Princeton University Press.
- Cairns-Smith, A. (1982). *Genetic takeover*. New York, NY: Cambridge University Press.
- Carbonaro, B., & Serra, N. (2002). Towards mathematical models in psychology: A stochastic description of human feelings. *Mathematical Models and Methods in Applied Sciences*, 12, 1453-1490. doi: 10.1142/S0218202502002197
- Cools, R., Clark, L., & Robbins, T.W. (2004). Differential responses in human striatum and prefrontal cortex to changes in object and rule relevance. *Journal of Neuroscience*, 24, 1129–1135.
- Damuth, J., & Heisler, I. L. (1988). Alternative formulations of multilevel selection. *Biology and Philosophy*, 3, 407-430
- Dawkins, R. (1986). *The blind watchmaker*. New York, NY: Norton & Company.
- Devoto, P., & Flore, G. (2007). Dopamine and noradrenaline coupling in the cerebral cortex. In K.Y. Tseng & M. Atzori, (Eds.), *Monoaminergic modulation of cortical excitability* (pp.189-197). New York, NY: Springer Science & Business Media.
- Di Matteo, V., Di Giovanni, G., Pierucci, M. & Esposito, E. (2008). Serotonin control of central dopaminergic function: focus on in vivo microdialysis studies. *Progress in Brain Research*, 172, 7-44.
- Dobzhansky, T. (1937). *Genetics and the origin of species*. New York, NY: Columbia University Press.
- Egbert, M. D., Barandiaran, X. E., & Di Paolo, E. A. (2010). Behavioral metabolization: Metabolism based behavior enables new forms of adaptation and evolution. In H. Fellermann, M. Dörr, M. M. Hanczyc, L. L. Laursen, S. Maurer, D. Merkle, et al., (Eds.), *Synthesis and simulation of living systems*, (pp. 213-220). Cambridge, MA: MIT Press.
- Eldredge, N. & Greene, M. (1992). *Interactions*. New York, NY: Columbia Univ. Press.
- Elkonin, B. D. (2005). The psychology of play. *Journal of Russian and East European Psychology*, 43, 1-98.
- Fink, K. B. & Göthert, M. (2008). 5-HT receptor regulation of neurotransmitter release. *Pharmacological Reviews*, 60, 142-170.
- Fokkink, W. J. (2000). *Introduction to process algebra*. London, UK: Springer.
- Frank, S. A. (2013). Natural selection. VII. History and interpretation of kin selection theory. *Journal of Evolutionary Biology*, 26, 1151–1184.
- Freeman, W. J. (2000). *Neurodynamics: An exploration in mesoscopic brain dynamics*. London, UK: Springer-Verlag.
- Freeman, W. J. (2001). *How brains make up their minds*. New York, NY: Columbia University Press.
- Freeman, W. J. (2003a). A neurobiological theory of meaning in perception. Part 1. Information and meaning in nonconvergent and nonlocal brain dynamics. *International Journal of Bifurcation Chaos*, 13, 2493-2511.
- Freeman, W. J. (2003b). Neurodynamic models of brain in psychiatry. *Neuropsychopharmacology*, 28, S54–S63. doi:10.1038/sj.npp.1300147
- Freeman, W. J. & Barrie, J. (2001). Chaotic oscillations and the genesis of meaning in cerebral cortex. In W. Sulis, & I. Trofimova (Eds), *Nonlinear dynamics in the Life and social sciences* (pp. 45-62). Amsterdam: IOS Press.
- Gardner, A., & Grafen, A. (2009). Capturing the superorganism: a formal theory of group adaptation. *Journal of Evolutionary Biology*, 22, 659– 671.

- Geodakyan V. A. (1985). Sexual dimorphism. In J. Mlikovsky & V. J. Novak (Eds), *Evolution and morphogenesis* (pp. 467–477). Praha, Czech Republic: Academia.
- Geodakyan, S. V. (2012). *Two sexes. Why? The evolutionary theory of sex*. Amazon CreateSpace: Wilmington, DE.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.
- Goldstein, J. (2002). The singular nature of emergent levels: Suggestions for a theory of emergence. *Nonlinear Dynamics, Psychology, and Life Sciences*, 6, 293–309.
- Goldstein, J. (2011). Probing the nature of complex systems: Parameters, modeling, interventions—part 1. *Emergence: Complexity and Organization*, 13, 94–121.
