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Would A Rigorous Knowledge Base in Systems Pathology Add Significantly to the SE Portfolio?

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Abstract

This paper introduces a new, systems-architecture-level of systems pathology that might contribute to SE and its core knowledge base, systems science. The new SysPath is contrasted with three existing strains of systems pathology, namely conventional pathology studied at the systems-level, cell-molecular biology, and systems biology. Several "classes" of systems-level diseases are named and presented as generic pathologies true across a very wide range of natural, human and social systems. Specific examples of each "class" of systems architecture disease (SAD's) are listed. Sources and methods for identifying and discovering new SAD's are suggested. The paper includes a preliminary analysis of what contributions the new SysPath might make to a much broader application of systems engineering, to systems pathology approaches, to understanding complex systems, and to understanding complex diseases. The paper closes by listing "caveats" or limitations to the new SysPath and key questions that must be addressed for it to be successfully added to the SE or systems science portfolios. An invitation is included to five practical action programs now underway.

1.0 Image of a New Systems Pathology: Working Hypotheses

The systems pathology introduced here is a spin-off derivative of a larger project that attempts to integrate the best findings of the new natural systems sciences (systems biology, systems chemistry, earth systems science, network theory and chaos theory) with the historical products of five generations of systems approaches (from general systems theory to systems management, circa the 1890's to the present). This unified product is called the System of System Processes Theory (SPT) and is the current version of a research plan that was first introduced 33 years ago (Troncale 1978, 1986). Both the project to synthesize past systems theories and the elucidation of the new Systems Pathology introduced here are official projects of the Systems Science Working Group (SSWG) of INCOSE. This paper is an initial, foundational report for the second project.

1.1. Basic Idea: Since introduced by Imhotep, ~4600 years ago, and Hippocrates, ~2500 years ago, the strategy of recognizing a human disease, describing its symptoms, and evaluating various treatments has proven successful. In the U.S. alone, human medicine has become a more than $2 trillion per year industry, about 16% of GDP. Every human life is marked by encounters

with disease and therefore medicine; we generally regard these encounters as some of the most critical milestones of our lives.

What our team of researchers proposes to do is expand the proven approaches of medicine far beyond humans to their social systems, and even to the natural systems upon which they ultimately depend. We are proposing to identify and describe diseases of systems architecture and diseases of how systems of systems work. We are proposing describing diseases not of the particulars or parts involved but rather diseases of the way the parts participate in becoming a system at the "systems architecture" or "top-down" level. Because these diseases are based on linkages that are isomorphic across may systems, any one adequately described would apply to a defined range of scales of complexity. They would be "scale invariant," "part autonomous," or "domain independent" diseases. A detailed knowledge of such significant systems malfunctions could become an important contribution to future human development and evolution.

This is not intended to be a *de novo* start-up. The successful 2000 years of human medicine provides us with a significant jump-start. We propose emulating several proven protocols that medicine has settled upon over its history. We propose elevating systems engineering to conscious use of such concepts and protocols as (i) association of a suite of symptoms with human awareness of a particular disease (identification, naming), (ii) separation of sets of symptoms from each other (diagnosis), (iii) clustering of groups of diseases based on their causes (taxonomy, ontology), (iv) research into causes of the disease (etiology), (v) comparison of ways to fix the mistakes in systems architecture (treatments), (vi) long term follow up of results of different treatments or not treating (prognosis), and (vii) shortening the time between basic research on systems and application of its findings (translational medicine).

Such extensive emulation of the long history of medicine requires a well-developed natural systems theory with both reductionist and systems architecture components. We include citations that present the skeleton of such a theory in section 5 It is the focus of the second INCOSE-SSWG project.

1.2 Proven Utility of "comparative" and "pathology" approaches: Emulating the above seven protocols of medicine would enable SE and systems science to add two additional successful protocols.

