The Systems Approach†

Aleksandra A. Nikiforova

Lomonosov Moscow State University Faculty of Soil Science,
1 Leninskie Gory, Moscow 119991, Russian Federation, < nikifsoil@gmail.com>

Aleksandra Aleksandrovna Nikiforova, Ph.D. in biology, is research fellow at Faculty of Soil Science, Lomonosov Moscow State University (MSU), Russia. She received her Ph.D. in soil mapping at the MSU and a specialist degree at the Department of Soil Geography of the MSU. Her main research interests are related to the theory of universal soil-landscape classification and multiscale soil-landscape GIS mapping, as well as its practical implementation. One of her significant achievements is the creation, together with other authors, of *The Agroecological Soil-Reclamation map of the Nonchernozem belt of the European part of Russia* on a scale of 1: 1,500,000.

Nikiforova, Aleksandra A. 2022. "The Systems Approach." *Knowledge Organization* 49(7): 529-542. 137 references. DOI:10.5771/0943-7444-2022-7-529.

Abstract: The review attempts to compare different points of view on the essence of the systems approach, describe the terminological confusion around it and analyse the numerous definitions of system. It is shown that the vagueness and ambiguity of the concept of the systems approach is manifested in the use of a number of terms which are similar in meaning and close in sound to it. It is proposed to divide the existing definitions of system into descriptive and formal ones. The concepts included in the descriptive definitions, as well as the numerous synonymous terms denoting them, are divided into five conceptual-terminological groups that differ in their content and logical meaning. The meanings of such concepts as minimal constituent parts, emergence, environment, boundaries, purpose, functions of system and systems hierarchy are revealed. Some uses of the concept in knowledge organization are mentioned. The problem of systems classification is touched upon. Separate sections are devoted to the highlights of the history of the systems approach, its criticism and the significance. Particular attention is paid to criticism of the mathematization of the systems approach. Possible reasons for the decline in interest in the systems approach are identified. It is concluded that the systems approach helps to find new ways to solve scientific and practical problems.

Received 3 March 2022; Revised 11 December 2022; Accepted 12 December 2022

Keywords: systems approach, systems theory, systems methodology

† Derived from the article titled "Systems Approach" in the ISKO Encyclopedia of Knowledge Organization, Version1.1 published 2022-12-20. Article category: methods, approaches & philosophies.

1.0 Introduction

Over the more than 70 year history of its existence, the systems approach (hereinafter referred to as SA) has been widely recognized and spread. An extensive bibliography is devoted to it (Bertalanffy 1968, vii; Sadovsky and Yudin 1969; Surmin 2003, 27), and conferences on its problems are held regularly. Principles and methods of SA are applied in psychology, sociology, political sciences, ecology, jurisprudence, engineering (Jackson et al. 2010); information theory, cybernetics, history, literature (Arnold 2013); biology (Dubitzky et al. 2013); landscape study (Nikolaev 2006); soil science (Juma 1999); information science (Mansfield 1982); documentation (Foskett 1980); business (Gleeson 2019) and many other scientific and practical areas of human activity. In addition, SA was originally developed in close connection with cybernetics and information and communication theory (Shannon 1948; Wiener 1948). However, at the turn of the 20th and 21st centuries, there was a noticeable decline in interest in SA, which, apparently, can be explained by the collapse of many hopes placed on it. The review compares the existing points of view on SA, its essence, significance and prospects. However, here we will start with the highlights of the history of SA.

2.0 Highlights of the history of the systems approach

The history of SA is described in many publications (Arnold 2013; Bertalanffy 1972; 1968, 10-17; Biggart et al. 1998; Blauberg et al. 1984; Blauberg 1973; Blauberg and Yudin 1973; Blauberg and Yudin 2012; Drack and Pouvreau 2015; Flood and Jackson 1991; Lai and Lin 2017; Kazaryan 2004, 275-7; Ramage and Shipp 2009; Sirgy 1988; Stichweh 2011), so here we will focus only on its main points.

The history of SA goes back to the origin of philosophy and science in Ancient Greece (Agoshkova and Akhlibininsky 1998; Blauberg 1973; Blauberg and Yudin 2012; Sadovsky and Yudin 1969). So, for example, the thesis of non-summativity of the whole (that is, the whole is something more than the sum of its parts) comes from Plato and Aristotle (Blauberg et al. 1984). In the era of the Enlightenment, a model of nature as a harmonious whole was proposed, the parts of which are perfectly combined with each other (Wilber 1996, 116). At the same time, until the middle of the 19th century, the idea of systemness (systematicity) was considered, according to Blauberg and Yudin (2012), only in relation to knowledge, which is primarily explained by the predominance in science of the mechanism, elementalism and reductionism associated with them. The collapse of the mechanistic worldview, elementary and reductionist ideas is considered one of the main reasons for the emergence of SA (Blauberg et al. 2010; Checkland 1984; Kazaryan 2004; Sadovsky and Yudin 1969). Checkland (1984) puts it this way: "Systems thinking is a response to the impotence of reductionism in the face of great complexity".

The originator of SA or general systems theory (these concepts are often used synonymously, as discussed in Section 3) is believed to be the Austrian biologist Ludwig von Bertalanffy (1901-1972) (Adams et al. 2013; Adams 2012; Sadovsky and Yudin 1969). At the same time, Bertalanffy himself (1968, vii) positioned himself only as one of many scientists who contributed the general theory of systems to science. In addition to Ludwig von Bertalanffy, Alexander A. Bogdanov, Kenneth E. Boulding, Walter B. Cannon, Walter Pitts, Warren McCulloch, Claude Shannon, Norbert Wiener, and William Ross Ashby are also considered the originators of SA.

Bertalanffy first put forward the idea of systems theory in 1937 at a philosophy seminar led by Charles Morris at the University of Chicago (Bertalanffy 1962). In articles of 1947, 1950 and 1956, Bertalanffy presented this idea already, in his words, in the form of a "project", but these articles dealt only with various elements of the general systems theory, without offering a unified theory (Bertalanffy 1962). Finally, in 1968, Bertalanffy published "General System Theory: Foundations, Development and Applications", which summarized his research. Therefore, it is 1968 that is considered the year of the official birth of SA (Gleeson 2019).

The term "systems approach" came into scientific use in the 60s and 70s of the last century (Blauberg and Yudin 2012), when, according to various researchers (Blauberg et al. 1984; László 1973; László 1972; Sadovsky and Yudin 1969), its rapid development was observed due to the perceived need to counteract excessive specialization in science (Bertalanffy 1968; Boulding 1956; Wiener 1948), the success and undoubted effectiveness of systems studies (Blauberg et al. 1984), scientific and technological revolution and the need to overcome the contradiction between the explosive growth of the amount of information and the limited possibilities of its assimilation through the systems reorganization of knowledge (Uyomov 1978, 28, 37). It is considered quite natural that in the early stages the development of SA was accompanied not by a decrease, but by an increase in contradictions in understanding its essence and role in modern science (Blauberg 1973; Blauberg et al. 1973, 5; Warfield 2003). The result was a noticeable disappointment in SA, which led, among other things, to a decrease in the number of publications devoted to it (Warfield 2003). We have to admit that until now there has been no renewal of the previous interest in SA. At the same time, SA is far from forgotten and continues to develop successfully in many areas. These areas are primarily social science, which applies Niklas Luhmann's sociological systems theory (Luhmann 1995), and systems biology (see Dubitzky et al. 2013).

3.0 Terminological confusion around the systems approach

First of all, we note the vagueness and ambiguity of the concept of SA in the scientific literature, which are manifested in the use of a number of synonymous terms that are similar in meaning and close in sound to it (Bertalanffy 1962; Blauberg and Yudin 2012; Sadovsky and Yudin 1969; Uyomov 1978, 37). In addition to the terms "general systems theory", such terms are "systems theory", "systems science", "general systemology", "systemology", "systems-based approach", "systems thinking approach", "system-structural approach", "systems research", "systems analysis" and others. How some of these terms relate to each other and what different researchers mean by them is described below.

