Systems of Innovation II:
The Emergence of Purpose

William D. Schindel

ICTT System Sciences

schindel@ictt.com

Abstract. Engineers design mindful of the purpose of a system. So, engineering conceptual definitions of the concept of "system" frequently include the idea of purpose.

However, we also use "system" to describe things not human-designed. We might refer to purpose in living systems, as in the immune system, but biologists use "function" to avoid this. What about inanimate natural systems? Do Saturn's rings have a purpose, or function? And what about pathologies, when systems don't work as they "should"? Do all these "systems" terms and concepts serve us well across these different domains, or are some force-fit?

Using the language of Model-Based Systems Engineering (MBSE) and Pattern-Based Systems Engineering (PBSE), this paper describes a framework in which "system" and "purpose" emerge at different levels, apply uniformly, naturally, or not at all, and inform. The framework is the Systems of Innovation (SOI) Pattern. Practical benefits include insights into the nature of innovation across these domains, improving ability to perform innovative systems engineering.

Introduction and Background

Systems engineering background. Definitions of the concept of "system" found in systems engineering references frequently refer to purpose or objective as part of the definition of that term. For example (emphases added):

Table 1: Reference Definitions of "System"

Reference	Definition of "System"
ISO/IEC 15288-2008	" . . . combination of interacting elements organized to achieve one or more stated *purposes*"
NASA Systems Engineering Handbook	"A system is a set of interrelated components which interact with one another in an organized fashion toward a common *purpose*."
INCOSE Systems Engineering Handbook	"A system can be broadly defined as an integrated set of elements that accomplish a defined *objective*."

We will argue here that such traditional engineering definitions of "system" may obscure an important perspective, diminishing the ability of human innovators. The organization of that argument and this paper begins with observations about varied perspectives of scientists and engineers, a paring down of the number of elementary concepts, rebuilding larger frameworks from those concepts, a system model of innovation in larger contexts, the emergence of purpose in that framework, and implications for improved innovation competency.

Different fields, different views. Biology has a long history and literature (Gould, 1971, 1997, 2002; Keller, 2003; Lander, 2004) about the exclusion of purpose, teleology, finality, and similar ideas from the evolutionary framework. A representative statement of position is:

- "Function is not the same as purpose in the teleological sense. Evolution is a blind process which has no 'goal' for the future." (Wikipedia 2012)

For a differing opinion about use of this terminology from a leading scholar of evolutionary biology, see (Gould, 1971, p. 258 footnote).

The systems community is not isolated from the sciences. Systems biology (Alon, 2007) illustrates the importance of being able to apply systems concepts to scientific study of the living world. Likewise, physicists consider systemic ideas such as selection to explain the development and structure of the physical cosmos (Smolin, 1997; Smart, 2009).

The arguments of this paper do not take issue with how biology describes natural selection, but rather with how engineers and others describe human-performed design, as well as the larger human-performed innovation process in which design is embedded.

Related perspectives have been heard within the INCOSE System Science Working Group (SSWG), from the engineers and biologists working together on a series of joint projects. (Troncale, Beihoff, and Schindel, 2011; Beihoff and Schindel, 2012; Troncale, 2011; INCOSE SSWG SOI web site) These differences might be viewed as incompatible perspectives or (within each domain) as settled business that offers scant practical value for reconsideration.

We argue that the two viewpoints can be integrated (not made identical) in a way that is not only philosophically sound, but also empowers human innovators, increasing their capabilities.

Minimization of concepts. Science, and particularly the organizing structures of mathematics, organizes our understanding to show all the consequences arising from a conceptual structure before more is added to it. For example, in mathematics, Groups are studied to understand all the properties native to Groups before adding more structure to create a Ring, having additional properties. Similarly, in science fundamental particles are studied to understand all the properties native to them, before building up and studying the properties of atoms, the elements, and chemistry.

By "before" here, we don't mean that the smaller structure is literally studied before the more complete structure is studied, but rather that we organize our knowledge (models, actually) hierarchically, so that these ideas and consequences can be better understood.

A similarly hierarchical approach is described in this paper. We will first describe "system" without reference to purpose, later adding purpose as an emergent aspect. As in the case of group theory and particle physics, hierarchy has important practical consequences.

Elementary Systems

In this paper, we will use the following.