The eighth would be "comparative" analysis. Many subspecialties of the biological sciences compare phenomena across many hierarchical levels or specific instances to achieve a much greater understanding of the dynamics. For example, comparison of species led to a much richer *Comparative Taxonomy*; one that eventually made possible the recognition of the grand unifying dynamic of evolution. *Comparative Anatomy*, the accumulation of very detailed structural analyses from cell levels to vertebrates revealed major class distinctions that became markers of dynamic origin events for those levels. Once sufficient data had been experimentally verified in physiology, *Comparative Physiology* enabled detection of essential networks that were retained even across unicellular to multicellular evolution allowing deeper explanation of variants for specific functions. And today the vast databases of bioinformatics and systems biology are enabling *Comparative Genomics* leading to dramatic new insights into human development and evolution. The point is that very significant new insights derive directly from "comparing" across huge data sets - well beyond those possible when we are restricted to looking within one data set. While this has happened within biology many times as described above, it has not happened sufficiently <u>across</u> science disciplines. The new systems pathology must be based on rigorous use of *Comparative Systems Analysis* (CSA). In fact, the Systems Processes Theory (SPT) used for the new Systems Pathology is based on CSA.

The ninth in our list of protocols to be emulated also results from the experiences of biomedicine. Approaching a very complex system from the outside is formidable. The complexity masks the details of the components and their interactions. Often in history, pathology has opened the door for study and understanding. When something goes wrong, we can use techniques to discover the details of the surrounding mechanics. The mistakes flag phenomena and give us a "handle" to examine the otherwise hidden workings. The "needle in the haystack" becomes fluorescent. It was not until we found mistakes in metabolic pathways (e.g. enzymopathies) that we were able to elucidate many metabolic networks. It was not until we found mistakes (specific types of injuries) to the brain that we were able to illuminate the functions of different parts of the brain. It was not until we recognized mistakes in cell architecture or organelle structure that we were able to clarify the functions of certain organelles (e.g. microtubules or mitochondria). It was not until we recognized deletions in certain chromosome bands that were able to reveal location of genes for certain functions. Thereafter, biology actually induced mistakes (e.g. radiation to cause mutations, knock-out mice to emulate diseases, mutant strains to study metabolism, knockout genes in genomes) in order to address complex systems. This new systems pathology suggests that knowledge of pathologies could explicate current mysteries of systems design and engineering.

1.3 Tenets or Working Hypotheses of "top-down" systems pathology: A philosophy or approach is often described in terms of its foundation axioms or tenets; things it holds to be true (L. *tenere*). The basis for the new systems pathology is natural systems science, so it is more appropriate to list our tenets as working hypotheses that enable the approach but that may be improved or falsified with continued work. Our working hypotheses are: (1) Processes – there exists a describable set of algorithms, defined as a series of steps or transformations in a series, that change one condition into another. (2) Isomorphies – some of these architectures or linkages of changes are the same across widely separated domains, disciplines, scales, times of origin of that class of entity, and types when compared via CSA. The range of applicability of their isomorphic nature can be proven. (3) Abstraction Level – these linkages are independent of the particulars or parts of the various manifest systems in which they are found. (4) Sustainable Systems – The span of natural systems shown to have the definable set of systems processes indicates the importance of their form and linkage to achieving sustainability of a system. Sustainability over time is defined as sustaining the lineage, not necessarily the exact reproduction of a system. (5) Errors – malfunctions on a systems level can be identified in the organization and function of these systems-level processes. (6) Naming is Significant – identifying these malfunctions with names and characteristics would be as important to the development of the understanding of systems as they were to understanding human health. (7) Medical Protocols – therefore rigorous application of the methods found to work in medicine, but to this much wider span of manifest systems, would be as beneficial as it has proven to be in human medicine. (8) Design – greater recognition of "sufficing" systems architecture would provide a very detailed compendium of useful configurations to consider in systems engineering. (9) Curation – There is a much wider range of systems that humans must respect and maintain beyond those currently respected and maintained. Taken together these give an overview or image of the new SysPath.

2.0 Distinguishing "Bottom-up" from the New "Top-down" Systems Pathology

Most current pathology is admirably rigorous but dedicated solely to "bottom-up" approaches. We identify and describe three. Each is distinguished from this new, "top-down" systems pa-

thology. We do not advocate conflict between these approaches. All are necessary and beneficial. The hope is that someday they might meet in the middle and inform each other.

2.1 "Systems" level conventional pathology: The field of medical pathology is very old and established. Consider that the first efforts in medicine involved dissection of humans *post mortem* and humans are clearly systems of systems. But recently, just as systems awareness seems to be spreading through many other fields, pathology has redoubled its efforts to relate their knowledge base to the systems-level. For example, "systems pathology" was the chosen theme for the 27th Annual Meeting of the Society of Toxicologic Pathology (Crissman 2007).

