IN-DEPTH EXPLORATION OF SYSTEMS THEORY PRINCIPLES: THE EMERGENCE OF SELF-PERFECTING SYSTEMS

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1. Introduction

Systems theory is an interdisciplinary theoretical framework that seeks to explain the behavior of any system found in nature, society, and various scientific fields. Systems thinking, as a key aspect of systems theory, involves shifting focus from isolated, individual parts to the broader context of the entire system

The systems approach asserts that a complex phenomenon cannot be fully understood if it is broken down into its constituent parts and analyzed independently. Instead, it is important to consider the relationships between the parts and the events that shape those relationships, as this is key to understanding how the system functions as a whole. While analyzing a system can start by examining its constituent elements, to grasp the processes at work, one must consider the system's behavior from a higher level. [Mele, Pels and Polese, 2010], [Bertalanffy, 1968]

Given the complexity of studying systems it is necessary to establish a certain technique of studying and managing system behavior.

Cybernetics is the science of the relationships within self-regulating systems. It studies complex, dynamic systems comprising subsystems and interconnected elements that are linked by causal relationships. Norbert Wiener, regarded as the father of cybernetics, was the first to demonstrate that control as a process obeys general laws, regardless of the nature of the control system, whether it is a mechanical or social system. Wiener proved that all systems, no matter what their origin, exhibit common regularities. Cybernetics can be said to be the science of the general principles governing various systems, specifically focusing on only those systems in which control occurs. [Wiener, 1948]

2. Basic concepts of general systems theory

2.1. System. Nature and definition

A system is called any finite set of interrelated objects that are considered as a whole. The connections between these objects can connect two or more elements, and the collective arrangement of these connections and elements defines the system's structure. The essential properties of a system emerge from the interactions between its elements, rather than the actions of individual elements in isolation. According to the general theory of systems, any object can be considered a system when analyzed in the context of a specific purpose. The term "system" has become increasingly prevalent in recent years due to the growing need to understand and manage complex systems. Given the complexity of studying systems, it's essential to establish specialized techniques for analyzing and managing their behavior.

A system is more than just a collection of individual components, it also encompasses the relationships and connections between these components. The introduction of even a single new element into the system can result in a change in its overall behavior or in some of its individual elements.

2.2. Structure of the systems. Elements of systems

Any system is a complex arrangement of evolving subsystems that are interconnected. On the one hand, each system can be viewed as an element of another system of higher rank, and on the other hand, the elements of each studied system can be considered as separate smaller systems or subsystems.

The smallest structural unit within a system is an element, which is indivisible in the context of that system and performs a specific function. Although they may be complexly arranged, they cannot be further divided within the system.

All characteristics of a system can be described thanks to its elements, their properties and relationships. The primary elements used to define

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any system are input, output, process, feedback and environment. These elements have fixed positions within the system and enable analysts to design and work with the system more effectively. [Karlekar, Palshikar and Talik, 2015]. Each system consists of several key components:

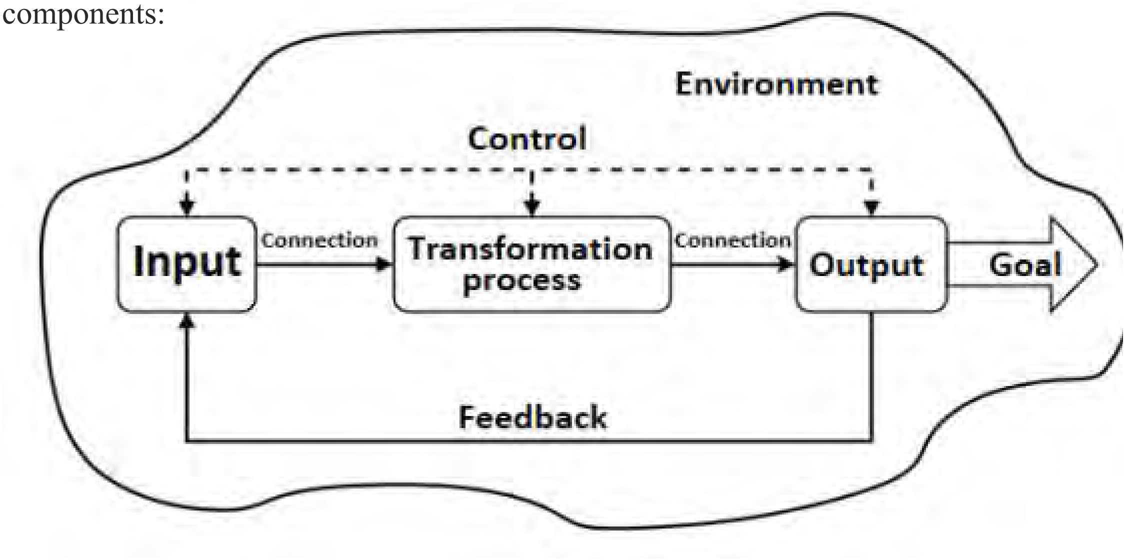

Fig. 1 - Main elements of the system

- <u>Input</u> - Refers to a specific component or components within a system where incoming information is collected. For a system to function, it requires a certain amount of information to be introduced through its input component. Any change to the input data will result in a change to the output data of the system.

- <u>Output</u> - Refers to the result produced by the system after completing its action. The output brings together all the elements of the system by which it influences its environment. The input of a system can serve as the output of a previous one, while the output of the current system can become the input of a subsequent one. The input and output are situated at the system's boundary and can function as the output/input of a preceding/succeeding system.

- <u>Transformation process</u> - Refers to the component that processes the information received through the input element, transforms it and parses it to the output element. It is responsible for all information transformations within a system, taking into account the influence of the environment. Any system functioning requires processing input parameters, taking into account the environmental influence and transforming them into output information.

- <u>Goal</u> - Every system has one or more purposes formulated during its construction. The purpose defines the reason for the system's existence and provides a starting point to measure its successful operation. [Davidov, Panayotova and Dyankov, 2017]

- <u>Control</u> - Refers to an essential component that evaluates the efficiency of system activities between its input and output. It acts as a monitoring mechanism that scrutinizes the transformation processes within the system and analyzes data from the output element. This ensures that the system achieves its objectives by regulating and measuring its performance. [Peneva, 2014] Complex systems are characterized by the absence of a single control body , the process of self-control and self-organization is inherent to them .

