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The Ubiquity of System Science

An Interview with Tibor Vámos

Tibor Vámos (1926) is Professor of System Science and Artificial Intelligence, a member of the Hungarian Academy of Sciences, and a Fellow of IEEE. In 1981–84, he was president of the International Federation of Automatic Control (IFAC), and continues as a Life Time Advisor of IFAC. He was Distinguished Professor at George Mason University, Fairfax, VA in 1992–93, and subsequently a Distinguished Affiliate Professor. Among several awards, he received the Chorafas Prize of the Swiss Academies in 1994 with Fischer Black, co-recipient of the subsequent Nobel Prize for the Black–Scholes economic investment model.

IKSM: You have characterized system science as the combined theory and practice of mathematical modeling and computer-aided design and control. Where does this concept of system science fit in this fast-paced world of distributed networks, complex emergent phenomena, and continual reengineering?

Vámos: System science is *the* philosophy of our age. This statement is not so much surprising if we review the history of philosophy. From the very beginning of human thinking, philosophical-religious theories have created complete models of the world's phenomena, about the fundamental components, the laws of their interaction, and the dynamics of the Universe.

It is because of contributions to these areas that we speak about the Aristotelian, Ptolemic, Copernican, Newtonian, Descartian, Leibnizian, Kantian, Darwinian or Einsteinian worlds. Thinking about the Universal System and about the basics of science was always closely related. Most of the great innovators of science claimed to be philosophers or even theologians in the quest for generic explanation of the final coherence.

Mathematics progressed mostly on the lines of the generalization of observed phenomena: regularities of visual shapes, dynamics of motion, especially the motion of celestial objects. These are the mental models of our abstracted mathematical-physical concepts even now.

System science is a result of that development. It unifies the achievements of mathematics and of views about interaction modes of different phenomena. From this viewpoint, system science is really an attempt to unify our knowledge about, and to provide instruments of coherence associated with, various phenomena. These efforts are now progressing much beyond the original observations of the physical world — towards biology, economy and social relations, too.

IKSM: What you are saying could have been said, and was said, 10 or even 20 years ago. Are you arguing that traditional characterizations still work? Or, are you suggesting something more novel?

Vámos: The question of novelty has three connected answers. The first is the computer revolution. From our point of view this means an immense possibility for calculation, and consequently the application of more and more complex mathematical models. These models have been, until now, simplified to the utmost, not only for the beauty of generalization but rather because of the very tight limits of computability. For the first time in history, we are now able to compute or manipulate highly complex models, take many effects into consideration, and reach factual, numerical results, that are applicable for various practical purposes.

The models of aerodynamics are now reliable tools for the design of and experimentation with any kind of vehicles. The same can be said for models of molecular arrangements for pharmaceutical research, and for models of physico-chemical and nuclear dynamics for controlling complex plants in industrial production. In spite of several, well-publicized failures, relevant progress can be registered in computational models of economy, biology, and many other earlier very softly modeled phenomena. In that view, system science — as the combined theory and practice of mathematical modeling and computer-aided design and control — is the basic instrument of creative work.

The second answer is related to the first one, due to the revolutionary progress in science, after the revolution created by electronics and computation. This progress of science is, in every aspect, aided by the results and achievements in these new technologies. We find electronics and computation in instruments for observation of phenomena in the nuclear world and in the billion light-year wide universe, extreme time relations of evolution and the finest details of subcellular biochemistry. These observations have resulted in new general and complex models, thereby enabling computations using enormous amount of data, which have earlier never been accessible for analyses.

The third answer is more philosophical. For the first time in human thinking, we are really conscious of the act of building models as models. All earlier world models were connected with firm beliefs of the eternal law expressed by the model. This is one reason why science has so long been related to theology.