- Goldstein, J. (2016). Emergence, self-transcendence, and education. In M. Koopmans & D. Stamovlasis (Eds.), *Complex dynamical systems in education* (pp. 39–57). New York, NY: Springer.
- Gould, S. J. (2002). *The structure of evolutionary theory*. Cambridge, MA: Belknap Press/Harvard University Press.
- Grantham, T. A. (1995). Hierarchical approaches to macroevolution. *Annual Review of Ecology and Systematics*, 26, 301–321.
- Grantham, T. A. (2007). Is macroevolution more than successive rounds of microevolution? *Palaeontology*, 50, 75–85.
- Grenhoff, J., Nisell, M., Ferre, S., Aston-Jones, G. & Svensson, T.H. (1993). Noradrenergic modulation of midbrain dopamine cell firing elicited by stimulation of the locus coeruleus in the rat. *Journal of Neural Transmission. General Section*, 93, 11–25.
- Guastello, S. J. (1995). *Chaos, catastrophe, and human affairs: Applications of nonlinear dynamics to work, organizations, and social evolution*. Mahwah, NJ: Lawrence Erlbaum.
- Guastello, S. J., & Gregson, R. A. M. (Eds). (2011). *Nonlinear dynamical systems analysis for the behavioral sciences using real data*. Boca Raton, FL: CRC Press/Taylor and Francis.
- Guastello, S. J., Koopmans, M., & Pincus, D. (Eds.). (2009). *Chaos and complexity in psychology: The theory of nonlinear dynamical systems*. Cambridge, UK: Cambridge University Press.
- Hebb, D. O. (1961). *The organization of behavior, a neuro-psychological theory*. New York, NY: Wiley.
- Heckman, T. M., & Kauffmann, G. (2011). The coevolution of galaxies and supermassive black holes: A local perspective. *Science*, 333, 182–185.
- Hennessy, M. (1988). *Algebraic theory of processes*, Cambridge, MA: MIT Press.
- Joel, D., & Weiner, I. (2000). Striatal contention scheduling and the split circuit scheme of basal ganglia-thalamocortical circuitry: From anatomy to behavior. In R. Miller & J. R. Wickens (Eds.), *Conceptual advances in brain research: Brain dynamics and the striatal complex* (pp. 209–236). Amsterdam, The Netherlands: Harwood Academic Publishers.
- Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.
- Keller, L. (1999). *Levels of selection in evolution*. Princeton, NJ: Princeton University Press.
- Kimura, M. (1982). *The neutral theory of molecular evolution*. Cambridge, UK: Cambridge University Press.
- Leontiev, A. N. (1978). *Activity, consciousness, and personality*. (Trans. M. J. Hall, 2000). New York: Prentice-Hall.

- Leontiev, A.N. (1981). *Problems of the development of the mind*. (Trans. M. Kopylova). Moscow, Russia: Progress Publishers.
- Leontiev, A. N. (1983). *Collection of selected work, vol. 1* [Isbrannye psichologicheskije proizvedenia]. Moscow, Russia. Pedagogika.
- Lewontin, R. C. (1970). The units of selection. *Annual Review of Ecology and Systematics*, 1, 1-18.
- Lewontin, R. C., & Dunn, L. C. (1960). The evolutionary dynamics of a polymorphism in the house mouse. *Genetics*, 45, 705-722.
- Lindquist, K. A., Wager, T. D., Kober, H., Bliss-Moreau, E., & Barrett, L. (2012). The brain basis of emotion: A meta-analytic review. *Behavioral and Brain Sciences*, 35, 121 – 143. doi: 10.1017/S0140525X11000446
- Lloyd, E. A., & Gould, S. J. (1993). Species selection on variability. *Proceedings of the National Academy of Sciences*, 90, 595-599.
- Luria, A. R. (1966). *Higher cortical functions in man*. New York, NY: Basic Books.
- Marshall, J. A. R. (2011). Group selection and kin selection: Formally equivalent approaches. *Trends in Ecology and Evolution*, 26, 325–332.
- Mayer, E. (1976). *Evolution and the diversity of life*. Cambridge, MA: Belknap Press/Harvard University Press.
- McClure, S. M., Gilzenrat, M. S. & Cohen, J. D. (2005). An exploration-exploitation model based on norepinephrine and dopamine activity. *Advances in Neural Information Processing Systems*, 18, 867–874.
