Systems of Innovation I: Summary Models of SOI Health and Pathologies

Bruce C. Beihoff
SYSDYNETIX
bbeihoff@sbcglobal.net

William D. Schindel
ICTT System Sciences
schindel@ictt.com

Abstract. Innovation is critical to viability in changing environments. In living ecosystems, innovation adapts to changes by predators, prey, and the rest of the environment (e.g., geology). For engineered systems, innovation exploits market interests in new capabilities, creates new markets, develops competitive advantage, and adapts to changes in technologies, infrastructure, regulations, and commercial environment.

In all these domains, the process of innovation may itself be described as a system—the System of Innovation, and studied by natural scientists, engineers, and technologists. The relative effectiveness of different systems of innovation impacts the competitive viability of the resulting series of innovated systems.

Modeling pathologies improves understanding of healthy systems, assessment of effectiveness, and ability to prevent or correct pathologies. "System pathologists" are found in medicine, field support and maintenance organizations, agriculture, the natural sciences, and other domains. This work is concerned with modeling Systems of Innovation, including characterizing their pathologies and health.

Introduction and Background

Systems science. This paper is connected to work in progress within the INCOSE Systems Science Working Group (INCOSE SSWG 2012; Troncale, Beihoff, Schindel, 2011). In connection with the Systems Processes and Systems Pathologies projects by Dr. Len Troncale (Troncale 2011), the authors of this paper are pursuing a narrower scope effort to describe (model) Systems of Innovation at a level of generality that encompasses both the natural world (e.g., biological innovation) and the human-engineered world (e.g., product and process development), including the characteristics of health and pathology in such systems.

As befits the INCOSE Systems Science Working Group and the innovation landscape, the perspective of this paper involves both science and engineering. The methods of science arise in this paper in two ways. First, for the subset of Systems of Innovation conducted by human beings, the rise of physical sciences has resulted in three hundred years of acceleration of innovation of the infrastructure of human civilization. So, one may expect that the process of science will appear prominently in at least the human-performed subset of Systems of Innovation. Second, the methods of science can be applied to study Systems of Innovation themselves. This is most obvious in the case of the study of biological innovation (one of the most famous scientific stories), and perhaps less obvious in the case of the study of innovation in commercial products. It only adds to these interests that some newer engineered products are themselves biological, with innovation processes merging scientific inquiry with engineering development.

There is a large business literature on commercial innovation, illustrated by (Christensen 1997, Kelley 2001, Lechleiter, 2010) and a large scientific literature on biological innovation, illustrated by (Darwin 1859, Thompson 1917, Gould 1989, Carroll, 2005). This paper takes a different path, focusing on an abstracted model of the underlying structure of Systems of Innovation found in both domains. (The natural world systems portion of this space is not limited to biological systems, although they are most frequently referenced.)

Evolution in engineered systems, markets, and methodologies. The evolution of the consumer's habits and practices (e.g., product operating models) and the improvement of "agent based systems" modeling have converged over the years. This convergence has created awareness among the innovation communities that consumer behavior can be understood as a system, and subject to the tools and knowledge of systems science. In turn, this understanding can be used to model that behavior, especially as it relates to new product innovation. These models have ranged from the quasi-deterministic statistics of business forecasting to the latest work in genetic algorithm agent models that have infinite number of final end state consumer buying predictions. As this understanding of the consumer's behavior (acceptance, use, and perception) have progressed, a number of major enterprises have developed their own versions of "consumer innovation" models that are utilized heavily as one of the major components of the innovation process. These models are not ultra-precise deterministic predictions as much as robust comparisons of innovation value and consumer acceptance between alternatives; e.g.:

- Two global leaders in consumer packaged goods utilized emergent system models matched with model based physical behavioral test sites to evaluate alternative innovations in product, packaging, and store shelving.
- Two major automotive manufacturers utilized regionalized "agent based" purchase intent models to evaluate alternative options and feature innovations.
- Two major consumer electronics companies utilized consumer models to evaluate usability of display and interface innovations across all of their product families

Table 1: Recent Innovation Waves and Associated Innovation Challenges

Industry / Market	Innovational Transition (Wave)	Innovational Trend	Key Challenge to System of Innovation
Mobile Devices	$4^{th} > 5^{th}$	Functionality and Capacity	Adaptation to Rapid Change and Competition
Consumer/Computer Electronics	5^{th} > 6th	Convergence	Adaptation to Rapid Change vs size of investment
Entertainment	5^{th} > 6th	Cross pollinated technologies	Race to dazzle using cross pollination from other technologies …
Transportation	3^{rd} > 4th	“Home on Wheels” to "Life on Wheels"	Break traditional trade space barriers cost-efficiency-performance
Military Aerospace	3^{rd} > 4th	Adaptation to changing mission.	Dynamics and complexity of changing missions; efficiency
Industrial Systems	3^{rd} > 4th	Deeper understanding of dynamics	Break traditional trade space barriers cost-efficiency-performance
Home Systems	1^{st} > 2nd	First large transition since WW II	Break traditional trade space barriers cost-efficiency-performance
Medical Systems	4^{th} > 5th	Cross pollinated technologies	Efficiency of Innovation Investment
Energy Systems	2^{nd} > 3rd	Major rebuild of system concept	Starting up after years of underinvestment
Raw Material Systems	2^{nd} > 3rd	Major rebuild of system concept	Starting up after years of underinvestment

Progress in Innovation. Not only products, but methods of innovation themselves evolve. Table 1 lists some recent innovation waves and associated challenges to systems of innovation. While there is not widespread consensus on the numbers of "generations" shown, those listed represent one perspective on the number of such waves. Both health and pathology in innovation are visible in this history, as in (1) the demise of the world's pre-eminent photographic enterprise, unable to innovate out of an entrenched position, and (2) a major textile enterprise that innovated beyond equally tectonic shifts (Bussey, 2012).