I should clarify this statement. Many scientists and philosophers — theologians, too — were aware of the limits of knowledge and were critical of the reigning models. We can quote a large and very diverse set of philosophers and scientists with that critical view. Nevertheless, a final belief in a certain ontological evidence ruled the view of systems. The quest for ontological evidence still exists, and nobody can argue against that very human endeavor. It looks for final certainties, final explanations of human life, what is essentially human, and to discover the purpose of our existence.

On the other hand, the more than 2000-year old story of the division of ontology from science (in this view the division of theology from science) reached a very practical point. Independent of anybody's beliefs about those final ontological questions, models of science are now treated as models, i.e. not as imprints of a final truth but as current knowledge about phenomena and relations. In that view, a model should correspond to the current evidence and criteria of scientific research but should never be an image of the final truth about the world, even not about the phenomena concerned. This result is an answer to all fundamentalist ideologies on the one hand, and to all those who would like to relativize the borders between science and all kinds of pseudosciences. This model view of models is an essential philosophical viewpoint of system science.

IKSM: Your arguments seem very philosophical. What is the relationship between philosophy and systems science as you characterize it?

Vámos: I discussed the relations to ontology earlier. Modern science is divided from ontology and this division is based on new developments of old ideas about the impossibility of self-reflectivity (the Liar's paradox), reaching its present height in the Gödelian innovation. Concern must be repeated about the misuse of the world ontology as employed in popular representations of artificial intelligence. What they name ontology is nothing else but categorization in the ancient sense of Greek philosophy.

The model view of models is essential for ethics. Fundamentalist ideologies always preferred a certain ontological belief and were based on supposed eternal rules of human conduct, values, morals, division of good and bad. This took place in spite of historical evidence of ongoing changes in all that seemed eternal, as well as revisions of earlier verdicts that had been clearly discredited by their inhuman cruelties.

While this horrible trend persists in present times, our system model view can be helpful to a more human ethical interpretation. We have the responsibility to judge each problem in the context of its complex relations, and not be bound by rigid prejudices. Deeper knowledge about the behavior of systems can support development of the necessary cultural background for this higher level of humanism.

System science has something to say about aesthetics, too. This message is related to the contexts of aesthetics. These contexts are related to metaphors of symbols, to historical, social environments, and to psychological states of individuals in their life relations. Aesthetics creates a psychological link between the models of individuals and epochs. That is the reason why erudition in the arts is so important for understanding deep model relations and erudition in systems supports the understanding of art.

IKSM: What are the implications of your views for those of us who are not philosophers?

Vámos: My rather philosophical reflections indicate the reasoning behind my assertion concerning the ubiquity of system science and the need for providing an understanding of the basics of system science for everybody. Without this basic knowledge, people cannot create suitable models to use in their own life activities. With such models, we should be able to make authentic judgments in problems of our environment. One must have the ability to look at phenomena within considerations associated with the contextual environment. This enables establishing models of these phenomena, and subsequently formulating model-based actions. In this process, one should maintain and have a critical view of one's own model, as well as those obtained elsewhere. One should handle them as models and not as final knowledge, without prejudice, and with continuous attention to improving and changing the model.

System science comprises our knowledge about general principles of coherence of phenomena and the instruments for building models of these phenomena. The difficulty lies in the essential nature of the instruments — the use of ever higher, more abstracted mathematics. This cannot be avoided. Mathematics is the clear expression of a model's ideas, all other verbal explications are soft and exposed to vague interpretations. Mathematics offers the link to computation and by that to practical applications. Computer science provides new ways that enable most people to pursue this indispensable knowledge, without a high-level of education in specialized mathematics.

IKSM: Are there a limited number of basic principles or models underlying application of what you say in all contexts?

Vámos: The basic model is very simple and has proven to be valid in all experience related to all phenomena observed until now, independently of their nature, e.g. in physics, chemistry, biology, economics, and social relations. The model expresses the fact that nothing is coming from nil and nothing is annihilated into nil.

