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From Classical Systems Thinking to Modern Dynamic Systems Theory: Beyond the Definitions and Conceptual Delimitations

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Abstract: *The present paper presents practically an introduction to the Modern Dynamic Systems Theory and the analysis of dynamic systems behaviour, exposing a series of information that is accessible to any reader without requiring any particular notions. The study undertaken as a mixture of theory and practical examples of definitions is dedicated to familiarizing the reader with the diversity of fundamental concepts and developmental stages specific to the General (classical) Systems Theory and to review the definitions and characteristics of the existing systems in the specialized literature.*

Keywords: *Systems Thinking, Systems Theory, Dynamic Systems Theory, conceptual delimitations.*

1. Introduction

Systems Theory is still a very current field of science; in this area, many articles have been published in the specialized magazines and many books in prestigious publishers. For this reason, however advanced the modern means of information (documentation, analysis and interpretation) may be, it is practically impossible to keep up-to-date information in this area, to select and write this information in a form easily accessible to the general public.

To write about a very topical field, such as Systems Thinking, Systems Theory or, as the case may be, Modern Dynamic Systems Theory, is, from this point of view, a great risk, because, by its dynamic nature, information is usually at least partially outdated at the time of publication. Aware of this shortcoming, we tried to arouse the interest of the general public for a current field of science through this paper, by synthetically exposing, at a theoretical level, what we have perceived to be systems, in general, and dynamic systems so far, in particular.

Without constituting a popularization study, the present material sets out besides a series of theoretical statements, which are still taught in some Romanian technical faculties, with reference to Systems Thinking and Systems Theory and their characteristics, and a series examples that come to illustrate the theory.

The Systems Theory, together with its consequences, is reflected in the current technical sciences, as a new point of view, as a new integrative approach. Until recently, some researchers believed that the secrets of nature are in the microcosm and have gone on to discover elementary particles of matter (energy and information carriers), while others have searched in the macrocosm, in the world of galaxies, black holes and other formations in the huge universe, both of them leaving the environmental world we still live in, because they have considered that are at the top of modern research, disregarding the research of those dealing with the environmental world research.

The present paper presents practically an introduction to the Modern Dynamic Systems Theory and the analysis of their behaviour, exposing a series of information that is accessible to any reader without requiring any particular notions regarding the dynamic systems. The study undertaken as a mixture of theory and practical examples is dedicated to familiarizing the reader with the diversity of fundamental concepts and developmental stages specific to the Systems Thinking and Modern Dynamic Systems Theory, relative to the existing systems in literature. Also, we found interesting here, as a natural place, to present even a non-exhaustive classification of the systems, respectively of the models, depending on their linearity, the relation to the time variable, the number of input-output variables or the behaviour in time (evolution). The problems associated with different types of systems and the necessity of studying dynamic systems, as well as the implications of dynamic behaviour analysis, are also reviewed in virtue of systems dynamics.

2. Systems Thinking vs. Modern Dynamic Systems Theory - the current state of knowledge

2.1 Background & conceptual approaches

Since ancient times, from the Babylonians, natural and social phenomena have been present in the daily scientific activities of researchers, engineers and mathematicians alike [1, 2], and as the human society has evolved, especially from a technical and scientific point of view, their importance in the complex system of human civilization has continuously increased [3, 4].
In this sense, the new information and communication technologies, which are in the process of developing, through the contribution of knowledge, have led to overcoming and dismantling the separating barriers - the time and space are no longer insurmountable obstacles to communication and relationship - as references to the Super Smart Society [5-7], composed by Information, Knowledge and Consciousness Society (see Fig. 1) [8-10].