Model-based context. Like science, models appear in this paper for two reasons. First, they are used to create a more explicit description (a model) of the System of Innovation as a system in its own right. Second, models and modeling will themselves appear as aspects of at least some Systems of Innovation.

The Rise of Model-Based Methods. The story of Model-Based Systems Engineering (MBSE) is extensively described in other references (Estefan 2008, Schindel 2005a, INCOSE 2009). Model-based methods have arisen across technical, scientific, and economics disciplines in recent decades. The software community and the systems engineering community (including INCOSE) have worked to improve the effectiveness of model-based methods through the development of modeling language standards, such as UML® (for software engineering) and SysML® (for systems engineering). The approach used in this project can readily use any of a number of system modeling languages, as it is about fundamental systems ideas that any systems modeling language should be capable of supporting.

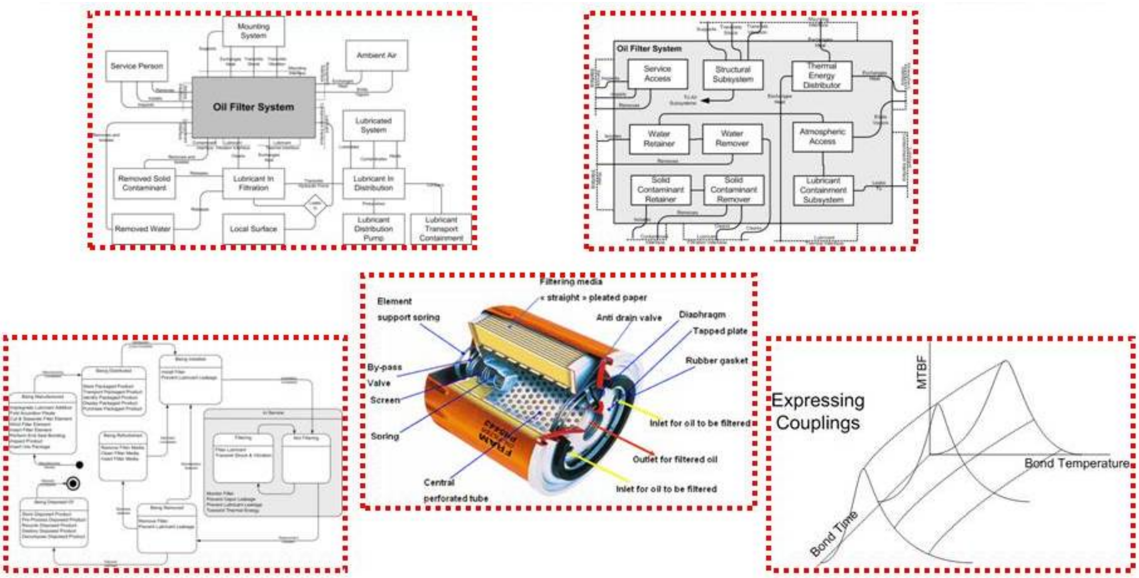

Figure 1: Models Increasingly Appear In Product Engineering

Most model-based engineering descriptions include and cite these benefits:

1) A more explicit representation of requirements, design, or other information than might otherwise have remained implicit or unstated in earlier approaches.
2) More effective processes of discovery of system requirements and systems causality.
3) Faster convergence on a common understanding across teams.
4) More effective capability to represent sets of innovative solutions and the trade-offs between them.

5) Greater leverage from model-supporting IT tools, including in some cases integration with specialty areas such as simulation or software construction.
6) Improved developmental testing.
7) More iterative design improvements.
8) Tighter coupling of requirements and designs.
9) Lower cost experimentation and learning in cyberspace.

The Model-Based Approach Used Here. The rise of model-based methods in engineering in general, and in systems engineering in particular, is transforming human's ability to imagine, represent, and communicate about innovated systems. The approach described by this paper makes use of model-based methods to extend what was available to technically integrate more scientific knowledge in the resulting description.

This approach makes use of modeling concepts drawn from the summary metamodel of Figure 2, further defined in Table 2 of Appendix 1:

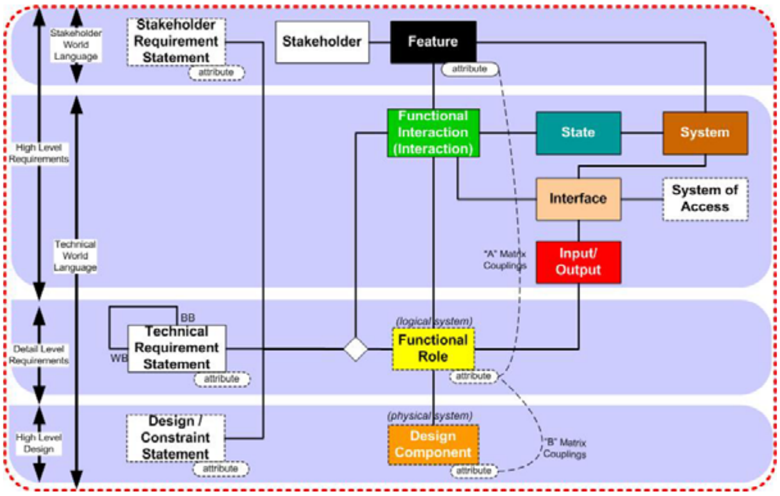

Figure 2. Summary of S* Metamodel (See also Table 2 of Appendix 1)

The metamodel of Figure 2 re-positions prose (as well as mathematical) functional "requirements statements", which become a formal part of the model. All functional requirements are modeled as external interaction behaviors. They become input-output relationships describing external system "black box" behavior exhibited during interactions with external actors. They become an extension of the idea of "transfer function", describing (prose) input-output relationships (Schindel 2005a). In addition, this same model data structure expresses mathematical relationships, when available, and this provides a basis for the embedding of known scientific laws and the development of new laws of science, as representations of their parameterized interactions, whether derived from first principles or DOE characterizations. The integration of attribute (parameter) coupling relationships is inherent to this metamodel. See also (Schindel, 2011) for a discussion of "how much model" is needed. The primary metaclasses of Figure 2 are defined in Table 2 of Appendix 1.