This is the model of dynamic equilibria expressed in the beautiful mathematical formulation of the Hamiltonian equations. The Hamiltonian was the result of two-hundred years of scientific development, starting with Newton, continuing with Jacob Bernoulli, LaGrange, Euler, and resulting in a form that is still presently used in the contemporary developments in partial differential equations, variational calculus and algebra. In all fields of observations, when this dynamical equilibrium appeared to be violated, research started to find new phenomena, thereby restoring the equilibrium.

This took place in astronomy in discovery of the utmost far planets, in electricity and magnetism, following the Maxwell equations, in the experimental realization of electrical waves by Hertz, in metabolisms of biology, in search for hidden effects in economy, and in nuclear science in the discovery of new elementary particles.

The model of dynamical equilibrium is a universally valid picture of our everyday phenomena and covers another long developed concept, inertia, the basic ingredient of the original Newtonian model which received a new interpretation in the Einsteinian world. Change processes for phenomena in dynamical equilibrium happen in time and this time is deeply related to the nature of change. If we keep in mind the wishful thinking of many people, desiring and enforcing sudden changes without considering the inertia-time relations of all existing subjects, people, relations, reserves, etc., we can appreciate the relevance of that basic model for everyday judgments and decisions. And now, we are at the verge of being able to compute those effects, not only to philosophize about them!

IKSM: You mention the transition from a Newtonian view to an Einsteinian perspective. How does this transition affect systems science?

Vámos: I mentioned time in relation to dynamic phenomena. The notion of this relationship was, at one point, a revolutionary idea! Earlier world models considered time as an independent, self-contained, eternal conceptual frame, a divine clock put at the eternal, unchanged frame of the whole world. The other ingredient that seemed to be eternally fixed was space. It was always more concrete than the divine time. Nevertheless, it was our everyday experienced terrestrial space, fixed also, primarily two dimensional, planar, extended to an additional third dimension of height. This is the evolutionary vision space, too, the typical 2+1 dimensional visual perception of human brain.

The present model considers a complex time-space system of all phenomena discerned and related among each other, in a steady interaction. This is the system view. In this multidimensional view, coordinates play a different role than earlier. Early coordinates were some fixed ingredients of a fixed frame. The Platonian view can be interpreted in this sense, as an existing, eternally sealed frame as a final reality with all phenomena being reflections of a metaphysical play. In literature, this view has been expressed in wonderful metaphorical compositions.

The coordinates of the modern system view return to the original meaning of the word: *co-ordinate*, i.e. organizing together the phenomena that are interacting. This view means that coordinates are not independent of the phenomena concerned. The coordinates, time included, have a cohesion among themselves and, this cohesion is the space of every action. We meet these phenomena everywhere: the coordination of life cycles of animals, e.g., our pets and ourselves, male and female, coordination of time in different geographical places, coordination prices, values among different social strata, different countries, different periods, effects of biological changes, diets, drugs. This creates different worlds and, these worlds should be considered in every action. The result is a new relativity, a conscious view of nonlinearities, cycles, the adaptation of the coordinate and scaling system, and changes of the system itself.

This view is not so much bound to notions of cause and effect, but rather to interaction considerations. Hence, this view is more free of linear reasoning and more inclined to see dynamics, i.e. the change of situations in its interacting, complex environment, in the extended time-coordinate space. The view, described above, was started by modern physics, and for a longer time, it was considered to be valid only in that relativistic micro world of quantum physics and macro world of the universe. In the view of modern system science, the concepts of relativity are generalized for everyday practice.

IKSM: Given these principles and models, what can we now do? What leverage do these principles and models provide?

Vámos: Having relative freedom and a new frame of interaction conditions, we can manipulate the representation system in order to get the best view for orientation (or computation) and control. We do this in primitive, everyday orientation: change the viewpoint to see as much as possible and those details that are relevant for our intentions in further actions. Focusing by the fovea is the next step of vision-attention. The change in viewpoints is a kind of deformation of the view. This liberty can help also in finding dangerous or advantageous similarities and dissimilarities, matching a situation to another one.

