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# DIALECTICS OF COMPLEXITY, EMERGENCE AND MANAGEMENT

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**Abstract**

The article is devoted to the dialectical analysis of such fundamental essences of modern organizations as complexity, emergence and management. It considers approaches to the quantitative assessment of complexity as a constructive feature of the system, while drawing attention to the fact that complexity is a direct result of the development of the system's ability to adapt. The appearance of emergent properties in an organization is accompanied by an inevitable increase in its complexity. This growth should be controlled and regulated, and the level of emergence of the organization should correspond to the complexity of the environment. The more uncertainty needs to be eliminated, the more complex the organizational system becomes. From the authors' point of view, the dialectic of entropy, complexity and emergence is as follows – strengthening the emergent properties of a set of elements requires minimizing entropy. In its turn minimizing entropy requires purposeful restriction of the freedom of system elements behaviour, which is provided by embedding into the system of managing elements and organizing the necessary set of connections, and that leads to an increase in the complexity of the organization.

*Keywords*: organisational system, complexity, emergence, nonlinearity, entropy

## 1. INTRODUCTION

The most important problem of modern management theory and practice is the problem of increasing complexity of organizations (Simpson, 2015; Worren, 2018; Fu et al., 2021; Reeves et al., 2021; Derkatsch et al., 2022). In a recent survey of CEOs of large companies around the world conducted by the Economist Intelligence Unit (EIU), more than half of respondents stated that complexity had reduced their profits over the past three years. Moreover, 38% of all respondents report that managing complexity took up 16-25% of their time - time that could have been spent on more

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productive activities. 17% of respondents spend a whopping 26-50% of their working day solving complex tasks (Simpson, 2015). The organization becomes so large that it becomes difficult to control and manage it: a quarter of the managers' time is spent struggling with complexity, trying to comprehend phenomena, processes, structure and causes, before they could actually proceed to making managerial decisions. Basically, all the works devoted to organizational complexity are aimed at overcoming it (Espejo, 2015a,b; Espejo, 2018; Schott et al., 2020; Eloranta et al., 2021; Popov, 2022; Modarres, 2023). Often, studies of the complex systems concept concerned specific objects: multinational corporations, ecosystems, services, digital platforms, integrated software (Burnes, 2005; Phillips & Ritala, 2019; Eloranta et al., 2021; Son, 2022).

Companies take various steps to achieve the goal of overcoming complexity: they change development strategies, consciously limit business growth, reduce the size of the company (for example, by selling part of the business), reform organizational management structures, form cross-functional teams, introduce new methods and processes for making managerial decisions, etc.

History provides enough examples of the large socio-economic systems collapse after the uncontrolled growth of the complexity. In this regard the study of the historian and archaeologist Joseph Tainter (1990) "The Collapse of Complex Societies" is interesting. He concludes that all the known empires and civilizations of antiquity collapsed not despite the social organization level or complexity for its time achieved, but because of it.

The authors believe that before developing measures to overcome complexity, first of all, it is necessary to study the complexity of organizational systems in terms of their nonlinearity, instability, integrity and emergence. What is organizational complexity, what are its sources, how does it manifest itself, what should be done to overcome complexity, how to measure or evaluate the level of complexity? All these issues continue to be relevant and debatable.

The purpose of the research, the results of which are presented in the article, was a dialectical analysis of such fundamental essences of modern organizations as complexity, emergence and management, consideration of approaches to the quantitative assessment of complexity as a constructive feature of the system.

## 2. RESEARCH AND RESULTS

The level of emergence of the organization should correspond to the complexity of the environment. The environment should be ready to recept the organization's activities results. In simple terms, supply must meet demand, available goods and services must satisfy needs. Therefore, the emergence of organizational systems arises and develops in their interaction with the environment that is adequate to them in terms of complexity. Moreover, these systems are actually determined by the environment to which they adapt and at the same time form this environment themselves in the process of adapting to it.

Some scientists (e.g. Holland, 1995; Rostami & Bucking, 2021; Skowroński, 2022) believe that the complexity of systems is a direct result of their ability to adapt in process of development. The more adaptive the system is, the more complex it is and vice versa.