Systems of Innovation

A working definition of Innovation. Following (Schindel, Peffers, Hanson, Ahmed, Kline, 2011), "Innovation" is defined here as the realization of significantly enhanced stakeholder benefit. This distinguishes innovation from invention, novelty, ideation, creativity, or similar concepts that become parts of innovation in at least some cases, but are not the entirety of innovation. For our purposes here, the definition of Innovation (and the rest of the model that follows) must also be as effective in the natural world of biological systems as it is in the commercial world of human engineered systems. The resulting level of abstraction may describe innovation in a way that is somewhat unfamiliar to biologists and engineers, but it can add insight in both domains. This level of abstraction is not without precedent in this area (Rosen, 1991, Kineman, 2011).

A system model of innovation process. To help us study innovation as a system, this project is constructing a system model. (Note that this should not be confused with the idea that a specific human-performed innovation process might be model-based in its methods—what is instead meant here is that our description of the innovation process is itself a system model.) For human-performed innovation, one might expect this model will include agent-based roles performed by humans and their tools, as well as the information with which they interact, the patterns to which they may or may not refer, the engineered system descriptions that emerge, and the construction and subsequent life cycles of the engineered systems. For innovation in the natural world of, say, biology, one might expect this model will include roles performed by genetic mechanisms, reproduction, natural selection processes, and the life cycle of the biological system. The objective is a single, but specializable, abstract model of innovation spanning this diversity. In the human-performed case, it should include the use of science to enable human understanding and innovation. In all cases, it should support the use of science to understand innovation as a system.

The domain diagram of Figure 3 establishes the context of a modeled System of Innovation.

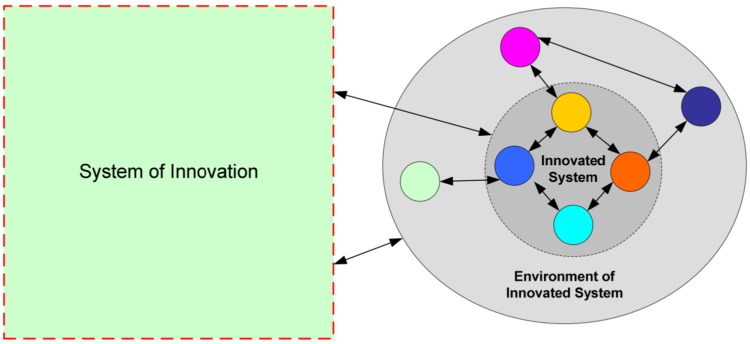

Figure 3: The Context of the System of Innovation

This diagram shows the relationship between three logical systems:

<u>The Innovated System:</u> The system which results from innovation. Also called the "Target System", because it is the target of the innovation process.
<u>The Environment of Innovated System:</u> The system within which the Innovated System will reside, containing the actors which will interact with the Innovated System.
<u>The System of Innovation (SOI):</u> The logical system that, interacting with the other two systems, accomplishes the innovation process.

The above are "roles" (logical systems), meaning they are behaviors (visible through external interactions), and do not express specific boundaries between physical systems. Aspects of both the System of Innovation and the Innovated System can occur within ("be allocated to") a single physical system, as in the case of a biological cell, which plays roles as both an Innovated System (say, with improved metabolism) and some aspects of a System of Innovation (for example, carrying genetic information). The three types of systems above represent functional categories, not physical system boundaries, which vary in different domains. Significant traditional sources of confusion can be unraveled by the use of systems engineering's paradigm of logical roles (behaviors) allocated to (various) physical instances. By convention of the above diagram, the System of Innovation is not shown as part of the Environment of Innovated System, but can clearly be part of its "extended" environment.

Specialized innovation domains. The intent is that the above model apply across a diverse range of domains, including innovation in the natural world (e.g., biological systems) as well as the human-engineered world (e.g., commercially engineered systems). Because of the differences in how these domains embody innovation, the constructs of our System of Innovation model will be more abstract and less familiar than those that were developed specifically for individual domains. The traditional systems engineering terminology (e.g., "requirements", "design", and "Vee Diagram") don't appear explicitly, but will upon specialization of the abstract model to the human-performed case. As illustrated by Figure 4, the interest is a general innovation model that can be specialized to fit different domains:

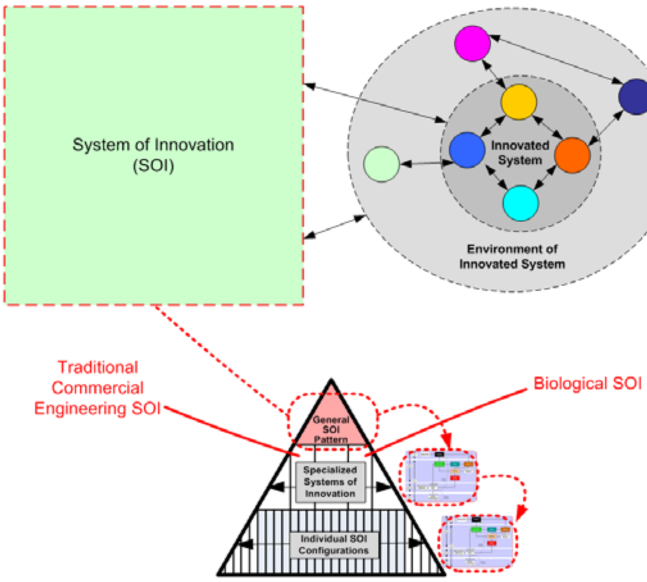

Figure 4: The SOI Specializes Differently in Different Domains

Logical Architecture of the System of Innovation: The SOI "black box" above has been partitioned into a logical architecture, shown in Figure 5. This is a functional decomposition sufficiently general to span the varied domains described. The model of the Innovated System and the Environment of Innovated System have also been formalized. The definitions of each of the blocks in this diagram are found in Appendix 2. They are not intended to describe "techniques for performing innovation", but instead set forth a general partitioning of interacting innovation processes into a relatively small set for additional study.

