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# An unambiguous language for systems process design and engineering

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**Abstract**

This research focuses on a language for specifying the necessary, sufficient and efficient capabilities of a system, particularly the processes by which a system responds to external stimuli and sustains internal integrity. Because process decisions are the more numerous in system design the ability of designers to exchange process knowledge becomes increasingly crucial as system extent, variety and ambiguity increases. This is particularly evident when designers must devise autonomous systems that learn, foster learning and even generate new capabilities from their repertoire of processes.
System engineering literature has not provided a comprehensive taxonomy of system processes. The text most often used to train systems engineering students cites only a very small number of systems processes[1]. Fortunately, systems biology and basic systems science research have already identified a robust taxonomy of systems processes. We will use the System Processes and Linkage Propositions as clarified by Systems Processes Theory (SPT)[2,3] as a reference and compare several actual physical and sociotechnical models to the reference set. One objective is to determine the degree to which the quality, parsimony and beauty of a system model can be improved by using the reference repertoire. If MBSE can be improved by the reference set, and SPT detail helps us understand systems dynamics more deeply, then it may further help use explain and improve systems sustainability and resilience. A second objective is to determine the effect on designer productivity and innovation. A third is to evolve a fundamental ontology for computer-aided system composition. The research plan seeks to involve volunteer co-learners from various domains in this endeavour.

Keywords: systems processes; systems processes theory; systems ontology; systems ontogeny; linkage propositions; efficacy assessment

## 1. Context

In 1990 (Ring) was assisting in the turn-around of Ascent Logic Corp., source of RDD-100, one of the [then] few tools for expressing descriptive and prescriptive models of a system. Their demonstration of modeling air traffic control included expressions such as ‘send message to cockpit’ in one place in the model ‘notify pilot’ in another and ‘inform crew’ in yet another. When asked why there were three distinct kinds of messages nobody had an answer or would hazard a guess as to whether this led to a minimal, least cost system. The RDD-100 demo failed to achieve parsimony and elegance[3] through simplicity that denotes beauty.

### *1.1. Purpose of Study:*

A prescriptive model for an intended system specifies what the system DOES (what actions it performs with resources when triggered), KNOWS (internal models of context, resources and system) and IS (consists of). Measures of effectiveness for such model are quality, parsimony and beauty.

This study will determine the utility of the System Processes and Linkage Propositions as the elements of a language for a) specifying the functions, processes and process linkages that b) will be adopted by a majority of systemists, and c) lead to a system model that exhibits minimum essential variety. Because SPT specifies and documents numerous universals common to many systems, it claims quality (as far as enhanced detail), parsimony (universals mark parsimony) and we will leave the beauty claim to others judgement.

A shared language is important. Modern intervention systems cannot be conceived, designed, realized and activated by one person or even by a Chief Engineer directing multiple persons. Such systems arise from dialogue among many, adequately informed systemists capable of acting in concert even when isolated from one another. In essence a sociotechnical system is of the goal-seeking kind. Because an ontology can help us understand words and their limits as well as significance we are intrigued with the possibility that the System Processes and Linkage Propositions (as distilled by Troncale from comparing a wide range of the natural science phenomena)[4] can serve as a basic ontology for all system design. In addition, from his studies in systems biology, we here suggest that the usual gains arising from discovery of the fundamental ontology for a phenomena may be aided by considering investigations in systems ontogeny. Advances in systems science are helping define what is common to many successful and sustained natural systems. System design and engineering people may want to emulate or mimic the achievements of sustainability of these natural systems.

