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Simplified models for describing multitasking modes in living recognition systems

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Abstract. The *purpose* of this study is to explore the possibilities and create versions of simplified languages that describe the variety of dynamic modes during the alternating execution of multiple tasks. These languages can be used for an adequate description of experimentally recorded variants of behavior in living systems under such conditions. *Methods.* The study was conducted using a physical methodology based on qualitative analysis of possible solutions and confirmed by the results of computational experiments. To qualitatively describe the versions of possible mechanisms for switching between dynamic modes of operation of living systems in situations presented by the environment for these systems (expressed through changes in emotional or energy states), the simplest basic model was used. This model includes two balance equations corresponding to either the first or the second solvable problem. For this system, a two-dimensional phase space is constructed, allowing for tracking characteristic changes in the trajectories of the representing points in the null – isocline system, which depend on the control parameters. Various trajectories of representing points are considered depending on the initial conditions, visually demonstrating the main modes of transitional processes in the developing system. *Results and discussion.* Classification of dynamic modes in the system has been conducted, depending on control parameters. Such dynamic modes form the basis for simplified language descriptions. The proposed simplified mathematical model allowed for the examination of a wide range of states and various types of its evolutionary changes in full accordance with known examples of behavior modes in living systems.

Keywords: neuron-like modules, balance equations, multitasking, mathematical modeling.

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Introduction

A living system can normally realize a wide range of possible states, between which different time-varying («episodic» and evolutionary) multivariate dynamic switching occurs. At the same time, there are several levels of representation of the features of dynamic modes of perception and response of living systems. The purpose of this study is to consider the possibilities and create versions of simplified languages describing a variety of dynamic modes when performing several tasks alternately, which can be used to adequately describe experimentally recorded behaviors of living systems in such situations.

Depending on the choice of specific areas of functioning and the type of tasks under consideration, the features of sensory signal processing can be described using simplified (reduced) basic recognition and decision-making models, which are usually derived from models similar to P. K. Anokhin schemes [1–3]. Modules of different levels in hierarchical model architectures are assembled into a single functional system in such a way that it is possible to achieve the goals set for the system. In addition, live systems have control modules that enable switching between various important goals. Accordingly, in order to achieve them, operations are managed to solve the necessary tasks.

In this paper, we consider one of the versions of the derivation of reduced models [4–17]. It is important to note that, following the steps of the physical research methodology [14, 17], it is possible to choose the most appropriate mode for comparison with the described experimental data from the potential multivariance of model descriptions [4–17]. It was previously shown [12, 13] that such a simplified model description language proved to be adequate for a large number of experimental data recorded when teaching children several languages (variants of bilingualism). Discussion of these results with interested researchers allowed us to hypothesize the fruitfulness of such a model description for a wider range of areas of multitasking functioning of living systems.

Thus, this study examines the possibilities of creating versions of simplified languages that describe a variety of dynamic modes in hierarchically organized recognition systems that are alternately focused on the implementation of different tasks. To prove the adequacy of the description, some examples of «standard» life situations taken from some literary works are used. The comparison of model results and the description of life experience in the work is carried out. In particular, fragments from the literary work «Gone with the Wind» M. Mitchell [18]. They trace the processes of choosing priorities among the ideological positions or stereotypes used by the heroine while unconsciously relying on a number of levels of generalized controls. For a qualitative description of the mechanisms of switching between the dynamic modes of functioning of living systems in the situations provided by the environment for these systems (emotional or energetic conditions), the simplest basic model of two equations was used. When it is necessary to consider hierarchical interactions, the number of balance equations increases. The time modes are obtained on the basis of computational experiments.

The article consists of three parts, each of which has its own purpose and logic of development. The first part is devoted to an important aspect of our research, the axiomatic provisions, which are a set of interpretations of experimental results [19–22]. Based on the axioms accepted by the researcher, one of the many possible versions of formalized descriptions for the future simplified language [4–17] is constructed.

The second part presents one of the many ways to transition from complex (and therefore ambiguously interpreted) schemes («images») to versions of balance equations corresponding to the chosen axiomatic provisions. These equations allow us to determine the requirements for the areas of functioning of the system under study. In other words, visualization of the transition conditions plays a key role in understanding the experimental conditions under which the solutions obtained from these equations can be effectively used. This is important for determining the areas of their adequate application.

The third part uses standard methods for analyzing solutions of differential equations, which make it possible to obtain a range of new dynamic modes. Until now, in our opinion, the study of the dynamics of multitasking modes has not received sufficient attention.

The proposed approach allows researchers to form their own versions of concepts that highlight the most significant fragments from huge amounts of experimental data. This is necessary to create simplified, formalized descriptions based on accepted basic models. The results of comparing experimental data with dynamic modes obtained from the basic models confirm the adequacy of the formalized description. The validity of the conclusion of simplified (basic) models is based on the use of another set of experimental data on the basic elements and the structure of their coupling in living systems, which are also accepted as axioms.

1. Elements of methodology for describing complex natural systems

Let us consider the main elements in the procedure of forming simplified (reduced) models from a variety of hierarchical relationships at different levels based on a large amount of experimental data. The physical research methodology contains the following stages [14–17]: formulation of axioms; selection of the most appropriate variables and basic models; finding a range of possible solutions; control of requirements to minimize the error between the selected solutions and the described experimental data. The main features of cognitive systems are associated with a wide variety of modes of their functioning. This is because signals from external influences, as well as internal control signals, are processed using three groups of algorithms focused on:

1) «figurative» representations;
2) «logical, engineering-oriented» descriptions and technical implementations;
3) a wide range of constructs arising from the joint use of algorithms from the first and second groups [17].

1.1. Initial versions of axiomatic schemes for describing living systems. The experience of researchers developing various models for describing living systems allows us to axiomatically divide their diversity into several classes [4–22]. For example:

a — level 1 models are focused on describing the direct processes of converting the source signal into the desired output signal without enabling offline settings. These include transformations that form sets of elementary features, detectors of predefined signals, as well as simplified semantic models that demonstrate the characteristic qualitative modes of more complex simulation models;

b — level 2 models simulate live prototypes using the simplest ways to transform external and internal signals. They are focused on the formation of sets of elementary decision-making operations using autonomous adjustment cycles, as well as demonstration examples of elementary psychological response modes of living recognition modules;

c — level 3 models simulate living prototypes through hierarchical relationships and a variety of transformations of external and internal signals. The models are focused on describing higher levels of behavior (psychological modes) in a complex architecture of systems from a hierarchy of recognition modules.