Insights from the SOI Logical Architecture. Absent from the left side of Figure 5 is most of the familiar terminology of engineering processes (e.g., requirements, design, validation verification, etc.). Replacing them in Figure 5 are more abstract ideas that arise from examining innovation in both the natural world (e.g., biology) as well as human-performed innovation. It is important to include the idea that even human innovation is not always performed in the framework of formal systems engineering processes. As a more fundamental view of the nature of innovation, this part of the SOI Pattern can be configured for specific domains by the SOI Feature Model discussed below, mapping it into the processes and terminology more familiar to specific domains.

In the case of innovation that occurs in the natural world without humans, experience is accumulated in genetic material (for biological systems), or in the form of the innovated phenotype systems themselves (for other natural systems). Performance observation occurs in the form of natural selection across populations of organisms, as well as selection processes at lower levels.

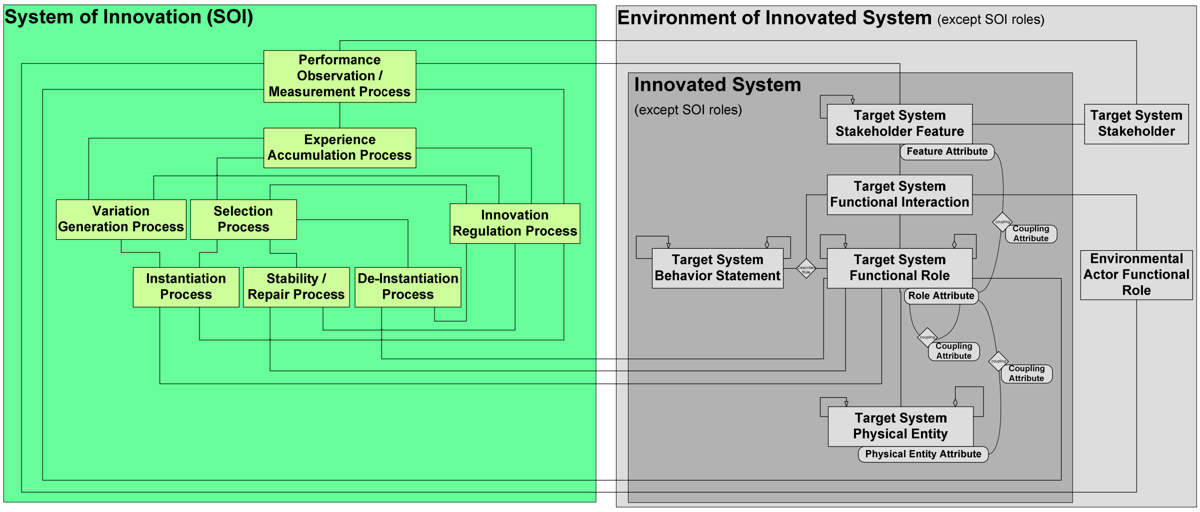

Figure 5: SOI Logical Architecture, Defined in Table 3 of Appendix 1; Download from https://sites.google.com/site/syssciwg/projects/o-systems-of-innovation/SOILogicalArchitecture1.1.5.pdf?attredirects=0&d=1

In the case of human-performed innovation, information is frequently accumulated in the form of explicit specifications and models, as well as in more implicit knowledge and experience, intuition, or habit. Some of this information is codified in engineering information artifacts, some in human brains, and some may reside nowhere other than the state of the Innovated System itself (frequently a cause of later reverse engineering). Some of this information describes regular patterns humans have learned about phenomena of the natural world, from the hard sciences. Other parts of the information describe environmental patterns such as market data and available commercial technologies. Performance observation may include scientifically-performed experiments, market studies, test stand or in-service data collection, and various forms of customer feedback. Selection occurs as a cognitive activity, picking candidates that have convinced the human selector of their superiority.

Variation, which at a sufficiently low level looks like new combinations, may be introduced in biological systems differently than in human-engineered systems, but is essential to innovation in both cases. Perhaps less obvious is the important role of stability and repair mechanisms, which in a sense have the opposite role to variation. Although biological systems may have their own form of processes for stability and repair, human-engineered systems are likewise surrounded by "war stories" about the challenges of preventing or correcting undesired change (for example, configuration management and maintenance stories about systems).

These processes of observation, experience accumulation, variation, selection, etc., occur at multiple hierarchical levels of the Innovated System, shown by the hierarchical containment "loops" on the right side of Figure 5. In the case of biological systems, selection is not limited to the organism as a whole. Selection processes at lower biological levels are evident in examples such as biological development (growth and unfolding of the individual), neural circuit development, immune system cell population responses, and other low level selection processes. In human-engineered systems, selection occurs at multiple system levels: new generations of computers are selected that are based on separately-selected new generations of electronic components and software technologies. The higher-level selection processes operate on combinations of selected lower-level building blocks, creating downward evolutionary pressure on the lower level components.

Exploring configuration spaces for logical and physical systems. The processes of variation, observation, and selection operate to explore configuration spaces, driving innovation. The right side of Figure 5 reminds us that this configuration exploration occurs at both multiple logical (behavior) hierarchical levels and at multiple physical hierarchical levels. The Target System Functional Roles of Figure 5 occur in their own hierarchy of behaviors, and the Target System Physical Entities of Figure 5 likewise occur in their own hierarchy of physical assemblies. Examples may be found in which exploration occurs first by “trying” different behaviors, and others may be found in which exploration occurs by “trying” different physical assemblies. These exploration cycles are summarized by Figure 6:

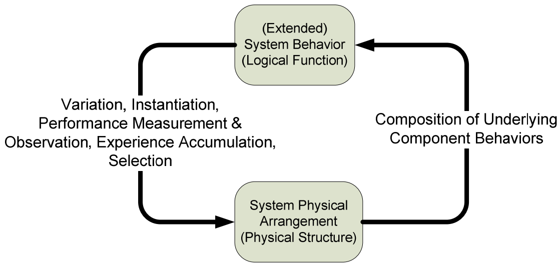

Figure 6: The Exploration Cycle

The fact that there is no universal “starting point” to the simple cycles of Figure 6 reminds us of the “unplanned” way that much innovation occurs, even in the case of human innovation. A humorous illustration is (Rogow, 2011), in which rubber mats were installed on a sidewalk in front of a Sydney bar to reduce the delivery noise of beer kegs on carts. This led to the observation that when rowdy patrons fell, they experienced fewer injuries. The reported result was scores of bars adding rubber mats to their sidewalks as well as interiors. Parallelling biological “exaptation” (Gould 1979), it also illustrates the importance of observation as an integrated part of more effective human-performed innovation, as in (Schindel, Peffers, Hanson, Ahmed, Kline, 2011) and (Dyer, Gregersen, Christensen, 2009).

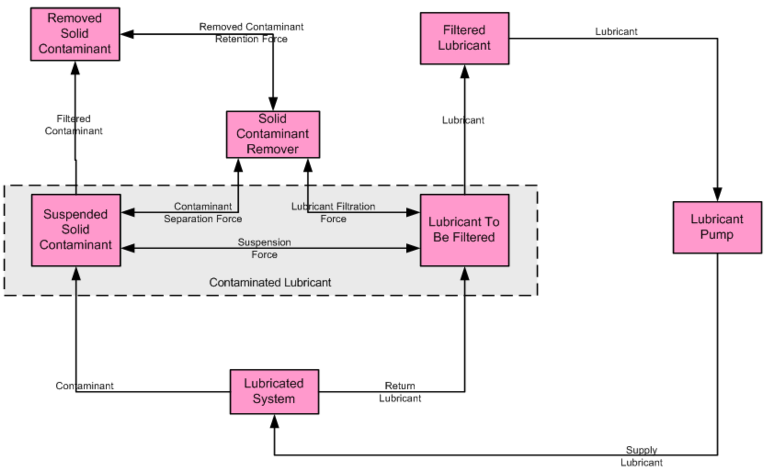

Figure 7: Example Model--Higher Level Functional Roles (Mechanism); download from: https://sites.google.com/site/syssciwg/projects/o-systems-of-innovation/Filter--Higher%20Level%20Functional%20Roles%20%28Mechanism%29.pdf?attredirects=0&d=1

Innovation explores configuration space at multiple levels. Consider the simple example of an oil filter, designed to remove suspended contaminants from a pressurized lubrication loop. Figure 7 illustrates a higher level behavioral modeling space, and Figure 8 illustrates a lower physical phenomena level modeling space—consistent with the Figure 5 Innovated System.

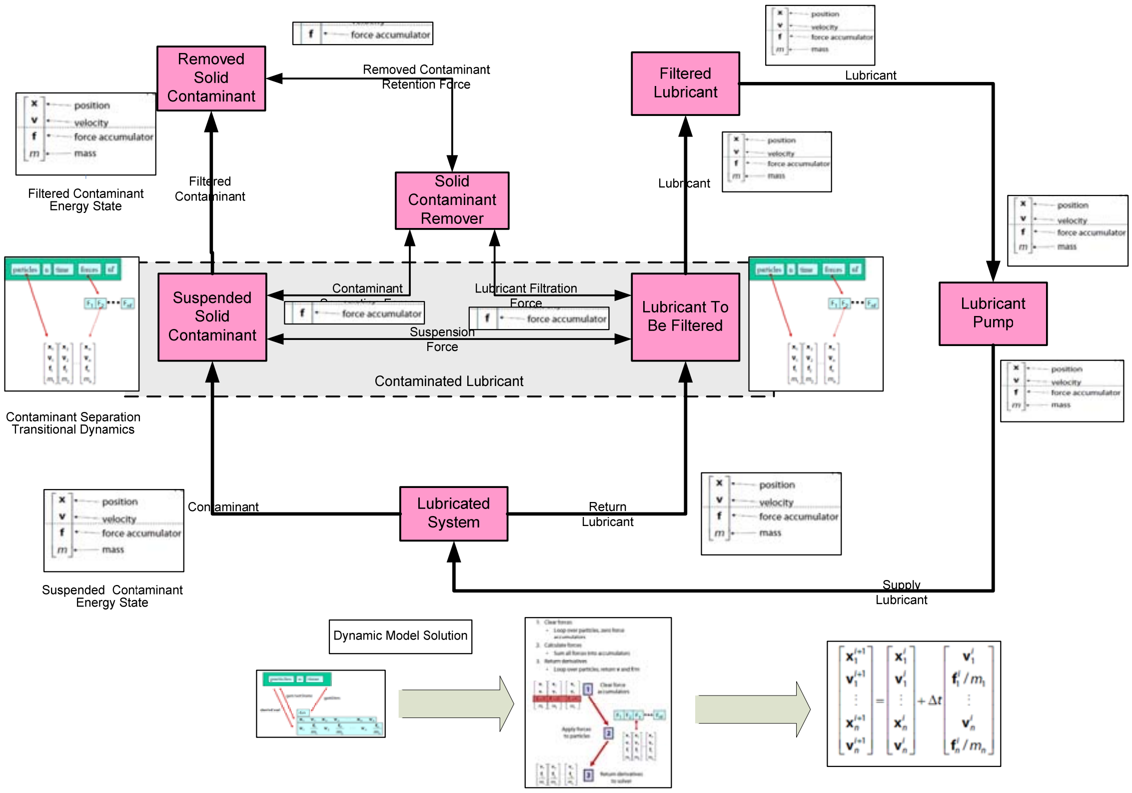

Figure 8: Example Model--Lower Level Physical Technology Capability (Phenomenon)

https://sites.google.com/site/syssciwg/projects/o-systems-of-innovation/Filter--Lower%20Level%20Physical%20Technology%20Capability%20%28Phenomenon%29.pdf?attredirects=0&d=1

System Health and Pathologies

A working definition of system health. This project defines a system as healthy if it performs (externally and internally) in a manner typical of other systems of the same type in like external circumstances. This conceptually includes performance as experienced by system stakeholders, but it also includes internal component performance which may or may not have immediate impact on stakeholders. The assertion of this definition is that a system cannot be healthy if it does not perform as well, overall and at lower component levels, as well as other systems of the same type in like external circumstances.