The freedom of viewpoints, a manifold of possible views, is very important. A single viewpoint is a prejudice, blindness related to the complexity of interaction phenomena, as noted earlier. Modern system science masters these viewpoint transformations, changing scales in time domains, investigating special frequencies for the discovery of different cycles in the events, identifying special waveforms in phenomena, their rise and diminishing. These transformations or mappings are all covered by regular mathematical-instrumental tools.

The transformations of coordinates and scales, time and frequency, macro and micro are done by a careful preservation of fixed points, i.e. of those qualities that warrant critical and authentic observation. The fixed point is similar to the lookout tower for the observer looking in different directions, with different telescopes with different lenses, sensitive also for different wavelengths of light. These methods are able to separate singularities, i.e. singular irregular situations, and follow their role in deforming the whole.

The mathematics of complex variables, nonlinear analysis, phenomena of chaos, catastrophe, fractals, methods of wavelet analysis, modern algebra and various procedures for uncertainty, probability, and statistics serve as a big armory of tools for all kinds of investigations of complex, interacting phenomena.

These investigations complete the model, a model reflecting all the previous observations of phenomena, including their behaviors in change and interaction. These models have predictive power, too, providing a basis for investigating future actions, similar to the earlier mentioned computer models of vehicles for their aerodynamic behavior.

These models and their related building apparatus are equipped with learning, adaptation abilities for improving the prediction power of the models. This happens just now with the economic investment models that worked well for a considerably long period of economic growth but could not predict recent phenomena of abundance of virtual capital.

The model with its prediction power is the basis of modern control. If the model works well, it can be adjusted by suitable controls. These controls perform orientation in the hypothetical space-time realm and search for the best next action. Best is also relative, depending on the constraints of action, on values set by users, time and action spaces of intentions. Robust control is only one relevant aspect of these trends, combining new freedoms with inherent constraints.

In this view an abstract operator shifts the system from one state to another one, though the system itself is real: plant, organism, economy. The operator in the final end is the active human intelligence.

IKSM: This all sounds very powerful, but also very abstract and esoteric. How can most people take advantage of this thinking?

Vámos: I have, in my comments, moved back and forth between concepts of high, modern mathematics and phenomena of everyday life. Your question concerns whether this gap is bridgeable. How can people in general satisfy the need for understanding the new — simultaneously freer and more constrained — view of complexity in their lives? Or, is this knowledge usable only by those who are educated in the realm of modern mathematics?

Computer science offers some very effective means — multimedia visualization and symbolic computation. Multimedia is able to visualize the complex dynamics hidden until now, mostly in abstract partial differential equations. Multimedia can show motion in nonlinear spaces, as well as different viewpoints, foci, and interpretations.

Symbolic computation permits bypassing the delicacies of exact mathematics, proofs, investigations of convergence, finding reliable approximations, etc. This remains the finer and finer work of experts. Even expertise in mathematics is currently highly specialized, with experts in one particular field of mathematics often very weak and uninformed in other fields. Great collective works of symbolic computation, e.g. Matlab and Mathematica, are widely available tools for reliable computation for those having only a general knowledge of methods and ways of thinking in mathematics.

Multimedia and symbolic computation are converging. More and more methods in symbolic computation have dynamic visual representations that can easily be manipulated. For example, an experimental multimedia CD is being prepared for the next Congress of the International Federation of Automatic Control, to be held in Beijing in June 1999. It addresses three levels with the same theme, the Master level for advanced research, the Student level for all with some university education in mathematics, and the Everyman level for the self-conscious citizen at the advent of the Information Society.

Nevertheless, needs for a certain bulk of basic knowledge are unavoidable. This need includes the general literacy developed between the 16th and 19th centuries. Even now, nations are more successful in modern times when their people start with a good general education. The roots of our present welfare lie deep in the history of education. This is now needed on a higher level — understanding present complex systems is a key for control, and a key for democracy, a key for our future welfare.