If the simulation models of the 2nd and 3rd levels can be reduced to models of the 1st level, thereby demonstrating the dynamics of a number of behavioral modes of the prototype, then the newly obtained models of the 1st level are called semantic models (for example, see [4, 12, 13]). In accordance with the purpose of this article, one of the implementations (out of many possible versions [14–27]) of the description of a number of dynamic modes of models of the 3rd and 2nd classes within the framework of models of the 1st class will be demonstrated below.

As a starting point on the way to simplified models, let us use the scheme of the basic recognition module in Fig. 1 with the main treatment cycle isolated from the well-known P. K. Anokhin scheme [1–3] (three such cycles were proposed in it). It is important to note that the recognition system of Fig. 1 can be aware of the internal interpretation of the input sensory signal that best matches the latter. Thus, modeling the operation of such modules allows for a deeper understanding of the information processing processes and the system's response to external stimuli in accordance with the objectives of the task being solved. The studies conducted in [4–10], provide a more detailed description of the basic recognition cell and its role in signal processing at various levels of the control hierarchy.

In the subsystem «Data on past and expected system modes» , a description of the states of the entire 2nd level module in the past and planned events is formed. The subsystem performs operations similar to episodic memory in living systems. In addition, it receives control signals from the «I–EGO». Taking into account its signals, the modes of the subsystem «Choosing a virtual image and making decisions», are controlled, which performs the functions of the operating system for this Quasi-autonomous Recognition Module (KARM).

In an integrated system, that is, in modules of the 3rd level, the KARM model system acts as

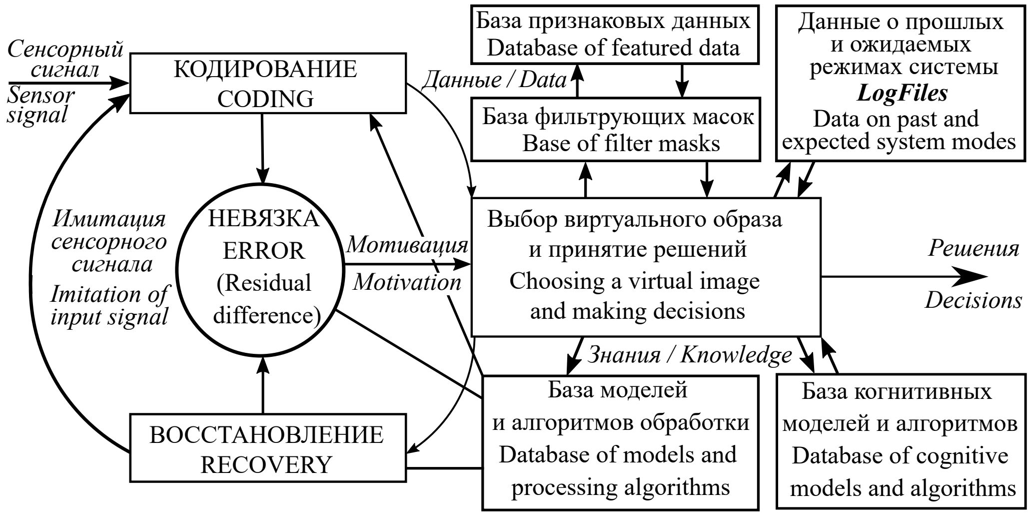


Fig. 1. KARM (Quasi-autonomous Recognition Module) (variants in works [4–10])

an elementary «building block» of the structure. KARM can be used both to form and describe signal processing modes at different levels of hierarchical control. With the help of KAPM , it is possible to design various architectures of living systems and explore dynamic modes focused on solving various tasks within the entire integrated system. Of particular interest are architectures corresponding to experimental data, in which the highest control modules, using KARM, perform functional operations «I – EGO» or «I – Self» [19–21]. These modules make the main (final) decision about what task the integrated hierarchical system is currently solving.

1.2. Variants of simplified schemes for hierarchical systems. The next step, which meets the requirements of the biological plausibility of the basic models, is related to the need to identify and describe the features of the passage of complex information signals (unconscious, conscious, intuitive). Such modes of operation are focused on managing the state of living recognition systems, which makes it possible to form adequate responses to external influences. The process of control of upper-level modules over the state and functioning of lower-level modules can be described by the psychological term «I – EGO». The upper-level modules assume simultaneous operation of recognition systems associated with the description of various behavioral scenarios (in accordance with E. Berne [21]): «teacher», «adult», «child».

A living system can be aware of information signals from the integral stream, which are passed through by the filter at the input of the «I – EGO» module. In an integral hierarchical system, optimization processes of analyzing past erroneous decisions can be perceived in the «I –EGO» block in both conscious and unconscious modes. At the same time, the analysis of past erroneous decisions from episodic memory occurs in a conscious mode. The control set from the planning block (the nearest «I – EGO») indicates which algorithms k_i from the set of tasks under consideration should be used. For example, in the simplest case with two tasks, k_1 and k_2.

Data from physiological experiments indicate that in living systems, control is carried out using at least four types of internal information signals [22]. The neuron-like modules that control these signals interact with each other as shown in Fig. 2. The features of signal processing control in the right and left halves of the brain (see, for example, [27]) will not be taken into account in this work. In further research, such control can be taken into account in the features of the signals from the «I – EGO» block.