2.2 Cell and Molecular Biology pathologies: CMB possesses an extensive literature reporting peer-reviewed experiments. It has accumulated sufficient information to now recognize "classes" of diseases based on malfunctions of particular molecules or organelles in cells. There are compendia of human diseases called "laminopathies", for example, which are dysfunctions of the nuclear lamina, a criss-crossed layer of protein fibers just underneath the nuclear envelope. There are specific instances of laminopathies, such as errors in processing of LMNA gene and product resulting in known human pathologies like Hutchinson-Gilford progeria (rare speed up in aging resulting in early death of the patient). Another example of a class of diseases would be "ciliopathies" due to malfunctions of the cilia organelle in cells. We obviously characterize these as "bottom-up" systems pathology because they study the many interactions involved but not on the level of systems architecture of systems processes but rather on the level of the lowest hierarchical parts in human systems.

2.3 Pathology in Systems Biology: The explosion of funding, journals, findings, databases, conferences, websites, etc. in the very new field of systems biology (Google hits = 7M) has produced significant findings in pathology on the bottom-up systems-level (see Cassman et. al. 2007 for an assessment of the field). This strategy is parallel to similar explosive developments in the new fields of systems chemistry (Google hits = 77K), earth systems science (Google hits = 50K), and systems neuroscience (Google hits = 143K). All of these new and wildly expanding fields emerge from the reductionist sciences and predicate their pathologies on problems that occur on the most reduced, part level of systems or are limited to their particular domains and disciplines. Systems biology moves to the level of systems in that it studies vast numbers of parts and their interactions, but the pathologies are still relegated to part-level explanations. Special subsets like the Systems Biology of cancer are contributing to a better understanding of non-linear causalities (like that covered in Section 6.4 below) even drawing distinctions between 'causal' and 'passenger' errors in carcinogenesis, but still these are not primarily systems architectures.

It should be noted here that the late J.G. Miller suggested cross-level pathologies across selected levels of living systems (Miller 1978) as summarized by (Swanson 2005). This was a first attempt at a systems architecture level of systems pathology to our knowledge.

3.0 Naming Classes of Systems Architecture Diseases (SADs)

Our project uses the centrality of systems processes to create a preliminary classification of systems architecture diseases (Troncale 2001 to 2008). While the SPT includes circa 100 systems processes, that large number is reduced significantly when "clustered" into sets of processes that are similar. This results in a taxonomy of systems processes of a dozen "classes" of systems pathology. Some examples are:

CYBERPATHOLOGIES: systems-level malfunctions in feedback architectures.

CYCLOPATHOLOGIES: systems-level malfunctions in cycling, recycling, solitons, or oscillations.

NEXOPATHOLOGIES: systems-level malfunctions in network architectures or dynamics.

RHEOPATHOLOGIES: systems-level malfunctions in architectures for flows.

HETEROPATHOLOGIES: systems-level malfunctions in hierarchical, modular structure & dynamics.

TERATOPATHOLOGIES: systems-level malfunctions in developmental patterns or sequences.

ALLOMETRIC PATHOLOGIES: systems-level malfunctions in proportionality or scalar structure.

It should be noted at this point that one of the "tenets" not mentioned in Section 1 is that structure or what might be called "form/patterns" are so intimately considered a product of their causative processes that structure and process are equal. That is to say structure and process are merely transforms of each other just as matter and energy are transforms of each other. It is only because of limited human perception that we perceive them as completely different things. So SPT argues that it is the process behind the occurrence of fractals or hierarchies that is important to focus on, not just the resulting forms. For example, in SPT, "heteropoiesis" is the process by which hierarchies form and maintain themselves.

This above illustrated strategy of naming classes of malfunction by that portion of the systems architecture that exhibits errors follows the strategy used by medicine to organize diseases in taxonomies. For example, in medicine specific diseases such as axonopathy, myelinopathy, and neuronopathy are contained in a class of diseases called polyneuropathy or the class of kidney diseases (nephropathies) include specific diseases like glomerulopathies or tubulopathies. Our project identifies more classes than those listed here. Hopefully future workers will suggest other strategies for classes of systems-level diseases.