3.1 Relationships with general systems theory (systems theory)

The terms "systems approach" and "general systems theory" ("systems theory") were used interchangeably in Bertalanffy's early work; however, later he began to separate them, meaning by the general theory of systems the unification of a number of disciplines that jointly implement the methodological functions of SA (Sadovsky 1970, 441-2; Blauberg and Yudin 1973, 86). An understanding of general systems theory, similar to the late Bertalanffy, is shared by Blauberg and Yudin (2012), who believe that the term denoting this concept, in comparison with the term "systems approach", has a narrower, specific meaning, and also Uyomov (1978, 55), who asserts that general systems theory is a special form of application of SA. At the same time, Gleeson (2019) and Sadovsky and Yudin (1969) express the point of view that the concept of "SA" has simply replaced the concept of "general systems theory", which did not have a strictly defined meaning. In fact, an equal sign between SA and systems theory is also established by Stichweh (2011), who defines systems theory as "a science which has the comparative study of systems as its object".

Understanding the relationship between the terms "systems approach" and "general systems theory" is complicated by the fact that the latter can be used both in a broader and in a narrower sense of the word. For example, according to Bertalanffy (1962), in a broad sense, general systems theory means a fundamental science that encompasses the entire range of problems associated with the study and design of systems, while in a narrower sense it is an attempt to derive concepts characteristic of organized wholes and apply them to specific phenomena (Bertalanffy 1968, 91). Other researchers suggest replacing the term "general systems theory" in a broad sense with the term "general systemology" (Pouvreau 2013; Pouvreau and Drack 2007; Rousseau et al. 2018).

It should be noted that the terms "systems approach" and "systems theory" can also be used in the plural (see Bahg 1990; Mele et al. 2010; Mokiy 2019; Olsson and Sjöstedt 2004). For example, Mele et al. (2010) suggest that general systems theory is just one of several key systems approaches alongside cybernetics. However, Bertalanffy believes that cybernetics is a more special theory than general systems theory (Uyomov 1978, 56).

3.2 Relationships with systemology

Uyomov (1978, 55) defines systemology as a method of SA. At the same time, Fleishman (1982) understands this as a theory of complex systems or fundamental engineering science.

3.3 Relationships with systems science

According to Bertalanffy (1962), general systems theory should be distinguished from systems science, which is the correlate of general systems theory in applied science. For his part, Troncale (2009) takes the opposite point of view, arguing that general systems theory is one of the "specialties" of systems science.

3.4 Relationships with systems research

According to Ashby (1958), research should be considered systemic if it is based on SA. At the same time, Blauberg et al. (1984) understand systems research as "a rather vast and ultimately diverse spectrum of scientific and technical disciplines, research and design studies etc". Also interesting is the point of view of Ackoff (1960), who believes that the subject of systems research is only behavioural systems that have behaviour and are controlled by people, as well as the point of view of Uyomov (1978, 45), who draws attention to the fact that the study of systems should not be confused with the study of objects as systems; for example, studies of the solar system and Mendeleev's system of elements can be non-systemic, i.e., not based on SA. In addition, Uyomov (1978, 46) sees some ambiguity in the very combinations of words "systems research", since, on the one hand, it can be understood as the study of an object as a system (and in this case it will be synonymous with the term "systems approach"), and on the other hand, as if the research itself were a system.

3.5 Relationships with systems analysis

According to Blauberg et al. (2010; 1984), SA provides a solid theoretical and methodological basis for systems analysis. Kazaryan (2004) and Mattessich (1982) take a slightly different point of view. So, the first of the authors believes that "systems analysis is a kind of SA that uses the methods of exact sciences to study objects of complex nature", and the second one - that systems analysis, along with systems philosophy, empirical systems research, and systems engineering - all together form SA.

It should be added that you can also find synonymous use of such terms as "systems science", "systems theory", and "systems thinking" (see Arnold and Wade 2015; Checkland 1999; Jackson 2003; László and László 2003; Midgley 2003; Ramage and Shipp 2009; Troncale 1988).

4.0 Definition and essence of the systems approach

First of all, let us give the Bertalanffy's definition of SA (1968, 33): "SA consists in considering all objects as systems". It should be said that after Bertalanffy, this definition, in fact, did not undergo changes, only the following characteristic has been added to it: the direction (branch) of the methodology of scientific (or special-scientific) cognition and social practice that claims to be of general scientific significance, interdisciplinarity and overdisciplinarity (Blauberg et al. 1984; Blauberg et al. 2010; Blauberg and Yudin 2012; Chen 1975; Sadovsky and Yudin 1969; Uyomov 1978, 5). A less standard definition was proposed by Kazaryan (2004): SA is "the purposeful application of the concept of a system to solve a scientific problem".

A distinctive feature and, at the same time, the novelty of SA, according to Bertalanffy (1968, 5, 32-3, 102), is "a new viewpoint", "a basic re-orientation in scientific thinking", the formulation and derivation of those principles which are valid for "system" in general, irrespective of whether they are of physical, biological or sociological nature". A similar opinion is expressed by Sadovsky and Yudin (1969), who define SA as the development of a new system of principles of scientific thinking and the formation of a new approach to the objects of research, and Yudin (1973), who calls SA "a tool for a new problem setting".

Some researchers (Blauberg and Yudin 2012; Rousseau 2017c; Sadovsky and Yudin 1969; Yudin 1973) note that SA does not exist in a more or less systematic form or in the form of a single rigorous methodological concept. In their opinion, it is rather a new direction of research activity (Yudin 1973), which is applicable "not to all scientific knowledge, but only to certain types of scientific problems" (Blauberg and Yudin 1973, 98). In other words, it is more expedient to interpret the general systems theory not as a general theory, more or less related to some systems, but as a generalized concept of studying systems of a certain type (Sadovsky and Yudin 1969).

Bertalanffy's definition of SA implies that understanding the essence of SA is impossible without understanding the essence of the system.

5.0 Definition and essence of system

The concept of "system" has been known since ancient times. Despite this, today there is no single, universal, comprehensive, formally agreed scientific definition of this key concept of SA (Adams et al. 2013; Drack 2009; Kazaryan 2004, 277; Sadovsky and Yudin 1969). The reasons for this are seen in the extreme heterogeneity of systems and scientific disciplines that study them (Blauberg 1973), the multiplicity of meanings and ambiguity of the concept of "system", its use in various contexts and wide distribution not only in science and philosophy, but also in everyday speech (Kazaryan 2004). The system can be traced literally in everything (Uyomov 1978, 23-24), so it seems that "there is nothing in the world that would not be a system" (Kazaryan 2004). As a result, the term "system" has become so generic that it is almost meaningless (Chen 1975). A variety of things are called systems: organisms and machines (Stichweh 2011), natural objects, buildings, governments, military complexes, and concepts (Tien and Berg 2003, 23-4, "Definition of system"); social institutions (Bunge 1979a; Luhmann 1995; Parsons 1977); economic formations (Chian 2007); engineering complexes (Magee and de Weck 2004); ecological communities and so on and so forth.

According to Sadovsky and Yudin (1969), there is an "almost endless sea of shades" in the interpretation of system, since almost every researcher of systems problems relies on his own understanding and definition of this concept. Evidence of this is contained, for example, in the work of Uyomov (1978, 103–21), who analyses more than forty existing definitions of system and, in conclusion, offers his own.

In this review, we understand the system as a form of representation of the subject of scientific knowledge (Agoshkova and Akhlibininsky 1998), a linguistic, cognitive construct for understanding the complexity and organization of knowledge (Barton and Haslett 2007), and a theoretical tool for studying an object (Kazaryan 2004). We try to analyze the existing definitions of system. To simplify this analysis, we have divided the definitions of system into two types - descriptive and formal, which differ from each other in the content and definitions included in them. Obviously, these two types do not exhaust the entire variety of existing definitions of system; there are so-called mixed definitions that can be attributed to both the first and the second type of definitions.

Before moving on to descriptive definitions, it is appropriate to recall that the term "system" comes from the Latin word *systema*, which, in turn, comes from the Greek *σύστημα*: whole made of several parts or members, composition.

5.1 Descriptive definitions of system and their terms

Descriptive definitions of system solve the problem of how to objectively distinguish the "system" from the "non-system", that is, how to recognize the system (Korikov and Pavlov 2007). There are many descriptive definitions of system, differing in their content and terminology. In order to generalize these definitions, the numerous synonymous terms included in them were divided according to their logical meaning into five conceptual-terminological groups. These groups unite synonymous terms denoting, in fact, the same or very close concepts.