The consideration of neuron-like mechanisms is based on cyclic processes known as informational, motor, vegetative, and emotional cycles. Such cycles are necessary to compare the expected (reference) signal with the input signal (the typical processing times of different types of internal control signals may vary and depend on the type, goals and conditions of the tasks performed). The degree of mismatch between these signals shapes the motivation and needs of the system in question.

a) *Information module* is responsible for forming models and making decisions based on information

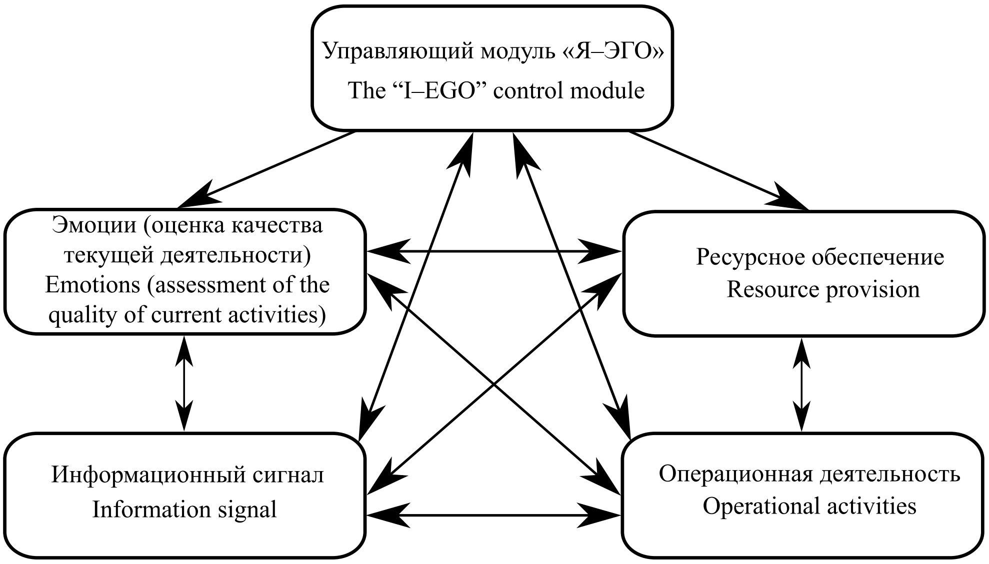


Fig. 2. The architecture of the "I-EGO" control unit

signals coming from various information channels (typical response times are usually from fractions of a second to minutes). Known sensory channels in living systems include the visual system, the auditory system, the skin and taste systems, the olfactory system, as well as the interoreception and vestibular system.

b) *Operational activities* control the functional state of the actuators and control the functioning of the muscular system (typical response times range from seconds to several minutes). This includes performing specific operations, coordinating movements, regulating muscle function, and other processes necessary to complete tasks and respond to external influences. Operational (muscular) activity plays a key role in ensuring the fulfillment of various functions of living organisms.

c) *Emotional system* calculates integral estimates for the states or operations performed by the modules using the «comfort-discomfort», «strength-weakness» scales and other similar parameters. The typical time for forming such estimates can usually range from seconds to several minutes, sometimes hours.

d) *Resource provision* is responsible for managing the energy provision levels, managed by the vegetative module. Typical times of change in energy supply levels can range from tens of seconds to several hours, and sometimes months or years.

The functioning of multimodule systems is determined by a scenario that takes into account the experience of the system and the duration of cycles for various types of internal signals. The main goal of this scenario is to reduce errors between internal signal predictions and the actual flow of input sensory signals.

1.3. Selection of the main variables and conditions for the transition to simplified equations. To conceptually describe and analyze the dynamic modes of functioning of a subject in a certain environment, we use the well-known physical approach of compiling balance equations. As the main characteristic of the evolving system, we will use the number of algorithms k_i, necessary to solve a particular problem. The more algorithms the system was able to generate, the better it solves the i task under the operating conditions set for it.

Algorithms, as defined by Yu. I. Alexandrov [28], represent units of individual experience. The interpretation of this experience can take various forms depending on the approach of the researchers. Some experimenters associate it with the creation of functional systems based on hierarchical neural networks, while others prefer to represent the process of recording experience through the creation of new «basic» instrumental algorithms that process information and control signals.

Given the variety of algorithms being designed for living systems, their number can be quite significant. To simplify the analysis, we normalize this amount to the maximum possible and consider the variable k_i as continuous (a fraction of the maximum value). Although in reality such fractions have a discrete character, the sampling step can be considered small enough for the purposes of our study.

A general view of a simplified mathematical model describing switching in multitasking modes (according to the diagrams in Fig. 1 and Fig. 2), can be represented by a system of differential equations (DE) (1):

$$\frac{dk_i}{dt} = Y_i(t)\Big(-\frac{k_i}{\tau_{2i}} + \frac{1}{\tau_{1i}}\ F_0[-T_i(M,U,Q,E) + \gamma_{ii}k_i - \sum_{i\neq j}\gamma_{ij}k_j]\Big), \tag{1}$$

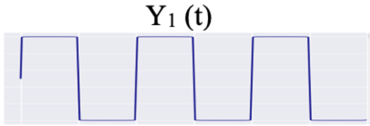
where k_i is the number of instrumental algorithms related to solving the i-th task that a particular system has learned; τ_{1i} is the characteristic time for mastering new algorithms; τ_{2i} is the characteristic forgetting time of old algorithms; F_i is a step function corresponding to the conditions for solving the i-th task; γ_{ij} are the weighting coefficients of the interconnection between the subsystems; $T_i(M,U,Q,E)$ is the threshold for launching learning algorithms in the i-th area of activity; $Y_i(t)$ is the control module for the i-th task, transmitting signals from the «I – EGO» block (varies from 0 to 1) and illustrated for the case of two solved tasks in Table, is set using continuous functions (varies from 0 to 1). In equations (1) we rely on experimental data showing that for most living systems, each task is performed alternately as part of a common multitasking procedure. This can be formulated as an additional axiom: if $Y_i(t) = 1$, then $Y_j(t) = 0$ for all j, not equal to i.

$U(t)$, $E(t)$, $Q(t)$ are important parameters determined by emotional, energetic, and stressful processes and affect the state of the developing subject (in the framework of this consideration, we will consider them constant, but different depending on the situation in which the subject is located). $M(t)$ represents the number of operations performed by active algorithms on images perceived from the environment, that is, the level of imaginative perception (worldview) of a living system.