Aggregation is associated with the transformation of several agents well-adapted to each other and involved in the formation of a complex system by their deep consolidation till creation the essence of a single agent and complete loss of such agency properties as autonomy, adaptability, self-directivity, self-sufficiency, and discreteness. The appearance of an aggregated agent in the system, as a rule, is associated with the creation of a higher level of organization, i.e., a radical restructuring of the entire system.

The non-linearity of the interaction between the elements (autonomous agents) reflects its complexity and unpredictability. The nonlinearity is connected both with the threshold sensitivity to perturbations and with the possibilities of the proliferation of small fluctuations in the state of instability. It can be characterized by periods of both linear and nonlinear interactions. For a certain period, the behaviour of the system may demonstrate linearity, and then suddenly the relations between the variables may change and lead to abrupt changes in behaviour. Such behavioural jumps are commonly called “bifurcations”.

Studies of the nonlinearity of the systems behaviour allowed us to determine the type of its time modes: (1) convergence to an equilibrium or steady state, (2) periodic behaviour or steady oscillation, (3) chaotic behaviour. The most widely used mathematical formula for these three behavioural modes is a first-order nonlinear differential equation called a logistic mapping[1] (Alligood et al., 1996; Fonseca Albuquerque Cavalcanti Sigahi, 2021; Pavlov & Micheli, 2022). This mapping looks like this: $x_{(t+1)}=kx_t\ (1-x_t)$. Here, the variable $x$ takes values from 0 to 1. The physical meaning of this variable is determined by the nature of the displayed process. For example, it can be the price of a product that is formed in the market. The value $x_0$ indicates the initial price at time 0, and the value $x_t$ indicates the price at time $t$. The positive parameter $k$ characterizes the rate of price change.

The nonlinear process described by the logistic mapping will converge to a stable equilibrium state if the values of the growth parameter $k$ are in the range from 0 to 3. At values of the growth coefficient $0>k\geq1$, the value of the variable $x$ will sooner or later become equal to 0 and the process will stop. If we are talking, for example, about the market prices, it means that the customers will simply stop buying the product. For the values of the growth coefficient $1>k\geq2$, the value of the variable $x$ will sooner or later enter the steady mode $x=(k-1)/k$. For values of the growth coefficient $2>k\geq3$, the value of the variable $x$ will also sooner or later enter the stationary mode $x=(k-1)/k$, but this will happen after a series of fluctuations around a stable trajectory.

The second type of nonlinear behaviour that can occur is periodic behaviour. The periodic behaviour is a cyclic or oscillatory behaviour, and it occurs at $k>3$. This mode reflects the instability that appears during the operation of the system. Such a change in the quality of the behaviour of a time series is called a bifurcation or branching to a new mode of behaviour. The changes in the values of $x$ at $k$=3,05 represent a two-period cycle, fluctuating between the values of 0.5+ and 0.7+. At $k$=3,5, a four-period cycle occurs, in which already four values of $x$ are alternating, and at $k$=3,567 an eight-period cycle appears, in which eight values of $x$ are

[1]Other names for the same equation are the quadratic map or the Feigenbaum map.

alternating. The greater the value of the growth coefficient $k$, the higher the frequency of fluctuations of the process.

The chaotic behaviour of the variable $x$ occurs at values of $k$ from 3.8 to 4. This nonlinear mode represents another clear bifurcation, or qualitative change in the behaviour of the system. The different values of $k$ provoke different forms of chaos. The closer the value of the growth coefficient $k$ to 4, the more unexpected the form of the process fluctuations becomes.

Chaos is distinguished from other modes of nonlinear behaviour by the absence of any periodicity of changes that can be determined. This can be judged by the shape of the curve and by carefully considering the decimal places in the values of $x_t$. It should also be noted that the chaotic behavior remains within the defined parameters. And although it may seem that the chaotic behaviour is accidental, it is absolutely not so. Chaos is generated by a completely deterministic equation, which, in fact, sets the rules for changing a variable. In everyday life, this means that deterministic rules can lead to chaos.

The nonlinearity in complex systems also means that such systems are very sensitive to even a small change in the parameters of their functioning. This can be demonstrated by comparing three time series of the parameter $x$, which are formed with very minor changes in the starting conditions. The initial value of the parameter $x_0$ changes by only one millionth of a fraction, and from a certain moment the parameter $x$ begins to behave in a special way (Figure 1).