5.1.1 The Group I terms: "set", "totality", "complex", "group" and others

Group I includes the terms "set", "totality", "complex", "group", as well as less used "arrangement", "conglomeration", "assemblage" and others. These terms can be complemented by various characteristics, for example, "ordered set", "finite set", "meaningful arrangement", "cohesive conglomeration". Group I also includes the terms "whole", "integrity" and "integral unit". We singled them out separately, since they, having a double logical meaning, can be assigned to both group I and group II (see Section 5.1.4).

Every set, totality, complex, etc. is far from a system, therefore the definitions of system contain other concepts that characterize the system, which are denoted by various terms.

5.1.2 The Group II terms: "elements", "components", "units", "parts", "subsystems" and others

Group II includes terms denoting the concept of "the minimal systems units" (Spirkin 1990, 142), that is, those parts of the system that, due to the homogeneity of their properties within the framework of this system, are indivisible (Surmin 2003), thus representing the fission limit of the system. These are the terms "elements", "components", "units", "parts", "subsystems", as well as "objects" and "things". To make these concepts more exact, the following characteristics are used: material, physical, natural or human-made, functional and others. Among the Group II terms used in the definitions of system, the most accurate and corresponding to the concept of "minimum systems units", in our opinion, is the term "elements", therefore we will use it below. The system elements can include real objects, mathematical variables, "hardware, software, humans, processes, conceptual ideas, or any combination of these" (Jackson et al. 2010). At the same time, it is known that the concept of Bertalanffy tended to view systems primarily as material formations (Agoshkova and Akhlibininsky 1998). We believe that the terms "components" and "subsystems" are much less successful, since they are often used to denote not only individual minimal components of a system, but also sets of these components (Ackoff 1971).

5.1.3 The Group III terms: "interconnection", "interdependence", "interaction", "relationship", "structure" and their derivatives

The elements of the system do not exist on their own; they are interconnected. To describe these links, the following terms are used: "interconnection", "interdependence", "interaction", "relationship", as well as their derivatives. We also refer the term "structure" to Group III, since it indicates not only a certain mutual arrangement of systems elements in space, but also the interconnection and relationships between these elements (Kazaryan 2004; Sadovsky 2010; Surmin 2003).

5.1.4 The Group IV terms: "emergent property", "emergence", "integrability", "integrity", "integral unity", "integrated totality", "unified whole" and others

The result of the interconnection and interconnection of systems elements is the appearance in the system of a qualitatively new, so-called emergent, or integrative property. This property is understood as a property of the system as a whole but not of any of its elements, or the fundamental irreducibility of the properties of the system to the sum of the properties of its elements (and, conversely, the non-derivability of the properties of its elements from the properties of the system) (Surmin 2003; Jackson et al. 2010). A common example of an emergent property is the sweet taste of sucrose as a system whose elements are carbon, hydrogen and oxygen atoms that do not have this property. We also include the terms "emergence", "integrity", "integral unity", "integrated totality", "whole", "unified whole", "integral unity", "integral property", and "single entity" to group IV.

Some researchers draw attention to the fact that the system as an integrity should be distinguished from a simple set of elements that do not interact with each other, and if they are connected, then only mechanically. An example of such a simple set is, for example, a pile of sand formed by grains of sand.

5.1.5 The Group V terms: "environment", "boundaries", "isolation" and their derivatives

Another feature that defines the system is the presence of the environment of the system, everything that is outside the system and in one way or another affects it; at the same time, the system itself can affect the environment as well (Ackoff 1971; Hall and Fagen 1956; Kazaryan 2004). The mutual influence of the system and its environment is carried out through the "inputs" and "outputs" of the system (Ashby 1958). Thus, it is obvious that the terms "environment", "boundaries", "isolation" of the system and their derivatives are interrelated and characterize the same property of the system. Therefore, we refer all of them to Group V.

It should be borne in mind that the boundaries of systems can be not only spatial, but also temporal. At the same time, the concept of "time", according to Uyomov (1978, 109), should not be introduced into the definition of system, since there are systems that do not have temporal boundaries.

5.1.6 Examples of descriptive definitions of system

Descriptive definitions of system can also be divided into groups depending on which group terms they include. Examples of descriptive definitions that include terms of groups I-III are as follows.

The system is:

- an integral complex of interconnected elements (Blauberg et al. 2010);
- "a set of objects together with relationships between the objects and between their attributes" (Hall and Fagen 1956).

Examples of descriptive definitions containing terms of groups I-IV.

The system is:

- "an assemblage of objects united by some form of interaction or interdependence in such a manner as to form an entirety or whole" (Patten 1971, 44);
- "a regularly interacting or interdependent group of items forming a unified whole" ("Definition of system");
- "a set of elements that are interconnected and connected with each other, forming a certain integrity or unity" (Sadovsky 2010).

Examples of descriptive definitions of system containing the terms of groups I-V.

The system is:

- "an integral whole internally organized on the basis of some principle, in which all elements are so closely interconnected that they form a single entity in relation to environment and to other systems" (Spirkin 1990, 142);
- a set of interconnected elements isolated from the environment and interacting with it as a whole (Peregudov and Tarasenko 1989).

An example of a descriptive definition of system, including the terms of Groups I, II and IV: the system is a whole compounded of many parts (Schumm 1977, 4). An example of a descriptive definition of system, including the terms of Groups I and III-V: the system is "an entity, which is a coherent whole [...] such that a boundary is perceived around it" (Mele et al. 2010).

5.2 Formal definitions of system

Formal definitions of system are usually formulated from a mathematical point of view and based on a set-theoretic language (Sadovsky and Yudin 1969). They are usually used to solve practical problems (Kazaryan 2004, 277) and are typical for disciplines operating with abstract concepts and terms, for example, mathematics, logic, linguistics, economics and cybernetics. In formal definitions, the system is described as an abstract (conceivable, ideal) object, which is a set or assembly of equations, rules, laws, processes, etc. or a set of variables with algebraic, topological, grammatical and other properties (Klir 1965), interconnected by relations and combined into one whole (Hall and Fagen 1956).

In addition to the concepts of "equations", "variables" and "properties", formal definitions can also include the concepts of "purpose", "function", "functioning", "observer" and "time" that are not characteristic of descriptive definitions. The terms "aspirations", "final outcome", "focused useful outcome", "motivation for activity", "plan" can be used as synonyms for the term "purpose". The system function is understood as the property of the system in dynamics, leading the system to the achievement of the purpose (Surmin 2003, 136). The system functioning is the manifestation of the system function in time while maintaining its purpose and degree of complexity. The natural change of the system in time, in which its state, physical nature, structure, behaviour and even the purpose can change, means the development and evolution of the system (Volkova and Denisov 2014). However, according to Blauberg and Yudin (1973), there is no clear boundary between functioning and development. The purpose and function of the system are determined by the observer (person, researcher), who is considered as part of the system environment and can be explicitly or implicitly introduced into the definition of system (Ashby 1958; Klir 1965). The following definitions are examples of formal definitions of system.

The system is:

- some part of the world, which at any moment in time can be described by assigning certain values to a certain set of variables (Rapoport 1966);
- "a set of interconnected components of one nature or another, ordered by relations with clearly defined properties; this set is characterized by unity, which is expressed in the integral properties and functions of the set" (Tyukhtin 1972, 11);
- "an integrated assembly of interacting elements, designed to carry out cooperatively a predetermined function" (Gibson 1960);
- reflection in in the human mind of the properties of objects and their relations when solving the problem of research and cognition (Chernyak 1975);
- any set of variables that the observer selects from those available on the real "machine" (Ashby 1960, 16); "machine" in this case means everything - from technical gadgets to the human brain and natural material objects (Arnold 2014);
- "a device, procedure, or scheme which behaves according to some description, its function being to operate on information and/or energy and/or matter in a time reference to yield information and/or energy and/or matter" (Ellis and Ludwig 1962a, 3).

6.0 Hierarchy of systems

All systems are hierarchically organized. In other words, our world is a system of systems or a system of systems of different hierarchical levels (from the objectivist and constructivist points of view, respectively). The hierarchy of systems consists in the fact that each system is an element of a system of a higher hierarchical level (or a supra-system); at the same time, its elements are systems of a lower hierarchical level (or sub-systems) (Hall and Fagen 1956; Mesarovic et al. 1970; Sadovsky and Yudin 1969; Sadovsky 2010; Simon 1962; Whyte et al. 1969). Every system is in relation with their supra-systems and sub-systems (Mele et al. 2010). According to Boulding (1956), one of the advantages of defining a hierarchy of systems is that it gives us some insight into the gaps in both theoretical and empirical knowledge. The examples of system hierarchies are the following chains or sequences: atoms – molecules – cells – complex organisms; cells – organisms – populations – ecosystems; protein crystals – cells – metazoan organisms – social units; matter – life – mind – society (see Gnoli 2020; Kleineberg 2017).

