SYSTEM BASICS

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Summary

This contribution introduces the system concept as being a generalization of any kind of relational phenomena. The article outlines an evolutionary theory of system philosophy as an interaction of reality observation and brain development. Modeling, and its most general instrument, mathematics, mirror the common nature of various phenomena. Computation is the tool of application of the general mathematical models. The basic principles of system dynamics are equilibria of different forms of energy transformations framed in space and time. That is, the Hamiltonian view of systems, applied in the analysis of any kind of changes, their performance characteristics, optimality, and stability. Computational models, supported by symbolic computation software, create a practical environment for system analysis, design and control. The models are based on linear concepts and extended to all kinds of nonlinear phenomena, chaos, and catastrophic changes. The treatment of uncertainty especially related to stochastic disturbances is an additional model family. Artificial intelligence - especially when associated with different kinds of logic, learning, representation of knowledge in and by large databases and their similarity and dissimilarity patterns - represents a powerful advance in modeling. Models are used for the control of large-scale systems of all types: technological, economic, social, and biological. The control of natural resources, environmental systems, and large-scale supply systems may be approached in this multidisciplinary manner.

1. Introduction

Systems are ubiquitous. System, after the Greek συστημα, had the same meaning in antiquity, and the word is derived from συν, meaning *together* and ιστημι, meaning *making stand.* A system is an organized integrated whole made up of diverse but interrelated and interdependent parts. At the present state of knowledge, only quarks may be exceptions, being—according to current hypotheses—the final primitives of material. Some new, as yet uncompleted hypotheses about further details of the Standard Model of elementary particles and forces imagine even more or less final components of the Universe. Ascending according to complexity, parts of atoms, nuclei, molecules, living cells, living creatures, societies of creatures, environments of these societies, the system of the Earth personalized by the idea of Gaia, (the Greek goddess of Earth), the solar system, the Galaxies, the Universe all are systems.

The philosophical and, simultaneously, highly practical problem is the question: does this linguistic generalization as a notion have any further consequences, i.e., can any general conclusion, beyond the definition, be drawn about the systems? If yes, then a general tool is given for solving some or most of the problems, which can be used as a key for creating working analogies between known phenomena and the still unknown ones. This is the way in which hypotheses are built, both in science and in everyday life. The complexity problem of systems is to be discussed later, but for the moment it is sufficient to say that no completely identical system situation can occur, or more precisely, the probability of completely identical system situations is close to zero. On the other hand, similar situations, similar phenomena, are all, in some sense, typical, and the question above relates to the possibility of having some keys to relate the infinite complexity of possible similarities.

The answer is the present state of system science, i.e., our current knowledge about the common features of all system phenomena. The language of system science is mathematics, supported by some metalinguistical means of natural language. This latter statement reflects a certain view, which also needs further explication.

The logic behind the existence of some general features of all systems is of a twin, interrelated origin. The first is reflected in the ancient and still prevalent teleological view on the world: that it was created on the basis of a certain, maybe hidden objective, and that the Genesis was a decision on a general rule of the world order. Modern science began with the Darwinian idea of developmental creation, which is based on some existence criteria, on the possible realization of surviving interactions. The motivation for this trend in science is a search for some further general coexistence conditions of system components, such as the idea of (Kauffman 1993), extending the Darwinian principles with the life conditions of surviving on the edge of chaotic and regular dynamic regimes. In this chapter symmetry, equilibria will be presented as basic coexistence conditions; the further principles of life conditions are corollaries "only".

The other stream of thinking about systems in a general way is to make the connection between system science, ways of commonsense thinking and Darwinian development of the brain. The basic metaphors of science and of everyday thinking are not very much different. All the most profound and esoteric models of various phenomena are all based on rather simple elementary structures of thinking. The structures of the human brain are the phylogenetic results of a many-millennia-long development, which have not themselves been changed too much by the course of scientific thinking. These elementary building blocks are individual and race survival experiences, visual phenomena of objects in the environment and dynamics of motion. Shapes of objects developed the notions of geometry. Visual and audio impressions and their relations to changing phenomena created the frequency related concepts. All further knowledge can be built only with the building blocks of this primitive looking ensemble, of course, resulting in an admirable building. The process with letters, words, texts, etc., is similar. Nevertheless, this intellectual building reveals not only the building blocks, but also the basic structures of thinking. The deep past of development in representations, relations of reality, sensory organs of creatures, representations in mind, verbal and graphical communication, written form, and last, in computer programs created the long way of transformations, matchings and mismatchings. Nevertheless, the *pattern primitives, which were the results of many-many-million-year-long neural system development,* are in some way basic connective structures in the central neural system, and this limitation cannot be neglected in the epistemic critic of higher representations.

The same stands for the dynamics of patterns, interrelations and changing of visually or otherwise viewable phenomena. These are superimposed on and by the basic patterns, and create *metapatterns,* i.e., the patterns of thinking. Most sophisticated human reasoning possesses no more than two basic metapatterns: *logical reasoning* and some statistically oriented estimation of regularities and irregularities, i.e., *probabilistic uncertainty*. These are the sublimes of everyday experience of consecution of events, all related by a direct and later indirect chain with survival conditions, observation of similarities, consequences, frequencies of situations.