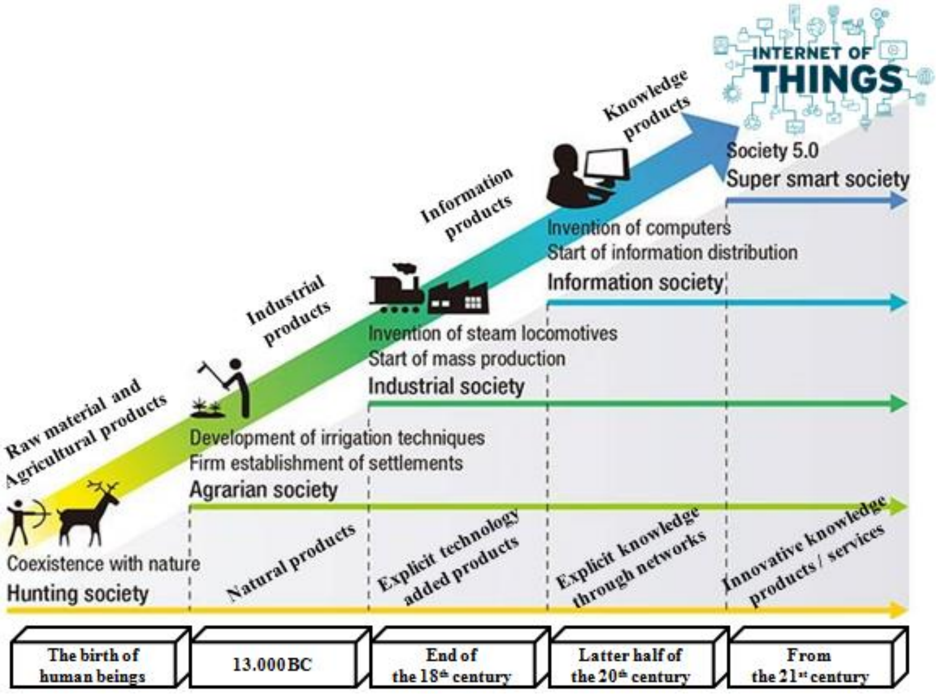

Fig. 1. Evolution of societies from the Hunting Society to Super Smart Society [10]

The study of natural and social phenomena has gradually led scientists to create mathematical representations (e.g. models) that embody their main features and characteristics in an abstract formulation. Long-term surveys have shown that both natural phenomena and social phenomena are evolutionary phenomena, with their own specific dynamics [3, 4]. The consecrated fundamental methods of research in the field of natural and technical sciences are therefore observations and measurements, concepts that are at the core of natural and technical sciences (see Fig. 2) [11-13].

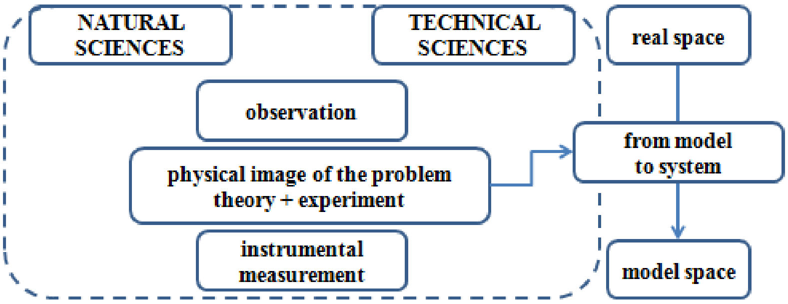

Fig. 2. Observation and instrumental measurement in relation to natural and technical sciences [4]

Starting from the identified observations, the researcher builds, first of all, a physical image of the problem that he analyzes and only then formulates a theory, that is, a concept about the aspect of the analyzed environment, which can take any form, based on the different scientific approaches of the actual system under consideration (see Fig. 3).