### *1.2. Hypothesis:*

(Troncale) has developed a rich resource regarding the science of system processes and not incidentally the way to see natural science as a system.[4] His teammates on the SP/SP (Systems Processes/Systems Pathologies) projects of the INCOSE-System Science Working Group (SSWG)[5] are comparing a wide range of real systems to abstract out the universal processes they have in common and also the common dysfunctions[6] thus revealed. They like to say this specifies “how systems work” and “how systems don’t work.”[6] This Systems Processes Theory (SPT)[2] purports to explain systems dynamics and sustainability. Both approaches were developed independently. We will determine the degree to which this forms a necessary, sufficient and efficient basis for a sharable language regarding system functions, processes and agility. A standardized language will not accomplish this. Instead we seek an ontology that penetrates so deeply into "systemness" that it replicates for our field what Mendeleev and Linnaeus did for theirs.

Other factors determine the degree of synergy that any given cadre of systemists might achieve. Exploration of these is beyond the scope of this paper. We seek a synthesis of the above-cited two that is not only sharable, but also is very detailed in the patterns and practices it advocates. The significance of its high level of detail provides a contrast with the usually vague formulations of those who argue for the systems approach, use off the shelf tools for systems management, or employ basic "systems thinking." The detail made possible in SPT and Systems Pathology is what systems engineers must express in order to design and engineer modern systems.

### *1.3. Measures of Objectives Achieved:*

The project will assess whether the current set of SP's and LP's are a) Necessary, b) Sufficient, and c) Efficient when used to generate d) Deterministic, e) Non-deterministic, f) Agile (Dove[8]) or g) Self-composing (Pizzarello[9]) systems.

### *1.4. Anticipated Effects of improvement in prescriptive modeling:*

An SE community suggested goal[10] is a 10X increase in Productivity and Innovation by 2020 across ≈ 1 million full time systemists world-wide even though they may have a ≈ 15:1 competency span. In any systems project numerous knowledge claims must be generated, exchanged and vetted by the participants. The knowledge claims must prescribe functions, processes and linkages for the intended Intervation system and for the Gestation (Project) system that produces the Intervention system.

A shared language will facilitate systemists' mutual ability to attend to the system they comprise as well as the system they engineer. That is, they comprise a distinct human system whose purpose is designing systems external to themselves by accomplishing efficient knowledge exchange and choice making and seeking collusion vs. collision.

## 2. The Systems Processes Reference set (SPT)

The above sequence of arguments support the necessity and possibility of a "system DOES ontology." It would rely on the ability to find and prove common patterns across most systems. Precedence exists. A wide range of findings and tools in the areas of systems thinking and systems science over the last fifty years provide a picture of systemness at its most basic level. There is such a wide range of what is called systems approaches that this is the problem we are addressing – lack of communication and especially significant integration and synthesis across the approaches. In addition, systems thinking tends to focus mostly on human systems and applications, and even general systems theory does not accomplish proof of isomorphy across a sufficient range of systems.[11] Here we focus on natural system science as the source of processes that are similar across many different systems. We focus on "processes" because they are the algorithms or ways that systems come into being, stay in being, and change to bring dynamics to the world, whether they are human or natural systems. They are simultaneously dynamics and ontology/ontogeny.

### *2.1. System Processes:*

The Systems Process Theory (SPT)[2,3] is a rich source of detail on how systems work and its spin-off, Systems Pathology of how systems don't work.[6] We are suggesting that the dynamics of influence between systems processes are as fundamental a glimpse into our expected "systems ontology/ontogeny" as we are likely to get. The level of specificity is also sufficient to help SE for systems conception, identification, design, and testing.

By becoming more and more familiar with these common systems processes designers will gradually evolve to share a vocabulary and communication and cooperation (synergy) across those working on a given system. Because processes can be (and have extensively have been) studied by experiment, there is an opportunity for making our discourse and use of terms more unambiguous. Further, the use of these processes enables asking much more answerable questions rather than our sense of hopelessness as we encounter chaos in systems, emergence, and ever increasing complexity. It purports to even be able to teach us to use chaos and emergence in our designs because numerous natural systems have and do.