- <u>Connections and information flows</u> - they are integral components of any system. Each system receives, processes, analyzes, and interprets information from its input element or environment. Every connection between the elements in the system represents a distinct information flow. The combination of various connections and elements ensure the proper functioning of a system and reflect its properties. They characterize the structure and dynamics of the given system. The simplest connection between two systems is a series connection, where the two connected systems have one input and one output, with the input of the second being the output of the first. If we have a connection from one system to two other systems, each of which has one input and one output, then we have a distribution connection. The system is characterized by having one input but two outputs. When the first system has two inputs and one output, it is a joining connection. A combination of these connections can form parallel branching or parallel serial connections. Figure 2 graphically displays the main types of connections in systems.

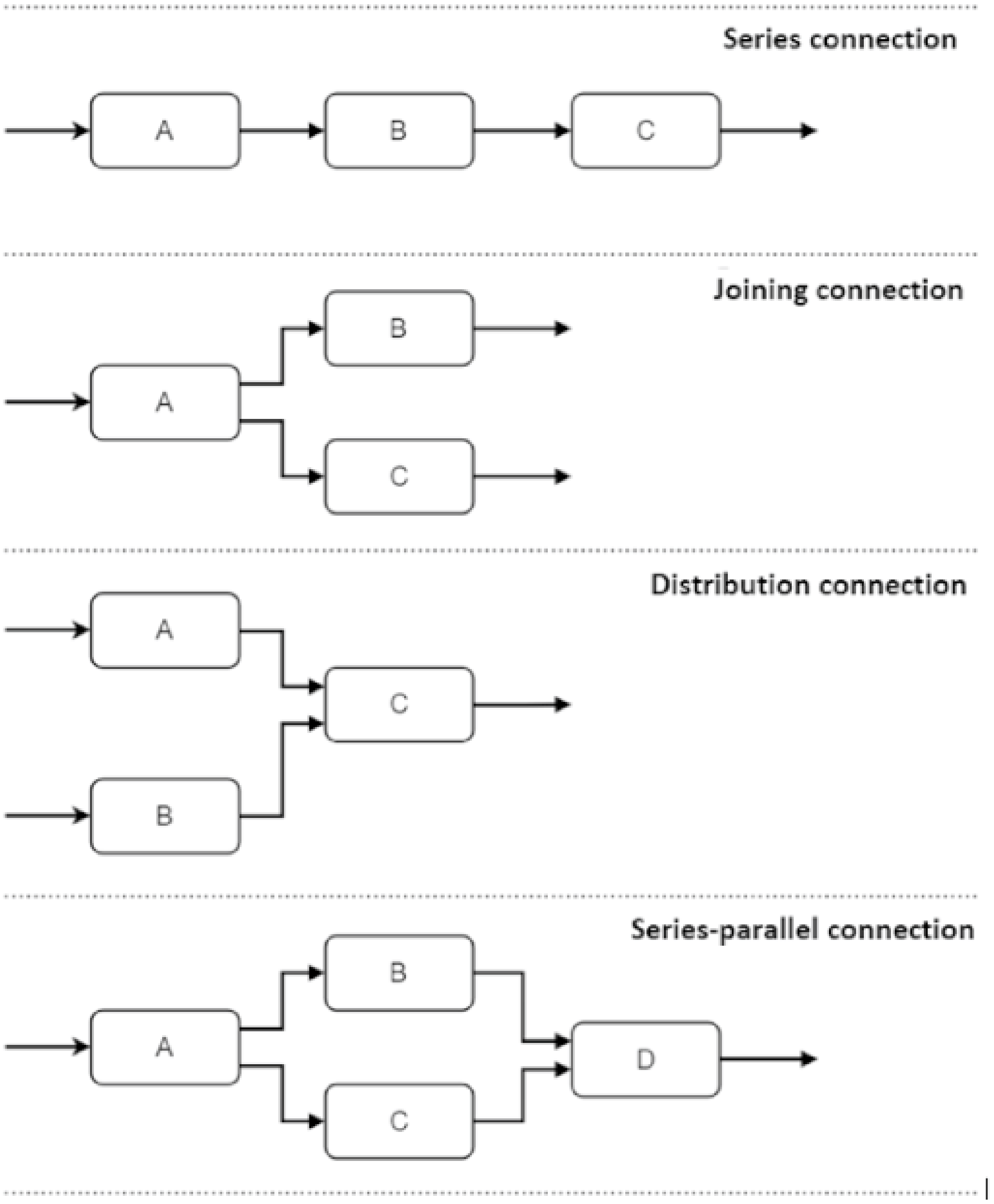

Fig. 2 - Types of connections

- <u>Feedback</u> - Refers to a type of connection that notifies changes in the system's state. Its primary function is to transmit information from the system's output to the control component. When the system goes outside the established limits, the feedback reports this occurrence, and corrective measures can be taken as needed. Simplified models of different types of feedback are presented in Fig.3.