- Moron, J. A., Brockington, A., Wise, R. A., Rocha, B. A. & Hope, B. T. (2002). Dopamine uptake through the norepinephrine transporter in brain regions with low levels of the dopamine transporter: evidence from knock-out mouse lines. *Journal of Neuroscience*, 22, 389–395.
- Morris, C. S. (2010). Evolution: Like any other science, it is predictable. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 364,133–145.
- Nation, J., Trofimova, I., Rand, J., & Sulis, W. (Eds.). (2003). *Formal descriptions of developing systems*. Dordrecht, The Netherlands: Kluwer Academic Press.
- Netter, P. (1991). Biochemical variables in the study of temperament. In J. Strelau & A. Angleitner (Eds.), *Explorations in temperament: international perspectives on theory and measurement* (pp. 47-161). New York, NY: Plenum Press.
- Norman, J. (2002). Two visual systems and two theories of perception: An attempt to reconcile the constructivist and ecological approaches. *Behavioral and Brain Sciences*, 25, 73 -96
- Otto, S. P. & Day, T. (2005) *A biologist's guide to mathematical modeling in ecology and evolution*. Princeton, NJ: Princeton University Press.
- Oyama, S., Griffiths, P. E., Gray, R. D. (Eds.). (2001). *Cycles of contingency: Developmental systems and Evolution*. Cambridge, MA: The MIT Press.
- Paladini, C. A. & Williams, J. T. (2004). Noradrenergic inhibition of midbrain dopamine neurons. *Journal of Neuroscience*, 24, 4568–4575.
- Pearce, W. B. (1995). A sailing guide for social constructionist. In W. Leeds-Hurwitz, (Ed.), *Social approaches to communication* (pp. 88-113). New York, NY: Guilford Press.
- Pickering, A. (2010). *The cybernetic brain: Sketches of another future*. University of Chicago Press, Chicago, USA.
- Pozzi, L., Invernizzi, R., Cervo, L., Vallebuona, F., & Samanin, R. (1994). Evidence that extracellular concentrations of dopamine are regulated by noradrenergic neurons in the frontal cortex of rats. *Journal of Neurochemistry*, 63, 195–200.

- Pribram, K. (1991). *Brain and perception: Holonomy and structure in figural processing*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Price, G. R. (1995). The nature of selection. *Journal of Theoretical Biology*, *175*, 389–396.
- Prigogine, I. (1977). *Self-organization in non-equilibrium systems*. New York: Wiley.
- Quartz, S., & Sejnowski, T. J. (1997). The neural basis of cognitive development: A constructivist manifesto. *Behavioral and Brain Sciences*, *20*, 537-596.
- Reason, J. (1979). Actions not as planned: The price of automatization. In G. Underwood & R. Steven (Eds.), *Aspects of consciousness: Vol. I, Psychological issues* (pp. 67-89). London, UK: Academic Press.
- Rey, H. G., Lew, S. E. & Zanutto, B. S. (2007). Dopamine and norepinephrine modulation of cortical and subcortical dynamics during visuomotor learning. In K. Y. Tseng & M. Atzori (Eds.), *Monoaminergic modulation of cortical excitability* (pp. 251-264). New York, NY: Springer Science & Business Media.
- Robbins, T. W. (2010). From behaviour to cognition: Functions of mesostriatal, mesolimbic and mesocortical dopamine systems. In L. L. Iversen, S. D., Iversen, S. B. Dunnett & A. Bjorklund (Eds.), *Dopamine handbook* (pp. 203-214). Oxford, UK: Oxford University Press.
- Robbins, T. W., & Everitt, B. J. (1996). Arousal systems and attention. In M. Gazzaniga, (Ed.), *The cognitive neurosciences* (pp. 703-720). Cambridge, MA: MIT Press.
- Rusalov, V. M. (1989). Motor and communicative aspects of human temperament: A new questionnaire of the structure of temperament. *Personality and Individual Differences*, *10*, 817-827.
- Rusalov, V. M., & Trofimova I. N. (2007). *Structure of temperament and its measurement*. Toronto, Ontario: Psychological Services Press.
- Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review*, *110*, 145–172.
- Salthe, S. (1985) *Evolving hierarchical systems*. New York, NY: Columbia University Press.
- Simonov, P. V. (1986). *The emotional brain: Physiology, neuroanatomy, psychology and emotion*. New York, NY: Plenum Press.
- Stoltzfus, A. (1999). On the possibility of constructive neutral evolution. *Journal of Molecular Evolution*, *49*, 169–181.