2. Simplified balance equations and their solutions

Here we consider a simplified situation where the system alternately solves only one of the two tasks under consideration. In this case, we move from a system of many DE (1) to a version of two balance

Table. Options for parameters in a simplified system for describing two-task modes

Control signals from the «Data on past and expected modes» module in Fig. 1 or the «I – EGO» module in Fig. 2	**Y_1 (t)**  **Y_2(t)** 
Emotions and energetic influence of cases on each other through time values and interaction coefficients	T_1; T_2 eps; $\overline{\gamma_{11}}$; $\overline{\gamma_{12}}$ $\overline{\gamma_{22}}$; $\overline{\gamma_{21}}$
A set of algorithms, the value of which characterizes the life experience of a given system	$\overline{k_1}/\overline{k_2}$

equations, which also belong to the class of models of the 1st level.

$$\frac{dk_1}{dt} = Y_1(t)\Big(-\frac{k_1}{\tau_{21}} + \frac{1}{\tau_{11}}\ F_0[-T_1 + \gamma_{11}k_1 - \gamma_{12}k_2]\Big), \tag{2}$$

$$\frac{dk_2}{dt} = Y_2(t)\Big(-\frac{k_2}{\tau_{22}} + \frac{1}{\tau_{12}}\ F_0[-T_2 + \gamma_{22}k_2 - \gamma_{21}k_1]\Big), \tag{3}$$

where the same nonlinear functions are selected for simplified consideration: $F_0[\ ]$ is the Heaviside step function for both the 1st and 2nd tasks. The types of solutions in such a system depend on 10 parameters.

2.1. Description of the derivation of simplified balance equations with normalization. The allocation of a reduced number of defining parameters is usually carried out using a normalization procedure. This makes it possible to simplify the analysis and standardize the numerical calculations of the system under study. If you enter new variables $\overline{k_1} = \frac{\tau_{11}}{\tau_{21}}k_1$, $\bar{t} = \frac{t}{\tau_{21}}$, $\overline{k_2} = \frac{\tau_{12}}{\tau_{22}}k_2$ and new defining parameters $\overline{\gamma_{11}} = \gamma_{11}\frac{\tau_{21}}{\tau_{11}}$, $\overline{\gamma_{21}} = \gamma_{21}\frac{\tau_{21}}{\tau_{11}}$, $\overline{\gamma_{22}} = \gamma_{22}\frac{\tau_{22}}{\tau_{12}}$, $\overline{\gamma_{12}} = \gamma_{12}\frac{\tau_{22}}{\tau_{12}}$, $\varepsilon = \frac{\tau_{22}}{\tau_{21}}$, then system (2)–(3) is rewritten as the following equations:

$$\frac{d\overline{k_1}}{d\bar{t}} = Y_1(\bar{t})\left(-\overline{k_1} + F_0\left[-T_1 + \overline{\gamma_{11}}\,\overline{k_1} - \overline{\gamma_{12}}\,\overline{k_2}\right]\right), \tag{4}$$

$$\varepsilon\frac{d\overline{k_2}}{d\bar{t}} = Y_2(\bar{t})\left(-\overline{k_2} + F_0\left[-T_2 + \overline{\gamma_{22}}\,\overline{k_2} - \overline{\gamma_{21}}\,\overline{k_1}\right]\right), \tag{5}$$

where $\overline{k_1}$ and $\overline{k_2}$ are the normalized number of instrumental algorithms that a particular system has learned; F_0 is the same Heaviside step function for the 1st and 2nd tasks; normalized values $\overline{\gamma_{ij}}$ is the weighting coefficients of the interconnection between subsystems, which, depending on the situations under consideration, can be both positive and negative; T_1, T_2 are the thresholds for launching learning algorithms for the first or second areas of activity, which can also be both positive and negative, depending on the situations under consideration; *eps* defines the ratio of the characteristic change times of $\overline{k_1}$ and $\overline{k_2}$; $Y_1(\bar{t})$ and $Y_2(\bar{t})$ are the control modules presented in Table, which were numerically set using continuous functions varying from 0 to 1. The correspondence of the parameters from equations (4)–(5) experimentally measured values are given and clearly demonstrated in Table.

In a normalized system, the solutions obtained depend on only 7 parameters.

2.2. Tools for analyzing solutions of simplified balance equations. The stages of the implemented modes in the system of equations (4)–(5) are clearly visible in Fig. 3–5, constructed in two-dimensional phase space (provided that $F_0[\ ] = 0$, if $[\ ] < 0$ and $F_0[\ ] = 1$, if $[\ ] > 0$). Equations (6)–(7) for null isoclines are derived from equations (4)–(5):

$$-T_1 + \overline{\gamma_{11}}\,\overline{k_1} - \overline{\gamma_{12}}\,\overline{k_2} = 0, \quad \overline{k_1} = 0, \quad \overline{k_1} = 1 \tag{6}$$

for the first task (Fig. 3 on the left);

$$-T_2 + \overline{\gamma_{22}}\,\overline{k_2} - \overline{\gamma_{21}}\,\overline{k_1} = 0, \quad \overline{k_2} = 0, \quad \overline{k_2} = 1 \tag{7}$$

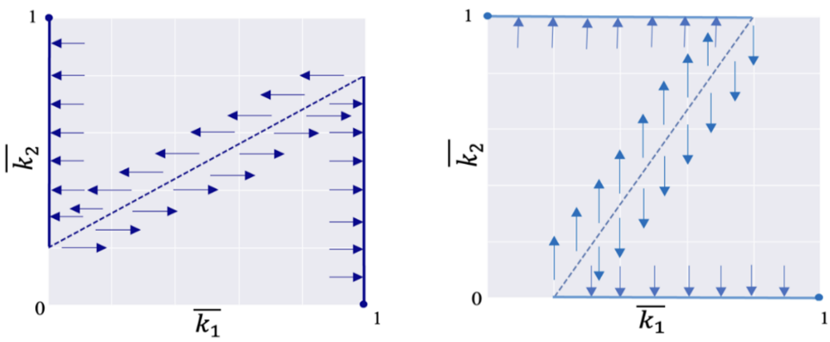


Fig. 3. Different types of zero-isoclines for equations (6) and (7) in solving the first ($Y_1 = 1$; $Y_2 = 0$) and second ($Y_1 = 0$; $Y_2 = 1$) problems

for the second task (Fig. 3 on the right).