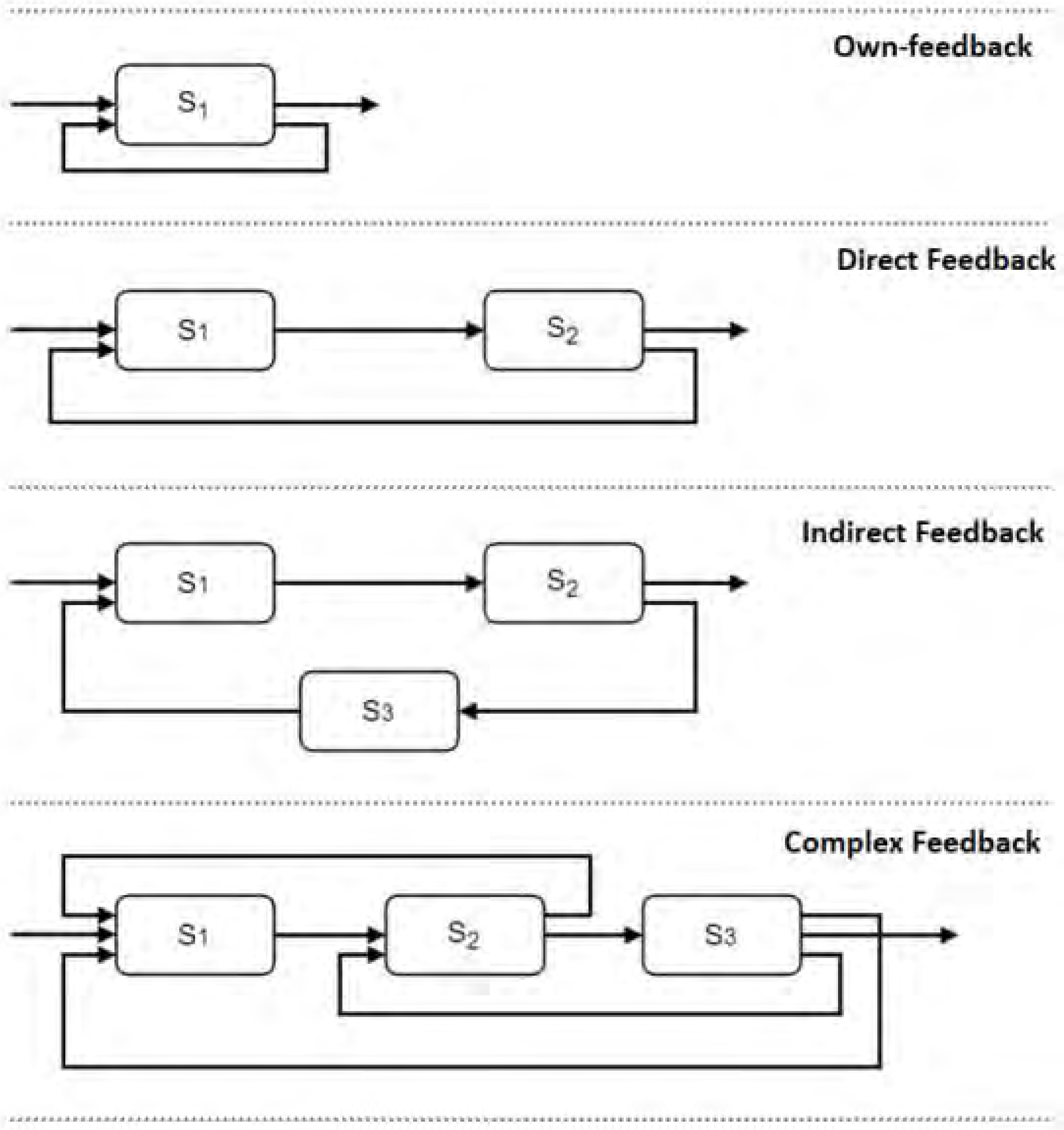

Fig. 3 - Types of feedback

- Environment - Complex systems are assessed based on their behavior within their environment. The system's scope, or what is included within its boundaries, determines its components, while everything outside it constitutes its environment. The change in the state of a system is often caused by the influence of various external factors that are in its environment.

3. General properties of systems

The components of a system determine its structure and its functioning. No matter how different they are, all systems have some common properties:

3.1. Unity

A system can be viewed as a unified entity limited in space and time. Depending on the research objectives, a system can be separated from other processes and phenomena through the use of established boundaries. Everything that falls within the boundaries of the system is part of it and is the object of study, and everything else - that remains outside the boundaries - is considered the environment. The components included in a system can vary depending on the study or examination's needs, with some elements being included for one study and different components for another. [Marchev, 2018-a]

3.2. Dissectability

A complex system is composed of interconnected elements, and it can be considered a black box in the research process. The researcher is interested in the inputs and outputs of the system under study, treating it as a whole unit. Any complex system can be considered a collection of simpler systems, and while the elements within the structure of a complex system are interconnected, none of them can describe the system's operation independently. The property of divisibility, or decomposition, involves breaking down a complex system into subsystems that can be studied independently. This approach helps to understand the interconnections between individual components and the overall operation of the system. In addition to the fact that any complex system can be divided into subsystems, it can also be viewed as a subsystem of a more complex one. The property of divisibility is extremely important in the study of complex systems. A good approach to studying their behavior is to initially divide it into simpler systems to model and subsequently combine them into a more complex model. [Agarwal and Mukkamala, 2005]

Modularity of systems follows from the decomposition property and is especially useful when systems become too large to track all the connections between individual components. It is often more convenient to study the dynamics of a system by building a model. Building a model of the system can help researchers study its dynamics, but it must accurately reflect all the necessary connections, reproduce the system's properties, and provide new information about the system that can be used for extracting useful knowledge. [Ethiraj and Levinthal, 2004]

3.3. Emergence

The sum of the properties of the individual elements of a system is not equal to the properties of the system. The properties of a system cannot be fully explained by analyzing the properties of its individual elements. Although each element may have its own behavior, when combined with other elements, it produces a specific behavior of the system that cannot be predicted based on the behavior of each element viewed in isolation. This is referred to as an emergent property, which arises from the interrelationships among the individual elements. For example, the elements sodium and chlorine individually have certain properties, but only when they are combined does the saltiness property appear. Emergence can be considered as unexpected behavior that arises from the interaction between the individual components of the system and its environment. [Johnson, 2006]

3.4. Interconnectivity

A system is a complex composition of interacting elements.The structure and connections of the components result in a unified whole. All elements are interconnected through various links, and each connection represents the influence of one element on another. The change in any element solely affects its state, ultimately resulting in a change in the overall state of the system. The behavior of each element of the system depends not only on itself but also on the behavior of the other elements and the relationships between them. Even a small change can result in an overall change in the system's state. Every impact inside the system is reflected by some connection. Connections can be serial (direct), distributive, conjunctive, parallel-serial and inverse. [Dalkalachev and Nedelcheva, 2006]

4. Functioning of the systems. State and behavior of systems

Influenced by both the environment and their internal structure, systems often change their state over time. The state of a system at any given point in time is defined by the collective meanings of all the essential structural components. The behavior of a system is characterized by its various states and the changes that occur between them over time. While states are specific discrete moments in time, behavior refers to a period of time.

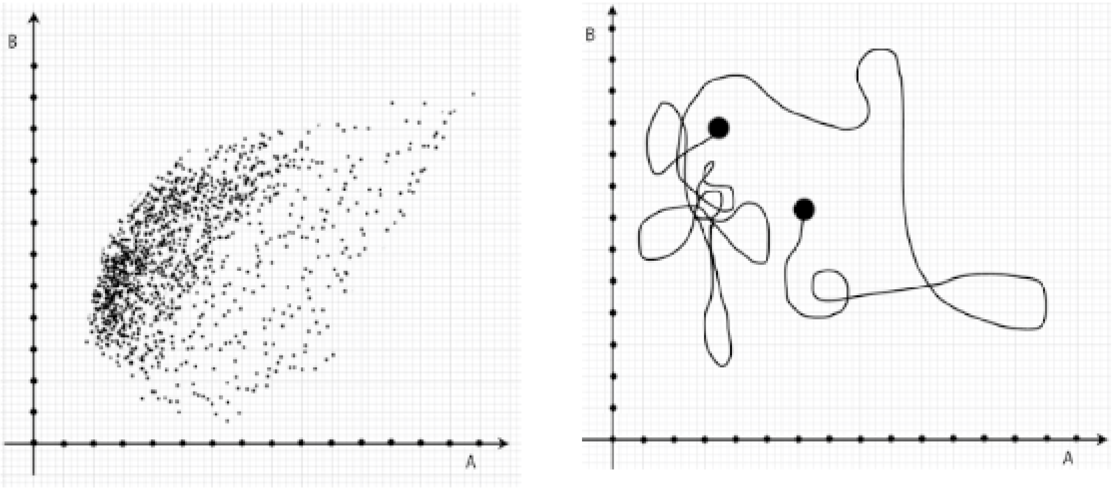

Fig.4. A. State space (left) and B. phase trajectory (right)