Any of the modes of nonlinear behaviour of a complex system described above may appear not immediately, but after a certain time. The main problem is that it is almost impossible to establish causal relationships between the level of regulatory parameters

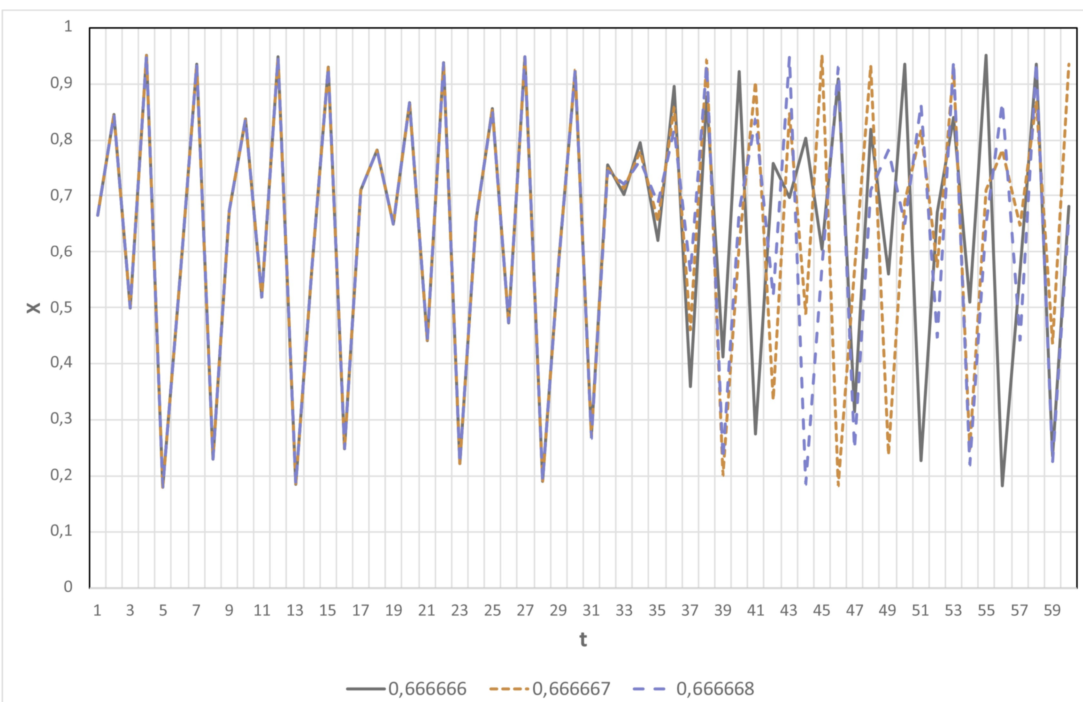


*Fig. 1. The value of the variable x at x_0={0,666666;0,666667;0,666668} k=3,8*

and the result of the behaviour of a complex system. The effect seems unexpected, random. In socio-economic practice we very often face completely illogical consequences of decisions aimed at material incentives for employees. For example, the rate of wage growth, starting from a certain level begins to slow down the growth of labour productivity.

## 3. DISCUSSION

If there is chaos, then there must be order. The creation of order is associated with the formation of complexity.

Diversity as a property of a complex system inevitably arises in the desire of aggregated elements to form completely new, emergent properties that provide them with a stable position in the environment in which they exist and function. The greater the variety of system elements and forms of their behaviour, the wider the variability of the appearance of emergent properties. This is pure combinatorics. However, out of all the abundance of possible combinations of connections and dependencies, the system must "choose" exactly the one that leads to achieving the desired state, to obtaining the desired result. For this, it is necessary to limit the elements in their choice of possible states. That is why, axiomatically, management is the form of activity in the organizational system that is aimed at limiting the freedom of choice of people who are employed in a certain organization and are integrated into the process of creating a certain emergent value. The greater the complexity of the organization, the greater the variety of methods and means of managing actions used in this process.

Any managing action is expedient and makes sense only when it unambiguously determines the actions of the performer, i.e., reduces the uncertainty of the subordinate's behaviour to 0. Otherwise, i.e., in the case of ambiguous regulation, the governing body is unable to either guarantee the transition of the managed object to the required state or evaluate the effectiveness of the performer's actions. But how possible and feasible is unambiguous regulation in general? What determines how the governing body restricts the space of the managed object states, actually reducing it to an obvious option? It is one case when the space of behavioural states of the managed object is known and can be analysed from the point of view of possible outcomes. Absolutely another case is when there is a probability for the occurrence of an unexpected state. It is difficult to imagine the dynamics of the change of integrated into the system states, interconnected and directly or indirectly interacting elements, otherwise than as a network (Figure 2).