4.0 Identifying Specific Diseases in Each SAD Class

There are many possible specific dysfunctions of systems architectures within each SAD class. Twenty-eight specific examples of process dysfunction are listed below for four of the above classes to give an idea of what particular named diseases might look like. Our project seeks to mount a sustained effort to discover and describe more complete lists of such diseases, their consequences, symptoms that implicate their presence, alternative prognoses and treatments for each, and the etiology and ontology they imply. This will require extensive case studies for each of the following.

4.1 Examples of Cyberpathologies: How many ways can a feedback architecture become dysfunctional? We are studying such systems-level malfunctions as: (i) delays in action of a feedback loop relative to response times needed (will we respond to climate changes soon enough); (ii) mismatch between increments of change effected by the feedback relative to magnitudes of change needed; (iii) mistakes in coupling of negative and positive feedbacks; (iv) feedback not present at all (consider the lack of negative feedbacks as the cause of both the recent loan scandals and mortgage disasters in the worldwide economy); (v) missing feedback across hierarchical or modular levels; (vi) feedback connected to the wrong part of the interacting net responsible for the response; and (vii) change in output no longer calibrated to the need in the systems environment.

4.2 Examples of Cyclopathologies: How can a cycle, soliton, oscillation, or recycling malfunction? We are studying such systems-level errors as: (i) mistimed cues or regulators for stages in a cycle; (ii) stages or steps occur out of obligate sequence; (iii) absence of regulatory controls for phases; (iv) imbalance of positive and negative, coupled feedbacks driving an oscillation; (v) coherence or incoherence or broken phase relations between two or more interlocked cycles; (vi) loss of 'entrainment' of population numbers for a cycle or oscillation, and (vii) loss of cycling at one level needed at another scalar level.

4.3 Examples of Nexopathologies: How many ways can a network architecture become dysfunctional? We are studying such systems-level malfunctions as: (i) too many or too few nodes or unstable connections; (ii) impact of 'degeneracy' or 'equifinality' inherent in a particular network structure; (iii) imbalance in diversity of connection types or nodes; (iv) disintegration of key or central nodes; (v) overloads of interaction numbers and/or flows on key nodes; (vi) incompatibility of subgroups or motifs of different, interlocked networks, and (vii) errors in development or evolution of network structure or dynamics. Actually the field of network research has more directly studied architecture malfunctions than any other, except perhaps the feedback cluster. See the research results of the Sante Fe Institute, Barabasi, Alon, etc.

4.4 Examples of Rheopathologies: How can something as fundamental as a flow go wrong? We are studying such systems-level malfunctions as: (i) deviation from fractal branching allometries; (ii) imposition of dysfunctional boundaries or limits on flow; (iii) interrupted transitions among laminar and turbulent flows; (iv) disruption of 'insulation' for flows; (v) dysfunctional inter-entity binding and interaction for entities in the flows; (vi) neglecting opposing field effects on flows; and (vii) disturbances in the asymmetries that cause the flow or incompatibilities between flow asymmetries.

This litany of mistakes will come alive when each is illuminated by case studies across a range of manifest systems. In this effort, top-down systems pathology will undoubtedly use an old but proven strategy in biology – "exaggerated function." Sometimes a case study on the human system level will tell us more than one on the physical or biological system level. Other times vice versa.

If you think this strategy would result in too much detail, then please note that OMIM (the Online Mendelian Inheritance in Man) identifies over 20,000 gene-to-phenotype relationships (McCusick 1998). More than 3,500 human genetic diseases have been identified. Just as the reach of medicine to heal advances with the detail it discovers, so also should the ability of SE to mount better designs and systems science to build more sustainable systems increase with the detail they discover.

5.0 Sources for Identification of Detailed Diseases of Systems Architecture

But where should one look for clues to how systems malfunction? There are many possible sources including any systematic treatment of past engineering case studies. The INCOSE SSWG project on Systems Pathology is linked to another SSWG project on Systems Process Theory (SPT).

5.1 Systems Processes Theory (SPT): Explication of this theory is not within the space limitations of this paper but it involves harvesting the widest range of products of past systems theories and interpreting them using the empirical results of the natural sciences. We call this "integrative eclecticism" because we do not value any one domain of systems approach or any one technique over another but rather examine all for anything they can tell us about systems

processes. Our argument is that systems-level processes are the most neutral yet fundamental integrators of the huge fragmented literature on systems.