- Definition: A <u>system</u> is a set of interacting components. (Refer to Figure 1.)

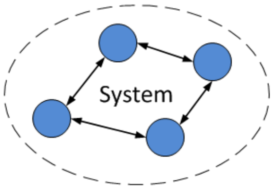


Figure 1: A System is a Set of Interacting Components

(If the omission of "purpose" from the above definition of "system" leads to confusion for those accustomed to the traditional engineering definition, we suggest substituting the term "Elementary System" in the above definition, in recognition that it is focused solely on physical interaction, without reference to purpose. The emphasis here is the concept, not the word chosen as its label.)

In the above definition:

- By "interact", we mean one component changes the state of another, through the exchange of energy, force, mass, or information. (The fourth of these is really a case of the first three.)
- By "state" of a component, we mean a property of the component in time that influences its behavior in future interactions.
- In circular fashion, the behavior of an interacting component depends upon its state, and the evolution of the state of a component depends upon its interactions.

The above perspective could be called closer to the perspective of physics than to the perspective of traditional systems engineering. However, the rise of Model-Based Systems Engineering (MBSE) offers to integrate these worlds (Schindel, 2005a).

Even though the above definition of "system" removes certain ideas (i.e., purpose), it retains what we consider a more fundamental idea and fact about the world: The behavior of a system as a whole arises from the physical interactions of its components with each other. This remaining idea is no small thing: Virtually all the laws of physics are stated in the language or framework of these interactions. Also, some of the most profoundly difficult engineering challenges (and opportunities) of systems are associated with the holistic behavior that arises out of these interactions. So, this simplified definition still leaves us with a lot to study.

More significantly, we will argue below that purpose arises out of this simple definition, at another level of description, solely as a consequence of the properties of certain properly arranged (elementary) systems, without adding any more underlying concepts.

The above definition of System also makes physical interaction a more central idea than some traditional systems engineering perspectives. For example, Figure 2 contrasts two different starting points for thinking about systems (Schindel, 2011a). The perspective of this paper will be that of Figure 2(a):

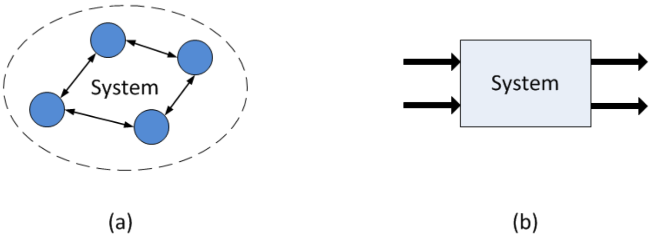


Figure 2: Different Starting Points for Thinking about Systems

The S* Metamodel. The Pattern-Based Systems Engineering (PBSE) approach used here is based upon the S*Metamodel shown in Figure 3 (Schindel 2005a, b, 2011a, 2012a). In this approach:

- An S*Model is a model of a system based on the S*Metamodel
- An S*Pattern is a re-usable, configurable S*Model for families of systems

Figure 2(a) begins to model interaction in the space of a physical system. The S*Metamodel helps us to understand in greater depth the information that we will use in these models:

