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Can a Theory that Integrates the Natural Systems Sciences Help Systems Engineering of Defense Against Security Threats?

Dr. Len Troncale
Institute for Advanced Systems Studies &
Dept. of Biological Sciences
California State Polytechnic University
Pomona, Ca. 91768, lrtroncale@csupomona.edu

Abstract

Citation of a range of security attacks across several scalar levels suggests shared commonalities of systems form and dynamics. These commonalities imply that one of the most powerful approaches to defense would be design that disrupts these pervasive underlying processes. We use a new, allegedly more comprehensive system of systems processes (SoSP) theory that enables expansion on just one of the key systems processes common to current security attacks, self-organization. We describe several words used in different disciplines that may be confused with self-organization and inhibit needed communication. We describe ten components of self-organization and seven linkage propositions that describe interactions between other systems processes and self-organization to increase resolution on this one vulnerable commonality of security attack. We suggest that the immense attention now given to "translating" lab results in medicine to new clinical treatments needs to be replicated in this domain. We need a "translational," top-down system of systems pathology to address widespread security attacks. We try to provide a glimpse of how the increased detail on just self-organization might help formulate better design of security systems. This serves as a case study of the even more fertile potential of using the 100+ systems processes and many linkage propositions from a unified SoSP as a rich source for security design.

Key Words: systems processes, discinyms, linkage propositions, self-organization, systems pathology.

1. Introduction: finding the commonalities across pirates, parasites, and pathologies

The title of this paper is put in the form of a question to promote a much-needed test. It challenges the efficacy of using abstract, but detailed systems theory to advance practical applications. Our case study is the crisis need to design more effective security systems to protect the ever more complex systems of systems found throughout our society.

Consider this pattern. Whenever a system appeared in nature of sufficient complexity, another appeared de novo that had evolved a way to live off that complex system. This has happened again and again back to the very origins of life on the planet and on every emergent level of complex system. Bacteriophages live off bacteria at the most primitive, first evolved level of cell complexity. Viruses live off cells at the unicellular level of organization. Parasites live off organisms; the multicellular level of organization. Cancers live off organs again at the multicellular level of organization. Pirates live off complex economic systems; the cultural level of organization. Terrorists live off our complex political system of organization. Each has evolved ways to attach, insert, alter, & command the organization of the host/victim to its detriment.

This list suggests that security attacks are a consistent "pathology" at a systems level. As such, it promises utility for a consistent systems-level response. For example, a series of papers by Rick Dove [1-3] suggest that six systems-level patterns are present in both the attackers and the attacked with "self-organization being the most important." This paper provides detail on how the process of "self-organization" works in systems across the very wide range of attack cited above and suggests how this more detailed knowledge might help defend against attacks on the human level of security.

1.1. Methods to find commonalities

How can we "harvest" the immense knowledge that has been recently produced on all these independent, but related emergent levels of self-organization to raise up a significant counterattack to the self-organizational behaviors of the widest possible range of threatening agents? Here we suggest use of a new integrated general theory of systems, the new natural systems sciences, comparative systems analysis, and the new studies in systems pathology, both top-down and bottom-up. In such a short paper we can only introduce these four methods here hoping they will attract sufficient attention and support to further develop the methods. A recent panel convened by the National Science Foundation ascertained whether or not the fields of “complex systems studies” were ready for funding [4]. That panel concluded the field was not ready; while a minority report by this author pointed out that without funding, such potential might never become “ready” for urgently needed uses such as security defense.

Comparative systems analysis (CSA) would be one new method that is derived from a long tradition of success in the natural sciences. Consider the many and revolutionary results from past studies in comparative taxonomy, comparative anatomy, comparative physiology and most recently comparative genomics & immunology. CSA would simulate and model the commonalities that are common across a wide range of threat modalities to find their most frequent vulnerabilities. Some of these strategies are already being used by our security forces, but without a conscious praxis of how they were devised. Many more could be systematically designed with use of CSA.

The emerging “natural systems sciences” of systems biology, systems immunology, earth systems sciences, systems chemistry, and systems neurology possess both direct and indirect applicability to design of systems-level security, the next generation. The worldwide university community has invested more than a billion dollars in the initial development of systems biology alone in just the last few years.