The behavior of a system is defined by successive changes in its states and transitions between them, which are influenced by factors such as the initial state, internal properties, and environmental conditions.The state of a system is not fixed and can change as essential variables evolve over time. In general, all essential variables of a system can change over time. [Marchev, 2018] The set of all possible states that can be obtained from an initial state is called the state space or phase space. The state space represents all possible states that a system can achieve, while a trajectory or phase curve illustrates its behavior over time. [Dalkalachev, Nedelcheva, 2006]

In conclusion, a system's behavior is shaped by the successive changes in its states and the transitions between them, which are influenced by both internal and external factors. The state space represents all the possible states a system can achieve, and a trajectory or phase curve represents the behavior of the system over time. A system's state is represented by a point, and its behavior is illustrated by a trajectory. The state space's dimensionality is equivalent to the number of independent variables that define the system's state. In most cases, the phase space is a multidimensional state space with n dimensions. [Dalkalachev, Nedelcheva, 2006]

The transition from one state to another is determined by several factors, including the initial state, external influences on the system, and the system's internal properties and transformations.

System behavior is generally characterized by:

- State of equilibrium - refers to a state in which a system can maintain its condition for extended period, either in the absence of external disturbances or in the presence of constant ones. Every system strives for a state of equilibrium but cannot reach it due to the interdependence of system elements. In a state of equilibrium, no disturbances act on the system. The achievement of equilibrium is influenced by the connections between individual internal elements and the system's interactions with the external environment. [Kovachev, 2008]

- Stability and resilience - Stability refers to a system's ability to return to a state of equilibrium after being disrupted by external factors or temporary disturbances. The ability of it to return to an equilibrium state after the removal of external disturbances is called the stability of the system. Resilience, on the other hand, refers to the capacity of systems to endure and adapt to changes and disruptions while preserving the same relationships between populations or state variables.Sustainable systems are those that are able to recover their original state or behavior after the removal of external disturbances. In more complex systems, it is possible to observe many unstable states, and the return to a stable state may involve an oscillatory process.

Changes in the state of a system can arise from both external influences and internal processes. There are many external influences on any system, but not all of them are significant to the system itself. The essential factors are taken as input to the system. In managerial problem solving, there are two types of input quantities - control and controlled variables. Control variables are the variables that can be chosen when implementing control, and they enable the system to reach a desired state. Disturbing factors are those that present the system's environment. The output values are those that reflect the system's impact on its environment. The set of changes in the output values determines the behavior of the system, and their set defines the state space of the system.

Real systems undergo a transient process where their state changes gradually over time rather than instantaneously. A dynamical system can exist in three phases: equilibrium, transient, and periodic. As previously mentioned, a system is in equilibrium when its state remains constant over time. In a periodic regime, the system cycles through the same states at equal time intervals. The sequence of changes that a system undergoes to reach a particular state is called a transient process or phase. This process involves the system moving from an initial state to a stable regime, either equilibrium or periodic.

5. Types of systems

Systems can be classified based on various criteria. In general, they can be categorized as either real or abstract. Real systems are material systems that exist in the physical world. On the other hand, abstract systems are conceptual constructs that represent various hypotheses, theories, or algorithms. They are a product of human understanding, they can be divided into descriptive and symbolic. Descriptive systems are used to describe real-world phenomena, while symbolic systems are used to represent abstract concepts and ideas.

Systems can be categorized according to their origin as natural, artificial, virtual, or mixed. Natural systems exist without any human intervention and function independently of human will. Artificial systems, on the other hand, include all mechanisms, machines, and tools that are created by humans for specific purposes. In recent times, virtual systems have become increasingly popular. They are primarily based on computer environments, and they employ complex mathematical algorithms to create a diverse and multivariate alternative environment that mimics the behavior of the system being studied. Virtual systems allow very quickly and safe study of the behavior of real systems. [Marinov, 2018]

On their interaction with the environment, systems can be classified as either open or closed (isolated). Open systems continuously exchange information with the environment, while closed systems do not interact with it. Social systems, in particular, are typically open systems, they interact constantly and intensively with their environment - exchanging materials, people and information.

When studying systems, it is important to consider how they change over time. If we only examine one particular moment in time and one specific state of the system, then we can say that the system is static, with constant internal properties. On the other hand, dynamical systems have non-stationary behavior, constantly changing their states. For example, a system of mathematical equations is a static system, while a mathematical model describing the swing of a pendulum is a dynamic system. As mentioned earlier - a dynamical system can exist in three different phases. When a system is in an equilibrium state, it can be assumed to be in a static state, as its state does not change over time. The study of system dynamics involves analyzing the transient states of the system as it changes over time. [Tonchev and Velev, 1971]

Dynamic systems can be categorized into two types based on their behavior: deterministic and stochastic (probabilistic). A deterministic system is one that has only one behavior. The elements of the system interact with each other in a certain way. There is no uncertainty when studying deterministic systems as each state leads to exactly one new state, which can be predicted. On the other hand, a stochastic system's behavior can be determined with a certain degree of probability from one moment to the next one. Interactions between elements are based on statistical dependencies and often random factors can cause different behavior of the system. Given one state of the system's behavior, the next cannot be predicted with certainty, there are several possible implementation alternatives, although some are more likely than others. An example of a stochastic system is the economy of a country. The future state of the economy cannot be accurately predicted due to the numerous random variables involved.

According to the number of structural elements and connections in the systems, they can also be divided according to their complexity into simple, complex and very complex. Complexity is one of the main characteristics of systems. Simple systems have a small number of elements and connections, making their structure easy to identify and their behavior relatively easy to study.

As the number of individual structural elements in a system increases, so does the number of potential connections between them. Describing complex systems with approximate accuracy can be a more challenging task because of the intricate interconnections between individual elements. When modeling complex systems, it is common practice to select only the features that are relevant to the current study. While any complex system can be modeled in various ways, different essential features can be filtered for different research purposes.

As the number of elements and connections in a system increases, its complexity also increases. Very complex systems cannot be fully comprehended by researchers, as they may have an unlimited or unknown number of elements with intricate and interconnected elements.Systems that involve humans as a component often fall under the category of very complex or complex systems. These systems are typically open, dynamic, probabilistic, and reflect real-world complexities.