7.0 Systems in knowledge organization

Systems lend themselves to be a structuring principle in knowledge organization systems (KOS). Hierarchies of systems, and emergence of some systems from others, can be expressed as series of integrative levels: these have indeed been taken as main classes in such KOSs as the Bliss Classification 2nd edition (BC2), the Broad System of Ordering (BSO), the Information Coding Classification (ICC) and the Integrative Levels Classification (ILC) (Kleineberg 2017).

The application of levels theory and of systems theory has been researched especially by members of the Classification Research Group, while drafting a new general classification based on phenomena, activities and properties instead of disciplines (Austin 1969). The first main class of this system, A, was labelled "general systems", and was followed by classes of "matter", "life" etc. The scheme included operators connecting the system taken as the basic class with additional notation for activity, "second system of environment", "passive subsystem", "active subsystem" etc. (Classification Research Group 1969, 125). For example, G78 "planets" could be specified by operator (5) "passive subsystem" to give G78(5)D47 "mantles" (Classification Research Group 1969, 130). This way of building classmarks reminds us of other synthetic KOSs of that time, such as Farradane's relational indexing or Gardin's Syntol, some of which were influenced by the recent theory of facet analysis. However, CRG authors importantly made an explicit reference to systems theory for developing KOSs (Jolley 1968, Chapter 9; Foskett 1972; 1974; 1980).

Although the project of a new general classification was not completed, it largely influenced Derek Austin's Preserved Context Index System (PRECIS) which was applied to generate subject headings in the British National Bibliography (BNB) and other national bibliographic services (Austin 1974). Indeed, PRECIS headings consist in a "lead term" connected to a "qualifier" and a "display" by encoded operators much similar to the ones described above; such operators automatically control the visualization of the qualifier and display in a way appropriate to the specific language of the system. This architecture implies a view of different natural languages as sharing a common deep structure related to general systems theory (Austin 1976), which was also inspired to contemporary research in linguistics (Fillmore 1968).

It has later been observed that such linguistic theory of "deep cases" has much in common with that of facet analysis (Gnoli 2008). Indeed, the operators or categories of such faceted systems as PRECIS or ILC, as well as their preferred citation order, can be analysed in light of systems theory: Gnoli (2017) discusses the categories of ILC2 (9 Kind, 8 Form, 7 Part, 6 Property, 5 Change, 4 Disorder, 3 Agent, 2 Location, 1 Time) and groups them into the three elements of any system as modelled by Bunge (1979b), composition, structure and environment: "those concerning the system composition (9 to 7), followed by those concerning its structure (6 to 4) and those concerning its environment (3 to 1)".

8.0 Systems classification

Systems classification, and the possibilities and methods of its development have been discussed for a long time (Korikov and Pavlov 2007). On the one hand, it is obvious that without a single definition of system, it is impossible to develop systems classification. On the other hand, it is believed that there is no need for unified systems classification at all since it is unproductive (Klir 1965). It is possible to distinguish between empirical (arbitrary), logical and combined (hybrid) approaches to systems classification. The differentiating criteria of empirical classification are usually determined by the purposes and interests of the researcher (Kazaryan 2004; Klir 1965). At the same time, the principles of choosing the differentiating criteria and the completeness of empirical classification, according to Korikov and Pavlov (2007), are not even discussed. The logical approach tries to logically deduce differentiation criteria from the definition of the system. The combined approach is aimed at overcoming the shortcomings of empirical and logical approaches (see Sagatovsky 1973).

Below are examples of empirical classification of systems:

- Open and closed (isolated) systems (differentiating criteria: the nature of the interaction of the system with the environment). The concepts of "open" and "closed" systems were introduced by Bertalanffy (1968). Most systems are open systems that interact with the environment and with other systems (Jackson et al. 2010) and exchange matter, energy and information with them (Hall and Fagen 1956). Open systems include, for example, living organisms (Bertalanffy 1968; Hall and Fagen 1956) and social systems. Closed systems are systems that are considered to be isolated from their environment (Bertalanffy 1968), that is, systems, when examining which, it turns out that, on the one hand, one can ignore the influence of the environment on them, and on the other, one can ignore their influence on the environment (Kazaryan 2004). At the same time, there is an opinion that systems are never completely isolated from the environment (Klir 1965).

- Simple and complex systems (differentiating criteria: complexity/simplicity of the system). Systems consisting of a small number of elements are called simple (Beer 1965), complex systems are systems with a large number of elements, a complex organization, a variety of the nature of the elements and the possible forms of their connection, a variety of purposes, variability of composition and structure (Hooker 2011; Korikov and Pavlov 2007). Complex systems also include systems whose parameters and behaviour tend to change over time (Kazaryan 2004) and in which the elements themselves act as systems (Spirkin 1990, 142).
- Natural and artificial (man-made) systems (differentiating criteria: origin of the system). Natural systems are the environment for human-made systems (Hall and Fagen 1956). However, there are also systems that can be attributed to both natural and artificial systems. Artificial-natural systems are examples of such systems (Ackoff 1960).
- Physical (concrete) and abstract (conceptual, imaginable) systems (differentiating criteria: materiality/immateriality of the system). If physical systems consist of matter, then abstract ones are a product of human thinking (Parsons 1979). All elements of abstract systems are concepts (Ackoff 1971). There are also "physical-abstract" (mixed) systems.
- Homogeneous and heterogeneous systems (differentiating criteria: homogeneity/heterogeneity of the system). Homogeneous systems are systems whose elements are interchangeable. An example of a homogeneous system is, for example, a population of organisms of a certain species. Accordingly, heterogeneous systems are composed of non-interchangeable elements.
- Discrete and continuous systems (differentiating criteria: discreteness/continuity of the system). Discrete systems are understood as systems consisting of clearly delineated (logically or physically) elements. However, such a division is considered rather arbitrary, since the same system can be discrete from one point of view and continuous from another.
- Stable and unstable systems (differentiating criteria: stability/instability of the system). Systems that have some stable properties are called stable. The division of systems into stable and unstable is also rather arbitrary (Hall and Fagen 1956).
- Adaptive (self-adaptive) and non-adaptive systems (differentiating criteria: the ability/inability of the system to adapt to changes in the environment). Adaptive systems have the ability to adapt to changing conditions (Miller and Page 2007). Accordingly, non-adaptive ones do not have such abilities.
- Deterministic and probabilistic (stochastic) systems (differentiating criteria: predictability/unpredictability of the state of the system). If the behaviour of deterministic systems is completely predictable, then probabilistic systems are not, which allows us to speak only about the probability of a system transition to a certain state (Sadovsky 2010). Examples of deterministic and probabilistic systems are the computer and the brain, respectively (Beer 1965).
- Behavioural and non-behavioural systems (differentiating criteria: presence/absence of system behaviour). Behavioural systems are systems that can be active, that is, they have behaviour (Ackoff 1960), and non-behavioural systems are systems that are not active.
- Dynamic (active) systems and static (passive) systems (differentiating criteria: variability/invariability of system behaviour over time). Dynamic systems are systems whose state changes over time, while static systems are systems whose state is constant. An example of a dynamic system is a living organism, and a static system is a gas in a limited volume in a state of equilibrium (Sadovsky 2010). However, it is believed that in fact, static systems do not exist, since almost all elements of systems, as well as the connections between them, are subject to changes to one degree or another (Gaase-Rapoport 1973).
- Developing (self-organizing systems) and non-developing systems (differentiating criteria: ability/inability of the system to develop). Systems that increase their differentiation and heterogeneity over time are called developing (Bertalanffy 1962). In the process of functioning, such systems can change their structure (Sadovsky 2010). Examples of developing systems are behavioural and social systems. The term self-organizing systems was introduced by Ashby (1962).
- Stable and unstable systems (differentiating criteria: stability/instability of the system). Stable systems are systems that can return to their original state after they have been removed from this state. Systems that cannot do this are accordingly called unstable.
- According to other differentiating criteria, systems are also divided into organismic (living) (Miller 1978) and non-organismic; organized and unorganized; learning and non-learning; cybernetic and non-cybernetic; governing and governed; technical (engineering), biological, economic and others (depending on the nature of the object considered as a system); mathematical, physical, chemical and others (depending on the scientific direction of system research); balanced (in equilibrium) and unbalanced; with and without feedback (some of the outputs of the feedback systems or the results of the behaviour of these systems act on the inputs again to trigger subsequent outputs) (Hall and Fagen 1956); purposeful and aimless (Ackoff and Emery 1972; Mesarovic 1964); self-regulating and non-self-regulating and others.