The network shown in Figure 2 reflects the alternativeness of object transitions from state to state. In this example, the space of possible states $S=\{s_1,s_2,s_3,s_4,s_5,s_6,s_7,s_8\}$. If there is no additional information about the probability or conditions of the transition of an object from state to state, then it can be assumed that alternative transitions are equally likely. The total entropy of such a system counted basing on the matrix of states will be equal to 6. If the probability distribution of an object transition from the state $s_i$ to the state $s_j$ is additionally known (Figure 3), the total entropy of the system will be equal to 4.9.

It is obvious that the possession of even primary information, which only probabilistically characterizes transitions from state to state, significantly reduces the uncertainty of the object's behaviour. At the same time, even a small uncertainty does not guarantee the transition of the object in the end to the required (target) steady state, and even more so does not guarantee a certain sequence of changes of such states.

In Figures 2 and 3, the oriented arcs indicate the presence of transitions between the states of the object, but there are no transitions themselves as intermediaries between the states. At the same time, transitions are also integral elements of the object's behavioural space since they can and should be qualified as transitional states. The regulation of the object's behaviour occurs through the impact on its transition states.

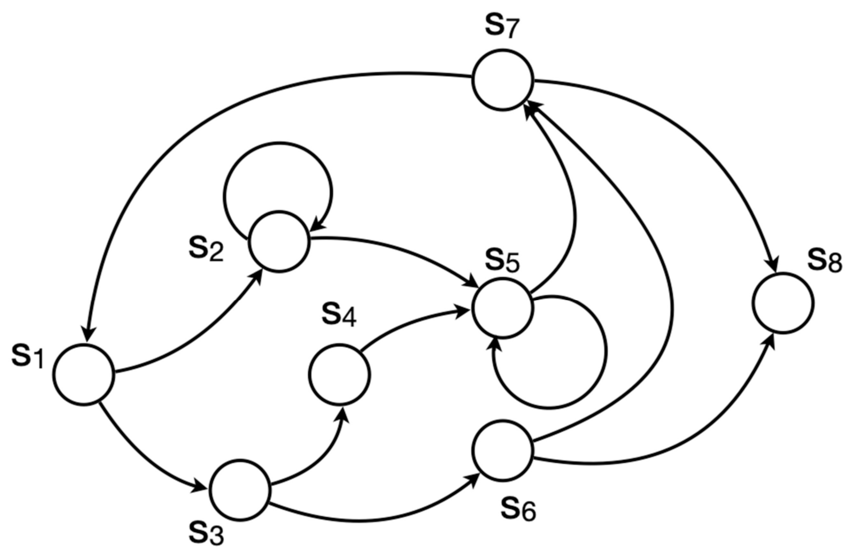


*Figure 2. Dynamics of the change of states integrated into the system*

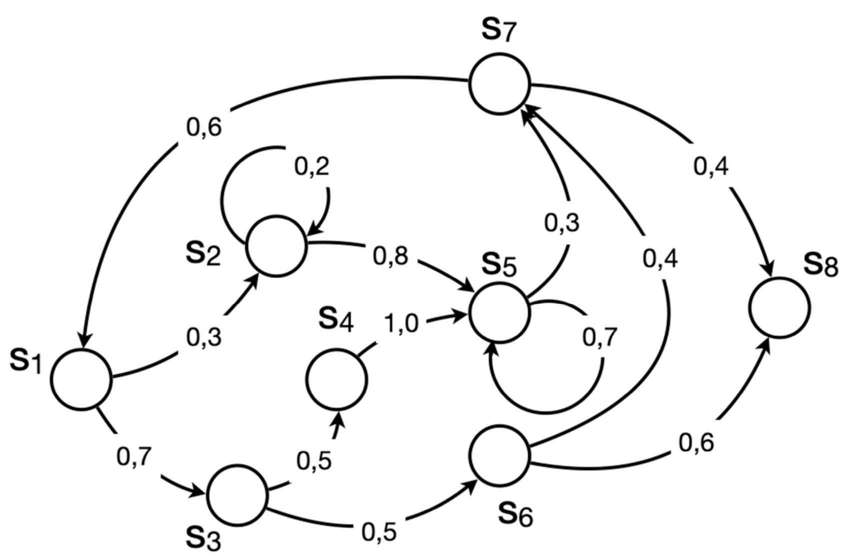


*Figure 3. Dynamics of the change of states integrated into the system, indicating the probability of the object's transition from state to state*