Previous surveys have noted that there are a plethora of disconnected efforts on elucidating the systems processes active in many or all systems. The System of Systems Processes theory (SoSP) [5-7], briefly described in this paper integrates and unifies the disorganized results of a century of effort to understand complex systems into a more coherent and usable form that, for example, gave rise to the analysis of the process of self-organization presented here. The greater the detail understood about self-organization, the greater the potential for using that detail in security design.

A “translational” systems pathology derived from the detailed SoSP is still another method of promise. This effort, now supported by formation of an international professional society [8], attempts to identify a wide range of common, innately “systems-level” diseases that threaten modern society to apply the proven methods of a well-developed medical and bioresearch community to treat and/or eradicate them. Systems pathology would study not only pirates and parasites, but also cancers and pathologies at all self-organizational levels.

Only the third of these four will be addressed in this paper.

2. “Discinyms” on self-organization: possible sources of miscommunication

Using the SoSP and CSA to increase the detail and resolution of understanding of the single systems process, Self-Organization (hereafter S-O) is the single focus of this paper. A first issue is the promiscuity inherent in the phrase. Different words exist that have significant overlap with S-O. The existence and use of these words can easily become sources of miscommunication between different research communities and different levels of design and decision making, as pointed out by Dove [3]. In the SoSP, we call these “discinyms” or disciplinary synonyms.

2.1. Autocatalysis

This S-O discinym is used primarily in the chemical, molecular biological communities. It refers to the widely observed capability evolved in certain protein families that enables them to assemble into functional aggregates without outside enzymatic help.

2.2. Autopoiesis

This S-O discinym literally means “self” “generation.” It is used in the complex systems research communities and leads to a wide range of philosophical and practical insights into how S-O works at different scales.

2.3. Self-Assembly

This S-O discinym is used primarily in the biological sciences as well as in the electronic, robotic and nanotechnology industries. This word refers to both human designed and naturally evolved cases of parts that have the capacity to join into larger complexes.

2.4. Stigmergy

This S-O discinym is used in behavior research to describe recursive building by social insects and beyond.

2.5. Origins

Because S-O often results in the appearance of a new level of structure, it is confused with generic words like “origins” that describe a much wider phenomena.

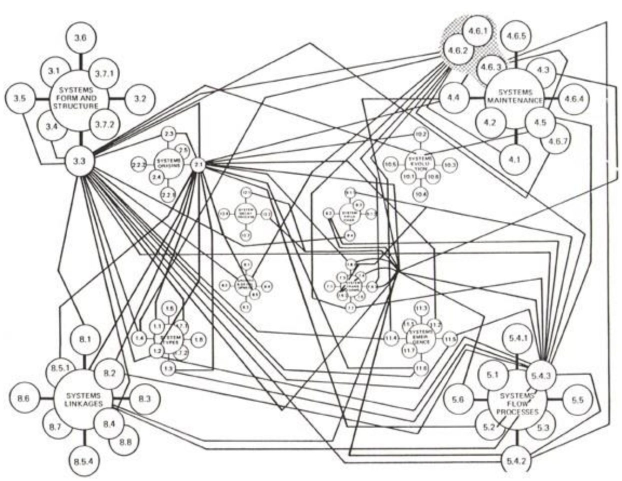
There are probably additional discinyms in use. It is essential that “tables” of discinyms be assembled for all the systems processes to increase awareness and thereby avoid possible barriers to communication. This would help overcome resistance to consensus on commonalities across systems. Not recognizing commonalities inhibits communication, command, design and decision.

3. System of Systems Processes (SoSP) theory as a source of security designs

The SoSP theory attempts to overcome four historical obstacles to an adequate general theory of how systems work, namely, (i) workers often limit themselves to their home discipline or domain in the search for explanations of how systems work; (ii) workers only use one or a couple of systems processes to explain how systems work leaving out large numbers of significant processes; (iii) many workers ignore numerous important interactions among systems processes; (iv) workers do not create tools that make their systems theory more usable and tractable; and (v) workers do not test their proposed theories with evidence. Limiting security design to social system knowledge impoverishes the design space.