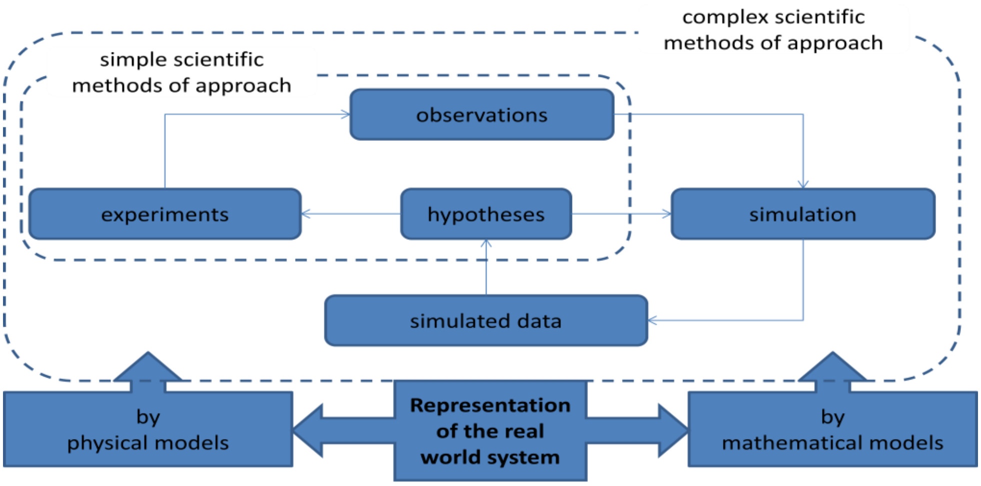

Fig. 3. Different types of scientific approaches of the real world system

Further, based on thoughtful and judiciously constructed experiments, results are obtained that can confirm the theory, determine its changes or reject it, as a result of the thinking and action plan, both defined based on inter- and transdisciplinary approaches (Fig. 4), specific to our days [13]. Based on the above arguments it can be stated that, within the vast field of research specific to the natural and technical sciences, observations and measurements (experiments) are fundamental elements, which come in the natural complement of the General Systems Theory (GST) [14, 15].

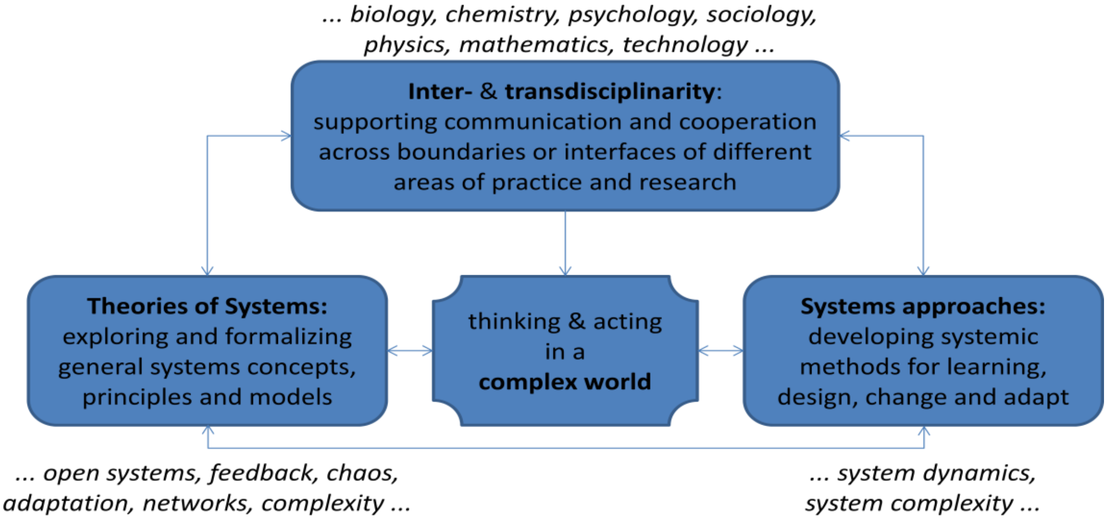

Fig. 4. Different types of scientific approaches of the real world system in relation to "Theories of Systems"

The General Systems Theory of as a field of research, by itself, follows the study of the properties of various types of systems [16], or "systemic approach" [17-20], as well as the enunciation of sets of principles [21-23], independent of domain, substance, type or time [11, 24].
By the emergence of the General Systems Theory, which includes Systems Theory (both classical and modern, respectively post-modern), the ways of designing and developing the modelling of the environment or of the various structures considered have been opened. The General Systems Theory is also the result of the symbiosis between applied mathematics and systems science, known in the literature as "Systemology" (as presented in Fig. 5).