Regulatory actions as impulses should also be considered as elements of the object's behavioural system, since it is with their help that the correct line of behaviour of the object can be achieved, and this will be expressed in the fact that the states of the object replace each other in the correct sequence. Then, in the example considered above, the space of possible states $S=\{s_1,s_2,s_3,s_4,s_5,s_6,s_7,s_8\}$ should be supplemented with a set of states that have a catalyzing effect in one case, and an inhibitory effect for certain transition states in the other $SU=\{s_1,s_2,s_3,s_4,s_5,s_6,s_7,s_8,u_1,u_2,u_3,u_4,u_5,u_6,u_7,u_8,u_9,u_{10},u_{11},u_{12},u_{13}\}$ .

In addition to the set of steady states, you need to specify a set of transition states $T=\{t_1,t_2,t_3,t_4,t_5,t_6,t_7,t_8,t_9,t_{10},t_{11},t_{12},t_{13}\}$. Then the state space network shown in Figure 2 should be transformed into the network shown in Figure 4.

In order to display the achieved states, it is customary in graph theory to mark vertices. It is possible to label both stationary states $\{SU\}$ and transition states $\{T\}$, however, marking the transition state is advisable when it is important to consider the duration of the transition. The marking is displayed by tokens at the corresponding vertices of the object's state graph, as shown below in Figure 5.

Consideration of the transition states $\{T\}$ along with marking the achieved ones allows us to accurately assess the regulating influence of managing impulses on the behaviour of the object. Figure 6 shows how the studied object will behave (in the sense of changing its state) if the initial marking of the vertices of its graph is the same as shown in Figure 5.

Three circumstances should be noted. First, the behaviour of such an object will be completely deterministic, in other words, the alternativeness of transitions from state to state is excluded, and in this case, we can say that labelling a subset of managing states $\{U\}$ has an unambiguous regulatory effect

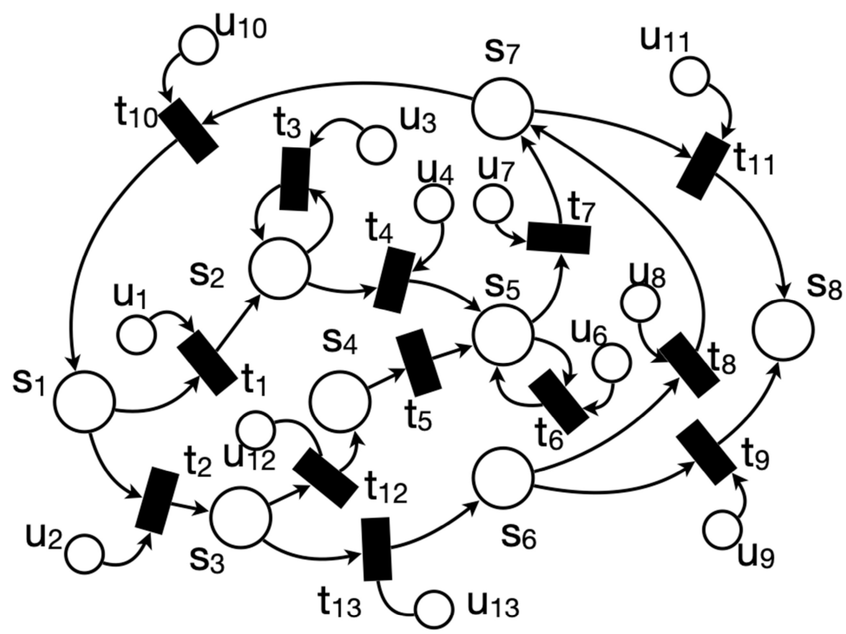


*Figure 4. Graph of object states*

on the behaviour of the object. The initial labelling of the vertices of the state graph turns out to be uniquely sufficient for the beginning of the transition state $t_1$, which transfers the object from the stationary state $s_1$ to the state $s_2$. Once in the state $s_2$ under the managing action $u_4$, the object is in the transition state $t_4$, which transfers it to the state $s_5$. This state turns out to be terminal for the object as there are no sufficient conditions for any other transition. In particular, either the transition state $t_6$ or $t_7$ could occur, but the corresponding managing actions $u_6$ and $u_7$ act as inhibitors, restraining the beginning of these transitions, which is displayed on the graph by the absence of markings at the corresponding vertices.