The result is a listing of ~100 systems processes and the 15 categories of data we collect on each systems process. The information collected on the processes sometimes includes the consequences of errors in performance of the processes. Alternative clustering of the processes leads to the "classes" of systems architecture diseases as well as to suggested ontologies for systems. Deeper examination of failures in systems processes and their consequences helps identify specific diseases for each of the "classes" of SAD as illustrated above. So elucidation of the SPT is simultaneously elucidation of systems pathology.

5.2 Linkage Propositions: Possibly one of the most important contributions of the SPT is its formulation of linkage propositions (LP's). These are formal language-based statements of observed influences of one systems process on another. They constitute a meta-level or higher level of description of system dynamics than just the systems processes alone. This is a more detailed system of systems model than many provided in the past. It yields a catalogue of system architectures for future systems design that have been used by manifest or past-engineered system. LP's also fall into classes leading to more ontologies for systems. LP's are considered as isomorphic as the systems processes they tie together. Thus, when LP's malfunction, this causes pathologies. So LP's studies are another source for identifying diseases.

5.3 Natural Systems Sciences or Natural Sciences: Our Institute has collected many hundreds of reprints from seven of the reductionist natural sciences reporting empirical or mathematical results in their study of specific phenomena within one discipline, but which when interpreted on the systems-level yield important results for one or another of the SPT systems processes or LP's. This database can be used as still another source of identifying and describing diseases of systems architecture.

6.0 Expected, Value-added Contributions of Systems-Level Systems Pathology

The primary expected use of the new Systems Pathology is the recognition of potential diseases to improve systems design and fix malfunctions. However, this approach may also make significant contributions to the underlying knowledge base of systems science and even the advance of the natural sciences.

6.1 Expanded View of Pleiotropy: This essentially means "more/many" "responses to a single stimulus." It is used in genetics to indicate that a single genetic change has multiple effects. A common example is sickle cell anemia wherein a change in one nucleotide base in the gene, changes the amino acid in position 6 (glu->val) of a 146 amino acid β-globin chain of hemoglobin. This results in hemoglobins stacking and distortion of the red blood cell. This one change causes multiple organ failures (from spleen to lungs to heart). Another e.g. would be phenylketonuria. Most examples of pleiotropy are on the molecular level. But using info from the new Systems Pathology, biology, genetics, and medicine could also add changes on the systems architecture or top-down level that are fundamentally pleiotropic.

6.2 New Conept of Pleioetiology: In many presentations (2001-2010) we have suggested a neologism to draw attention to the observation in SPT and its linkage propositions that on the systems architecture level there are also multiple "causes" of one condition. This is the opposite of pleiotropy. It maintains that certain systems-level conditions require multiple inputs as their cause.

6.3 New Systems Ontology: The classification of systems-level pathologies described in Sections 4 and 5 could contribute to the long sought and much needed "ontology" of systems. Without discovery of this fundamental explanation of how systems work, all of systems science is stuck in a pre-Linnaean or pre-Mendeleyev stage.

6.4 More Detailed Explication of Non-linear Causality: Non-linear causality is the root source of many of the problems encountered in trying to devise a science of systems. It also obscures the search for systems-level diseases and their etiology. The SPT with its cloud of linkage propositions could enable a much deeper view of non-linear causality. SPT and SysPath recognizes, defines, and investigates the following types or classes of non-linear causality and their consequences: (i) quorum, (ii) threshold, (iii) network, (iv) mutual, (v) heterotropic, (vi) conditional, and (vii) equifinal. Some of these are also relevant to investigation of complex diseases by medicine, complex traits in genetics, and complex nets of biochemical reactions in systems biology. A more detailed understanding of the "specifics" of non-linear causality might ease problems encountered in addressing such complex systems.

7.0 Possible Uses of the new Systems Pathology for Systems Engineering

It is natural and expected for engineers to challenge theory on its utility. They want to ask, "what can this abstract theory do for me today? SE is very practical and the clients and industries that SE serves expect pragmatic results. Here are some possible benefits SysPath could do for SE as a discipline.

7.1 Motifs and Patterns: Wider Recognition and Use: As observed in network theory, small sets of systems architecture appear to be found in a wide range of systems. These are called variously, subcircuits, subgraphs, motifs, patterns. Availability of a catalogue of such found in the SPT, and mistakes in same documented by SysPath, would be a useful addition to the toolbox of SE.