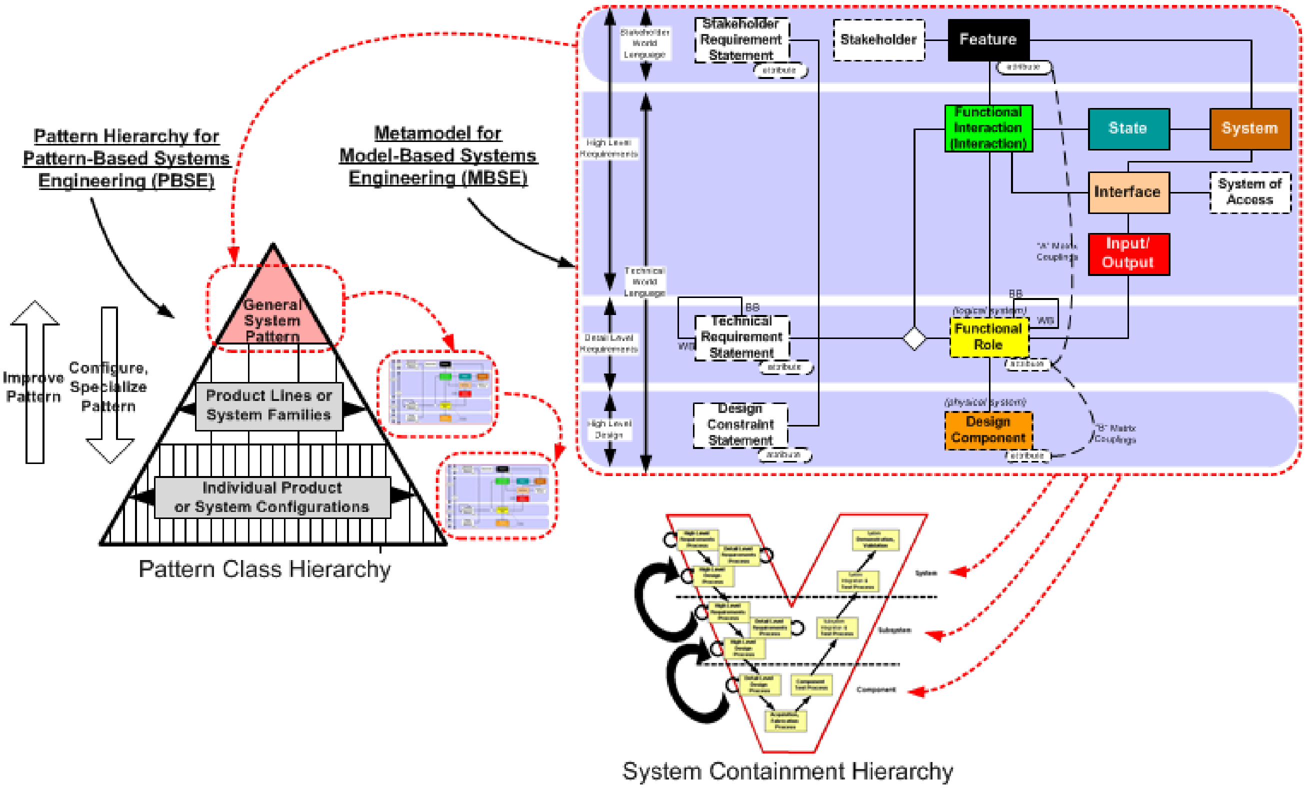


Figure 3: The S* Metamodel

Further described in (Schindel 2005a, b, 2011a, b, Schindel and Peterson, 2012, 2013), some of the concepts the S*Metamodel defines relationally include:

- Functional Interaction (Interaction): An exchange of energy, force, mass, or information by two entities, in which one changes the state of the other. Examples: Refuel Vehicle; Travel Over Terrain; Cook Food; Devour Prey
- Functional Role (Role): The behavior performed by one of the interacting entities during an Interaction. Example: Vehicle Operator; Vehicle Passenger Environment Subsystem; Scene Recognition Subsystem; Digestion Subsystem
- Input-Output: That which is exchanged during an interaction (generally associated with energy, force, mass, or information). Example: Fuel, Propulsion Force, Exhaust Gas, Visual Signal
- Design Component: A physical entity that has identity, whose behavior is described by Functional Role(s) allocated to it. Examples: Acme Model 332 GPS Receiver; Klondike Model 155 Tire, Carbohydrate

Equally important in the S*Metamodel are the relationships, shown as connection lines in Figure 3. The "smallest model" of a system is seen through a set of information instances (whether rendered as SysML diagrams, documents, or other artifacts) that are populations of the classes and relationships summarized in Figure 3 (Schindel, 2011a). The Systems of Innovation perspective describes combinatorial populations (specialized) of these classes and relationships, whether as physical instances or information constructs.

The Systems of Innovation (SOI) Pattern

Is there a conceptual framework and terminology for systems that applies uniformly well across the domains of the systems engineer, systems biologist, particle physicist, and astronomer? In particular, can we understand the ideas of systems and purpose in an integrated way that adds insight and capability to our work as human innovators, embedded in a combined world of commercial products and markets, biological systems, and the natural sciences?

The Systems of Innovation (SOI) Project of the INCOSE Systems Science Working Group (SSWG) was summarized in (Beihoff and Schindel, 2012). This project is generating a generic, configurable model (an S*Pattern) of Systems of Innovation, that can be specialized one way to represent the SOIs of the natural biological world, and specialized another way to represent human-performed SOIs.

