FORMAL APPROACHES TO SYSTEMS

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Contents

Summary

Several relevant formal approaches to systems are presented and compared with reference to a practical case. The possibilities of an eventual unified formal theory of systems, and other open questions, are presented.

Targets of formal approaches to systems are analyzed. The following formal approaches are considered: those of Klir, Mesarovic/Takahara, Wymore, Lin/Ma, Zeigler, and Caselles. Basic concepts and properties of each approach, with regards to the elements of a system and the relationships between these elements, are analyzed. Possible equivalencies between those concepts and properties, either direct or obtained through transformations, are suggested.

An intuitive and practical comparison of the applicability of the concepts and properties of each approach to complex real life problems is presented. This comparison is made through trying to apply the different formal systems approaches to study the evolution of the population of a city.

1. Introduction

There are several well-known objectives of systems theories, to provide:

- a common language, isomorphism between disciplines, and transdisciplinary knowledge;
- a standard to represent knowledge, models, and simulators;
- help for making decisions in real life problems.

Methodologies are derived from trial and error from practical work and are explained by a corresponding theoretical approach that may progress by itself and suggest new improvements for practical purposes that then have to be tested. The results of these tests suggest modifications for the methodology and in the theoretical approach, and so on. There are different methodologies and corresponding theoretical approaches coming from different aspects, facets, or fields of systems thinking. The question is whether it is possible to unify them at the same time as their corresponding theoretical approaches; or whether a "critical systems approach" is preferable as a way to link each type of problem to its correspondingly appropriate set of organized methods and theoretical approaches.

A unified theoretical and methodological approach to systems thinking should be as general as possible. It should be useful for building models of all kinds of systems, both static and dynamic, qualitative and quantitative, linear and non linear, models that consider time but also other dimensions for change, models that consider scalar type entities but also array type entities, etc., and that are able to represent all kinds of knowledge (including search and learning systems, for instance). In this way, some theoretical and/or methodological approaches to systems thinking will be discussed and compared by using some basic concepts and simple applications, including: discrete event systems (Zeigler et al), abstract systems theory (Mesarovic and Takahara), inductive approaches (Klir et al), and attempts to generalize (Lin and Ma, Caselles, et al).

By looking at the popular definition of *system*—"a set of interrelated elements"—two essential components of every system can be found: a set of elements, E, and a set of relationships, R. So, a system may be defined as a pair (E, R). According to Klir, this definition must be refined in the sense that specific classes of ordered pairs (E, R), relevant to recognized problems, are introduced. The restriction of E leads to the classification of Science into disciplines and specialties, and the restriction of R leads to different classes of systems. A prerequisite of classifying systems by their properties is a conceptual framework within which these properties can be properly codified. Several conceptual frameworks capturing the full scope of systems currently conceived have been proposed (Klir, Mesarovic and Takahara, Zeigler, etc.). The differences in terminology and mathematical formulation between them are considerable. Thus, it is necessary to compare them and to obtain conclusions regarding their compatibility or their restriction to a certain kind of problem.

First, the targets of a general systems theory, and the types of real-life situations that could be represented by such a formal system should be specified. Secondly, current general systems approaches should be compared to those targets and situations. Finally, strengths and weaknesses of each approach should be highlighted, and as a consequence, the possibility of a unified approach to general systems, or the possibility of relating every situation to its respective and most adequate approach, should be elucidated. This discussion will be performed using basic systems concepts and a simple practical case. This analysis will be neither exhaustive nor rigorous but rather introductory and brief (otherwise more room would be required).

2. A Template to Analyze General Systems Approaches

In order to assess the adequacy of a given formal general systems approach to its objectives, the first step, logically, is to specify those objectives clearly. The key word here is "generality", but a single word is not enough, so it has to be broken down into sub-targets, and a possible classification of real life situations that can be modeled has to be specified.

2.1 Targets of a General Systems Approach

First, the target of Systems Science (SC) should be "the study of systems" so, if systems are "sets of interrelated elements", SC has to study the properties of elements and the properties of relationships. When a particular class of element is considered, a particular discipline is defined (biological systems: Biology, etc.). Secondly, the object of study is the set of existing relationships among the elements of the class. The classical assumption that the only way to study a composed object is to study its parts has to be completed with a study of the relations between these parts and the focusing of the object as a whole. The possible lack of this perspective would be a shortcoming of classical science. When problems affecting complex systems are of interest, the systemic perspective becomes unavoidable and Science becomes Systems Science.

Modern Science has to be SC. Particular sciences (Biology, Chemistry, etc.) emerge when particular kinds of elements are selected, but we ask ourselves: "Do some features, concepts, or frameworks that are common to all particular sciences exist?" If the answer is "yes" then a new science has emerged: general systems science. The same consideration may be given, for instance, to Zoology, Botany, etc., as to Biology. Accordingly, a general biological science would emerge. And, so on. Given this point of view, general concepts of Biology could become particular concepts of systems; general concepts of Zoology could become particular concepts of Biology, etc. Consequently the first targets of Systems Science would be:

- To promote the global focusing of problems, studying complexity (the whole is more than the sum of its parts, analytic thinking is insufficient because it neglects some interrelations, etc.);
- to find a common language for all sciences;
- to find isomorphism among different sciences, making it possible to transfer knowledge from one discipline to another;
- to obtain transdisciplinary knowledge;
- to find a standard for knowledge representation, for instance, rule bases, model bases, simulator bases, etc.;

- to discover a methodology for knowledge acquisition (for model building);
- to discover a general methodology (organized set of methods not dependant on discipline) to help people to use knowledge to solve real-life problems and to make decisions, making it easier, faster, and less risky to experiment (using models instead of reality);
- to find a methodology to improve the efficiency of working groups and individuals, and to use the available tools (computers, etc.) efficiently.