By this reasoning we can accept the idea that systems have some very general interrelated features, and this can be more or less represented by our mind activity, being our mind an organic part of the overall system, and developed by adaptation to the interrelation conditions of the same. This reasoning makes us cautious, too: all kinds of inferences starting by and from the temporally accepted basics (*Ding an sich*, thing as that, self-representing things in Kantian philosophy) are "only" the hypothetical consequences of a current knowledge and, this knowledge is always limited by the sometimes apparent, sometimes hidden megastructure of thinking, based on long imprinted pattern primitives, analogies, metaphors. The words "natural" and "obvious" are related concepts to some variable contexts of education, social, historical environment.

Considering all these assertions and cautions, we can state that system theory is a very general discipline of understanding and control of an extremely wide range of phenomena. The problem with different stages of representations, i.e., their relation to the reality, was mentioned above. In this line of development, representation by mathematics is a special art of linguistic representation, using symbols, like a vocabulary, and functions, operators, like the referred metapattern connections among the symbols of that special vocabulary, i.e., a special syntax and syntax-based semantics. The specialty of mathematical symbol vocabulary and syntax are the generic feature of formal languages combined with avoiding ambiguities. All those emerge in precision.

Natural language uses conceptual words and metaphors that transfer the linguistic communication to a level where a reduction to the original, conceivable material background of these linguistic elements is a difficult additional task. The same is valid, even more so, for the language of mathematics. The difficulty of a commonsense understanding is highly compensated for by the generic nature of representation, its precision, and especially by its power to generate new interrelations. These new interrelations, retranslated to the natural language of specific phenomena, frequently herald new discoveries.

2. Basic principles of system performance

All systems' existence is framed by space and time. These concepts, too, developed from the primordial two-dimensional scenery and vague temporal impressions of the environment to an esoteric multidimensional, time-related world-view of current Einsteinian physics. In that world the related concepts of equilibrium and symmetry, conservations and transformations are the fundamental corner points. The equilibrium between static and kinetic states, conservation of some basic qualities in the phenomena of changes and transformations are the guidance for all kinds of system analyses and syntheses. The substance of equilibrium is energy, the capacity of action. The energy-equilibrium concept developed similarly from the mechanical notion of static potential energy and kinetic dynamic energy by the transformation equilibria between mechanical energy and heat, material and nuclear, radiational energy, and for the time being between elementary particle material and elementary forces, held together by the supersymmetry ideas. That generalized energy concept is expressed by the Hamiltonian function, generally notated by ***H***. Following a two-century-long development of science, marked by Newton, Leibnitz, Descartes, Lagrange, Euler and others, the Hamiltonian equation of equilibrium and symmetry in space and time has the concise form:

$$\dot{x} = \frac{\partial H(x,p,u)}{\partial p}, \qquad \dot{p} = \frac{\partial H(x,p,u)}{\partial x} \tag{1}$$

$\boldsymbol{x}$ = state (position), $\boldsymbol{p}$ = momentum (mass. velocity), and

$$\dot{x} = \frac{\partial x}{\partial t}, \quad \dot{p} = \frac{\partial p}{\partial t}$$

Expressing the balance between events in space and time by the general state coordinates $\boldsymbol{x}$, and motion-related momenta $\boldsymbol{p}$ containing the differential of $\boldsymbol{x}$, or further generalized by contracting the static and dynamic coordinates in the variable, $\boldsymbol{q}$.

The state is defined by geometrical coordinates; physical quantities, such as temperature, pressure; chemical and biochemical characteristics, e.g., density, viscosity, component percentage; economic indicators, say, GNP/capita; social indicators, such as percentage of illiterate people, ethnic distribution. The co-state variables of momenta refer always to the change of the state.

The Hamiltonian covers all kinds of energy, related to motion, the Lyapunov function of stability reserves, chemical energy, reserves, and values in economy. The formula and its deep meaning is now a basic mathematical representation for various system descriptions, and is used in every chapter of physics, in biology, economy and social sciences. The next step of modeling is the definition of the coordinates in the system world concerned, and the definition, and mathematical representations of, the constraints of the change. Constraints relate to the permissible ranges of changes, such as the borders of a geometrical space, constraints of velocity and acceleration, body temperature, percentage of components in a compound, say, blood, permissible limits of debts, inflation, unemployment. One of the major constraints is the optimal performance of the system, static and dynamic optimality over a certain period, within a certain range of changing state, e.g., cost and profits of any operation. The other special constraint is stability, the feature of not exceeding certain bounds of performance, in a more rigorous condition, the return to initial values or other preset constant conditions after a certain intervention, should it be a conscious control operation or any kinds of noise, i.e., not intended external influence.

The solution of these very general and, on the other hand, practical tasks, met in any motion of body and vehicle, control of mechanical, chemical and nuclear technologies, biomedical control by diet, pharmaceutical products, monetary and fiscal control of an economy, is a solution of the interpreted Hamiltonian-like partial differential equations under the predefined constraints. The check of these calculations is always the check of equilibria, formulated in the transformational relations of the different quantities.

The general picture has relevant interpretations in environmental control, the quantitative and qualitative measures of water reserve, soil and atmospheric conditions, transformations due to the changes of nature and human interventions are all well translatable into the Hamiltonian frame.

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Biographical Sketch

Prof. Dr. Tibor Vámos, was born on June 26, 1926 in Budapest, Hungary. He received the DSc in Technical Sciences (Computer Control) from the Hungarian Academy of Sciences, Budapest, in 1964. He has been a member of the Hungarian Academy of Sciences since l979. He was President of the International Federation of Automatic Control (IFAC) during the period 1981-1984. He was elected a Fellow of the Institute of Electrical and Electronic Engineers (IEEE) in 1986. He is the author or co-author and co-editor of a vast number of publications, mostly in automatic control.