Thus, to analyze changes in the values of $\overline{k_1}$ and $\overline{k_2}$, six null isocline variants from equations (6) and (7) are used. Four of them (stable) define the sides of the square of a two-dimensional phase space ($\overline{k_1} = 0$, $\overline{k_1} = 1$ and $\overline{k_2} = 0$, $\overline{k_2} = 1$), within which various dynamic system modes. With two other (unstable) null isoclines $-T_1 + \overline{\gamma_{11}}\overline{k_1} - \overline{\gamma_{12}}\overline{k_2} = 0$ and $-T_2 + \overline{\gamma_{22}}\overline{k_2} - \overline{\gamma_{21}}\overline{k_1} = 0$ from equations (6) and (7) operations of parallel transfers or angular rotations are possible by changing the parameters: T_i, $\overline{\gamma_{ii}}$, $\overline{\gamma_{ij}}$, $\overline{\gamma_{jj}}$, where $i = 1, 2$ and $j = 1, 2$. This creates conditions for the implementation of at least eight qualitatively different dynamic modes of change $\overline{k_1}$ and $\overline{k_2}$ in the process of alternating execution of both the first and second tasks.

The features of constructing trajectories during the movement of the image point on the phase plane $\overline{k_1}$ and $\overline{k_2}$ are shown in Fig. 4. In Fig. 4, *a* two types of unstable null isoclines (6) and (7) are depicted on the same phase plane; the integral solution trajectory for both the first and second tasks is also shown. In Fig. 4, *b* the null isoclines (6) are depicted on the phase plane, and the solid line shows the trajectory changes corresponding to the first task. In Fig. 4, *c* the null isoclines (7) are depicted on the phase plane, and the solid line shows the trajectory changes corresponding to the second task.

When switching from one task to another and analyzing each equation separately, the variable determined from the other equation remains constant, which allows, during the solution of one of the tasks, to translate the image point through an unstable null isocline for the equation that is unsolvable at that moment.

In Fig. 4 two types of null isoclines corresponding to equations (5) and (6) are depicted on the same phase plane. When analyzing each equation separately, the other equation is not taken into account, which allows the null isoclines to intersect on the graph of phase trajectories. That is, each null isocline has its own parameter space that does not intersect in any way with the parameter space of the other null isocline.

Calculations in Fig. 3 and in Fig. 4 were performed with the following system parameters: $T_1 = -10$, $T_2 = -10$, $\overline{\gamma_{11}} = 30$, $\overline{\gamma_{22}} = 30$, $\overline{\gamma_{12}} = 50$, $\overline{\gamma_{21}} = 50$, $\varepsilon = 1$.

2.3. Analysis of possible transitional processes in a simplified model. The possible dynamic modes in this system are illustrated further in Fig. 5. Let us first consider examples of the location of null isoclines and the trajectories of the image points. For clarity, unstable null isoclines are shown as dotted lines.

Based on the examples of the implementation of the changes $\overline{k_1}$ and $\overline{k_2}$ during the alternating execution of the first and second tasks shown in Fig. 5, let us identify eight qualitatively different modes of behavior:

1) simultaneous «development» mode — an increase in the number of algorithms for both tasks (in zone 1);

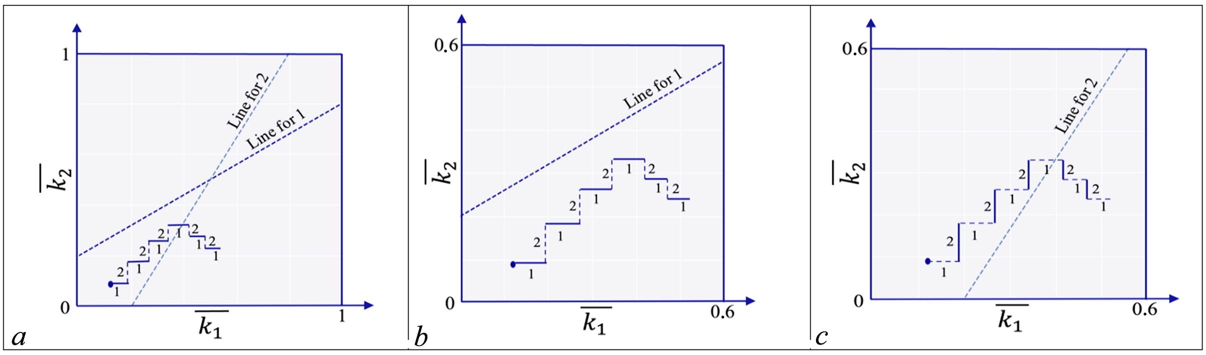


Fig. 4. A two-dimensional phase space in which all dynamics occur during the controlled switching procedure for solving two tasks. The training stages for the first set of algorithms (horizontal lines) are marked with the number 1, while the training stages for the second set of algorithms (vertical lines) are marked with the number 2; *b* — One null isocline for the first set of algorithms is depicted; *c* — One null isocline for the second set of algorithms is depicted, and as we can see, they do not intersect with each other