6. Large complex systems

Large systems are characterized by a significant number of variables, the presence of nonlinearities and uncertainty. The term complexity is used to define something with multiple components that are intricately combined.The property of separability is crucial when dealing with large systems, as it is best to break them down into smaller subsystems that are easier to analyze. [Filip, 2005]. The complexity of large systems grows by several times compared to the increase in the number of structural elements. In some complex systems, there are different levels of importance that are established when making decisions about their management. These systems are referred to as hierarchical systems, where subsystems at a higher level take precedence over those at a lower level. A hierarchical system is represented as a set of sequentially related, interacting subsystems. To describe a large complex system, it is crucial to choose existing models or create new types of control models that evaluate uncertainties and events that cannot be easily described or formalized.

Large complex systems lie somewhere between complete order and total chaos. They have an evolutionary character, meaning that the interrelationships between individual elements can change over time under the influence of some external influence. Therefore, predicting the future state of such systems becomes a challenging task. Adaptability is one of the main characteristics of these systems. For instance, while every human being can adapt to their surroundings, a robotic system imitating human behavior can also adjust to its environment, but not to the same extent. This example illustrates that adaptability directly correlates with complexity - the more adaptive a system is, the more complex it becomes. Adaptation can be viewed as a self-perfection process concerning the environment in which the system operates. Measuring the complexity of a system is essential particularly when modeling it and when we want our model to improve over time. In such cases, we should expect an increase in the complexity of the model. [Gros, 2011]

The behavior of complex systems is highly sensitive to initial conditions and environmental changes, often resulting in seemingly random and unpredictable outcomes. Mathematical modeling is a crucial tool in the study of such systems.

The interaction of the system with the external environment can lead to the emergence of new linkages between its elements, which in turn can lead to an unexpected deviation from its equilibrium state. These random deviations can lead to system rearrangements and unexpected behavior. At such moments, the system is chaotic and has a strong sensitivity to the environment, which in turn leads to an unstable, non-equilibrium state and an inability to predict its future state. These concepts of large complex systems are closely associated with chaos theory, an interdisciplinary field of study that encompasses mathematics, physics and philosophy. [Mihnev, 2012]

Complex nonlinear systems are often unpredictable and impossible to describe with exact equalities. Their behavior is stochastic. The states of these systems can only be represented as results in some defined range or by attractors or fractals. An attractor is a visual representation of the system's equilibrium state or trajectory that characterizes its long-term behavior in phase space. The attractor is what the system strives for and represents a region of possible states that the system can move into but cannot escape from. A fractal is a complex structure whose individual parts resemble the structure of the whole, and studying fractals can reveal regularities in systems that may otherwise appear completely unpredictable and absolutely chaotic. Fractal analysis is one approach within chaos theory. It is based on the property of fractal phenomena to preserve their statistical properties even when changing scale.

The Koch curve is a well-known example of a fractal (Fig.5). It is a simple curve where each segment is divided into three equal parts, forming a triangle.The triangle's sides are equal to 1/3 of the total length of the segment. Koch curves are used to optimize spaces. They help to compress the resources that need to be implemented into small spatial objects.

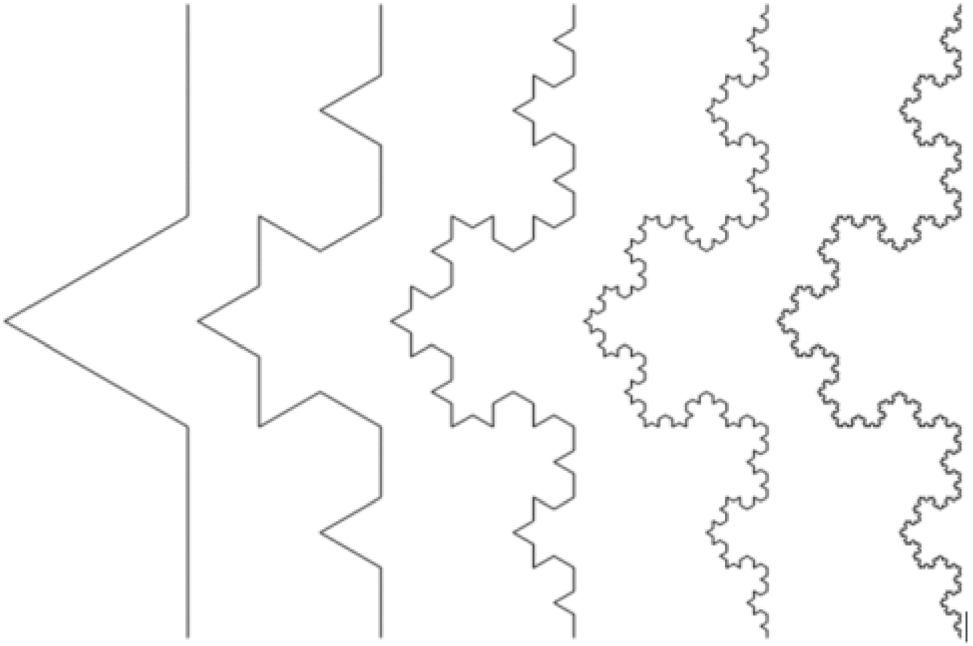

Fig. 5 - Koch curve

Chaos theory is a scientific discipline that allows us to predict with a certain degree of probability the behavior of the most complex and unstable systems. As the diversity of a system increases, so does the number of its potential states. In accordance with the principle of equilibrium, certain states are preferred over others – the system tends towards them. For each of these states, there is a different probability of being reached by the system. Entropy provides an answer to the question of which state a given system will fall into under particular conditions, reflecting the level of organization of the system. When a system's movement is chaotic, it is equally likely to fall into any of the possible states.

When delving into the study of complex systems, it's essential to work with a wide range of stochastic processes. The transformation of a system describes its transition from one state to another. In the presence of uncertainty, the transformation is characterized by the fact that the system passes from one possible state to one of several possible but mutually exclusive states. The probabilities of each potential state can be calculated. The sum of these probabilities is always equal to 1. When it is known with certainty which state the system will enter, then the probability of that state is 1, and all other probabilities are 0. In this case, there is no lack of information, and the entropy is also 0, indicating that there is no uncertainty. [Milic, 2010]

When analyzing stochastic systems in a particular state, we can make predictions about its future behavior with some degree of probability. If there is only one possible future state, then the outcome is predetermined. As the number of possible states increases, so does the level of uncertainty. The measure of this uncertainty can be seen as a function of the number of possible states that the system can transition into. The diversity of a system is determined by the number of possible states, hence why in information theory and cybernetics, the terms "uncertainty" and "diversity" are often used as synonyms.