2.2 Towards a Unified General Systems Theory

Some relevant authors and their respective conceptual frameworks will be studied. When studies are carried out, concepts detected by the authors will be linked with general concepts in order to compare the different approaches. Some concepts are probably not used by some authors. Others will probably be formalized in different ways. The result of the comparison may be a way to pass or translate models from one formal language to another, or to highlight a new formal theory that takes advantage of the partial advantages of each existing theory.

Any given composed entity will be called “a system”. The system has parts and interrelations (or not) between these parts. Every part may also be considered as a whole and so on. If we want to make classes of systems we need properties applicable to these parts (we will call them “elements” or “objects”) and properties applicable to relations. How are parts determined? How are relations determined? We can assume that an “agent” (a human being, for instance, who has an “aim” or “target”) determine them. Consequently, elements and relations are assumed to be arbitrary. A bird, or the solid part of the contents of a room, are examples of elements. To be in a higher position, or to have a weight that is the sum of two other weights, are examples or relations. Obviously, this principle of arbitrariness must join a principle of coherence with facts, and a principle of generality if we want to build a model of reality or to represent knowledge.

To start with, elements are real-life objects but we need to represent them by a symbol (a name) in order to refer to them. Nevertheless, an object has a lot of aspects that can be considered (called *attributes* by Klir) such as weight, color, etc. If we take for instance the color attribute, and each attribute has several options (called *appearances* by Klir) such as red, yellow, etc., then we need a way to determine the appearance of a given attribute (called an *observation channel* by Klir). Once elements are determined, the next step is to determine or to discover relations between them (“to be higher than”, “to give money to”, “to be the sum of”, etc.)

At this early phase of the analysis some properties of elements and some properties of relations can be identified. For instance:

Properties of elements

- To be qualitative or to be quantitative. That is, to be isomorphic with a numeric set, or to be isomorphic with a set of names or symbols.
- To be an item or to be a set (array, etc).

- To be abstract or to be concrete. That is, to be a symbol (a variable) representing one of the elements (a value for the variable) of a set (the domain of the variable), or to be an element and nothing more.

Properties of relations

- To be binary, ternary, etc. That is, the relation involves pairs, triplets, etc. of elements.
- To be directed or not. That is, the order in which the elements are considered is relevant or not.
- To associate values of variables or to associate elements of the system.
- To be given by tables, rules, equations or mix of them.

Observe that only static and crisp systems have been considered. The range of possible classes of systems can be widened by adding properties related to change and to uncertainty. Some properties of this kind may be:

- To change or not to change.
- To change along time, space, population, or mix.
- To change along continuous or discrete time, space, etc.
- To change according to discrete events or not.
- To change elements, relations, or values of variables.
- To have uncertainty or not.
- To have probabilistic, possibilistic, or other types of uncertainty.

These properties lead to the definition of new classes of systems, for instance: static systems, time systems, dynamic systems, continuous or discrete time systems, discrete event systems versus continuous systems, evolutive systems, crisp systems versus fuzzy systems, stochastic systems, possibilistic systems, etc.

Changing systems may be classified with more structure, depending on the type of change, as:

- Static systems: no changes previewed.
- Dynamic systems: values of variables change when time, spatial position, etc. vary. Dependent on the number of changing coordinates (time, spatial directions etc.) these will be of unidimensional or multidimensional change. Depending on continuity of changing coordinates, these can be discrete systems (in which states change discretely), or continuous (or differential) systems (in which states change continuously).
- Evolutive systems: some elements or relations appear or disappear when time, etc. varies.

Other properties affecting elements and relations that would lead to the definition of new classes of systems can also be introduced. For instance: time invariance (time does not influence the system's objects explicitly), linearity, stability, goal-seeking capacity, autonomy, memory, search ability, learning capacity, intelligence, reproductive capacity, life, Etc. Therefore, in order to build an eventual unified general systems theory, a wide range of properties of elements and relations ought to be defined in a consensual way among the scientific community. At present, the scientific community has several proposals for a general systems theory. These proposals need to be evaluated comparatively in order to take the best part of each one, and to add it to the unified theory or, at least, in order to extract from them ideas that help somebody to construct the required theory.