The following list shows candidate Systems Processes that initial comparative systems analysis indicates are isomorphic (para-universal) to many systems. This set provides a considerably increased level of detail for understanding a prototype "systems ontology or ontogeny" and the fundamentals of how systems came into being in the first place as well as how they currently work. Part of the development plan for this unique body of knowledge is adding 25 categories of information on each candidate systems process leading to a new specialty we call SysInformatics.[12]

**Currently vetted list of System Processes: [see[13]]**

1) Feedback, Several Types of
2) Cycles/Oscillations/Hypercycles
3) Network-Forming Processes
4) Hierarchy-Forming Processes
5) Flow Processes (includes I/O)
6) Equilibrium & Steady State Proc's
7) States, Transitions (Phases)
8) Boundary-Forming Processes
9) Chaos & Chaotic Processes
10) Fractal-Forming Processes
11) Binding Processes/Interactions
12) Self-Organization/Autopoiesis
13) Symmetry-Forming Processes
14) Synergy/Synchrony/Cooperation
15) Non-Equilibrium Thermodyn-Irrever
16) Duality/Complementarity Processes
17) Origin Processes
18) Emergence Processes
19) Self-Criticality/Catastrophes
20) Information-Based Processes
21) Replication Processes
22) Variation/Innovation Processes
23) Competitive Processes
24) Systems Adaptation Processes
25) Systems Evolution Processes
26) Field Processes & Potentials
27) Allometry-Forming Processes
28) Exaptation, Cooption Processes
29) Growth Patterns & Laws
30) Development Patterns & Laws
31) Integration Processes
32) Dysergy/Decay/Death as a Process
33) Decay, Autolytic & Senescent Proc's
34) Amplifiers as a Process
35) Limits as a Process
36) Power Laws, Cross-Disciplinary
37) Function-Satisficing Processes
38) Broken Symmetry as a Process
39) Quantum Processes
40) Allopoiesis Processes
41) Minimization Processes
42) Maximization Processes
43) Constraint Fields as a Process
44) Neutralization Processes
45) Metacrescence Process (I/D Cycles

## *2.2. Universal Linkage Propositions (LPs):*

LPs show how one systems process influences, impacts or relates to another systems process ("linkage aspect"). We call these linkage propositions because we have not yet proved their absolute range of validity ("proposition aspect").[14] The collection of all of these "statements" or rules of influence between SPs makes the SPT not only a description of how an individual process causes observed systems dynamics, but how an entire network of processes (system of systems processes) describes systems dynamics in a more detailed way then heretofore possible.

## 3. Assessing Relevance of Systems Processes/Linkage Propositions/Systems Pathologies

It is now time to assess the value of the ideas presented in Section 2.0 above to typical system design work in the non-biological realm The assessment of the relevance and saliency of systems processes, linkage propositions, and systems pathologies (hereafter abbreviated to SP/LP/SP) will address six questions.

### *3.1. Requisite Variety?*

The repertoire of what we think about and how we think must accommodate the kind of systems that societies world-wide will require. We will use 10 distinct categories of systems as described in[15] to determine whether SP/LP/SP can span their variety.

What a system DOES is determined by the processes it executes. Some processes may be executed to produce outputs while others may be executed to configure the system to meet the demands of the variations in Input actualities, Output preferences and Resources availability.

### *3.2. Requisite Ontogeny?*

We take the well-developed and researched case of origins of all levels of biological systems as a case study. In this specialty, the origins and especially development of individuals, species, even life itself is called "ontogeny." This technical term in that field refers to the "genesis" (-geny) of the individual (-ontos).

Ontogeny has a restricted and very specific meaning in biology. It is the development of the entity at whatever scalar level. Developmental bio, developmental psychology, and cognitive neuroscience have active programs in ontogeny and their experiments inform us how such entities come into being from scratch, as in the progress of an ovum to a mature multicellular entity.