Secondly, it is easy to count that the presence of an object managing system through regulating its transition states reduces its entropy to 0.

The third circumstance that should be noted is related to the price at which it is possible to reduce the uncertainty of the object's behaviour to zero. This price is the increase in the complexity of its organization. Even a visual comparison of the representation of the system in one case

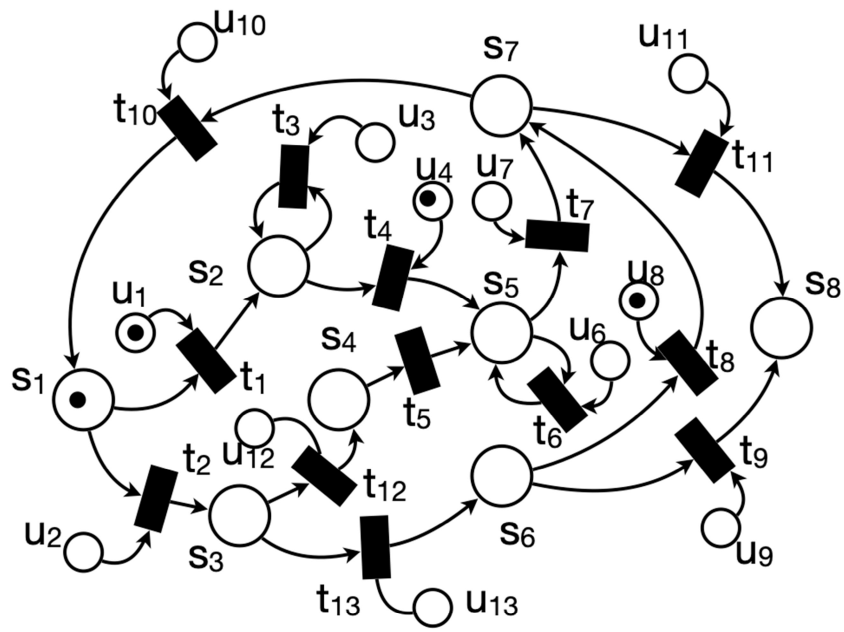


*Figure 5. A labelled graph and a vector of labelling states of an object*

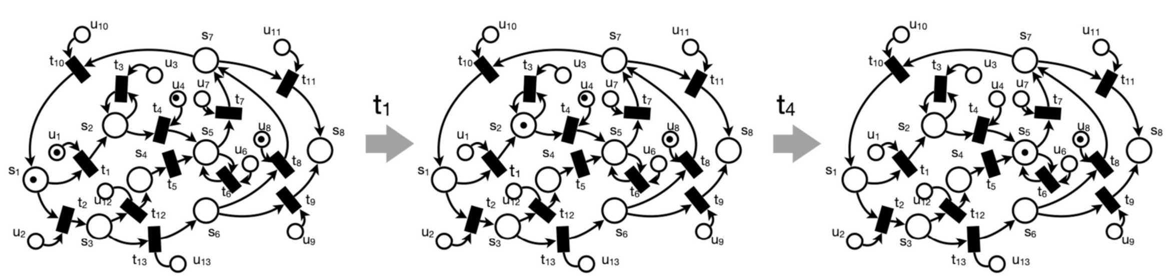


*Figure 6. Display of the change of object states on the marked graph*

using a simple one-sided oriented graph (Figure 2) and in the other using a labelled bipartite oriented graph (Figure 5) gives reason to conclude that in the second case the system is organized much more complex.