Its origins, as a mathematical theory (see Fig. 5), are especially situated in complexity theory, thus, through the multidisciplinary vision and the use of mathematical language, complexity theory constitutes the matrix of GTS evolution. As an interdisciplinary epistemological model GTS represents a "*set of concepts, knowledge, methods and principles of independent applications, necessary and useful for the study of the structure, properties and characteristics of systems with variable degree of complexity*" [12].

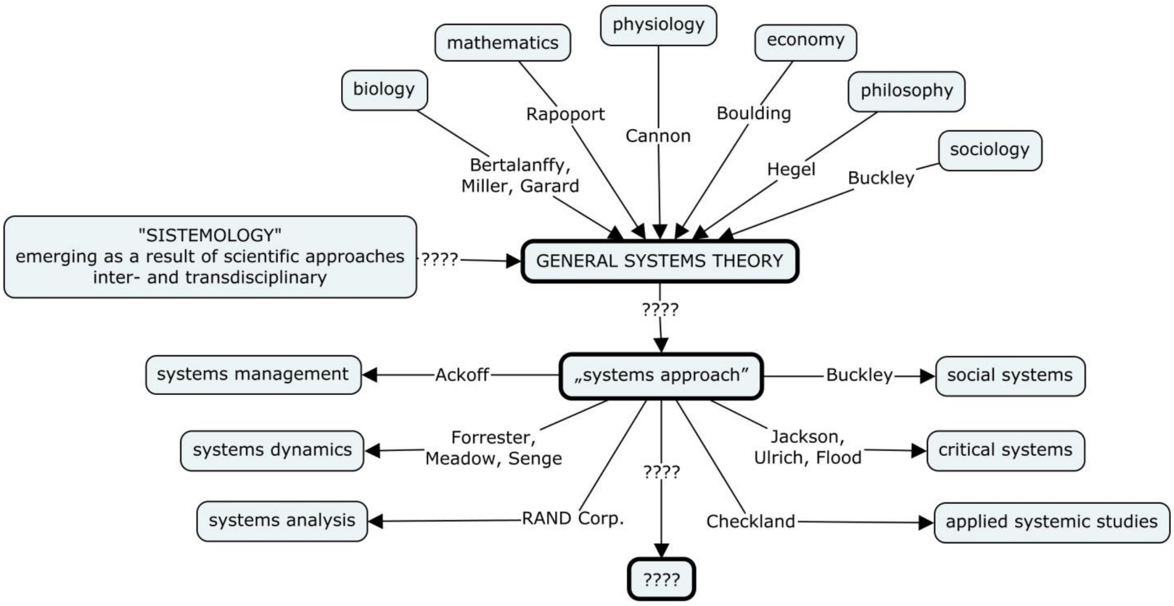

Fig. 5. The position of "Systemology" in relation to "General Systems Theory"

The GTS concept used in different scientific environments, such as computer science, physics, electrotechnics, pedagogy, chemistry, geography, biology, mathematics, physiology, sociology, psychology, ethnology, ecology, computer science and so on, has undergone a well-defined development, through the scientific approaches of the numerous promoters, some of them being reviewed in Fig. 6.