Information theory is a fundamental concept in the study of complex cybernetic systems. It views any large system as a machine, characterized by great variety and uncertainty, aimed at processing information. This theory is based on the works of Norbert Wiener's "Cybernetics" and Claude Shannon's "Mathematical Theory of Communication", and is related to probability theory and mathematical statistics. The basic concepts used in information theory are entropy, amount of variety, and quantity of information. According to Wiener and Shannon, the quantity of information is equivalent to entropy, as information helps reduce uncertainty. The more information is known about a system, the more its uncertainty is reduced. Conversely, when we have no information and every possible state has an equal probability of occurring, entropy is at a maximum, and uncertainty is also at a maximum level. [Dalkalachev, Nedelcheva, 2006][Shannon, 1948][Wiener,1948]

7. Management of complex systems

Assume that in its initial state a system is completely undetermined and its behavior is absolutely unclear. As the system operates, certain patterns in its behavior begin to emerge, and knowledge and information about the system accumulates. This information reduces the initial indeterminacy, limits the diversity and the system becomes more manageable. When a system can be controlled, its behavior can be directed towards a desired state. [Tonchev and Velev, 1971]

From a cybernetic perspective, management is the process of receiving, storing and processing information aimed at achieving some specific goal. As mentioned there are interconnected elements within a system that interact with each other. For the management of the systems, their material form is not of interest, what is important is their information content - the information received from one object about the state of another object. [Marchev, 2018-b]

Control actions can be used to bring a system to a desired state by transmitting signals carrying information to the controlled system through certain communication channels. The control system is the set of controlling systems, controlled systems and the communication channels connecting them. Figure 6 illustrates the general control scheme.

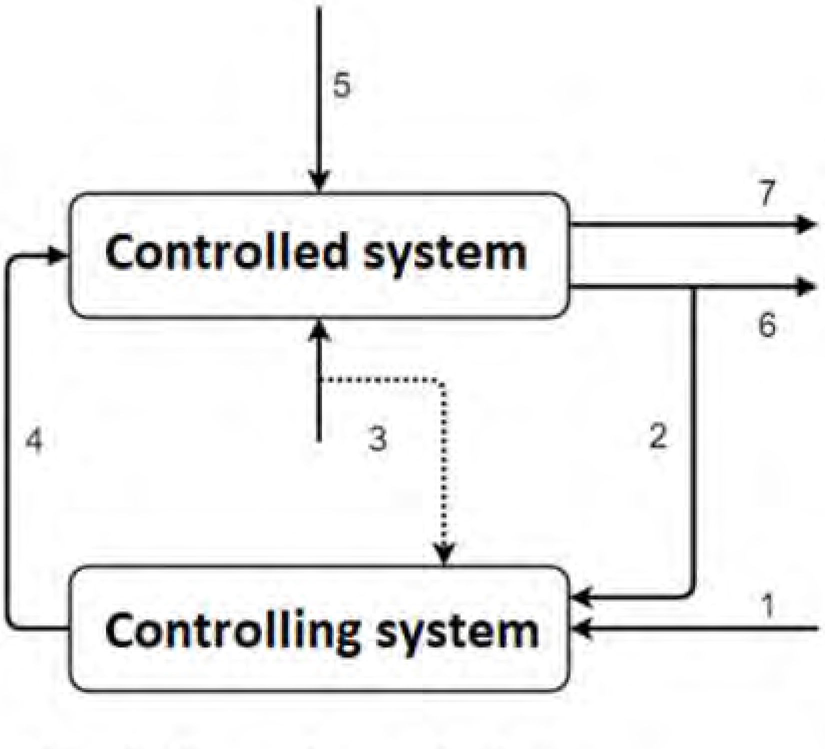

Fig. 6 - General control scheme

1. Goals
2. Feedback
3. Observed influences from the environment
4. Controlling influences
5. Unobserved influences from the environment
6. Significant variables
7. Insignificant variables

In cybernetics, the same components can perform both the functions of a controlled and controlling system at different times. The act of management involves a deliberate effort by a controller to impact a system under a supervision, utilizing available information and aiming at changing the state of the controlled system. Cybernetics studies only controllable systems, focusing on the information that flows within them and their ability to adapt their behavior. The control of a cybernetic system can only be accomplished with a highly complex control system that covers the majority of all possible states of the controlled system. This principle is known as Ashby's law of requisite variety. The philosophy of this principle is that the more information is known about the controlled system, the more effective the control process will be. Increasing the diversity of the controlling system can reduce uncertainty in the controlled system.

A closed control system is a system that utilizes information from its output values to create a control signal. When managing a complex probabilistic system, feedback is the most efficient mechanism for control as it enables the system to receive additional information and reduces uncertainty.

Feedback refers to the exchange of information between the outputs of a controlled system and the inputs of a controlling system. Without feedback, it is impossible to control the system effectively because without information about the changes that occur in the system, no correction actions can be taken to change the behavior of the system.

Management is the process of planning, decision making, organizing, and controlling systems, involving some purposeful influence on a system, which requires making choices from a set of options. All control systems face limitations of various kinds on the possible control effects. The goal of management is to bring the system to a better state aligned with the system's goal, than it would be in the absence of control actions. This better behavior results in a greater level of independence of the system from its environment.

Depending on the system and the conditions in which it functions, different actions for control efficiency can be used. Optimal management involves selecting and implementing strategies that achieve the most advantageous outcome based on the chosen performance criteria. Control effects are subject to limitations within a certain range, known admissible control, therefore the optimal control action must be selected from the set of admissible control effects.

The optimality criterion for each system may be different and should be carefully chosen.

The extreme complexity of probabilistic complex systems is often studied with the "black box" method. It is a system where only the inputs and outputs are known. By observing how the output variables react to changes in the input variables, valuable insights can be extracted regarding the system's operation, performance and behavior. This method is used when the system is so complex that its behavior cannot be determined by causal connections between its individual elements.

The "black box" and the researcher together form a complex system. The researcher influences the box through specific signals, and the box influences the researcher through feedback. The resulting relationship between them obeys information theory, just like any other interaction between two subsystems. The process of studying systems using this method often takes a long time. The researcher must gather logical conclusions from the output data. By using specific inputs and observing certain output variables, data can be collected and presented in the form of a report. This report can be considered as a message that contains information about the behavior of the "black box". It is possible that some patterns characterizing the system's behavior can be discovered in the report, thereby reducing the indeterminacy and uncertainty of the black box.