3. Current General Systems Approaches

Normally, when a general systems approach emerges, it comes from a particular perspective of the world of its creator or proposer. Maybe all of them are correct, but are they general enough? Is any one able to embody the others? If the answer to this last question is "no", could a new approach embedding all current ones be found? In order to begin the search of an answer for these questions, the basic concepts of the approaches of Klir, Mesarovic and Takahara, Wymore, Lin and Ma, Zeigler, and Caselles will be studied. And, in order to clarify understanding, they will be applied to a simple case, and conclusions from a comparison of these approaches, from a practical point of view, will be drawn. A rigorous theoretical transformation of each approach into each other approach (if at all possible) will be the objective for a specific study.

3.1 Klir's Approach

The core of this approach is a "hierarchy of epistemological categories of systems". The concept of "experimental frame" is at the lowest level of this hierarchy, followed by data system, behavior system, structure system, and metasystems. (See *General Systems Problem Solver*.)

Klir defines an "experimental frame" or source system in terms of "appropriate variables, their state sets (value sets) and the interpretation of these real-world attributes. In addition, some supporting medium (such as time, space, or population) within which the variables change their states must also be specified. Furthermore, variables may be classified into input and output variables". That means for us that, at the lowest epistemological level, Klir assumes that:

- A system can always be represented by a set of variables, each with its respective set of possible values.
- The values of these variables change with time, space, etc.
- A relation is supposed, but it is not given explicitly.

The implicit relation mentioned above can be seen, for Klir, to be a matter for other levels of the epistemological hierarchy; specifically for behavioral systems. Implicitly Klir considers that the eventual relation among the variables has to be discovered from data or, if stated as a hypothesis, to be validated with data. Suppose that you want to know the evolution of the population of a city, taking into account births, deaths, and migration balance. In this case, the concepts used by Klir would be applied as follows:

Source system

- Object system

Attributes and appearances.

Let $a_1 =$ Population, $a_2 =$ Births, a_3=Deaths, $a_4 =$ Migration-balance .

Let $A_1 = A_2 = A_3 = A_4$ be the respective sets of possible appearances of the previous attributes, that can be "integers from 0 to 20 million".

Backdrops and its elements. Let $b_1 =$ Time and $B_1 = \{$years from 1996 to 2006$\}$.

- Specific image.

$b_1 =$ Time and $B_1 = \{$years from 1996 to 2006$\}$ *Specific variables*. Let $v_1 = POP$ (for population), $v_2 = BIR$ (for births), $v_3 = DEA$ (for deaths), $v_4 = MIG$ (for migration balance). Let $V_1 = V_2 = V_3 = V_4 = \{$integers from 0 to 20 million$\}$ the set of its possible values. *Supports of the backdrops*. Let $w_1 =$ year-number, and $W_1 = \{1970, 1971, \ldots, 1995\}$.

- General image.

Generic variables. There is no reason to change either the names or the domain of the specific variables. Therefore, it would be the same of the specific variables.

Supports of the backdrops. In order to simplify the informatic treatment, it is probably convenient to let w_1 be a counter k, beginning with year 0 and ending with year 25.

- Observation channel.

In order to pass from attribute a_1, etc. to specific variable v_1, etc., and from backdrop b_1 to support w_1, we need to use a statistical yearbook as observation channel.

- Exemplification/abstraction channel.

There is no need to build a channel to pass from specific to generic variables because they are the same. In order to pass from the specific support of the time backdrop (1970, 1971, etc.) to the generic one (0, 1, 2, etc.) we need only to subtract 1970 to all its possible values. This would be the abstraction channel. The exemplification channel would consist of adding 1970 to the values of generic variables.

Data system

This is composed of the general image system plus a mapping that assigns a value to each variable at each time value. It would be a table with four columns headed by *POP*, *BIR*, *DEA*, *MIG*, and 25 rows headed by the generic indices of the considered years (0, 1, 2, ..., 25).

Behavior system

This consists of the generic image, plus a mask, plus the behavior function. A mask is a subset of generic variables associated with time (in this case). In our example a mask would be $M = \{POP(k),\ BIR(k),\ DEA(k),\ MIG(k),\ POP(k-1)\}$. The behavior function assigns 0 or 1 (true or false) at each set of values for the variables of the mask taken from the data system. The behavior function determines which sets of values for the variables of the mask are possible and which are not. This function can be specified by means of a table but also by means of an equation. In our case, it is evident that the behavior function is: $POP(k) = POP(k-1) + BIR(k) - DEA(k) + MIG(k)$ but to find out such a function by trying with different masks (the approach Klir suggests) may lead the process to a combinatory explosion.

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Biographical Sketch

Antonio Caselles was born in 1945 in Valencia (Spain). He was an Agricultural Engineer in 1970, undertook postgraduate courses in Fruitculture with a OECD grant, and pursued cold-conservation, cooperation, management, and operations research. He took his PhD in 1978, and has been teaching Mathematics in the University of Valencia since 1974, specifically he has taught Operations Research and Systems since 1977. His Research interests and publications focus on Systems Thinking (Abstract Systems Theory, applications to Social Systems and Ecosystems, Simulation, Automatic Programming, Data Mining). He was also Director of the Operations Research School of the University of Valencia from 1992 until 1997, a Founder member (1979) of the Spanish Society of General Systems (SESGE), Vice-President of this Society from 1994, and has been Editor of "Revista Internacional de Sistemas" since 1999.