The obvious conclusion is that guaranteed receipt of the desired state (result) requires removing the uncertainty of the transitions of the system (system elements) in the space of states. This is ensured by changing the organization through including managing elements in its structure. As a consequence, the number of connections increases sharply, although the entropy of the system also sharply decreases. That is the dialectic of entropy, complexity and emergence: to strengthen the emergent properties of a set of elements it requires of minimizing entropy, to minimize the entropy it requires purposeful restrictions of the freedom of system elements behaviour, which is achieved by embedding of the necessary set of managing elements into the system and organizing the necessary set of connections and leads to an increase in the complexity of the organization. Bipartite oriented marked multigraphs, which, as was shown above, are quite well suited for displaying not only steady, but also transition states of the system and make it possible to regulate the properties and behaviour of the modelled system managing elements, are in fact Petri nets.

An object can move from one state to another under certain circumstances. There can be many states, both stationary and transitional, but the object remains an integral entity. Fortunately, the formalism of Petri nets makes it easy to transform the representation of an object as a dynamic space of connected states into its representation as an integral entity with a space of states. Figure 7 shows how the network from Figure 5 can be transformed so that it corresponds to one integral object with many states.

In Figure 7, the object entity corresponds to a single position in the centre (a red circle). Marking this position $s_1$ means that the initial state of the object is exactly the state $s_1$. The transition states $T=\{t_1,t_2,t_3,t_4,t_5,t_6,t_7,t_8,t_9,t_{10},t_{11},t_{12},t_{13}\}$ in

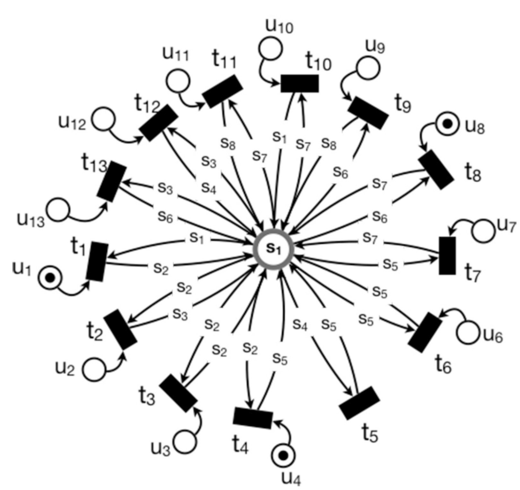

*Figure 7. Representation of an object in terms of Petri nets as an integral entity with a space of states*

the form of transition vertices display how and under what circumstances the change of the object states occurs. These states define a boundary of the object integrity, beyond which its emergent properties disappear. The managing elements $U=\{u_1,u_2,u_3,u_4,u_5,u_6,u_7,u_8,u_9,u_{10},u_{11},u_{12}, u_{13}\}$ are the elements of the space of states of the managing subject external to this object. They serve as the necessary circumstances for the object transition from one state to another.

The definiteness and finiteness of the space of states of any system depends on the presence and nature of its boundary. The boundary of the system is understood as such ways of its isolation from the external environment and connections with it (like a membranes), which provide it with the maintenance of its identity, the preservation of the internal structure. The boundary can be stationary and impenetrable, or vice versa mobile and permeable, but in any case, it is the presence of a boundary that is a necessary condition for the appearance of structural and operational combinations that lead to the fact that integrity with emergent properties occurs. The boundary is necessary not for just isolating a certain set of interrelated and interacting structural elements (for example, employees, if we are talking about an organization), giving it some distinctive features in the external environment. This boundary is necessary to prevent the destructive influence of inflows of matter, energy, and information from the external environment on organization's internal processes. The results of internal processes are precisely those products produced by the system that determine its features, distinctive (emergent) properties, place and role in the world.

## 3. CONCLUSION

The emergent features of an organization are inevitably accompanied by the increased complexity. This growth must be controlled and regulated, otherwise the organizational system becomes so inert that any adaptation processes in it simply fade away as soon as they begin. The complexity of systems is a direct result of the development of their ability to adapt. The more adaptive the system more complex and vice versa. Simple systems have less possibility to adapt to external environment changes.

It is vital that the level of emergence of the organization corresponds to the complexity of the environment. The results of the organization must be accepted by the environment, so the environment should be ready to them. In this case supply meets expectations, goods and services are able to satisfy needs. Therefore, there are deep connections and interaction between the emergence of organizational systems and the environment which is suitable to them in complexity.