Systems of Innovation, combined with the Target Systems that they innovate, together form complex adaptive systems. Figure 4 illustrates the “folded-up” abstract SOI Logical Architecture, the definitions of which are found in (Beihoff and Schindel, 2012). Figure 4 includes functional relationships: the network of influences across the extended system.

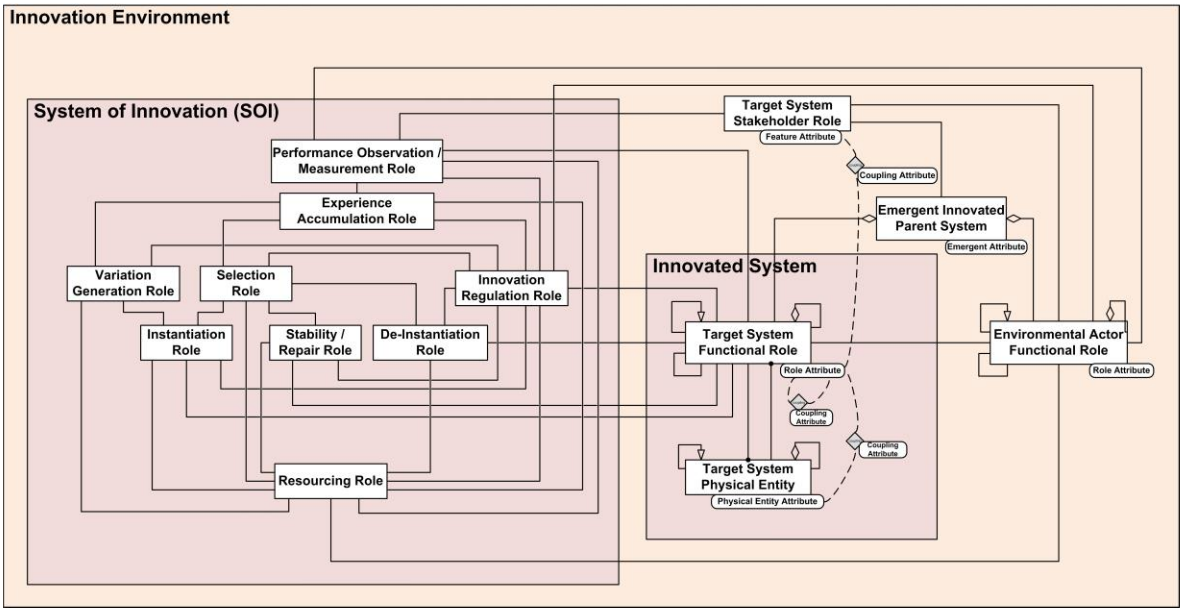


Figure 4: The SOI Logical Architecture

Human-performed innovation frequently (but not always) includes representations of systems, as in the tangible sketches, blueprints, or models of the engineer, or the less tangible mental images, ideas, or conversations of human innovators. All these are information-bearing constructs. In evolutionary biology, genetic information is encoded in DNA. Without equating these very different representations of very different things, we know that models of innovation need to include the ideas of such representations (information). We are also interested in innovation in which no such separate representations are immediately apparent. Examples include informal evolution of buildings after construction, as in (Brand 1994).

Many of the ideas of the Figure 4 SOI model apply not just to the physical systems (designed products, biological organisms, etc.) (Carroll, 2005; French, 1988; Thompson, 1917), but also to information representations (ideas, models, genomes) “about” those systems. For example, selection can apply to models (Goldberg, 1989; 2002), variation can apply to genomes or blueprints, with the abstract logical architecture of Figure 4 “unfolded” in different physical instantiations. Figure 5 summarizes some illustrative signaling paths in innovation.