9.0 Criticism of the systems approach

SA is systematically criticized (see Berlinski 1976; Blauberg et al. 1984; Churchman 1979; Hammond 2002; Rousseau 2017a). It is criticized for the lack of a theoretical basis and connection with specific scientific disciplines (Anokhin 1971); failure to formulate a uniform definition of system (Adams et al. 2013); the lack of progress in identifying and clarifying general systems principles (Dubrovsky 2004; Rousseau 2017a); unsuccessful attempts to create a generally accepted unified systems concept (Agoshkova and Akhlibininsky 1998); reducing all subjects to objects in the "holistic" system (Wilber 1996, 116). It is also believed that "systems thinking remains marginalized from mainstream science" (Barton and Haslett 2007). In addition, according to Yudin (1973), SA did not justify the hopes for solving the problem of integrating modern scientific knowledge and achieving the unity of science, therefore, according to Anokhin (1971), it should not claim the universality of his status. In this regard, Arnold (2014) notes that "explicit forms of systems theory today survive more as heuristic approaches to problems than as a full-blown research program".

Separately, one should dwell on the criticism of the mathematization of SA (or the mathematical theory of systems), which manifests itself in the identification of systems with mathematical models and the transfer of attention from the specific (physical, biological, social) nature of systems to their mathematical structure (Kalman et al. 1969; Polderman and Willems 1998; Rapoport 1966; Wang 2015). The mathematization of SA is associated with the names of scientists such as Norbert Wiener, Ross D. Ashby, Mesarovic (1967), Ellis and Ludwig (1962b), O. Lange (1968). At the same time, its most prominent critic, according to Agoshkova and Akhlibininsky (1998), is Edmund Husserl, who believed that the absolutization of the mathematical form of knowledge leads to a fragmentary examination of phenomena and a dead-end direction in the development of science. Agoshkova and Akhlibininsky (1998) themselves adhere to the same point of view and emphasize that the mathematization of SA leads to such a division of the object into separate groups of properties, when the object as a whole disappears from the field of view of science. Moreover, according to Rapoport (1966), some systems, such as the brain, defy mathematical description at all.

The criticism of SA is largely related to the lack of progress in solving problems associated with the difficulties of drawing the line between its theory and the methodological field of its application (Sadovsky and Yudin 1969); various ways and forms of solving systems problems in different areas of knowledge (Kazaryan 2004; Sadovsky and Yudin 1969); the multiplicity of descriptions of systems (Sadovsky 2010); the variety of types of object relationships (Blauberg et al. 2010); the identification of the concepts of the system and the object and the misunderstanding of SA as an ordinary complex study (that is, a simple summation of data from different sciences) (Kazaryan 2004); the violation of the boundaries of application of SA, when its conceptual and methodological limitations are not taken into account; equation the organic system with social system (Unit-4 Systems Approach 2017).

Criticism of SA does not negate its importance, as this is discussed in the next Section.

10.0 Significance of the systems approach

From our point of view, Kazaryan (2004) spoke most succinctly and at the same time unambiguously about the importance of SA, expressing the opinion that before the emergence of SA "no one knew what follows from the fact that something is a system". However, more important is the fact that before the emergence of SA, the strategy of scientific research mainly consisted of analysis, while science aimed mainly to find the simple in complex systems, isolate and determine the elements in them, and then study the properties of these elements (Ashby 1958). SA orients the study "towards disclosing the integrity of an object and the mechanisms that ensure it, towards identifying various types of connections of a complex object and bringing them into a single theoretical picture" (Blauberg and Yudin 2012), that is, first of all, towards synthesis, not analysis and such a synthesis that does not complete the analysis, but acts as the initial principle of research (Rapoport and Ashby, quoted in Blauberg et al. 1969). By focusing on synthesis, SA serves as a means of overcoming knowledge fragmentation and helps to find new ways to solve scientific and practical problems (Jackson et al. 2010; Mobus and Kalton 2014; Skyttner 2006). Yudin (1973) takes a similar point of view, pointing out that "often even an old, seemingly dead-end problem can be solved if it is subjected to a systemic consideration".

The orientation of SA towards synthesis determines its interdisciplinary significance (Ackoff 1960; Adams 2012; 2014; Bertalanffy 1962; Mansfield 1982; Mobus and Kalton 2014; Solntsev 1981). Mansfield (1982) puts it this way: "systems methodology provides a common language among disciplines, with a standardization of terms and methods that facilitates communication and transfer of research findings across disciplinary boundaries". At the same time, Adams (2012) believes that systems theory can be applied "as a lens when viewing multidisciplinary systems and their related problems", since it is the basis for understanding them. A figurative illustration of the importance of SA is the story of the blind who could not describe the elephant, due to the fact that each of them touched only one part of the elephant's body (see Churchman 1968).

Barton and Haslett (2007) provide a generalized assessment of systems thinking, highlighting its central role in mainstream science. Arnold (2014) details this assessment by pointing to varied and multifaceted impact of systems theory on chaos and complexity theory, constructivist epistemology, artificial intelligence, robotics, digital culture in general, and the ecology movement. At the same time, it is believed that the importance of SA will only increase in the future (Olsson and Sjöstedt 2004), as systems science seems still to be in a formative stage (Warfield 2003) and "a scientific understanding of systemness is still nascent" (Rousseau 2017b). Based on a fairly large experience in the application of SA in soil science and landscape sciences (Nikiforova 2019; Nikiforova et al. 2019; Nikiforova et al. 2020), we cannot but agree with this. First of all, SA should play a decisive role in solving such an ambitious task as the global (overarching) integration of attributive and coordinate data on all elements of natural landscapes: soil-forming rocks, natural waters, atmospheric air, organisms and soils, as well as the properties of these elements and the patterns of their geographical distribution and changes in time. This is due to the fact that SA allows one to define soils and landscapes as systems objects, on the basis of which a soil-landscape classification system - the fundamental basis for the global integration of soil and landscape information - can be created.

11.0 Conclusion

All of the above allows us to conclude that at present SA is only at the initial stage of its development. This is evidenced, for example, by the fact that so far, no unambiguous answers have been received to such fundamental questions as: is it possible to formulate a uniform definition of system and create a single classification of systems? what are the limits of applying SA? what are the reasons for cases of its failure? There is no doubt that the answers to these questions will revive interest and confidence in SA and justify many of the hopes that were originally placed on it. It is also obvious that in the future it is necessary to use SA in the development of hierarchical classification systems of system objects, the basis for integrating information on these objects. The result of this may be, if not a complete elimination of the existing gaps in our knowledge, then at least their significant reduction.

Acknowledgments

I express my sincere gratitude to IEKO editors Prof. Birger Hjørland and Dr. Claudio Gnoli for the idea of writing the article, as well as for important comments that greatly improved the manuscript. Section 7 has been written by Dr. Gnoli. This work was supported by Lomonosov Moscow State University, Faculty of Soil Science [number of state assignment AAAA-A15-121040800146-3, CITIS number: 121040800146-3].

References

Ackoff, Russell L. 1971. "Towards a System of Systems Concepts." *Management Science* 17: 661-71.

Ackoff, Russell L. 1960. "Systems, Organizations and Interdisciplinary Research." *General Systems* 5: 1-8.

Ackoff, Russell L. and Fred E. Emery. 1972. *On Purposeful Systems*. Chicago; New York: Aldine Atherton.

Adams, Kevin MacG. 2012. "Systems Theory: A Formal Construct for Understanding Systems." *International Journal of Systems Engineering* 3: 209-24.