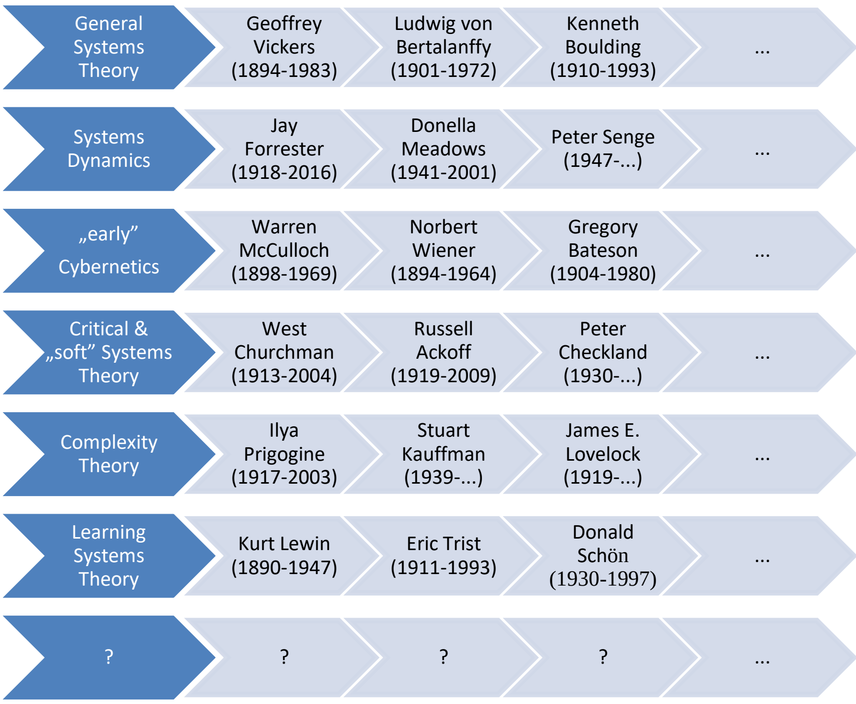

Fig. 6. General Systems Theory in relation to the "promoters of Systemology"

Having the abstract system as object of study, separated from its concrete physical nature, the GTS, which interlocks, at times, with the Complexity Theory and also has links with the Chaos Theory, the Adaptability Theory etc., is a "field of study that harmoniously combines the phenomenological aspects of real systems, as well as the mathematical elements needed to describe the behavior and dynamic interaction of systems" (see Fig. 7).

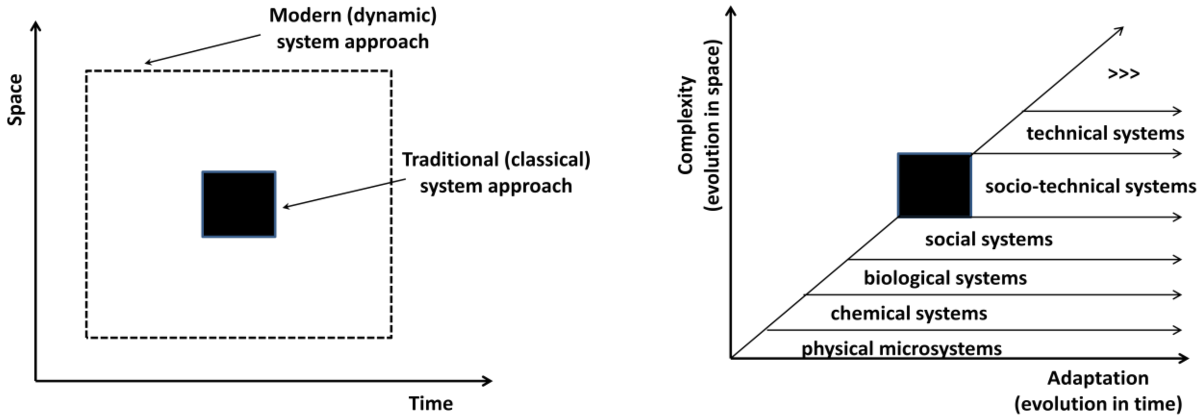

Fig. 7. "Systemic approach" - schematic representation and in relation to various "systems"

In the previous context, the Systems Thinking is by itself a part of GST, which study systems derived from their concrete forms; the extraction is done by retaining the essential components, the defining ones, from each type of system. Thus, in the GST one starts from the conception that a system is "a complex of interacting elements"; the system is highlighted by its internal structure and connections (as in Fig. 8), which constitute a delimited unit with respect to the environment.