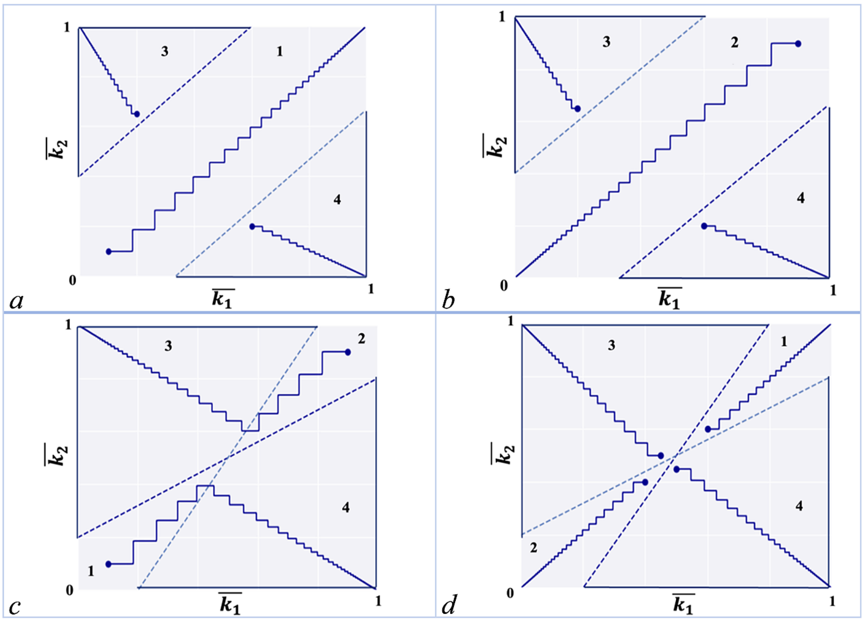


Fig. 5. Types of zones with characteristic processes of changes in $\overline{k_1}$ and $\overline{k_2}$. *a* — The optimal location of unstable isoclines with zone 1, where there are no thresholds for two-variant modes of development: $T_1 = -10$, $T_2 = -10$, $\overline{\gamma_{11}} = 30$, $\overline{\gamma_{22}} = 25$, $\overline{\gamma_{12}} = 30$, $\overline{\gamma_{21}} = 25$, $\varepsilon = 1$. *b* — Zone 2 with a "depressive" effect, which reduces the development of systems, is located along the central axis up to the upper right corner: $T_1 = 10$, $T_2 = 10$, $\overline{\gamma_{11}} = 30$, $\overline{\gamma_{22}} = 25$, $\overline{\gamma_{12}} = 30$, $\overline{\gamma_{21}} = 25$, $\varepsilon = 1$. *c* — The "depressive" state (zone 2) is located at the top along the axis and limits the growth of two-variant modes of development (zone 1) at the bottom along the axis: $T_1 = -10$, $T_2 = -10$, $\overline{\gamma_{11}} = 30$, $\overline{\gamma_{22}} = 30$, $\overline{\gamma_{12}} = 50$, $\overline{\gamma_{21}} = 50$, $\varepsilon = 1$. *d* — The area with optimal two-variant modes of system development (zone 1) is located along the central axis up to the upper right corner, while the "depressive" state (zone 2) in the lower left corner forms a threshold for two-variant modes of development: $T_1 = 10$, $T_2 = 10$, $\overline{\gamma_{11}} = 50$, $\overline{\gamma_{22}} = 50$, $\overline{\gamma_{12}} = 30$, $\overline{\gamma_{21}} = 30$, $\varepsilon = 1$

2) «depressive» mode — reduction in the number of algorithms for both tasks (in zone 2);
3) developing only the first task and suppressing the second (in zone 4);
4) development of only the second task and the oppression of the first (in zone 3);
5) development modes for the two tasks switch to the development of only the first task and the suppression of the second (transitions from zone 1 to zone 4);
6) two-variant development modes switch to the development of only the second task and the suppression of the first (transitions from zone 1 to zone 3);
7) «depressive» mode, with a decrease in the number of algorithms for both tasks, switches to the development of only the first task and the suppression of the second (transitions from zone 2 to zone 4);
8) with a decrease in the number of algorithms for both tasks, the «depressive» mode switches to the development of only the second task and the oppression of the first (transitions from zone 2 to zone 3).

The existence of additional switching modes that are qualitatively different from the modes with the most obvious behavior already listed above may be due to a change in the duration of a particular task.

3. Types of solutions corresponding to the episode from the literary work «Gone with the Wind»

Let us turn to one of the most touching episodes of the novel «Gone with the Wind» by Margaret Mitchell. At this moment, the Civil War in the United States begins, and the Yankees (the military allies of the North) come to the city. The main character, Scarlett O'Hara, sits and listens to the sounds coming from the city, trying to calm the chaotic thoughts that are racing through her head [18] (volume 1, chapters 23–24).

«As she sat straining her ears toward town, a faint glow appeared above the trees. It puzzled her. She watched it and saw it grow brighter. The dark sky became pink and then dull red, and suddenly above the trees, she saw a huge tongue of flame leap high to the heavens. She jumped to her feet, her heart beginning again its sickening thudding and bumping. The Yankees had come! She knew they had come and they were burning the town. The flames seemed to be off to the east of the center of town. They shot higher and higher and widened rapidly into a broad expanse of red before her terrified eyes. A whole block must be burning. A faint hot breeze that had sprung up bore the smell of smoke to her» [18].

The main character, Scarlett O'Hara, is in a state of panic and fear after the Yankees began to take over the city. She realizes that she needs to leave Atlanta and go to Tara, her native estate. Scarlett confesses to Rhett Butler that she is scared and wants to return home. Rhett warns her about the fighting and the dangers on the road, but Scarlett insists on her decision. She shows her resilience and determination despite possible threats.

«She stood shaking, listening to his words, hardly hearing them. But, at his question she suddenly knew where she was going, knew that all this miserable day she had known where she was going. The only place.

— I'm going home, — she said.

— Home? You mean to Tara?

— Yes, yes! To Tara! Oh, Rhett, we must hurry!

He looked at her as if she had lost her mind.

— Tara? God Almighty, Scarlett! Don't you know they fought all day at Jonesboro?

Fought for ten miles up and down the road from Rough and Ready even into the streets of Jonesboro? The Yankees may be all over Tara by now, all over the County. Nobody knows where they are but they're in that neighborhood. You can't go home! You can't go right through the Yankee army!

— I will go home! — she cried and her voice broke and rose to a scream. — I will go home! You can't stop me! I will go home! I want my mother! I'll kill you if you try to stop me! I will go home!

Tears of fright and hysteria streamed down her face as she finally gave way under the long strain. She beat on his chest with her fists and screamed again:

— I will! I will! If I have to walk every step of the way!

Suddenly she was in his arms, her wet cheek against the starched ruffle of his shirt, her beating hands stilled against him. His hands caressed her tumbled hair gently, soothingly, and his voice was gentle too. So gentle, so quiet, so devoid of mockery, it did not seem Rhett Butler's voice at all but the voice of some kind strong stranger who smelled of brandy and tobacco and horses, comforting smells because they reminded her of Gerald.