Adams, Kevin MacG., Patrick T. Hester, Joseph M. Bradley, Thomas J. Meyers and Charles B. Keating. 2014. "Systems Theory as the Foundation for Understanding Systems." *Systems Engineering* 17: 112–23.

Adams, Kevin MacG., Patrick. T. Hester and Joseph M. Bradley. 2013. "A Historical Perspective of Systems Theory." In *Proceedings of the 2013 Industrial and Systems Engineering Research Conference*, edited by A. Krishnamurthy and W.K.V. Chan. Abstract ID: 434.

Agoshkova, Ye. B. and B.V. Akhlibininsky. 1998. "Эволюция понятия системы [System Concept Evolution]." *Voprosy Filosofii* 7: 170-9 (in Russian).

Anokhin, P.K. 1971. *Принципиальные вопросы общей теории функциональных систем* [*Fundamental Questions of the General Theory of Functional Systems*]. Moscow (in Russian).

Arnold, Darrell P. 2014. "Systems Theory: A Secret History of the Twentieth Century." In *Traditions of System Theory: Major Figures and Contemporary Developments*, edited by Darrell P. Arnold. London; New York: Routledge, 10-20.

Arnold, Darrell P. (Ed.). 2013. *Traditions of Systems Theory: Major Figures and Contemporary Developments. Routledge Studies in Library and Information Science*. London: Routledge.

Arnold, Ross D. and Jon P. Wade. 2015. "A Definition of Systems Thinking: A Systems Approach." *Procedia Computer Science* 44: 669–78.

Ashby, W. Ross. 1962. "Principles of the Self-Organizing System." In *Principles of Self-Organization*, edited by Heinz Von Foerster and George W. Zopf, Jr. U.S. Office of Naval Research, 255–78.

Ashby, W. Ross. 1960. *Design for a Brain*. 2nd rev. ed. London: Chapman and Hall.

Ashby, W. Ross. 1958. "General Systems Theory as a New Discipline." *General Systems* 3: 1-6.

Austin, Derek. 1969. "Prospects for a New General Classification." *Journal of Librarianship* 1, no. 3: 149-69.

Austin, Derek. 1974. "The Development of PRECIS. 2: The Classificatory Backgrounds of PRECIS." *Journal of Documentation* 30: 53-63.

Austin, Derek. 1976. "Citation Order and Linguistic Structure." In *The Variety of Librarianship: Essays in Honour of John Wallace Metcalfe*, edited by W. Boyd Rayward. Sydney: Library Association of Australia, 19-46.

Bahg, Chang-Gen. 1990. "Major Systems Theories throughout the World." *Behavioral Science* 35: 79-107.

Barton, John and Tim Haslett. 2007. "Analysis, Synthesis, Systems Thinking and the Scientific Method: Rediscovering the Importance of Open Systems." *Behavioral Science* 24: 143-55.

Beer, Stafford. 1965. *Кибернетика и управление производством [Cybernetics and Production Management]*. Moscow: Nauka (in Russian).

Berlinski, David. 1976. *On Systems Analysis: An Essay Concerning the Limitations of Some Mathematical Methods in The Social, Political and Biological Sciences*. Cambridge, MA: MIT Press.

Bertalanffy, Ludwig von. 1972. "The history and Status of General Systems Theory." *Academy of Management Journal* 15: 407-26.

Bertalanffy, Ludwig von. 1968. *General System Theory: Foundations, Development and Applications*. New York: George Braziller.

Bertalanffy, Ludwig von. 1962. "General System Theory: A Critical Review." *General Systems* 7: 1-20.

Biggart, John, Peter Dudley and Francis King (Eds.). 1998. *Alexander Bogdanov and the Origins of Systems Thinking in Russia*. Aldershot: Ashgate.

Blauberg, I.V. 1973. "Системный подход как предмет историко-научной рефлексии [The Systems Approach as a Subject of Historical and Scientific Reflection]." In *Systems Research. Yearbook 1973. Institute for the History of Natural Science and Technology of the Soviet Academy of Sciences*. Moscow: Nauka, 7-19 (in Russian).

Blauberg, I.V., E.M. Mirsky and V.N. Sadovsky. 1984. "Systems Approach to Systems Analysis." In *Rethinking the Process of Operational Research and Systems Analysis. Frontiers of Operational Research and Applied Systems Analysis. Volume 2*, edited by Rolfe Tomlinson and István Kiss. Oxford: Pergamon Press, 19-32.

Blauberg, I.V., V.N. Sadovsky and E.G. Yudin. 2010. "Системный подход [The Systems Approach]." In *Новая философская энциклопедия [New Philosophical Encyclopedia]. 2nd rev. and add. ed.*, edited by V.S. Styopin. Institute of Philosophy RAS, National Social Science Foundation. Moscow: Mysl (in Russian).

Blauberg, I. V., V. N. Sadovsky and E. G. Yudin. 1969. "Системные исследования и общая теория систем [Systems Research and General Systems Theory]." In *Системные исследования. Общая теория систем: задачи и методы. Приложения системного подхода. Ежегодник 1969 [System Research. General Systems Theory: Tasks and Methods. The Systems Approach applications. Yearbook 1969]*. Institute for the History of Natural Science and Technology of the Soviet Academy of Sciences. Moscow: Nauka, 7-29 (in Russian).

Blauberg, I. V. and E. G. Yudin. 2012. "Системный подход [The Systems Approach]." In *Большая советская энциклопедия, БСЭ [Great Soviet Encyclopedia, GSE]* (in Russian). https://slovar.cc/enc/bse/2041524.html.

Blauberg, I. V. and E. G. Yudin. 1973. *Становление и сущность системного подхода [Development and Essence of the Systems Approach]*. Moscow: Nauka (in Russian).

Blauberg, I. V., V. P. Zinchenko, V. Zh. Kelle, V. A. Lektorsky, A. A. Lyapunov, A. A. Malinovsky, D. L. Pospelov, V. P. Sadovsky, A. L. Takhtadzhyan, A. I. Uyomov, K. M. Khailov and E. G. Yudin (Eds.). 1973. *Системные исследования. Ежегодник 1973 [Systems research. Yearbook 1973]*. Institute for the History of Natural Science and Technology of the Soviet Academy of Sciences. Moscow: Nauka (in Russian).

Boulding, Kenneth E. 1956. "General Systems Theory – the Skeleton of Science." *Management Science* 2: 197–208.

Bunge, Mario. 1979a. "A Systems Concept of Society: Beyond Individualism and Holism." *Theory and Decision* 10: 13-30.

Bunge, Mario. 1979b. *Treatise on Basic Philosophy. 4: Ontology 2: A World of Systems*. Dordrecht: Reidel.

Checkland, Peter B. 1999. *Systems Thinking, Systems Practice*. New York: Wiley.

Checkland, Peter. 1984. "Rethinking a Systems Approach." In *Rethinking the Process of Operational Research and Systems Analysis. Frontiers of Operational Research and Applied Systems Analysis. Volume 2*, edited by Rolfe Tomlinson and István Kiss. Oxford: Pergamon Press, 43-60.

Chen, Gordon K.C. 1975. "What is the Systems Approach?" *Interfaces* 6: 32-7.

Chernyak, Yu.I. 1975. *Системный Анализ в Управлении Экономикой [Systems Analysis in Economic Management]*. Moscow: Economika (in Russian).

Chian, Abraham C.-L. 2007. *Complex Systems Approach to Economic Dynamics*. Berlin; New York: Springer.

Churchman, C. West. 1979. *The Systems Approach and its Enemies*. New York; London: Basic Books.

Churchman, C. West. 1968. *The Systems Approach*. New York: Dell Publishing.

Classification Research Group. 1969. *Classification and Information Control*. London: Library Association.

Merriam-Webster Dictionary. n. d. "Definition of System." https://www.merriam-webster.com/dictionary/system.

Drack, Manfred. 2009. "Ludwig von Bertalanffy's Early System Approach." *Systems Research and Behavioral Science* 26: 563-72.

Drack, Manfred and David Pouvreau. 2015. "On the History of Ludwig von Bertalanffy's "General Systemology", and on its Relationship to Cybernetics - Part III: Convergences and Divergences." *International Journal of General Systems* 44: 523–71.

Dubitzky, W., O. Wolkenhauer, H. Yokota, K.-H. Cho (Eds.). 2013. *Encyclopedia of Systems Biology*. https://www.springer.com/gp/book/9781441998620

Dubrovsky, Vitaly. 2004. "Toward System Principles: General System Theory and the Alternative Approach." *Systems Research and Behavioral Science* 21: 109-22.