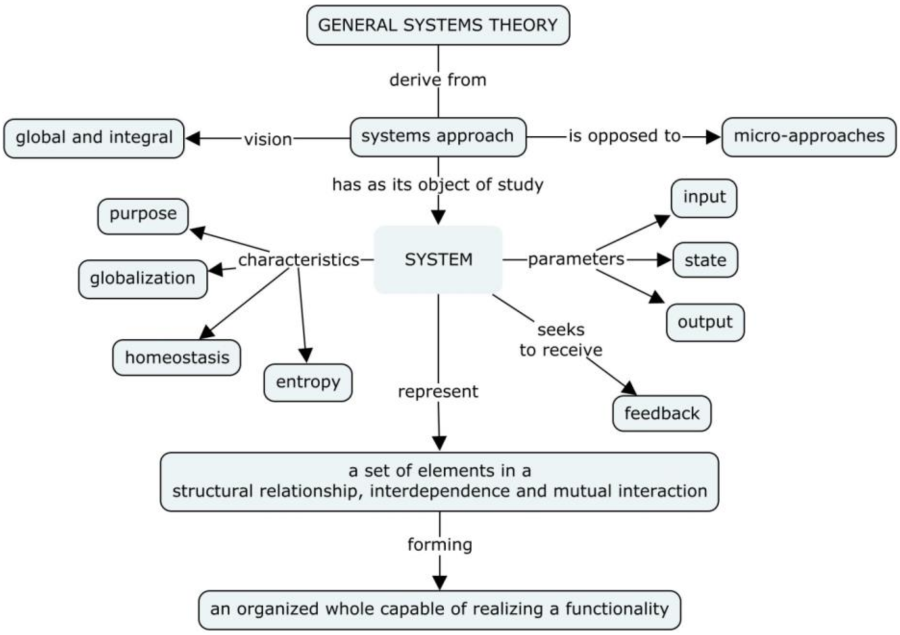

Fig. 8. The "system" as an object of study of the "General Systems Theory"

The systems behavior depends not only on the properties of its elements, but especially on the interactions between them. Similar concepts, appearing simultaneously and autonomously, in various scientific fields have led from the concept of *static system* to that of *dynamic system*, respectively from the formulation of laws governing the whole set of systems to the discovery of isomorphisms between various systems existing in nature and technique. Modern Dynamic Systems Theory introduces, a logical, so-called systemic scientific way of thinking, based on the *principle of causality*, which allows the inter- and transdisciplinary approach of the surrounding reality, respectively the "*compact sets of entities that interact and be like one*".

2.2 A few system approaches & definitions

One of the major breakthroughs in understanding the complexity of the world is the field of Modern Dynamic Systems Theory (MDST). The field studies systems from the perspective of the whole system, its various subsystems and the recurring patterns in the relationships between the subsystems. MDST has greatly influenced how we understand, change and adapt our organization system, based on different systems approaches [27].
The systems approach has a few caracerisics ...

- considers two basic components: elements and processes. Elements are measurable things that can be linked together. They are also called objects, events, patterns, or structures. Processes change elements from one form to another. They may also be called activities, relations or functions. In a system the elements or processes are grouped in order to reduce the complexity of the system for conceptual or applied purposes.
- distinguishes itself from the more traditional analytic approach by emphasizing the interactions and connectedness of the different components of a system.
- emerged as scientists and philosophers identified common themes in the approach to managing and organizing complex systems.

Four major concepts underlie the systems approach:

- *specialization*: a system is divided into smaller components allowing more specialized concentration on each component;
- *grouping*: to avoid generating greater complexity with increasing specialization, it becomes necessary to group related disciplines or sub-disciplines;
- *coordination*: as the components and subcomponents of a system are grouped, it is necessary to coordinate the interactions among groups;
- *emergent properties*: dividing a system into subsystems (groups of component parts within the system), requires recognizing and understanding the "emergent properties" of a system; that is, recognizing why the system as a whole is greater than the sum of its parts.

An extremely important notion, for the following approaches, which subscribes to the GST, is the notion of *system*. As it was natural, the notion of system appeared and developed over time, as a result of highlighting common features and behaviors for a number of processes and phenomena in different fields, which allowed their identification, analysis and treatment, from a structural-functional point of view, and not only, in a unitary way, from a emergence perspective (see Fig. 9).