3.1. A detailed network of influences among 100+ systems-level processes

SoSP theory [5-7] catalogues detailed information on more than one hundred systems processes. These key systems processes describe how systems come into being, maintain themselves, change and adapt. It provides (i) an ontology, (ii) a taxonomy, (iii) an alternative clustering by function, (iv) a dependency and prerequisite chart, and (v) a general systems lifecycle of the 100+ systems processes. Lists of discinyms are available for some of the key processes to help ease communication. All of these features are in continual extension and development. Tools to help users access the data have been planned and are seeking support for development. The thumbnail chart below is a sample of 64 linkage propositions (the lines) between 33 systems processes (the numbered circles) contributing to 5 specific clusters of systems functions. The Linkage Propositions on Self-Organization (section 5.0, this paper) are not shown. This thumbnail graph gives some indication of the detail available in the SoSPT.



3.2. Natural systems science and the SoSP goes beyond the self-organization of living systems

Dove and others [1-3] have cited S-O as an important systems process that characterizes those groups attacking our societal systems. It should be evident from the SoSPT that there may be several other systems processes that are important to know more about the commonalities across the several organizational levels of attack systems. They argue that if S-O is important to the attacker, it could be utilized by the defender to mount better defenses. So all these additional systems processes should be designed into the defense systems. The various natural systems sciences study real systems that have existed for billions of years and have tested the systems processes they use across uncountable numbers of events, on all possible scales. Thus, the SoSP and the natural systems sciences and their collected literature are a both a test bed and a rich source of detail for our own human systems defense designs. What do they say about the process of self-organization that may help us better understand how to use it in next generation security designs?

4. Twelve components of self-organization: what security systems must have for defense

The SoSPT uses “identifying features” in order to give greater detail on each systems process. Here are some of the ID features we have collected to date for self-organization (S-O) as a systems process. Some of these are systems processes prerequisite to S-O, and others are necessary conditions. This is not an exhaustive list nor is it in any order of importance or prescriptive sequence.

4.1. Positive feedbacks

Positive feedback is usually associated with growth, often an increase in output of a system and promotes change in a system. In the case of S-O, positive feedback accelerates the addition of components to create the pattern or tendency typical of that S-O process. Thus aggregation of individuals is an input to further increase in aggregation of individuals, described in [9] as an “infective” quality. It tends to strengthen change in the same direction as the original change. Positive feedback itself has multiple, additional ID features and Linkage Propositions in the SoSPT.

4.2. Negative feedbacks

This systems process usually restricts deviation or change in a system beyond a relatively narrow range of values around a point set by nature or man. In S-O cases, negative feedback provides the balancing “counterparitor” function [10] to the aggregation of the positive feedback to keep it under control. Negative feedback itself has multiple, additional ID features and Linkage Propositions in the SoSPT.

4.3. Context asymmetry

The pattern making output of S-O often occurs because of a net flow direction in the environment of the system. We call this an asymmetry of the context. Sometimes this asymmetry is built into the individual components such that the addition of each component recreates the asymmetry of the context in the growing assembly to assist the overall process. The flow is caused by the asymmetry. Symmetry and asymmetry have multiple, additional ID features and Linkage Propositions in the SoSPT.

4.4. Nucleation (or hierarchical clustering)

Many cases of self-organization require an initial unit complex to expedite the addition of new components to the pattern. In the absence of the initial assembly, the S-O process proceeds so slowly it is not considered relevant to pattern formation. We call this hierarchical because it involves heterogeneity of component distribution in either space or time. The heterogeneity combines with positive feedback to enhance aggregations. Sometimes the initial complex is not provided by the system directly, but arises simply from random fluctuations, some of which may result in uneven distribution which then amplifies (see 4.10) Hierarchies have multiple, additional ID features and Linkage Propositions in the SoSPT.

4.5. Thermodynamics of Context (Environment)

For S-O, an example would be the aggregation of proteins into very large, but highly ordered assemblies of organelles (or also virus particles) due to the water-based clathrate structure of the assembly involving significantly less water molecules than the community of unassembled proteins. As nature tends toward entropy increase, it drives the change of individual components to the aggregate ones. Thermodynamic processes have multiple, additional ID features and Linkage Propositions in the SoSPT.