The design of a system that has the ability to adapt for objective reasons cannot be simple in terms of the number of interacting elements and their diversity. Organizations actively adapt to changes in their environment primarily because these changes affect the interests of their employees. The employees are the first who react to external changes, thereby they are changing the behaviour of the organization as a whole. The management of the organization must catch these signals and rebuild the organization in time so that the process of its functioning as a system leads to the achievement of common goals.

Management of the system must bring its behaviour into a certain order, associated with limiting the freedom of its choice of a sequence of states to form integrity (emergence) and leads to an inevitable complication of the system organization. The more uncertainty needs to be eliminated, the more complex the organizational system becomes, which is associated with an increase in the number of interacting elements, their steady and transition states, the number of managing states and connections between all states. This is ensured by including managing elements into the system structure and therefore changing its organization. As a result, the number of connections rises dramatically, although the entropy of the system also decreases sharply. This is the revealed dialectic of entropy, complexity, and emergence: strengthening the emergent properties of a set of elements requires minimizing entropy, in its turn minimizing entropy requires purposeful restriction of the freedom of system elements behaviour, which is provided by setting the managing elements into the system and organizing the necessary set of connections. That obviously leads to an increase in the complexity of the organization.

The growing complexity of organizations makes them not only less manageable, predictable, and stable in conditions of external uncertainty, but also reveals a number of objective contradictions between the fundamental provisions of the classical theory of management and the real management practice. These contradictions are both system-wide and at the level of individuals. For example, at the system level there is a contradiction between the theoretically required functional limitation of the employee's area of responsibility and the real situational uncertainty at the moment of decision making.

At the personal level, there is an increasing contradiction between the level of economic motivation of employees required for effective work and the economic interests of the system, between the principles of command unity and accountability and the requirement of initiative, etc. Such contradictions indicate the presence of theoretical and methodological problems in management. They have become most clearly manifested precisely in modern conditions with the transition of developed economies to a new organizational and technological structure. The understanding of such contradictions makes us turn to the basic concepts and statements of the general theory of management in order to critically assess the degree of their compliance with modern conditions. Further research should be aimed at proving the need and determining the theoretical prerequisites for the formation of a new management paradigm for modern organizations which are complex socio-economic systems, based on the principles of managing the context of the organization.

For any organization a reduction in profitability especially due to external reasons beyond its control, is a stress to which the natural and expected response would be to simplify its system and reduce the corresponding costs. In this regard, managers may prefer simplicity to complexity, but the truth is that complexity is becoming more and more necessary for viability and competitiveness in today's dynamic, unpredictable business environment. This can be easily explained by the following facts - companies have an increasing clientele, an expanding range of products and services, an increasing intensity of interaction between the employees, and hence the rising productivity, an increasing number of regions in which the company operates, etc., i.e., its characteristics, on which the profitability depends, are improving. In this sense, the increasing complexity of organizations looks not only inevitable, but also obviously useful. If we try to imagine the process of simplifying the company, it will most likely be associated with the loss of its emergent properties as a whole in the process of narrowing of the range of manufactured goods and services, compression of sales markets, simplification of production technology, reduction of personnel qualifications, etc. In fact, if some part is taken away from the whole, then the remaining whole will have different properties. Therefore, maintaining complexity within a certain framework remains an urgent task that requires compromises and further research.

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# ДИЈАЛЕКТИКА СЛОЖЕНОСТИ, НАСТАНКА И УПРАВЉАЊА

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**Извод**

Чланак је посвећен дијалектичкој анализи таквих фундаменталних суштина савремених организација као што су сложеност, настанак и управљање. Приступе квантитативној процени сложености разматра као конструктивну особину система, при чему скреће пажњу на чињеницу да је сложеност директан резултат развоја способности система за прилагођавање. Појаву насталих својстава у организацији прати неминовно повећање њене сложености. Овај раст треба контролисати и регулисати, а ниво настанка организације треба да одговара сложености окружења. Што више неизвесности треба да се елиминише, организациони систем постаје сложенији. Са становишта аутора, дијалектика ентропије, сложености и појаве је следећа – јачање насталих својстава скупа елемената захтева минимизирање ентропије. Заузврат, минимизирање ентропије захтева сврсисходно ограничавање слободе понашања елемената система, што се обезбеђује уграђивањем у систем управљачких елемената и организовањем потребног скупа веза, а то доводи до повећања сложености организације.

*Кључне речи*: организациони систем, сложеност, настанак, нелинеарност, ентропија

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