- Stoltzfus, A. (2012). Constructive neutral evolution: Exploring evolutionary theory's curious disconnect. *Biology Direct*, *7*, 35. doi: 10.1186/1745-6150-7-35
- Sulis, W. (1995). Driven cellular automata, adaptation, and the binding problem. In F. Moran, A. Moreno, J. J. Merelo, & P. Chacon, (Eds.), *Advances in artificial life* (pp. 824-840). New York, NY: Springer-Verlag.
- Sulis, W. (2008). Stochastic phase decoupling in dynamical networks. *Nonlinear Dynamics, Psychology, and Life Science*, *12*, 327-358.
- Sulis, W. (2009). Collective intelligence: Observations and models. In S. Guastello, M. Koopmans, & D. Pincus (Eds.), *Chaos and complexity in psychology: The theory of nonlinear dynamical systems* (pp. 41-72). New York, NY: Cambridge University Press.
- Sulis, W. (2014). *A process model of non-relativistic quantum mechanics*. Ph.D. Thesis. Waterloo, ON: University of Waterloo. Canada.
- Sulis W. (2016). Synchronization, TIGoRS, and information flow in complex systems: Dispositional cellular automata. *Nonlinear Dynamics, Psychology, and Life Sciences*, *20*, 293-317.

- Sulis, W. (2017a). Completing quantum mechanics. In K. Sienicki, (Ed.), *Quantum mechanics interpretations* (pp. 350-421). Berlin, Germany: Open Academic Press.
- Sulis, W. H. (2017b). Modeling stochastic complexity in complex adaptive systems: Non-Komolgorov probability and the process algebra approach. *Nonlinear Dynamics, Psychology, and Life Sciences*, 21, 407-440.
- Sulis, W., & Trofimova, I. (Eds.). (2001). *Nonlinear dynamics in life and social sciences*. Amsterdam, The Netherlands: IOS Press.
- Thompson, J. N. (1994). *The coevolutionary process*. Chicago, IL: University of Chicago Press.
- Treisman, A., & Gelade, G. (1980). A feature integration theory of attention. *Cognitive psychology*, 12, 97-136.
- Trofimova, I. (1999). How people of different age, sex and temperament estimate the world. *Psychological Reports*, 85, 533-552.
- Trofimova, I. (2000). Functional differentiation in developmental systems. In Y. Bar-Yam (Ed.) *Unifying themes in complex systems* (pp. 557-567). New York, NY: Perseus Press.
- Trofimova, I. (2001a). Principles, concepts and phenomena of ensembles with variable structure. In W. Sulis, & I. Trofimova (Eds.), *Nonlinear dynamics in life and social sciences* (pp. 217-231). Amsterdam, The Netherlands: IOS Press.
- Trofimova, I. (2001b). Universals and specifics in psychology. In W. Sulis, & I. Trofimova (Eds.), *Nonlinear dynamics in life and social sciences*. (pp. 286-307). Amsterdam, The Netherlands: IOS Press.
- Trofimova, I. (2003). Sociability, diversity and compatibility in developing systems: EVS approach. In J. Nation, I. Trofimova, J. Rand, & W. Sulis, (Eds.), *Formal descriptions of developing systems* (pp. 231-248). Dordrecht, The Netherlands: Kluwer Academic Press. doi: 10.1007/978-94-010-0064-2_13
- Trofimova, I. (2010). An investigation into differences between the structure of temperament and the structure of personality. *The American Journal of Psychology*, 123, 467-480. doi: 10.5406/amerjpsyc.123.4.0467
- Trofimova, I. (2012). Who is in charge of science: Men view "time" as more fixed, "reality" as less real, and "order" as less ordered. *Cognitive Systems Research*, 15-16, 50-56. doi:10.1016/j.cogsys.2011.07.001
- Trofimova, I. (2014). Observer bias: How temperament matters in semantic perception of lexical material. *PLoS One*, 9(1):e85677. doi:10.1371/journal.pone.0085677.
- Trofimova, I. (2015). Do psychological sex differences reflect evolutionary bi-sexual partitioning? *American Journal of Psychology*, 128, 485-514. DOI: 10.5406/amerjpsyc.128.4.0485.