4.6. Large Numbers of Entities & Interactions

From astronomical systems, to nanotechnology, to crystals, to geological features, to cell organelles, to plant animal and human societies, many cases of S-O require very large numbers of interactors, each with simple rules for their interaction built into their components. But it is interesting to note that while cases of S-O in physical, chemical, and biological (from molecular to ecological) systems require these large numbers, many cases in social systems do not require large numbers. Rather these cases require higher interaction frequency, refinement, and strength of information transfer as a surrogate for large numbers of interacting components. Indeed, numbers on the social level that are as large as those on the other levels serve as an inhibitor of S-O rather than a promoter.

4.7. Chaotic attractors

In S-O as in other dynamic systems, the initial states of the components are random or chaotic with no observable order. However, there often exists a particular structural state to which the components converge after a change in time or environmental input. The name of this state is an attractor. Just as in phase changes, the shift from one attractor to another happens suddenly or at least very rapidly compared to other time dimensions for that system's changes. Similarly, some systems exhibit multiple attractors due or multiple bifurcations when there is just a small change in parameters. These types of systems can be described as multi-stable systems via their self-organizational characteristics. Chaos has additional ID features and Linkage Propositions in the SoSPT.

4.8. Micro- coupled to macro-dynamics

In the cases cited in 4.6, the individual component carries the macro pattern within itself but in a codified manner. This results in a coupling of the dynamics on the micro-level to the pattern that ultimately appears on the highest levels. It is often difficult to predict the macro pattern from knowledge of the micro codifications.

4.9. Emergent consequences

In many S-O cases, the pattern that appears from the dynamics of the components has qualities that were not present in the unassembled components. We describe the interactions of the components in 4.6 as non-linear and so cannot be traced from the interactions and easily predicted. Emergence processes have multiple, additional ID features and Linkage Propositions in the SoSPT.

4.10. Information and its amplification

In many cases of S-O, for example those of 4.8, but also schools of fish, herds, etc. a constant flow of information (exchange) is required between the individual components and the resulting pattern that they maintain. Flow of information is also critical between the nucleation aggregate and the population of aggregating components. Often the flow is most intense between so-called "nearest neighbors." Often signals and cues are exchanged with signals being the most specific and directional while cues are more conditional. The former constrain or direct the action of the components while the latter only favor "cannules" of behavior (with greater degrees of freedom).

4.11. Symmetry breaking

One spin-off from the system of systems processes theory is a 5-step process that explains emergence of the major hierarchical levels at different scales in the universe. This theory of emergence begins with distinguishing evolution decisively from emergence and continues with an empirical approach to determining quantitatively what are and are not the emergent levels in nature. This reduces the "noise" in real systems that obscures recognition of the process of emergence. In the course of investigation of the emergence process as the source of hierarchical levels, it became clear that one key event common to the "gaps" between levels was a symmetry break at the point where one symmetry pattern gave rise to another, new symmetry at the next higher level of complexity. If one considers emergence of new levels of scalar order and stability to be new self-organization events, then symmetry breaks are another characteristic of some S-O phenomena. Symmetry and asymmetry have multiple, additional ID features and Linkage Propositions in the SoSPT.

4.12. Coupled Feedbacks

In order for S-O to work well both negative and positive feedbacks have to be coupled through interlocked effects on the same system mechanics producing the specific S-O output. This is not a trivial arrangement. At other times the two work on different domains of the S-O system to create much more refined patterns than possible without the coupling. This higher level of coupling is considered a separate systems process and has multiple, additional ID features and Linkage Propositions in the SoSPT.

SoSPT studies more than these dozen identifying features of self-organization. But we here introduce these dozen to test the feasibility of using SoSPT to inform the next generation of security defenses following Dove's suggestion that S-O is the most important of security threats and so should be the most important for designing security defenses in the next generation.

5. Linkage Propositions on self-organization

The SoSP adds a critically important descriptive level and detail by making formal statements of how one systems process influences another to help systems work. These cross-influences are called "linkage propositions" because they tie together the many putative mechanics of systems and also because they are working hypotheses that are known to be true in some cases of systems but not necessarily all cases – a matter under continuous study. Linkage propositions take the form "<u>systems process A</u> (influence described) <u>systems process B</u>." The statements describing the influence may seem strange to those unfamiliar with non-linear causality. But they have the advantage of contributing a new ontology and taxonomy of types of non-linear causality to our modeling and understanding of complex systems. Use of phrases like "is a partial cause of" or "is a partial result of" give rise to network, quorum, and threshold causalities more explanatory than our usual reliance on linear causality.