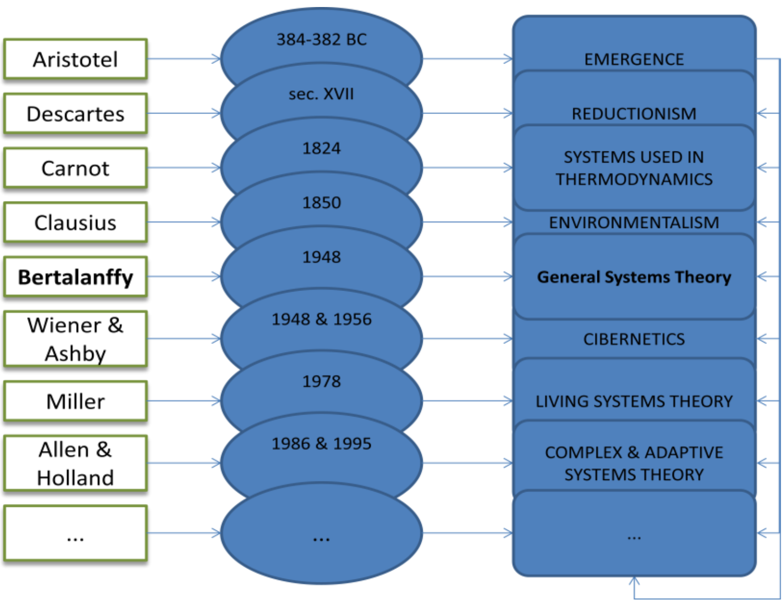

Fig. 9. The "system preoccupation" starting from the definition of the "emergency"

The system, at least from a strictly conceptual point of view, appeared in an embryonic form, for the first time, in ancient Greek philosophy, thus, stating that "*the whole is more than the sum of the component parts*", Aristotle was the one who gave a first definition of the system.

In the specialized literature there are various definitions of the concept of system, some reflecting the tendency to define the system in a broader generality, others the tendency to particularize to a certain domain of knowledge. The system can be defined as "*any set organized by resources or procedures in interaction or interdependence, real or abstract, for the realization of a set of specific functions*" [12], respectively in [13] as a "*set of elements that work and interact with each other and with the outside according to certain rules. and laws, in order to achieve a meaning or purpose*”.
By focusing on the entire system, we can attempt to identify solutions that address as many problems as possible in the system. The positive effect of those solutions leverages improvement throughout the system. In that case, a system is defined as ...

- “(...) a collection of elements or components that are organized for a common purpose; the word sometimes describes the organization or plan itself and sometimes describes the parts in the system.”
- “(...) an organized, purposeful structure that consists of interrelated and interdependent elements (components, entities, factors, members, parts etc.); these elements continually influence one another (directly or indirectly) to maintain their activity and the existence of the system, in order to achieve the goal of the system.”
- “(...) a set of things working together as parts of a mechanism or an interconnecting network; a complex whole.”
- “(...) a collection of parts which interact with each other to function as a whole. Therefore, systems have a purpose as a whole and the whole is not the pure sum of the parts of the system. From systems we have also the concept of synergy, that is the mutual interaction of the parts is more worth than the sum of the individual parts.”
- “(...) an entity that maintains its existence through the mutual interaction of its parts.”
- “(...) any set (group) of interdependent or temporally interacting parts; parts are generally systems themselves and are composed of other parts, just as systems are generally parts or components of other systems.”
- “(...) a combination of components (elements) that act together to perform a certain objective; it contains of interacting components connected together in such a way that the variation in one component affect the other components.”

All systems have (a) inputs, outputs and feedback mechanisms, (b) maintain an internal steady-state (called homeostasis) despite a changing external environment, (c) display properties that are different than the whole (called emergent properties) but are not possessed by any of the individual elements, and (d) have boundaries that are usually defined by the system observer.
The system concept is known to us and we frequently use it in everyday life. We often talk about economic, political, social, philosophical, and technological systems. We are also familiar with particular systems, such as the monetary system, computer systems, communications systems, etc. [4]. In the literature, there are several definitions for the concept of system, some reflecting the tendency of defining the system in a general scope, others the tendency to customize for a certain area of knowledge. The notion of system therefore has a broad scope, being frequently encountered in science and technology in all fields of human thinking and action, but it is almost always associated with a specification attribute. For example, phrases such as "automatic system", "transmission system", "information system", "signaling system", "production system", "social system" [1, 4] are used as special terms, in the same way as in the context of dynamic system.
A dynamic(al) system is defined as ...