This definition avoids forcing concepts such as "intended use" or "works as designed", found in the domain of engineered systems. Instead, it suggests the idea of a "norm", based on the capabilities of other systems of the same "type".

A working definition of system pathology. This project defines a pathology of a system as any failure of the system to perform (externally or internally) in the manner typical of other systems of the same type in like external circumstances. Thus, the typical locomotion rate of a tortoise is not a pathology, even though it is slower than a hare. Conversely, a failure of a filter caused by a break in its filtration media (permitting contaminants to flow through) is (or causes) a pathology.

By the above definition, all pathologies are pathologies of systems. Perhaps, however, all such pathologies are not systemic. Using a perspective similar to the SSWG project on Systems Pathologies, we consider a pathology systemic if it impacts either (1) interactions of the first level subsystems with each other or (2) interactions of the system with its environment. It is these "systemic" pathologies that are called System Pathologies in this paper, and it can be seen that this definition is relative to a reference boundary of a system.

System boundaries and system pathologies. For example (call it Case A), a person suffering from rheumatoid arthritis and already unable to perform the normal range of arm motion illustrates a System Pathology at the level of the overall human, because it impacts the ability of the person to interact with its surroundings. At a certain earlier stage of the disease (call it Case B), the same person was still able to perform the normal range of arm motion, but the interaction between the immune system and the musculoskeletal system was already abnormal. Even though the person did not notice the condition, this is also a System Pathology at the level of the overall human, because it impacts the interaction between two first-level subsystems. At an even earlier stage (call it Case C), the interaction between the immune system and the musculoskeletal system was still normal, but the immune system was already internally abnormal. This third case is not classified as a System Pathology at the overall human level. Note that the definition of System Pathology is system boundary-relative, since Case C would still be considered a System Pathology at the subsystem level. (In the case of a disease or other anomalous condition, a pathology that is not a System Pathology at the human level may later lead to a System Pathology at the human level if the organism is not robust with respect to the condition.) A System Pathology may be stakeholder-impacting (as in Case A) or not stakeholder-impacting (as in Case B)—the latter might also be called a "anomaly". All the System Pathologies require deviation from the (statistical) envelope of behaviour normal for systems of the given type in like circumstances.

System Stakeholders. The Innovated System and the System of Innovation shown in Figures 3-5 both have stakeholders. For this project's purposes, "stakeholder" means a person or thing that has something to gain or lose (a "stake") in the performance of a subject system. For these purposes, this stakeholder need not be a human or even an organization of humans, for this model to work in domains that may not involve humans even indirectly.

System Features. Per Figure 2, Features of a class of systems represent beneficial capabilities of the system in the perspective of its stakeholders, showing what benefits or avoided harms the stakeholders will derive from "normal" members of a class of systems. This establishes the "normal" reference point defining "health" for the system type, against which any System Pathologies that impact on stakeholders may be seen. Also, as the model of what is beneficial to stakeholders, Features provide the measure of progress in Innovation.

Both the Innovated System and the System of Innovation have Features. Since the Innovated Systems may include jellyfish, oil filters, biological ecologies, and industrial manufacturing equipment, one expects the Features of the Innovated Systems will vary dramatically across these different cases. However, the special focus here is with the Systems of Innovation, and even though these also vary greatly from human engineering to biological systems, one expects that their features will be somewhat more related, by innovation. Figure 9 (compressed on paper final page and available from project web site) is a Feature Overview Diagram from the

General System of Innovation Pattern. It expresses a “catalogue” of General Features for Systems of Innovation, from which one may populate a specific type of SOI having some of those features. Different types of SOIs have different configurations of these Features. The Features of Figure 9 are further defined in Appendix 2. The Features in the lower half of Figure 9 illustrate some of the many different variations of specialized System of Innovation Features, while those of the upper half of Figure 9 represent a candidate set of universal abstract SOI Features.

Insights from the SOI Features. The SOI Features remind us of certain insights, including:

1. There are many ways to “observe” (experience) relative performance of systems; e.g.
    - At a test bench for a new design
    - As a scientific experiment
    - In a market study, clinical trial, or focus group
    - In a digital or other type of simulation
    - In a design review, FMEA, or risk analysis
    - As the survival or other performance of a product in a competitive market
    - In random observations while walking down the street
    - As differential biological survival rates and life spans.

2. There are many ways to represent experience captured and accumulated; e.g.
    - As human-built formal information artifacts (models, specifications)
    - As human knowledge, expertise, and intuition known but not formalized
    - As the configuration of a system or population of systems
    - As molecularly encoded genetic material (i.e., DNA)

An initial catalogue of pathologies in systems of innovation

Describing SOI pathologies. Having established the above framework for describing the “normal” capabilities for a given System of Innovation class, the project shifts to describing the System Pathology deviations from that norm. An initial SOI Pathologies catalogue has been constructed, and the building out of this catalogue continues within the SSWG project.

For each named pathology, this project will summarize (1) its behavioural (interactions) description, (2) its impact or potential impact on the SOI, (3) means of detection of the pathology, (4) causes of the pathology, and (5) potential “treatments”. The initial SOI pathologies set is summarized by name in Appendix 3.

Conclusions and future work

1. We have begun the Systems of Innovation (SOI) Logical Architecture Model and Feature Model, including related examples and insights. Next steps here include the Dynamic State (flow) model.
2. We have begun accumulating the catalogue of SOI Pathologies, and this work continues in the related SSWG sub-project, improving understanding of SOI effectiveness. A related workshop is planned for IS2012. This is important for assessing and improving of SOI effectiveness, including preventing or “treating” SOI Pathologies.
3. For human-performed innovation, there are needs to improve historical functional modeling approaches by developing further science and related models. This includes integration of science-based models of system interactions, phenomena, and mechanisms.