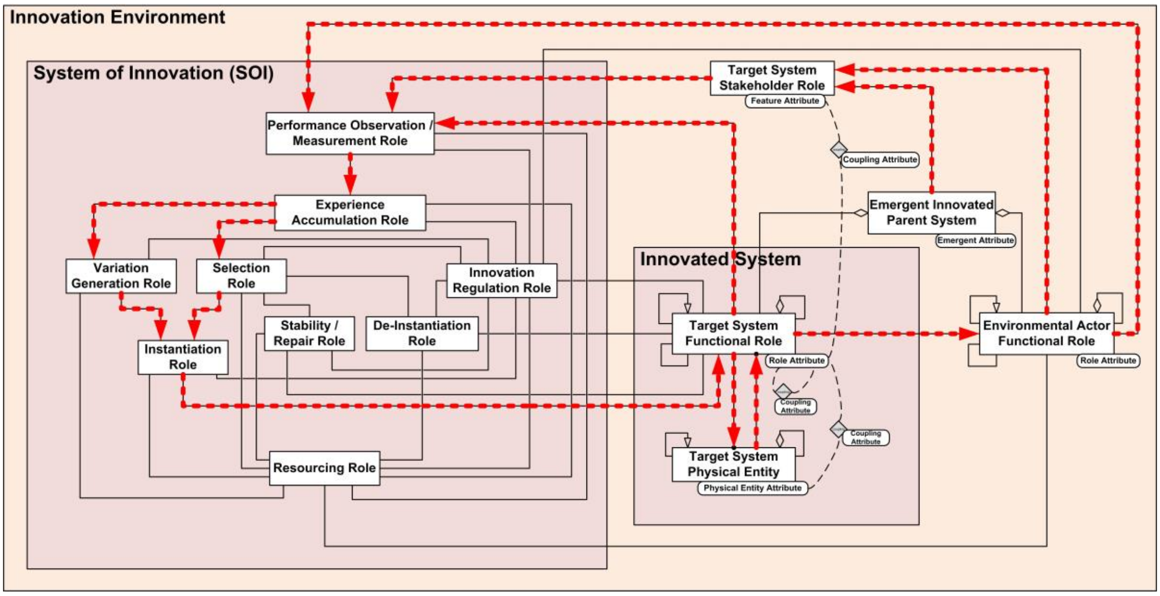


Figure 5: Illustrative Innovation Signaling Pathways and Loops

The Emergence of Purpose

When engineers think of purpose in systems, they may have in mind ideas such as:

1. What the engineer designs a system of interest to do;
2. What designers intend a sub-system or component to do;
3. What stakeholders want a larger system-of-systems to accomplish;
4. What the customer buys or selects the system to do.

Reference to a typical description of a systems engineering process (ISO, 2008; Haskins, 2010) tells us all these are important, but leave the clear impression that some come "before" others, when performing a sequential engineering process. While traditional SE process descriptions emphasize the iterative nature of architectural design and "later" steps, the identification of stakeholders, their needs, the system environment, and system requirements are treated as important information that needs to be discovered as early as possible, and they are portrayed as information we hope to have to revise as little as possible "downstream". Indeed, some of the key value paradigms of systems engineering are avoiding larger downstream costs caused by "late" discoveries. Valid and important within a certain context, these viewpoints can nevertheless limit the innovator's or systems engineer's perspective to only a subset of the total innovation cycle. This can limit the range of innovations that emerge.

Figure 6 reminds us that it is not just architectural solutions that are synthesized through iteration. Stakeholders, needs, and purpose are likewise subject to iterative synthesis. The use of loops in both cases reminds us that neither architectural solutions nor stakeholder problems are arrived at by linear deductive processes alone. The discovery process culminating in selection applies to all of them.

Engineers may react to this perspective by objecting that their role is to design solutions to problems, and that it is the job of someone else to decide what problem the world (or the customer) needs to have solved. While this objection may carry some weight for the discipline-specific engineer, we argue that the responsibilities of the systems engineer (and especially the innovator), include linking to and representing the stakeholders. So, who better than the systems engineer to identify (populate, synthesize) the stakeholder model, along with the purposes for which they will select systems?