7.2 New Tools for SE: Many systems theories have been converted to tools for use by practitioners. The SSWG and its collaborators are planning tools to enhance direct use of SysPath & SPT by SE's.

7.3 Improve Awareness/Avoidance of Design Errors: Systems pathology would describe how systems don't work. Detailed knowledge of these malfunctions may enable SE's to avoid design mistakes.

7.4 Checklists for Model Based SE – Improving Simlations: Even in fields as sophisticated and established as surgery, checklists have been advocated. The numerous systems processes and LP's of the SPT, and the numerous pathologies of SysPath could be organized as checklists for the modelers who might now ask not only "have I included all feedbacks," but additionally other systems processes.

7.5 Much Wider Application Space for SE: If a top-down Systems Pathology becomes generally recognized, it would open the SE profession to virtually all natural systems that need to be cared for from the geological to the biological – considerably beyond the current application space of SE.

7.6 New Knowledge Base for SE: Just as modern engineering is largely based on mathematics and physics, future SE might well be based on a better knowledge of how systems work & don't work.

7.7 New Education & Certification for SE's: If 7.6 is true, then preparation and post-graduate education in SE might want to include systems science and systems pathology as courses of study.

8.0 Caveats on the new Systems Pathology

When suggesting a new approach, it is probably best to try to anticipate the various ways the approach could go wrong, or obstacles that must be overcome. We have a list of a dozen concerns that should be addressed as work on the new top-down systems pathology proceeds. Here are some. (1) One stakeholder's disease is another stakeholder's paradise. (2) We anticipate challenges defining a "healthy" system. (3) What is healthy in one environment may be unhealthy in another environment. Environments change. (4) Systems do not evolve to the optimal; they evolve to suffice. (5) Costs of engineering and producing a completely healthy system may exceed the acceptable. (6) Costs of repairing a damaged system may exceed the acceptable. (7) Systems are meant to evolve. Too rigid maintenance of existing systems might inhibit further development and evolution of descendant systems.

9.0 Conclusions and Future Work

Given the interest of some in the SE community, what can be done now to develop the new Systems Pathology. Here are some alternatives.

9.1 Key research questions and obstacles: Interested SE can help by identifying new pathologies, suggesting compelling and fundamental questions that need answers, and identifying obstacles to the development of the field. Part of this is demanding from Systems Pathology products that SE needs. Participate in the Wiki pages and Websites listed below.

9.2 Official INCOSE-SSWG Projects: The Systems Science Working Group of the International Council on Systems Engineering has identified both the Systems Processes Theory (SPT) and the new top-down Systems Pathology as official projects. Interested SE's can join these efforts and contribute to production of useful products every 6 months as planned. Go to https://sites.google.com/site/syssciwg/

9.3 International Society for Systems Pathology (ISSP): This author and colleagues are founding a new professional society to guide development of the new field. 2011 is the year of foundation of this non-profit and we are assessing ourselves $100 each to finance the initiation of the Secretariat ($50 for founding students). Please see the initial website at xxxxx or send Founding Member dues to the author. The "founding member" category will be available only until Dec., 2012.

9.4 ISSS, ICCS, AAAS Conference Sessions: We have secured special sessions on Systems Pathology on the programs for the 55th International Conference of the International Society for the Systems Sciences, University of Hull, England (July 17-22), and the Eighth International Conference on Complex Systems, Boston, Massachusetts (June 26th to July 1st). We will seek a half-day session at the next available annual conference of the American Association for the Advancement of Science.

9.5 Webinars, Websites, and Systems Radio: Two INCOSE webinars have been produced on the these topics. Two temporary MobileMe Websites are active. The first interviews on the new Systems Radio program (http://systemsradio.net) are focused on the SPT and Systems Pa-

thology. For a video introduction to these approaches, please view the first of Cal Poly University's Systems Science Series at http://bit.ly/gbX4e.

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Biography

Troncale is Professor Emeritus, past Chair of the Biology Dept. and Director of the Institute for Advanced Systems Studies at California State Polytechnic University. He has served as VP and Managing Director of the International Society for General Systems Research and President of the International Society for the Systems Sciences (ISSS). He has published 87 articles, abstracts, editorials, posters, and reports, served as Editor on 11 projects, delivered 115 invited

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