— There, there, darling, — he said softly.

— Don't cry. You shall go home, my brave little girl. You shall go home. Don't cry» [18].

In this episode of the novel «Gone with the Wind» one of Scarlett O'Hara's main priorities is her own safety and returning to her homeland in Tara. First of all, she is afraid for her life and is trying to find a way to escape from the possible danger caused by the fire and the Yankee attack. For Scarlett, returning to Tara is an attempt to return to her roots, to find support and protection in her native home during a period of historical upheaval.

Scarlett's next but no less important priority is saving Melanie's life and the children's. She shows courage and determination to overcome obstacles and risks on the way to Tara, striving to ensure the safety of her loved ones and find a refuge for them from the war. «Blinking in the sunlight, her eyes fell on Melanie and she gasped, horrified. Melanie lay so still and white Scarlett thought she must be dead. She looked dead. Then Scarlett saw with relief the faint rise and fall of her shallow breathing and knew that Melanie had survived the night» [18]. The heroine's priorities reflect her individual experience.

In this situation, Scarlett's main priorities have become:

- $\overline{k_1}$ is about ensuring your security through the use of appropriate algorithms;
- $\overline{k_2}$ is about ensuring the safety of your loved ones' lives by taking the necessary measures.

This situation, depending on the initial state of the subject and the location of the null isoclines on the plane, could have at least four different behaviors. Let us consider the relevant examples of the

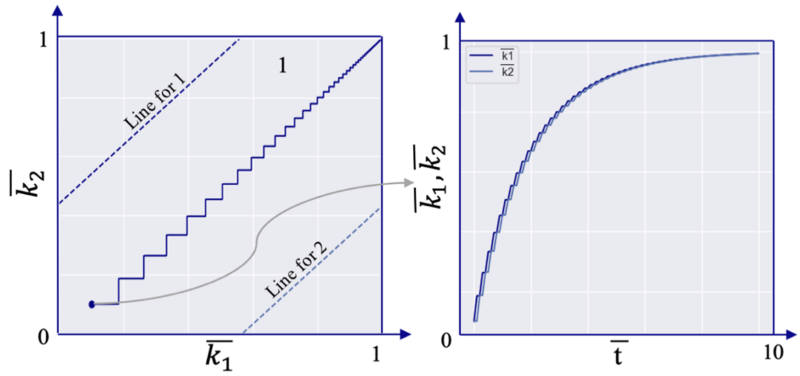


Fig. 6. A mode with two-variant development

movement of the image point on the phase plane and in time. The dotted lines show the switching thresholds for $\overline{k_1}$ and $\overline{k_2}$.

1. Scarlett, being brave and determined, immediately recognizes the danger and instantly switches to action. She quickly gathers the necessary things for herself, Melanie and the children, leaving everything superfluous behind. Calling everyone to gather together, she heads to the nearest shelter or place where they can find protection from fire and war. This behavior would be typical for the heroine in the case of a null isocline arrangement, as shown in Fig. 6, with a zone where there are no thresholds for a two-variant development of events, which is also shown in Fig. 5, *a* (zone 1). Calculations in Fig. 6 were performed for the following system parameters: $T_1 = -11$; $T_2 = -17$; $\overline{\gamma_{11}} = 30$; $\overline{\gamma_{22}} = 25$; $\overline{\gamma_{12}} = 30$; $\overline{\gamma_{21}} = 25$; $\varepsilon = 1$.

2. When the position of the null isocline changes, the external environmental conditions in which the living system is located, respectively, and its state also change, which leads to a change in its behavior. In Fig. 7 shows a zone with a two-variant development, but with a transitional mode, which also corresponds to Fig. 5, *c* (zone 1). In the novel «Gone with the Wind» the situation could develop as follows: initially, when Scarlett and Melanie are forced to flee with the children because of the war, Scarlett feels responsible for the safety of Melanie and the children. She strives to ensure their protection by assuming a leadership role in this situation. However, as the danger increases, their path becomes more dangerous, and Scarlett begins to realize that her own safety is becoming a priority. This episode could show the evolution of Scarlett's character, her ability to adapt to extreme circumstances and make difficult decisions in the face of danger. She goes through an internal conflict related to balancing between caring for others and caring for herself in a crisis.

Calculations in Fig. 7 were performed for the following system parameters: $T_1 = -13$; $T_2 = -15$;

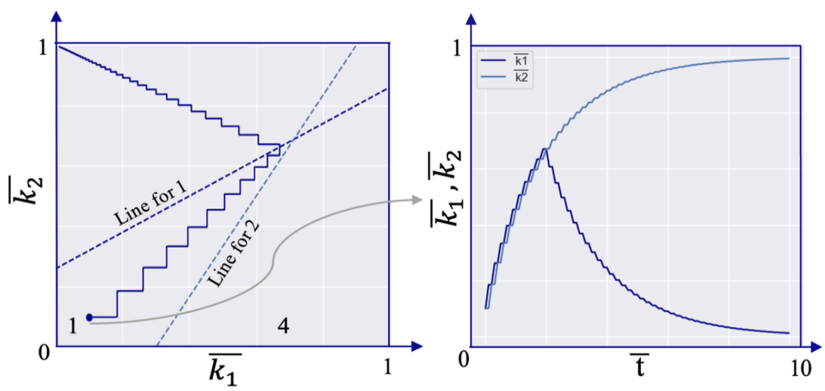


Fig. 7. The mode of transition from two-variant to one-variant development

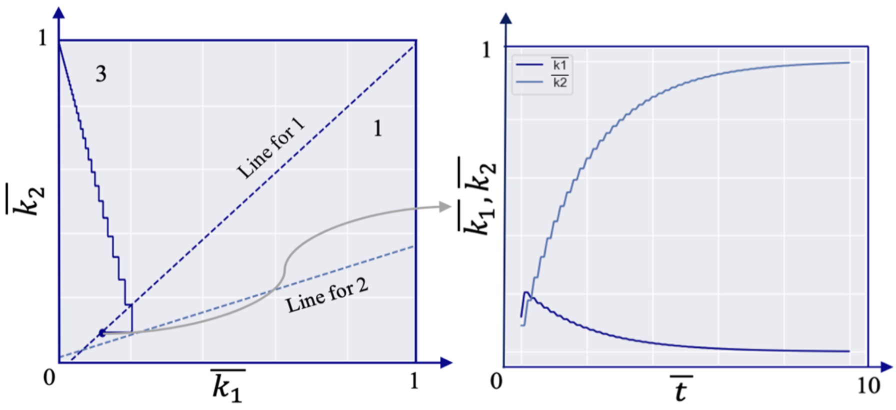


Fig. 8. A mode with a single-variant development, after overcoming the threshold

$\overline{\gamma_{11}} = 30$; $\overline{\gamma_{22}} = 30$; $\overline{\gamma_{12}} = 50$; $\overline{\gamma_{21}} = 50$; $\varepsilon = 1$.