It is important to answer the question of if knowledge of the current state of the system and the conditions in which it operates is sufficient to determine the system's future state. It is not necessary to know the internal structure of the system to answer this question. Answering it helps identify whether the system has consistent probabilistic characteristics - or what type of behavior it exhibits.

It is important to distinguish between the concepts of regulation and management of a given system. The essence of regulation is to keep the system in a specific state, while management involves selecting a state that aligns with a specific goal and directing the behavior of the system towards that desired state. Regulation is used to maintain one or more values of the system at a certain level.

Systems management may have some similarities with regulation, which is typically carried out automatically, while in general the management is not an automatic action. Management involves decision making and decision taking, making it a deliberate and intentional act.

The controlling system generates management instructions and it is taking management decisions in order to influence the controlled system. These decisions are based on information from the environment and the output data received from the controlled system.

It should be emphasized that, in a general, typical case, management decision making and decision taking are made by humans rather than automatically. Choosing an action gives purpose to the researched, and the ability to make the right choice is a valuable quality. Taking a decision involves considering multiple alternatives and selecting one. To do so, it is necessary to generate multiple options and define the purpose of the choice. The alternatives can be evaluated based on one or more quantitative or qualitative criteria.The consequences of the choice can be precisely known - under conditions of certainty; to have a probabilistic character - in conditions of risk; ambiguous outcome and impossibility of introducing probability - in conditions of uncertainty. [Tonchev and Velev, 1971]

A decision can be made under conditions of certainty when the decision maker is fully aware of which environmental condition will occur, or when only the most likely scenario is considered. When the decision-maker does not know with certainty which state of the environment will occur, but has a probabilistic estimation of the realization of each state, a decision is taken under risk. In contrast, under conditions of uncertainty, the decision maker has no knowledge of the probability of each state and must make a decision based on incomplete information.In such a situation, there are various selection criteria: [Marchev Jr., 2018]

- Wald's decision criterion of a pessimistic view and conservative moderation - consider the worst possible consequences of each strategy and choose the least bad one.
- Optimistic criterion - the best possible consequences of each strategy are considered and the best one is chosen
- Hurwicz Criterion of balancing pessimism and optimism in decision-making under uncertainty. The level of optimism of the decision maker is measured by an "optimism coefficient" α, which lies between 0 and 1 (0 = total pessimist, 1 = total optimist). The best result is multiplied by α and the worst by 1-α, then the results are summed. The best alternative is selected.
- Laplace's criterion of equal probability - The basic assumption is that since the probability distribution is not known there is no reason to assume that one state of the environment is more likely than another - all states are equally possible. This is a special case of decisions under risk, but with equal probabilities of occurrence of each of the environmental states
- Savage criterion for the optimal decision - For each state of the environment, there exists an optimal outcome that can be compared with all other outcomes for that state. In this way, “suboptimal strategy regret” can be established for any combination of environment state and alternative. Forgone benefits can be seen for all combinations.

The process of decision making typically involves selecting the best alternatives under given conditions - the optimal ones according to a chosen criterion. The concept of optimality is fundamental in cybernetics. In some cases, multiple criteria may need to be considered when making a decision, which is known as a multi-criteria approach.This approach involves identifying and evaluating various factors that should be taken into account when making a decision.

8. Automated self-perfecting control systems

When dealing with a highly complex controlled system with unknown characteristics, the controlling system is developed with limited information. Such systems often demonstrate non-stationary behavior, where their internal properties and structures may change over time.

A controlling system developed with limited information cannot remain constant and therefore cannot provide effective control under all possible future states. Self-perfecting control systems offer a solution to this problem by allowing the controlling system to adapt and evolve during operation. As the controlled system and the environment change, the controlling system must adapt to effectively manage the future states. Over time and in the course of its operation, the controlling system gathers information and experience about the past processes and uses this knowledge for self-perfection.

A self-perfecting system is self-learning when it automatically changes its parameters with a constant internal structure and is self-organizing when it independently changes its internal structure in an expedient way. Self-perfecting system is a system which is self-learning and self-organizing.

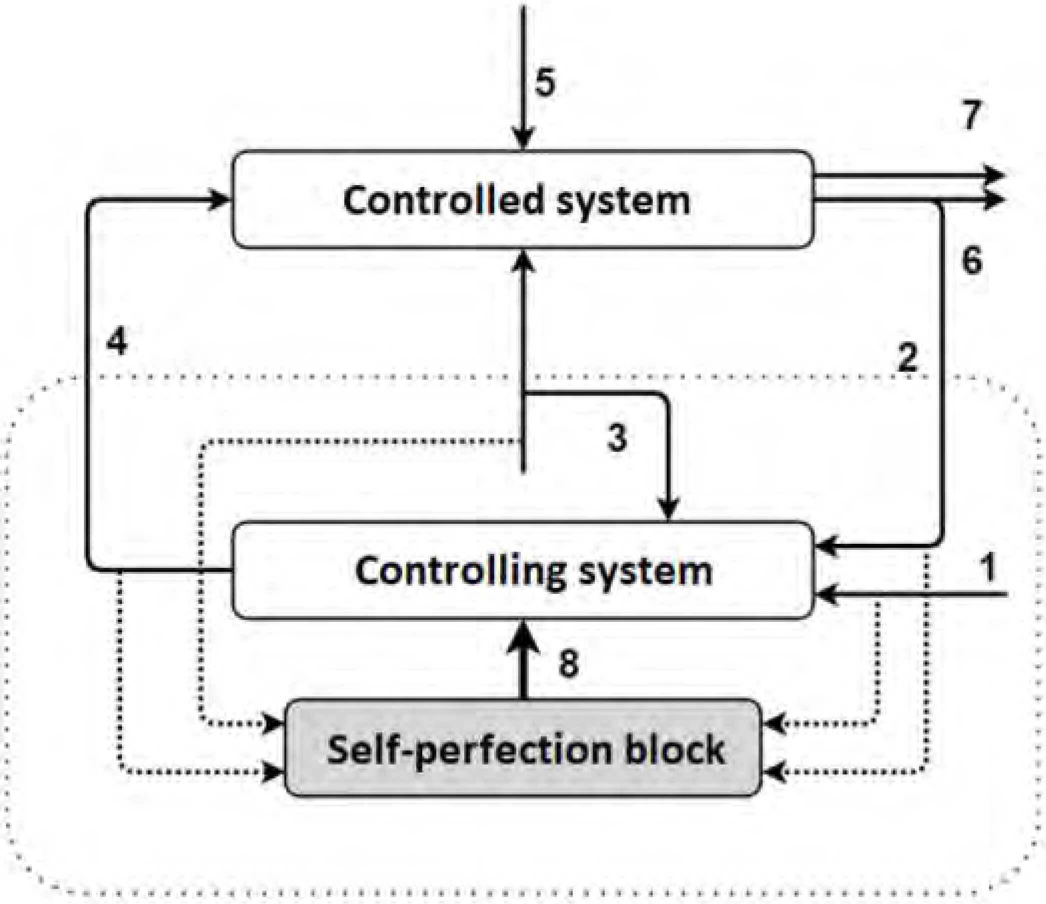

Fig. 6 - Self-perfecting control scheme

1. Goals
2. Feedback
3. Observed influences from the environment
4. Controlling influences
5. Unobserved influences from the environment
6. Significant variables
7. Insignificant variables
8. Adjusting the internal structure and/or the values of the variables