We are suggesting a similar set of studies broaden the concept of ontogeny in particular cases to a study of "ontogeny of systems." We have been comparing all these origin scenario's to decipher what processes they have in common when looked at (abstracted to) the level of systemness. We compare isomorphic patterns that contribute to origins whatever the entity or level. This results in a domain-independent, scale-independent, discipline-independent, and tool-independent explanation. It drills down to the essence of their emergence into being.

We claim that this would constitute the ultimate description of their ontology, although this is a departure from the classical use of that word. An ontogeny-based ontology would explain both their "being" and "becoming" at the most fundamental level. It would provide for testing that would enable gradual evolution and improvement of our knowledge of how systems in general come into being – an ultimate goal of ontology.

A science of origins approach has several strong points. (i) It is backed by a vast literature on the sciences of origins, very rich in detail, although weak in consensus. (ii) It is unique in that this approach has not been tried before to our knowledge. (iii) This approach allows for falsifiability and simultaneously congruence testing. It would constitute an evidence-based ontology to guide use of terminology and reach consensus and cooperation.

### *3.3. Applicable to sociotechnical systems?*

When human activities are studied as "systems" and the study is not restricted to a specific domain, then it becomes apparent that work groups share many of the same processes as natural systems. Sociotechnical systems have cycles, hierarchies, self-organization, self-criticality, numerous feedbacks, fractal organization, network dynamics, and more, just as natural systems do. Their functions are similar in both human and natural spheres. So while domain, scale, or discipline-limited ontology's might be different, "systems-level" ontology's would be much more similar and so synergistic. It would, by its nature, help grow a shared, unambiguous, process language.

### *3.4. Enables modeling of self-evolving systems?*

Systems engineering of the future will probably be greatly expanded from its current version to the study and repair of dysfunctional human-natural systems. We emphasize that the human-natural hybrid cases encompass most of the critical crises problems facing our species. Think global warming, war, famine, massive pandemics, etc. Using domain-, scale-, discipline- and tool-restricted ontology-ontogenies would show major differences in approach to these crises. But focusing on a "systems-based" ontology-ontogeny would be more domain-, scale-, discipline- and tool-independent and more likely lead to or enable a synergistic ontology capable of supporting an unambiguous systems design and engineering.

### *3.5. Supports modeling of higher order systems?*

This research is concerned with the kind of system that fosters other systems. This kind of system is variously called system design and engineering, system architecting and engineering, system engineering, engineering of systems, system of systems engineering, and other commercial labels such as prediction markets and wisdom of crowds. This kind of system is composed primarily of people operating as a sociotechnical system. The advent of autonomous systems adds a further consideration; how can a system be enabled to evolve itself? The SP/LP/SP taxonomy may yield insight into that question.

### *3.6. Interoperable with other aspects of a system model?*

While the immediate emphasis of the approach suggested here is on assessment of the SP/LP/SP set, we must also attend to the question of whether the set interferes with other design and engineering decisions. This can be assessed from three perspectives, a) A system DOES (stimulus:response), KNOWS (embedded models) and IS (content and structure, aka configuration). b) System value is measured by Quality, Parsimony, Beauty. c) System value is conditioned by [competency of elements X synergy of interrelationships].

## 4. 4. Assessment Projects Candidates

The INCOSE-SSWG adopted as two of its projects (i) using the Systems Process (SP) framework to unify fragmented sources of systems knowledge, and (ii) application of that framework to initiate a new level of Systems Pathology (SP) in 2010. Various sub-projects have self-organized within this SP/SP framework.[16] The above six measures to assess relevance of the SP/SP constitutes another of these subprojects.

### *4.1. Candidate Domains:*

Candidate contexts for this assessment project are suggested here. Volunteer participants may choose others.

- **A SysML-based model** selected from the several available in the INCOSE MBSE Initiative is already underway guided by the SE team of Schindel, Marzolf, and Smith.[17]
- **An OPM-based model** selected from those available in the IEEE-SMC Technical Committee on MBSE.
- **An Executable SPT in Cyberspace:** is also underway by two INCOSE members.[18]

*4.2. Candidate larger-scale projects:*

If enabled by volunteers or project funding one or more of the following may be conducted.