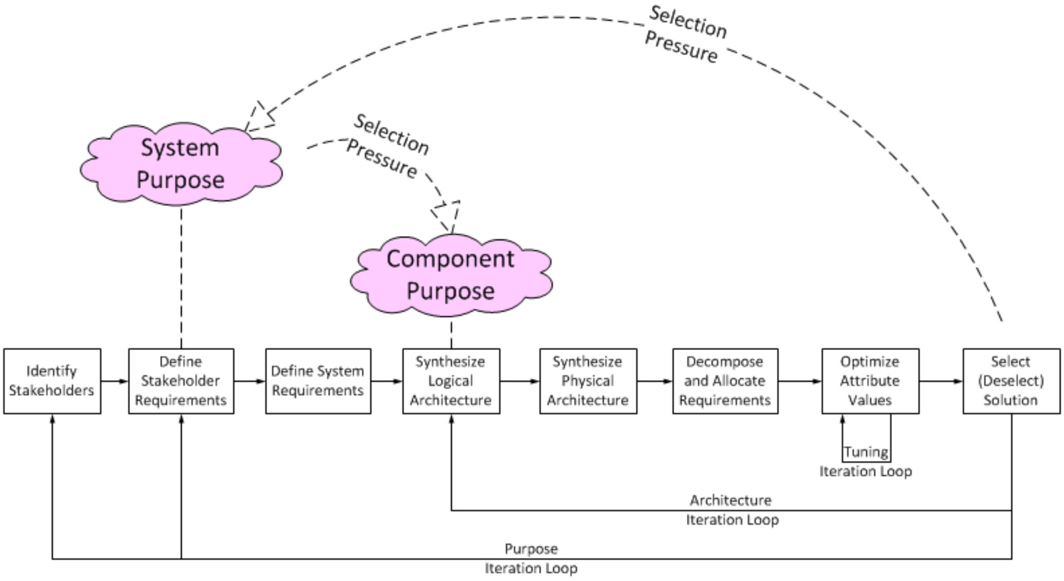


Figure 6: The Purpose Iteration Loop

An implication of this perspective is that the purpose of a system might seem more "adrift". What is the purpose of a future system we are to design, if it is not already identified as a "given", and part of the definition of that system? In this work, we use a broader definition of the purpose of a system:

- Definition: The purpose of a system is the functional role for which the system is selected, or the role it performs within a (larger) selected system.

(The selection referred to in this definition is that which is performed by the Selection Role of Figures 4 and 5.) Similar definitions in this form can also be used for purposes of components, behaviours, interfaces, or other aspects of a system.

Note that this definition does not appear to require that purpose be fully determined before a system is synthesized. Figure 6 and the above definition of purpose are intended to keep some of the focus of the human innovation cycle on synthesis of more than just the solution to a fixed problem—it includes the synthesis (and re-synthesis) of the continuing (re)definition of the problem to be solved that would result in a selection. It means the entire innovation cycle involves synthesis (evaluated by analysis)—that synthesis is not limited to only the later design stages. It means there is no single "starting point" in this cycle: we can start with a physical phenomenon and go looking for applications and stakeholders. Or, we can start by identifying classes of future stakeholders (those with capital to expend, those who are underserved, etc.), then seek out their values, system behaviours, technologies, etc.

This definition can also help unify or integrate our understanding of (1) human-performed innovation and (2) innovation as it occurs in nature without human involvement (Gould 2002).

The resulting view is that purpose emerges as a systemic property of the entire cycle. Individual designers may perceive purpose as relatively fixed if they join the innovation cycle late in its unfolding, or view it as "not my job", but this view misses the true origin of purpose, and potential innovations.

Consider following examples (one humorous but real, the others having innovation impact measured in billions of dollars) of human-performed innovations that were purpose-seeking—their innovations included (eventual) "discovery" of purpose:

1. A purpose for rubber mats: (Rogow, 2011) provides a humorous news story 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. This illustrates a human-performed equivalent of biological "exaptation" of (Gould and Vrba 1982)
2. A purpose for web search: Search engines first appeared on the Internet at least as early as 1993 (Search Engine History 2012), for the purpose of finding information. It was not until 2002 that search-based advertising as the primary revenue stream of the search business appeared as (Google 2012). Web search thus illustrates an innovation in which its primary economic "purpose" (measured in billions of dollars per year) did not emerge for about ten years. The system paradigm morphed from the user finding information into the information finding its user, pulling billions in additional revenues into the picture.
3. A purpose for weak adhesive: The story of the 3-M Post It™ Notes is chronicled by (Petroski, 1993). An "inadequate" adhesive was used to create a new medium in which notes can be temporarily and reversibly attached to sheet music, books, papers, refrigerators, walls, or other surfaces. In this case, a system component (the adhesive) enabled a purpose for a new system (the Notes system).
4. A purpose for material failure: Screw caps on beverage bottles, squeeze tubes, and other containers exploit plastic structures weak enough to fracture when twisted, providing a purpose for mechanical fracture. In this case, selection pressure sought out a new purpose for a material—to fracture at a given stress level.