3. In this case, Scarlett, who has a high self-protective reaction, decides to act on her own. She doesn't wait for help from Rhett Butler or anyone else, but quickly makes a decision about what needs to be done. Scarlett collects only the essentials and takes the children by the hand to make sure they are safe. She chooses the safest path and hurries with the children to the place she has previously identified as a shelter. A similar development of events is reliably described by the variant in Fig. 8, in which there is a sharp transition over the threshold.

Calculations in Fig. 8 were performed for the following system parameters: $T_1 = 1$; $T_2 = 1$; $\overline{\gamma_{11}} = 31$; $\overline{\gamma_{22}} = 85$; $\overline{\gamma_{12}} = 30$; $\overline{\gamma_{21}} = 30$; $\varepsilon = 1$.

4. Scarlett, initially experiencing panic and fear, finds herself paralyzed and unable to make a decision. She gets lost in her thoughts and can't focus on her actions. When Rhett Butler appears, Scarlett is inspired with hope for salvation from this terrible situation. Based on Fig. 9, we can say that the heroine was able to overcome the threshold of launching the algorithms $\overline{k_2}$ to start the action and came out of the «depressive» zone, where it is impossible to develop any of the given behaviors Fig. 5 from (zone 2). Scarlett begins packing the necessary things into the cart for Melanie and her newborn baby, taking care of them. This development of events exactly corresponds to what is described in the novel and reflects a realistic plot.

Calculations in Fig. 9 were performed for the following system parameters: $T_1 = -1$; $T_2 = -1$; $\overline{\gamma_{11}} = 30$; $\overline{\gamma_{22}} = 30$; $\overline{\gamma_{12}} = 50$; $\overline{\gamma_{21}} = 50$; $\varepsilon = 1$.

Studying possible scenarios for the development of the plot, we see that a change in the position of

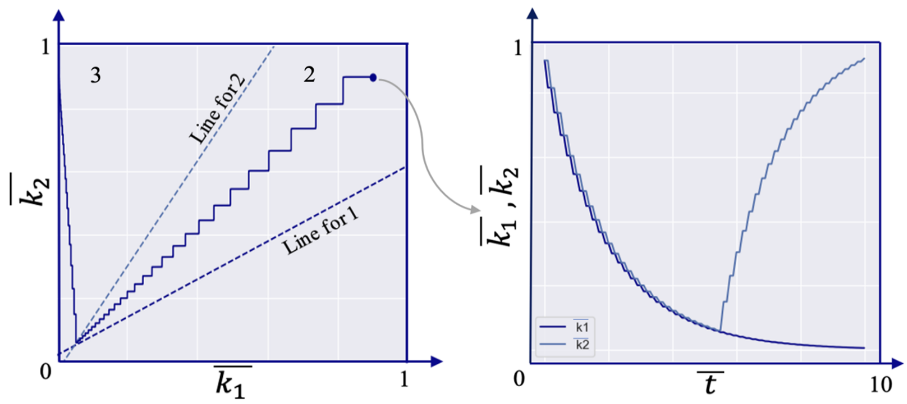


Fig. 9. A mode in which the possibilities for the development of both behavioral options are initially reduced. After overcoming the threshold, the system enters a single-variant development

the null isoclines and the initial state of the living system could lead to a change in the course of events in the novel. These changes in switching thresholds (depending on the reactions of perception through the «imaginative» channel, emotional state, current energy supply) could influence the choice of behavior of the main character.

Summary and conclusions

Thus, the conducted review allows us to draw the following conclusions.

1. Based on the physical research methodology, it is possible to propose a variant of the transition from hierarchical control schemes to a simplified basic model in the form of differential equations, which make it possible to consider the dynamics of the acquisition or loss of individual experience in living hierarchical systems through a change in the number of algorithms involved in this process.

2. It has been demonstrated that these types of equations adequately describe not only experimental data related to teaching children bilingualism [12, 13], but are also applicable to a wider range of descriptions of multitasking modes of functioning of living systems (they contain at least eight types of modes of functioning). The demonstration of an adequate description of the processes of switching between two modes of functioning of a living system was performed using the example of episodes from the literary work «Gone with the Wind» [18]. The results obtained lay the foundation for creating versions of simplified languages that explain the variety of dynamic modes in hierarchically organized recognition systems when they alternately solve various types of tasks.

3. There are various methods for generating versions of simplified models and their corresponding languages for describing switching modes in live systems. For example, the approaches developed by M. I. Rabinovich [23, 29], V. A. Lefevre [24, 25] and his students [26], are focused on simplified models and their corresponding description language. This paper presents a new approach to the description of multitasking modes (various operational actions) in living systems using mathematical modeling based on the functional system of P. K. Anokhin. The high effectiveness of this approach has previously been shown in the analysis of experimental data observed in teaching children bilingualism [12, 13].

The simplified model description is aimed not only at a better understanding of data on the behavior of living systems, but also opens up, in our opinion, new horizons for analyzing and predicting their functioning in various conditions. Working with such mathematical models will contribute to the formation of a language for describing the switching mechanisms used by living systems in solving situational tasks. In the future, it will be possible to conduct a comparative analysis of the results obtained here, in [12,13] and, for example, in [23–26,29], to find out how different initial basic approaches affect the features of the previously described descriptions. Due to the volume of such consideration, we are forced to leave such a comparison outside the scope of this article.

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