Ellis, David O. and Fred J. Ludwig. 1962a. *Systems Philosophy*. Englewood Cliffs, NJ: Prentice-Hall.

Ellis, David O. and Fred J. Ludwig. 1962b. "Precise Definition of System." In *Systems Philosophy*. Englewood Cliffs, NJ: Prentice-Hall, 128-31.

Fillmore, Charles J. 1968. "The Case for Case." In *Universals in Linguistic Theory*, edited by E. Bach and R.T. Harms. New York: Holt Rinehart & Winston, 1-88.

Fleishman, B.S. 1982. *Основы Системологии [Fundamentals of Systemology]*. Moscow: Radio i Svyaz (in Russian).

Flood, Robert L. and Michael C. Jackson. 1991. *Critical Systems Thinking: Directed Readings*. Chichester; New York: Wiley.

Foskett, Douglas J. 1972. "Information and General Systems Theory." *Journal of Librarianship* 4, no. 3: 205-9.

Foskett, Douglas J. 1974. "Information and Systems Philosophy." *Journal of Librarianship* 6, no. 2: 126-30.

Foskett, Douglas J. 1980. "Systems Theory and Its Relevance to Documentary Classification." *International Classification* 7: 2-5.

Gaase-Rapoport, M.G. 1973. "Кибернетика и Теория Систем [Cybernetics and Systems Theory]." In *Системные Исследования. Ежегодник 1973 [System Research. Yearbook 1973]*. Institute for the History of Natural Science and Technology of the Soviet Academy of Sciences. Moscow: Nauka, 63-75 (in Russian).

Gibson, Ralph E. 1960. "The Recognition of Systems Engineering." In *Operations Research and Systems Engineering*, edited by C.D. Flagle, W.H. Huggins and R.H. Roy. Baltimore, MD: Johns Hopkins Press.

Gleeson, Patrick. 2019. *Importance of the System Approach Principle*. https://smallbusiness.chron.com/importance-system-approach-principle-81413.html

Gnoli, Claudio. 2008. "Facets: a Fruitful Notion in Many Domains." Axiomathes 18: 127-30.

Gnoli, Claudio. 2017. "Classifying Phenomena, Part 3: Facets." In *Dimensions of Knowledge: Facets for Knowledge Organization*, edited by Richard Smiraglia and Hur-Li Lee. Würzburg: Ergon, 55-67.

Gnoli, Claudio. 2020. "Integrative Levels Classification (ILC)." In *ISKO Encyclopedia of Knowledge Organization*, edited by Birger Hjørland and Claudio Gnoli. https://www.isko.org/cyclo/ilc

Hall, Arthur D. and Robert E. Fagen. 1956. "Definition of System." *General Systems* 1: 18-28.

Hammond, Debora. 2002. "Exploring the Genealogy of Systems Thinking." *Systems Research and Behavioral Science* 19: 429-39.

Hooker, Cliff (Ed.). 2011. *Philosophy of Complex Systems*. Oxford: Elsevier.

Jackson, Michael C. 2003. *Systems Thinking: Creative Holism for Managers*. Chichester: Wiley.

Jackson, Scott, Derek Hitchins and Howard Eisner. 2010. "What is the Systems Approach?" *Insight* 13: 41-3.

Jolley, J. L. 1968. *Data Study*. London: Weidenfeld and Nicholson.

Juma, N.G. 1999. *The Pedosphere and its Dynamics: A systems Approach to Soil Science. Vol. 1. Introduction to Soil Science and Soil Resources*. Edmonton: Salman Productions.

Kalman, Rudolf Emil, Peter L. Falb and Michael A. Arbib. 1969. *Topics in Mathematical System Theory*. New York: McGraw-Hill.

Kazaryan, V.P. 2004. "Системный Подход в Современном Естествознании [The Systems Approach in Modern Natural Science]." In *Философия Современного Естествознания: Учеб. Пособие Для Вузов* [*Philosophy of Modern Natural Science: Textbook for Universities]*, edited by S.A. Lebedev. Moscow: Fair-Press, 275-98 (in Russian).

Kleineberg, Michael. 2017. "Integrative Levels." *Knowledge Organization* 44: 349-79. Also available in *ISKO Encyclopedia of Knowledge Organization*, edited by Birger Hjørland and Claudio Gnoli. https://www.isko.org/cyclo/integrative_levels

Klir, George Jirl. 1965. "The General System as a Methodological Tool." *General Systems* 10: 29-42.

Korikov A.M. and S.N. Pavlov. 2007. *Теория Систем и Системный Анализ: Учеб. Пособие [Systems Theory and Systems Analysis: Manual]*. Tomsk: Tomsk State University of Control Systems and Radioelectronics (in Russian).

Lai, Chih-Hui and Sapphire Huili Lin. 2017. "Systems Theory." In *The International Encyclopedia of Organizational Communication. Historical Development of the Systems Theory,* edited by Craig R. Scott, Laurie Lewis, James R. Barker, Joann Keyton, Timothy Kuhn and Paaige K. Turner. Wiley, 1-16. https://doi.org/10.1002/9781118955567.wbieoc203

Lange, O. 1968. *Введение в Экономическую Кибернетику [Introduction to Economic Cybernetics]*. Translation from Polish. Moscow: Progress (in Russian).

László, Ervin. 1973. "The Rise of General Theories in Contemporary Science." *Journal for General Philosophy of Science* 4: 335-44.
László, Ervin (Ed.). 1972. *The Relevance of General Systems Theory*. New York: George Braziller.
László, Ervin and Alexander László. 2003. "The Systems Sciences in Service of Humanity." In *Systems Science and Cybernetics*, edited by Francisco Parra-Luna. Oxford: EOLSS Publishers, 32–59.
Liddell, Henry George and Robert Scott. n. d. "Σύστημα". *A Greek–English Lexicon.* http://www.perseus.tufts.edu/hopper/text?doc=Perseus%3Atext%3A1999.04.0057%3Aentry%3Dsu%2Fsthma
Luhmann, Niklas. 1995. *Social Systems*. Stanford, CA: Stanford University Press.
Magee, C.L. and de Weck O.L. 2004. "Complex System Classification." In *Proceedings of the 14th Annual International Council on Systems Engineering International Symposium.* France, Toulouse, 20-24. https //doi.org/10.1002/j.2334-5837.2004.tb00510.x
Mansfield, Una. 1982. "The Systems Movement: An Overview for Information Scientists." *Journal of the American Society for Information Science* 33: 375-82.
Mattessich, Richard. 1982. "The Systems Approach: Its Variety of Aspects." *Journal of the American Society for Information Science* 33: 383-94.
Mele, Cristina, Jacqueline Pels and Francesco Polese. 2010. "A Brief Review of Systems Theories and their Managerial Applications." *Service Science* 2: 126-35.
Mesarović, M.D., D.C. Macko and Y. Takahara. 1970. *Theory of Hierarchical Multilevel Systems*. New York: Academic Press.
Mesarović, Mihajlo D. 1967. "General Systems Theory and its Mathematical Foundations." In *Proceedings of Systems Science and Cybernetics Conference, IEEE, Boston, Massachusetts*.
Mesarović, M.D. 1964. "Foundations for a General Systems Theory." In *Views on General Systems Theory: Proceedings of the Second Systems Symposium at Case Institute of Technology*, edited by Mihajlo D. Mesarović. New York: Wiley.
Midgley, Gerald (Ed.). 2003. *Systems Thinking. Volumes 1-4*. London: SAGE. https://www.schumacherinstitute.org.uk/download/docs/fellow_documents/Book-Systems-Thinking-Gerald-Midgley.pdf
Miller, James Grier. 1978. *Living* Systems. New York: McGraw Hill.
Miller, John H. and Scott E. Page. 2007. *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. Princeton: Princeton U.P.
Mobus, George E. and Michael C. Kalton. 2014. *Principles of Systems Science*. New York: Springer.
Mokiy, Vladimir. 2019. "Systems Transdisciplinary Approach in the General Classification of Scientific Approaches." *European Scientific Journal* 15: 247-58.
Nikiforova, Aleksandra A., Maria E. Fleis, Maxim V. Nyrtsov, Nikolay N. Kazantsev, Klim V. Kim, Nina K. Belyonova and Julia K. Kim. 2020. "Problems of Modern Soil Mapping and Ways to Solve Them." *Catena* 195. Article id: 104885.
Nikiforova, Aleksandra A. 2019. "Soil Classification." *Knowledge Organization* 46: 467-88.
Nikiforova, Aleksandra A., Olaf Basian, Maria E. Fleis, Maxim V. Nyrtsov and Aleksandr G. Khropov. 2019. "Theoretical Development of a Natural Soil-Landscape Classification System: An Interdisciplinary Approach." *Catena* 177: 238-45.
Nikolaev, V.A. 2006. *Ландшафтоведение: Семинарские и Практические Занятия [Landscape Study: Seminars and Workshops]*. Moscow: Faculty of Geography, Moscow State University (in Russian).
Olsson Mats-Olov and Gunnar Sjöstedt. 2004. "Systems and Systems Theory." In *Systems Approaches and their Application: Examples from Sweden*, edited by M-O. Olsson and G. Sjöstedt. Dordrecht: Luwer, 3-29.
Parsons, Talcott. 1979. "Concrete Systems and "Abstracted" Systems." *Contemporary Sociology* 8: 696-705.
Parsons, Talcott. 1977. *Social Systems and the Evolution of Action Theory*. New York: Free Press.
Patten, Bernard C. (Ed.). 1971. *Systems Analysis and Simulation in Ecology. Volume 1*. New York: Academic Press.
Peregudov, F.I. and F.P. Tarasenko. 1989. *Введение в Системный Анализ [Introduction to Systems Analysis]*. Moscow: Vysshaya Shkola (in Russian).
Polderman, Jan Willem and Jan C. Willems. 1998. *Introduction to Mathematical Systems Theory: A Behavioral Approach. Texts in Applied Mathematics. Volume 26*. New York: Springer.
Pouvreau, David. 2013. "The Project of "General Systemology" Instigated by Ludwig von Bertalanffy: Genealogy, Genesis, Reception and Advancement." *Kybernetes* 42: 851–68.
Pouvreau, David and Manfred Drack. 2007. "On the History of Ludwig von Bertalanffy's "General Systemology", and on its Relationship to Cybernetics." *International Journal of General Systems* 36: 281–337.
Ramage, Magnus Alastair and Karen Shipp. 2009. *Systems Thinkers*. London: Springer.
Rapoport, Anatol. 1966. "Mathematical Aspects of General Systems Analysis." *General Systems* 11: 3-11.
Rousseau, David, Jennifer Wilby, Julie Billingham and Stefan Blachfellner. 2018. *General Systemology: Transdisciplinarity for Discovery, Insight and Innovation.* Tokyo: Springer.