The above formal definition of "purpose" has two parts. The second part of the definition allows that not all purpose is directly selected purpose. This essential point was emphasized by (Gould and Leontin, 1979) and (Darwin, 1859).

What about a system environment in which no selection is evident? The above definition does not say that all purposes are selected, or even that all purposes can at least be associated with components of selected systems. The definition is silent on the case of systems (or components) in which there is no evident selection process involved. However, it begs the question, "If there is no selection evident, what would purpose mean?"

Primary Purpose Roles, Roles for "-ilities", and Component Roles. Even at the top-most black box system level, required system behaviour is sometimes divided by systems engineers into "primary purpose" requirements versus "-ilities". For example, a vehicle may have a primary purpose of providing transportation for people or materiel, but the vehicle must also satisfy maintainability requirements. The roles for which the vehicle is selected will certainly include providing transportation, but will also include the role of being maintained. The decomposed vehicle may even include parts whose sole purpose is maintainability—as in a grease gun lubrication fitting.

Emergence of Technologies. Just as a purpose can emerge from a System of Innovation, so can a technology:

- Definition: A <u>technology</u> is the (Figure 3) combination of a Functional Role that expresses a purposeful behaviour (in the sense of the definition of Purpose), and a Design Component, the physical entity capable of performing that behaviour.

The innovation loop, whether human-performed or biologically-performed, seeks out and discovers purposes and the technologies capable of accomplishing them. (Arthur, 2009; Basalla, 1988; Reinganum, 1981; Rogers, 2003)

Emergence of Pathologies. The Systems of Innovation Project arose out of the Systems Pathologies project started by Dr. Len Troncale, involving the INCOSE Systems Science Working Group (Troncale, 2011). The systems pathologies definition approach taken in the SOI project is found in (Beihoff and Schindel, 2012), where a system pathology was defined 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".

The current paper allows us to improve upon this definition, by bringing purpose into the picture:

- Definition: A <u>system pathology</u> is any failure of a system, or system component, to perform its purpose in a manner typical of others of the same type in like circumstances. (Refer to definition of "purpose" provided earlier above.)

Summary. Figure 7 graphically summarizes the main point of this section: the emergence (Kauffmann, 1993) of higher conceptual behavior and its models (i.e., purpose in the presence of selection and variation), arising out of lower level conceptual behavior and its models (i.e., elementary systems). (The upper level of Figure 7 is closed under efficient causation, per (Rosen, 1991; Kineman, 2011).)