- “(...) a concept in mathematics where a fixed rule describes the time dependence of a point in a geometrical space; the mathematical models used to describe the swinging of a clock pendulum, the flow of water in a pipe, or the number of fish each spring in a lake are examples of dynamical systems.”
- “(...) a state determined by a collection of real numbers. Small changes in the state of the system correspond to small changes in the numbers. The numbers are also the coordinates of a geometrical space - a manifold.”
- “(...) a system that have a response that is not instantaneously proportional to the input or disturbance and that may continue after the input is held constant, so the system is not in a equilibrium state.”

- "(...) a system for which the present output depends on the current and the previous input, and can respond to input signals, disturbance signals, or initial conditions."
- "(...) a system whose state evolves with time over a state space according to a fixed rule."
- "(...) a system or process in which motion occurs, or includes active forces, as opposed to static conditions with no motion."

Considering the definitions from above, in the analysis of any system it must be taken into account that it cannot be separated from the environment to which it belongs as a subsystem, and that one system only functions as a subsystem within another more complex system [28]. The detachment of a system from its environment can only be realized as an abstraction technique, the existence of a system itself takes place through a permanent exchange of substance, energy and information, which takes the form of the inputs and outputs of the system.
Knowing a system based on the methodology of system analysis, means and involves, first of all, the study of system inputs and outputs, as well as the concrete ways in which inputs are transformed into outputs, in other words the functionality of the system [28]. The inputs and outputs of a system, analyzed as causal relationships between subsystems, form the structural-functional connections between them, and the study of these connections is of interest for identifying the behavior that the system presents over time.
As we have already mentioned, systems theory operates with the concept of abstract system, in the form of a mathematical model, which allows the description of the characteristics and behavior of systems. Below we highlight some basic features of the systems, respectively:

- the structural-unitary character reflects the property of a system to be represented as a connection of subsystems whose action is oriented towards a certain meaning (purpose);
- the causal-dynamic character reflects the property of a system to evolve in time under the action of internal and external factors, respecting the principle of causality (according to which, any effect is the result of a cause, the effect is delayed to the cause and, in addition, identical causes generates the same effects under the same conditions);
- the informational character reflects the property of a system to receive, process, store / store and transmit information.

In the sense of systems theory, information means any factor that contributes qualitatively and / or quantitatively to the description of the behavior of a system. In technical systems, the physical quantities used as a support for the transmission and storage of information are called signals.
The variables associated with a system, regardless of its nature, have two essential properties, namely the mediation of the input-output transfer (I→O), which thus becomes an input-state-output transfer (I→S→O), respectively of accumulation in a concentrated (synthetic) form of all the useful information regarding the previous evolution of the system, that is to say of the past history of the system, being of three types:

- input variables - independent system sizes (so of type cause), which influence from outside the system status and evolution;
- state variables - quantities dependent on the input quantities (thus effect type), having the role of characterizing and describing the current state of the system;
- output variables - sizes dependent on the state and / or input (so effect type) sizes, having the role of transmitting information about the current state of the system (especially to neighboring systems); some output sizes may be state sizes at the same time.

A system interacts with neighboring systems only through input and output sizes. Output sizes of a system are input sizes for neighboring systems. Output sizes of technical systems are measurable, while status sizes are not always accessible for measurement.

3. Conclusions

According to Systems Thinking, the structure of a system, regardless of its form of representation, is characterized by the elements of the system, the properties and the relationships between them. Classic systems theory (General Systems Theory, GST) operates with type I-O systems, while modern and post-modern systems theory (MDST) operate with type I-S-O systems. An abstract system (model) of type I-S-E and an abstract system (model) of type I-E can be associated to a physical or a real system, often subjected to disturbances or excitations.

It should be noted, however, that the system response is not uniquely determined by excitation. For example, the current charged by a capacitor depends both on the value of the voltage applied to the terminals, but also on the electrical charge existing in its dielectric when the voltage is applied. It turns out that the system also depends on a third size, called its state when the excitation is applied. The knowledge of the general and specific properties of the systems is particularly useful in the investigation, analysis, modeling and design phases of the systems.

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