Some of the linkage propositions that the SoSP has been researching for self-organization are the following:

- <u>Hierarchical clustering</u> is a partial cause of <u>S-O</u>
- <u>Entropy</u> is a partial cause of <u>self-organization</u>
- <u>Symmetry breaking</u> is a partial cause of <u>S-O</u>
- <u>Positive feedback</u> is a partial cause of <u>S-O</u>
- <u>Hierarchical clustering</u> is a partial cause of <u>nucleation</u>

The reciprocals are also true, creating a network of mutual influences, for example,

- S-O is a partial cause of Hierarchical clustering
- S-O is a partial cause of Entropy
- S-O is a partial cause of Symmetry breaking
- S-O is a partial cause of Positive feedback
- Nucleation is a partial cause of Hierarchical clusters

The more complex network of LP's active on S-O (partly shown in the diagram for section 3.1) both increases the understanding of how S-O works and broadens the potential design space for all of its uses. We suggest better security design could be one of these uses.

6. Translational Systems Pathology: Glimpse of applications of SoSP to security designs

The critical question to ask after this preliminary review is whether or not the increased resolution of detail on self-organization from the SoSPT informs security design. What is the practical value-added? This presumes that self-organization is one of the key systems processes that characterize security threats. But even if so, notice the many other systems processes we have cited could also be involved in explaining how S-O works. Therefore security threat systems may be characterized by many more than solely the S-O process. It is here that SoSPT could make a significant contribution of greater detail for design of defenses against a wider range of security threats due to its top-down coverage of systems architectures combined with bottom-up detail.

It is important to note that the discussion of ID features on self-organization (S-O) above is based on the broadest range of S-O examples spanning physical, biological, and social systems. So our list includes more features than a list restricted only to current knowledge of social systems.

But most design of defense against security threats solely focus on social system attributes. Next generation design space may be significantly enriched by incorporation of the more extensive list of domains that show evidence of self-organization processes.

There are multiple possibilities to enhance or disrupt self-organization using the details just summarized. We suggest calling this "translational" systems pathology to enable use of the recent advances in medicine promised by "translation" of biomedical research to the clinic to save lives. Just as there is a need to conceptualize and plan for transfer of basic research in biology to immediate medical practice, there is a need to design practical protocols for transfer of basic research in the architecture of systems to defense against security threats.

For example, the obligate requirements for successful S-O can be subjected to interventions that have very significant effects on the origins, evolution, and future states of the threat systems in their own terms. Here are some specific strategies to pursue.

(1) Feedbacks both negative and positive could be disrupted or the necessary coupling between them could be thrown out of balance. It is strange to think that increasing positive feedback that seems an aid to the attacker could disrupt the attack. But creating a hyper version of a positive feedback disrupts systems balance as much as removing it entirely. Disruption of the S-O-based group formation process is as effective a defense as its' opposite.

(2) Disruption of the nucleation event could be effective. The starting conditions of a terrorist cell would be analyzed for possible disruptions of those starting events. In cases of terrorists cells in the U.S., nucleation events are those associated with internet contact with organizers or imams in local mosques, or the lead persons in the local cells.

(3) Better understanding of the aggregation and information flows could be vulnerabilities. In the case of terrorist cells in the U.S. this would mean analysis of the characteristics causing individuals to commit to the cells.

(4) Use of knowledge of the context or environment thermodynamics in the case of organizing a terrorist cell could lead to programs that would change the context to disallow S-O of the cell. For example, recent studies indicate that the forces active in bringing individuals in the cells together are not just the attraction between those individuals, but rather the great distance between their characteristics and the culture in which they are contained. Assimilation is an antidote.

A full review of the complete set of Linkage Propositions that connect self-organization processes with several other system processes further widens the detail available to stimulate the design of next generation security systems.

The recognition of systems diseases in the SoSPT spin-off, Systems Pathology could add additional avenues of design.

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