The self-perfecting element monitors the system's behavior and evaluates the quality of the controlling process. Its main objective is to identify areas that require improvement and develop effective strategies to achieve optimal management results. This may involve setting goals or criteria for management effectiveness and evaluating the performance of the controlled system against these standards. If the self-perfecting element identifies any deficiencies or areas that require restructuring, it will work to make appropriate improvements and modifications to the controlling system system.

The process of self-organization is characterized by the absence of centralized control and any imposed restrictions. This means that the behavior of the system is solely dependent on internal elements of the systems and their correlations. Self-organization is closely related to the complex behavior of systems and arises directly from it.

Self-organization is an ongoing process that occurs through continuous communication between the elements within the system, as well as between the system and its environment. The elements of the system communicate only with those closest to them, transmitting information and adapting the system's behavior to new circumstances dictated by the environment. This behavior is characteristic of all self-perfecting systems. [Comfort, 1994]

Most artificial self-perfecting systems and models are inspired by nature. The non-deterministic and dynamic nature of large complex systems results in the emergence of new complex properties that surpass human ability to control them. Modern research is increasingly oriented towards the introduction of various automated self-organizing and self-learning software models in complex system control systems. This aims to solve the problem of increasing dynamics and uncertainty of most systems. [Di Marzo Serugendo, Gleizes and Karageorgos, 2011]

Any complex system, under certain external conditions, tends to target and take its most stable state. The possible states can be categorized based on the probability of the system assuming them, with the most stable state having the highest probability. The challenge with dynamical systems is that they change their structure, therefore the corresponding probabilities of the possible states also change. The system strives to self-organize until it reaches its most stable structure. Automated management decision making works the same way. A self-iperfecting control system searches for the most preferred alternative or the most stable one characterized by the highest probability.

Decision theory helps in creating or selecting a decision when faced with uncertainty and multiple alternative courses of action that require evaluation before a final decision can be reached. It examines various types of decisions, defines the fundamental rules and reasoning for making them, and creates techniques and models for decision-making using different models or procedures. It is assumed that the persons responsible for choosing an alternative are rational and are able to accurately assess the relevant situations and alternatives. Unfortunately, this is impossible, as decision-makers are always susceptible to subconscious feelings, emotions, and biases. The only way to achieve an entirely impartial and unbiased decision is to make it automatically, without human intervention. [Yukalov and Sornette, 2014]

9. Acknowledgment

The author would like to extend special gratitudes to UNWE project NID NI 23/2023/B for funding this research.

References:

- Agarwal, N., R. Mukkamala, "Design Of Complex Systems: Issues And Challenges", Old Dominion University, IEEE Norfolk, VA, 2005
- Comfort, L., "Self-Organization in Complex Systems", University of Pittsburgh, USA, 1994
- Dalkalachev, H., E. Nedelcheva, "Information Theory and Message Transmission", UNWE Publishing House Stopanstvo, Sofia, 2006.
- Davidov, K., T. Panayotova, P. Diankov, "Systems approach in designing logistics systems", lecture course, Shumen, 2017.
- Di Marzo Serugendo, G., M. Gleizes, A. Karageorgos, "Self-organising Systems", Springer-Verlag Berlin Heidelberg, New York, USA, 2011
- Ethiraj, S., D. Levinthal, "Mdularity and Innovation in Complex Systems", Informs - Management Science, USA, 2004
- Filip, F., "Large Scale Complex Systems", IFAC, Romania, 2005
- Gros, S., "Complex systems and risk management", University of Zagreb, Zagreb, Croatia, 2011
- Johnson, C., "What are Emergent Properties and How Do They Affect the Engineering of Complex Systems?", Elsevier, New York, USA, 2006
- Karlekar, S., J. Palshikar, D. Talik, "System

Concepts And Environment", Tilak Maharashtra University, India, 2015

- Kovachev, A., "Development of Economic Systems", UNWE - Faculty of Economics, Sofia, 2008.
- Marchev Jr., A. "Rational-Normative Approach to Decision Analysis", lecture course, UNWE, 2018
- Marchev, A., "Cybernetics", lecture course - Summer School for PhD students, UNWE, SU, TU, 2018-b
- Marchev, A., "General Systems Theory", lecture course - Summer School for PhD students, UNWE, SU, TU, 2018 -a
- Marinov, R., "Virtual and Mixed Reality", New Bulgarian University, Sofia, 2018.
- Mele, C., J. Pels, F. Polese, "A Brief Review of Systems Theories and Their Managerial Applications", University of Napoli, Italy, 2010
- Mihnev, G., "Theoretical Foundations of Coevolutionary Development", UNWE, Sofia, 2012.
- Milic, D., "Synergy of Mathematics, Informatics, Cybernetics and Computing", Josip Juraj Strossmayer University of Osijek, Croatia, 2010
- Mirats-Tur, JM., R. Verde, "Subsystem identification within a complex system", Conference: 14th European Simulation Multiconference on Simulation and Modelling, Belgium, 2000
- Panchev, S., "Chaos Theory", Marin Drinov Academic Publishing House, Sofia, 2001.
- Peneva, Y., "Information Systems", lecture course, NBU, Sofia, 2014.
- Shannon, C., A Mathematical Theory of Communication, The Bell System Technical Journal, 1948
- Tonchev L., Velev, S., "Basic Concepts and Ideas of Cybernetics", Publishing House "Nauka i izkustvo", Sofia, 1971.
- Von Bertalanffy, L., "General system theory", George Braziller, New York, USA, 1968
- Wiener, N., Cybernetics: or Control and Communication in the Animal and the Machine, MIT Press, Cambridge, MA, 2 edition, 1948
- Yukalov, V., D. Sornette, "Self-organization in complex systems as decision making", Swiss Federal Institute of Technology, Zurich, Switzerland, 2014