- Trofimova, I. (2016). Phenomena of functional differentiation (FD) and fractal functionality (FF). *International Journal of Design & Nature and Ecodynamics*, 11, 508-521. DOI: 10.2495/DNE-V11-N4-508-521
- Trofimova, I. (2016). The interlocking between functional aspects of activities and a neurochemical model of adult temperament. In M. C. Arnold (Ed.), *Temperaments: Individual differences, social and environmental influences and impact on quality of life* (pp. 77-147). Hauppauge, NY: Nova Science.
- Trofimova, I. (in press). Functionality vs dimensionality in psychological taxonomies, and a puzzle of emotional valence. *Philosophical Transactions of the Royal Society-B*.
- Trofimova, I. & Christiansen, J. (2016). Coupling of temperament traits with mental illness in four age groups. *Psychological Reports*, 118, 387-412. doi: 10.1177/0033294116639430

- Trofimova, I., Mitin, N. A., Potapov, A. B. & Malinetsky, G. G. (1997). Description of ensemble with variable structures. New models of mathematical psychology (in Russian). *Preprints of the Keldysh Institute of Applied Mathematics*, 34. Moscow, Russia: Russian Academy of Science Press.
- Trofimova, I., Potapov, A. & Sulis, W. (1998). Collective effects on individual behavior: In search of universality. *International Journal of Chaos Theory and Applications*, 3, 53-63.
- Trofimova, I., & Robbins, T. W. (2016). Temperament and arousal systems: A new synthesis of differential psychology and functional neurochemistry. *Neuroscience and Biobehavioral Reviews*, 64, 382-402.
- Trofimova, I., & Sulis W. (2010). The lability of behavior as a marker of comorbid depression and anxiety. *Advances in Bioscience and Biotechnology*, 1, 190-199. doi: 10.4236/abb.2010.13027
- Trofimova, I., & Sulis W. (2011). Is temperament activity-specific? Validation of the Structure of Temperament Questionnaire – Compact (STQ-77). *International Journal of Psychology and Psychological Therapy*, 11, 389-400.
- Trofimova, I., & Sulis, W. (2016a). Benefits of distinguishing between physical and social-verbal aspects of behaviour: an example of generalized anxiety. *Frontiers in Psychology*, 7, 338. doi: 10.3389/fpsyg.2016.00338
- Trofimova, I., & Sulis, W. (2016b). A study of the coupling of FET temperament traits with major depression. *Frontiers in Psychology*, 7, 1848. doi: 10.3389/fpsyg.2016.01848.
- Trofimova, I., & Sulis, W. (in press). There is more to mental illness than just negative affect: comprehensive temperament profiles in depression and anxiety. *PLoS One*.
- Tsein, J. Z. (2006). Learning and memory. In G. J. Siegel, R. W. Albers, S. T. Brady, & D. L. Price (Eds.), *Basic neurochemistry* (7th edition) (pp. 859-874). Amsterdam, The Netherlands: Elsevier.
- Vrba, E. (1983). Macroevolutionary trends: new perspectives on the roles of adaptation and incidental effect. *Science*, 221, 387-389.
- Vrba, E. (1989). Levels of selection and sorting with special reference to the species level. *Oxford Surveys in Evolutionary Biology*, 6, 111-168.
- Vrba, E., & Eldredge, N. (1984). Individuals, hierarchies, and processes: towards a more complete evolutionary theory. *Paleobiology*, 10, 146-171.
- Vrba, E., & Gould, S. (1986). The hierarchical expansion of sorting and selection: Sorting and selection cannot be equated. *Paleobiology*, 12, 217-228.
- Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. *Trends in Cognitive Science*, 9, 585-594.
- Vygotsky, L. (1998). *The collected works of L. S. Vygotsky, vol.5. Child psychology*. New York, NY: Plenum Press.
- Waldhoer, M., Bartlett, S., & Whistler, J. (2004). Opioid receptors. *Annual Review of Biochemistry*, 73, 953-990
- West, S. A. (2009). *Sex allocation*. Princeton, NJ: Princeton University Press.
- Whitehead, A. N. (1978). *Process and reality*. New York, NY: The Free Press.
- Wilson, D. S., & Wilson, E. O. (2007). Rethinking the theoretical foundation of sociobiology. *The Quarterly Review of Biology*, 82, 327-348.
- Yamamoto, B. K., & Novotney, S. (1998). Regulation of extracellular dopamine by the norepinephrine transporter. *Journal of Neurochemistry*, 71, 274-280.
- Yin, H. Y., & Knowlton, B. J. (2006). The role of the basal ganglia in habit formation. *Nature Neuroscience*, 7, 464-476.