- **SySTEM Learning Leadership.** This presumes that STEM education can be greatly accelerated by placing it in a system context, thereby making science, technology, engineering and math more meaningful and rewarding to students. The SPT has already been used to design, deliver and test an innovative curriculum that satisfies all the requirements for STEM courses for undergraduates at most colleges. ISGE (Integrated Science General Education) teaches the students to recognize nine key systems processes in each of seven natural sciences thereby showing them that a vast number of natural phenomena all work according to the same universals. They obtain a broad sense of natural phenomena as studied by the conventional sciences (>114 case studies), the scientific method, the fundamental unity of the cosmos, and the promise of the new field of systems science, at one and the same time. Design of this year-long course was supported by $1M of grants from the National Science Foundation, the California State University, and various foundations. Another independent project focuses on guidance of leaders of learning who can leverage the innovative curriculum at the undergraduate level as well as use a system-oriented curriculum at primary and secondary levels. (Cabrera[19])
- **A Learning Maximization Chaord.** This pursues the conceptual design of a co-evolving network of learning environments that will enable kids of all kinds, world-wide to achieve the equivalent of a Bachelors degree by the age of 16. The design point is a 10,000 node network by 2017. This is not about courseware. This research will demonstrate the degree to which SPT can foster a shared language for specifying system processes that can initialize a self-evolving system involving leaders of learning. A specific goal is to determine the level of systems competencies can be achieved at respective ages up through age 16.
- **FAA NextGen V&V.** The way of ensuring persistent readiness of the NextGen system is key to its success. Past experience in larger-scale, complex, evolving systems indicates that V&V and T&E as currently organized, funded and conducted produce too many false positives and negatives. Accordingly, it is prudent to determine whether NextGen as conceived is capable of qualifying the readiness of its evolving increments.[20]

*4.3. Effect on Synergizing Systemists:*

If the foregoing projects indicate that the SP/LP/SP enhances system design and engineering then this project will assess the utility of the SP/LP/SP for synergizing systemists. Note that synergizing may be done by 'management' or a leader but in high performance sociotechnical systems the participants implicitly, mutually discover their best synergy. One way to meld this approach is to use the SP/LP/SP assets as a mutual framework and language among system design participants. This would leverage the already detailed synergy. Also interesting will be to assess the asset utility in achieving interface agreements and to measure the degree to which the mutual assets enable communication with systems development staff.

Synergized systemists will be able to perform system science, design and engineering as needed, when needed, and to do so collaboratively at the rate of opportunity. This entails both what systems people think about and how systems people think. This experiment is included in the Synergizing Systemists research being planned in the INCOSE Systems Sciences WG.

## 5. 5. Project Members Welcome

We welcome project members who are dedicated to discovering an ontology that allows greater communication and cooperation between a wide diversity of systems workers. We seek an ontology-ontogeny that is so fundamental to systemness that it might enhance engineering of particular systems. Further, although a set of functions and processes may be arranged in an ontology-ontogeny for quick and unambiguous reference, we note that the field of systems continually increases in variety, complexness and mystery. Accordingly we intend to look behind ontology to discover the ontogeny of system processes evolution.

We seek one, unambiguous and consensual ontology that informs both the makers of systems and the systems thus made. We maintain that elucidation of this ontology could change the way systems workers think and perceive the world in ways that might improve both their thinking and the systems that result from their thinking.

Little guidance has been given in this regard in the fifty-plus years of textbooks, standards, guides, and handbooks for system engineering. Conversely, in the nearly 70 years of system science some researchers have de-tangled living systems and built taxonomies of the kinds of process and functions devised in the natural world of living systems. We believe that the detailed systems ontology-ontogeny described above can now enable a science of systems -- an evidence-based systems science. These have not made their way into the engineering view of systems. Now is the time.

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