Acknowledgments

The authors thank Dr. Len Troncale and anonymous reviewers for their feedback. The authors invite others interested in participating in this project, or otherwise interacting, to contact them.

Appendix 1: Definitions

S* Metamodel Definitions. Table 2 briefly defines the metaclasses shown in Figure 2. For more information on this subject refer to (Schindel 2005a, Schindel 2011).

Table 2: Definitions of Major Metaclasses (of Figure 2)

System	A collection of interacting Components. Components can be Systems.
(Functional) Interaction	An Interaction occurs when Components change each others' States by exchange of Input-Outputs.
Input-Output (IO)	Input-Outputs are energy, force, or mass (or information encoded on them), exchanged between Components during Interactions.
State	States are conditions of Components that determine their behavior in future Interactions.
Interface	Interfaces are associations of Input-Outputs, Systems of Access, and Interactions, associated with Systems, through which the Input-Outputs are said to flow.
System of Access (SOA)	Systems of Access are systems that mediate the Interaction of systems.
(Functional) Role	Roles are the behaviors performed by interacting systems.
Physical Component	Entities defined by their identity, not behavior, which may be assigned Functional Roles.
Stakeholder	People, organizations, or other entities with a stake in the performance of a System.
Feature	System behaviors, named and defined in the conceptual framework and language of Stakeholders, of value to Stakeholders.
Requirement Statement	Requirements Statements (associated with Interaction-Role pairs) describe the behavior of Roles during Interactions, in the form of (parameterized) input-output relationships.

SOI Logical System Definitions. Table 3 briefly defines each of the roles shown in the Logical Architecture Diagram of Figure 5.

Table 3: Definitions of SOI Logical Architecture Systems (of Figure 5)

Innovated System	The system which results from innovation. Also called the "Target System" as it is the target of the innovation process.
Environment of Innovated System	The system in which the Innovated System will reside, containing the actors which will interact with the Innovated System.
System of Innovation	The logical system that performs the innovation process. (Note that some types of Innovated System may contain parts of the System of Innovation, and some types of Environment may contain parts of a System of Innovation. For purposes of this analysis, they have been shown separately.)
Performance Observation / Measurement Process	The system that steers the innovation process based on the performance of Innovated Systems in their environment.
Experience Accumulation Process	The system that guides innovation to improve over history through the accumulation of experience.
Variation Generation Process	The system that generates candidate changes for innovation.
Selection Process	The system that expresses preferences for selection of candidate innovations.
Instantiation Process	The system that creates new instances of Innovated Systems.
Stability / Repair Process	The system that maintains stability of Innovated Systems, by preserving or repairing them.
De-Instantiation Process	The system that causes Innovated System instances to cease to exist.
Innovation Regulation Process	The system of interactions between the subsystems of the innovation process that leads to an organized result.
Target System Stakeholder	The system that establishes an effective fitness landscape for Innovated Systems.
Environmental Actor Functional Role	A logical role of a system in the Environment that interacts with an Innovated System, creating that Environment.

Target System Stakeholder Feature	A behavior of the Innovated System which has a degree of fitness.
Target System Functional Interaction	The Innovated System physically interacts with the Environment, changing their respective states.
Target System Functional Role	During an interaction, the behavior of each of the interacting entities is called its functional role in the interaction, describing its physical input-output behavior.
Target System Behavior Statement	These describe individual input-output behaviors of interacting roles, and may take the form of equations, prose requirement statements, or other representations.
Target System Physical Entity	A physical component or type of physical entity, described by its name, composition, dimension, part number, or other existence, but not behavior.

SOI Feature Definitions. Table 4 briefly defines each of the General Systems of Innovation Features shown in Figure 9.

Table 4: Definitions of SOI Features (of Figure 9)

Overall Innovation Feature	The capability of a System of Innovation to effectively create instances of Innovated Systems that improve stakeholder benefits.
Innovation Process Feature	A capability of a System of Innovation to perform an aspect of the overall innovation process.
Performance Observation & Measurement Feature	The capability of a System of Innovation to effectively observe and measure relative performance of a real or potential Innovated System within an Environment of Innovated System.
Experience Accumulation Feature	The capability of a System of Innovation to accumulate information representing its experience over time with real or potential Innovated Systems in Environments of Innovated Systems.
Variation Generation Feature	The capability of a System of Innovation to generate different configurations of potential Innovated Systems.
Instantiation Feature	The capability of a System of Innovation to generate real instances of Innovated Systems.
Selection Feature	The capability of a System of Innovation to select, from among a set of real or potential Innovated Systems, one or more members.
De-Instantiation Feature	The capability of a System of Innovation to de-instantiate members of a set of real or potential Innovated Systems.
Stability / Repair Feature	The capability of a System of Innovation to resist, prevent, or repair damage to an Innovated System.
Innovation Regulation Feature	The capability of a System of Innovation to carry out internal and external regulatory interactions with Systems of Innovation and their environment.
Infrastructure Feature	The capability of a System of Innovation to provide internal resources or services necessary for its effective performance.

Appendix 2: An Initial System of Innovation Pathologies Set

The catalogue below is a current snapshot of the Systems of Innovation Pathologies being classified in the System Sciences Working Group sub-project. We expect to continue to develop this within the working group during the following year.