Rousseau, D. 2017a. "Strategies for Discovering Scientific Systems Principles." *Systems Research and Behavioral Science* 34: 527–36.

Rousseau, D. 2017b. "Systems Research and the Quest for Scientific Systems Principles." *Systems* 5: 25.

Rousseau, D. 2017c. "Three General Systems Principles and their Derivation: Insights from the Philosophy of Science Applied to Systems Concepts." In *Disciplinary Convergence in Systems Engineering Research*, edited by A. M. Madni, B. Boehm, R. G. Ghanem, D. Erwin and M. J. Wheaton. New York, NY: Springer.

Sagatovsky, V. N. 1973. *Основы Систематизации Всеобщих Категорий [Basics of Systematizing General Categories].* Tomsk: TMI (in Russian).

Sadovsky, V. N. 2010. "Система [System]." In *Новая Философская Энциклопедия [New Philosophical Encyclopedia]. 2nd ed.*, edited by V.S. Styopin. National Social Science Foundation. Moscow: Mysl (in Russian). https://iphlib.ru/library/collection/newphilenc/document/HASHd77bbce481b4406a90ced7

Sadovsky, V. N. 1970. "Логико-методологический Анализ "Общей Теории Систем" Л. Фон Берталанфи [Logical-Methodological Analysis of L. von Bertalanffy's "General Systems Theory"]." In *Проблемы Методологии Системных Исследований [Systems Research Methodology Problems]*, edited by I. V. Blauberg, V. N. Sadovsky and E. G. Yudin. Moscow: Mysl, 411-42 (in Russian).

Sadovsky, V. N. and E. G. Yudin. 1969. "Задачи, Методы и Приложения Общей Теории Систем [Problems, Methods and Applications of General Systems Theory]." In *Исследования по Общей Теории Систем [Research in General Systems Theory].* Moscow: Progress, 3-22 (in Russian).

Schumm, Stanley A. 1977. *The Fluvial System*. New York: Wiley-Interscience.

Shannon, C.E. 1948. "A Mathematical Theory of Communication." *The Bell System Technical Journal* 27: 379-423, 623–56. Reprinted with corrections http://people.math.harvard.edu/~ctm/home/text/others/shannon/entropy/entropy.pdf

Simon, Herbert A. 1962. "The Architecture of Complexity." *Proceedings of the American Philosophical Society* 106: 467-82.

Sirgy, M. Joseph. 1988. "Strategies for Developing General Systems Theories." *Behavioral Science* 33: 25–37.

Skyttner, Lars. 2006. *General Systems Theory: Problems, Perspectives, Practice. 2nd ed.* Hackensack, NJ: World Scientific Publishing.

Solntsev, V.N. 1981. *Системная Организация Ландшафтов: Проблемы Методологии и Теории [Systems Organization of Landscapes: Problems of Methodology and Theory].* Moscow: Mysl (in Russian).

Stichweh, Rudolf. 2011. "Systems Theory." In *International Encyclopedia of Political Science. Volume 8*, edited by B. Badie, D. Berg-Schlosser and L. Morlino. New York: SAGE, 2579-88.

Surmin, Yu P. 2003. *Теория Систем и Системный Анализ: Учеб. Пособие [Systems Theory and Systems Analysis: Manual].* Kiev: MAUP (in Russian).

"System." In *Webster's 1913 Dictionary*. https://www.webster-dictionary.org/definition/System

Tien, James M. and Daniel Berg. 2003. "A Case for Service Systems Engineering." *Journal of Systems Science and Systems Engineering* 12: 13-38.

Troncale, Len. 2009. "Revisited: The Future of General Systems Research: Update on Obstacles, Potentials, Case Studies." *Systems Research and Behavioral Science* 26: 553-61.

Troncale, Len. 1988. "The Systems Sciences: What are they? Are they One, or Many?" *European Journal of Operational Research* 37: 8-33.

Tyukhtin, V. S. 1972. *Отражение, Системы, Кибернетика [Reflection, Systems, Cybernetics].* Moscow: Nauka (in Russian).

"Unit-4 Systems Approach." 2017. The Indira Gandhi National Open University (IGNOU). http://hdl.handle.net/123456789/20896

Uyomov, A. I. 1978. *Системный Подход и Общая Теория Систем [The Systems Approach and General Systems Theory].* Moscow: Mysl (in Russian).

Volkova V. N. and A. A. Denisov. 2014. *Теория Систем и Системный Анализ: Учебник [Systems Theory and Systems Analysis: Textbook].* Moscow: Yurayt (in Russian).

Wang, Yingxu. 2015. "Towards the Abstract System Theory of System Science for Cognitive and Intelligent Systems." *Complex & Intelligent Systems* 1: 1–22. https://doi.org/10.1007/s40747-015-0001-5

Warfield, John N. 2003. "A Proposal for Systems Science." *Systems Research and Behavioral Science* 20: 507-20.

Whyte, Lancelot Law, Albert G. Wilson and Donna Wilson (Eds.). 1969. *Hierarchical Structures.* New York: Elsevier.

Wilber, Ken. 1996. *A Brief History of Everything*. Dublin: Gill & Macmillan.

Wiener, Norbert. 1948. *Cybernetics: Or Control and Communication in the Animal and the Machine.* Paris: Librairie Hermann; Cambridge, MA: MIT Press.

Yudin, E.G. 1973. "Методологическая Природа Системного Подхода [Methodological Nature of the Systems Approach]." In *Системные Исследования. Ежегодник 1973 [Systems Research. Yearbook 1973].* Institute for the History of Natural Science and Technology of the Soviet Academy of Sciences. Moscow: Nauka, 38-52 (in Russian).