Table 5: Pathologies in Systems of Innovation

1) Pathologies of Feedback and Observation	
	a) Distortion
	b) Interruption
	c) Accuracy and Drift
	d) False Lags and Leads
2) Pathologies of Environmental Boundary Dynamics	
	a) Policies of Government
	b) Policies of Industries
	c) Intellectual Property Policies
3) Pathologies of Knowledge Management and Flows	

	a) Lost data and Information
	b) Distortion of Interpretation
	c) Interruption of Interpretation and Flows
	d) Accuracy Drift of Information as Processed
	e) False leads and lags
4) Pathologies of Decision Making and Flows	
	a) Distortion of Reasoning
	b) Prejudice
	c) Distortion of Risk Model
	d) False Lags and Leads
5) Pathologies of Inventing and Innovation Development	
	a) Distortion of Validation and Verification
	b) Poor Modelling Practice
	c) Poor Experimental Practice
	d) Poor Design Practice
	e) Accuracy and Drift

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Biographies

Bruce C. Beihoff is Chief Technologist for SYSDYNETIX a newly formed company aimed at utilizing and extending the use of physics based causal models to invent and perfect solutions for product, infrastructure, enterprise, and governmental systems. Bruce spent 32 years as a development and research engineer/scientist/ director working around the world in a number of leadership positions for global enterprises such as Whirlpool, Rockwell, Eaton, UPS, GE. He has a mechanical engineering degree and MSc(c). from the University of Wisconsin having attended both Milwaukee and Madison campuses. Bruce holds 44 patents with 4 pending and has been awarded engineering and innovation awards by two major corporations and one university. Bruce has participated in the development of two invention and innovation methodologies utilizing systems mapping and simplified modeling.

William D. Schindel is President of ICTT System Sciences, a systems engineering company, and developer of the Systematica™ Methodology for model and pattern-based systems engineering. His 40-year engineering career began in mil/aero systems with IBM Federal Systems, Owego, NY, included service as a faculty member of Rose-Hulman Institute of Technology, and founding of three commercial systems-based enterprises. He has consulted on improvement of engineering processes within automotive, medical/health care, manufacturing, telecommunications, aerospace, and consumer products businesses. Schindel earned the BS and MS in Mathematics, and is an INCOSE CSEP.

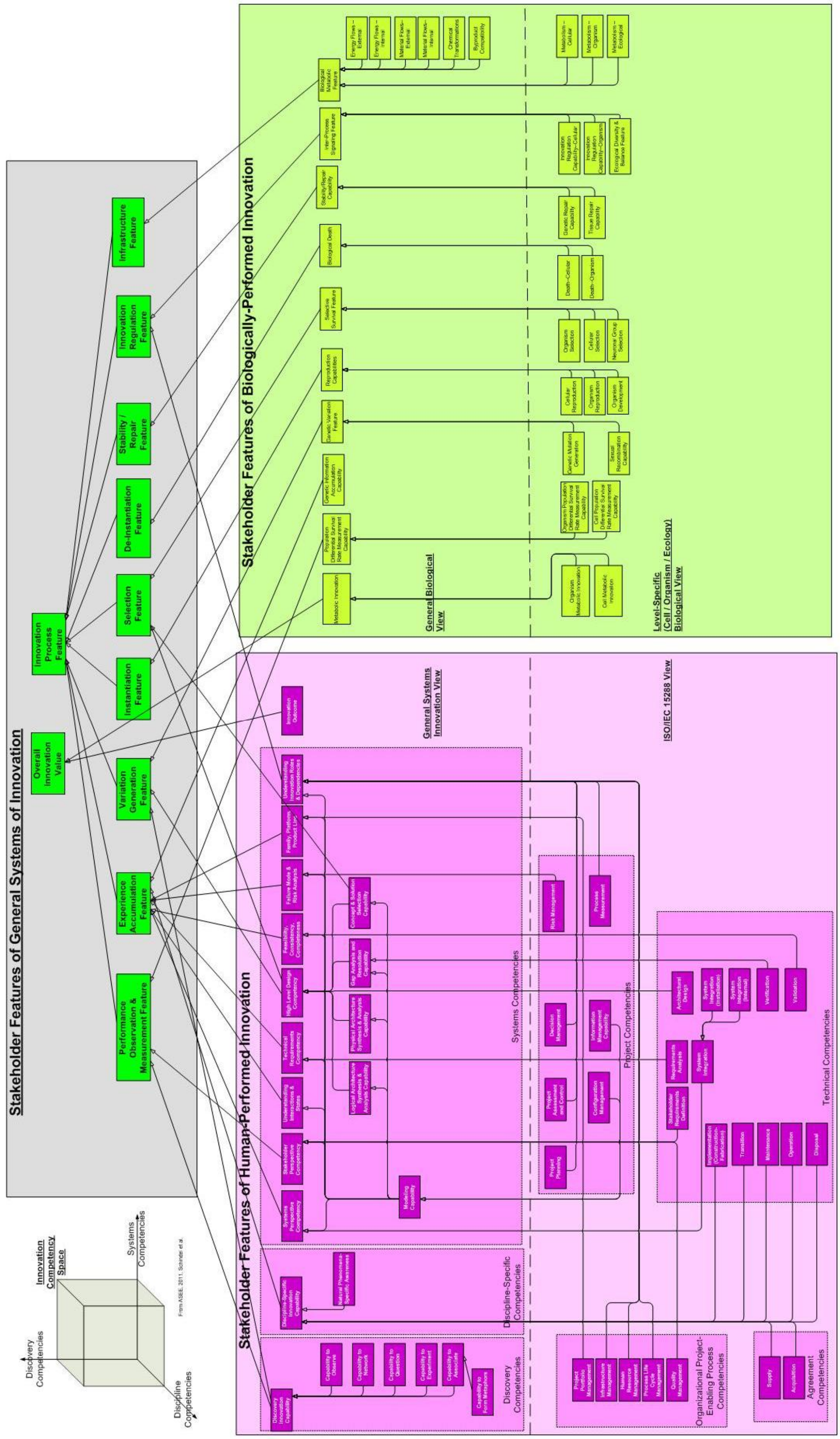

Figure 9: SOI Features, Defined in Table 4; Download from
https://sites.google.com/site/syssciwg/projects/o-systems-of-innovation/SOIFeatureOverviewDiagramV1.1.5.pdf?attredirects=0&d=1