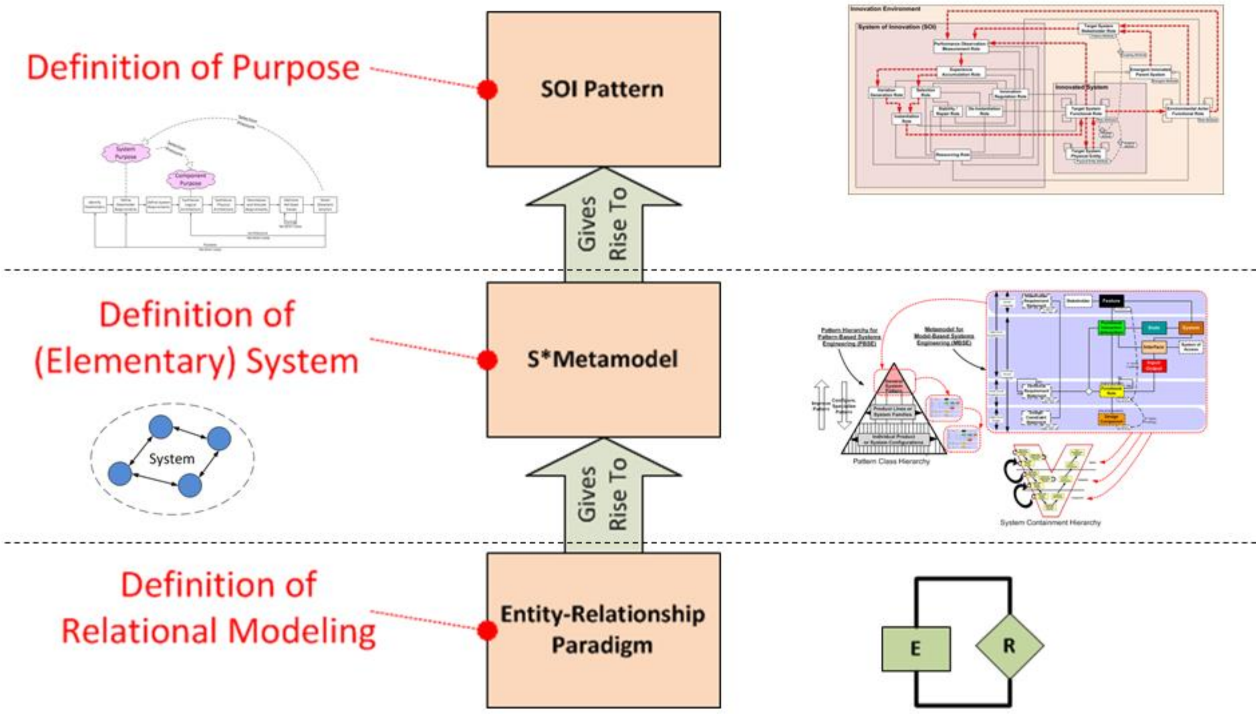


Figure 7: Conceptual Hierarchy

Accumulation, Representation of Discovery Experience (Learning)

Patterns, Accumulation and Representation of Experience. "Discovery" of purpose, or other emergent aspects, is less valuable if we don't remember what we've discovered, and later have to re-discover it the hard way. Discovery without learning is sub-optimal.

Accordingly, the Systems of Innovation model of Figure 4 includes Experience Accumulation as one of the vital roles of innovation. Ironically, the "change" (Variation) aspect of innovation cannot be effective if the "stability" (Experience Accumulation) aspect is absent.

Pattern-Based Systems Engineering (PBSE) is an extension of Model-Based Systems Engineering (MBSE), and is concerned with representing re-usable, configurable descriptions of systems, for use across families, product lines, platforms or other similar but not identical systems (Schindel and Smith, 2002; Schindel, 2005b, 2011a, 2011b, 2011c, 2012; Schindel and Peterson, 2012, 2013; Meyer and Lehnerd, 1997). The work described by this paper uses S*Patterns, which are re-usable, configurable S*Models. Refer to Figure 3. Figure 8 adds the roles of an innovation system with memory, to accumulate pattern learning:

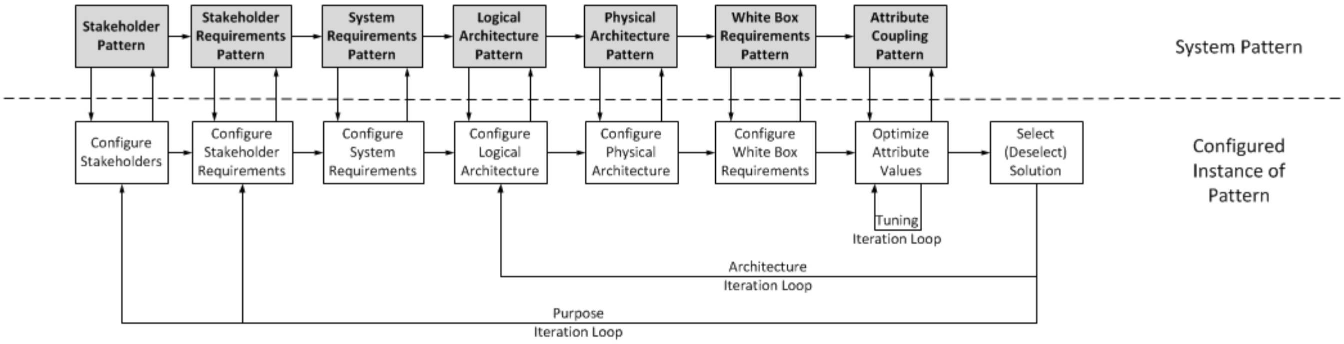


Figure 8: Adding Pattern Memory to the Purpose Iteration Loop

A key element of the emergence captured by system patterns is the emergence of standard modules, components, or sub-systems. The selection pressure illustrated by Figure 6 creates learned portions of the pattern which can be used multiple times. PBSE encourages the development of <u>portfolios</u> (Schindel, 2012c), containing "islands of learning" that can be connected together over time. Figure 9 illustrates a model of the related portfolio databases.

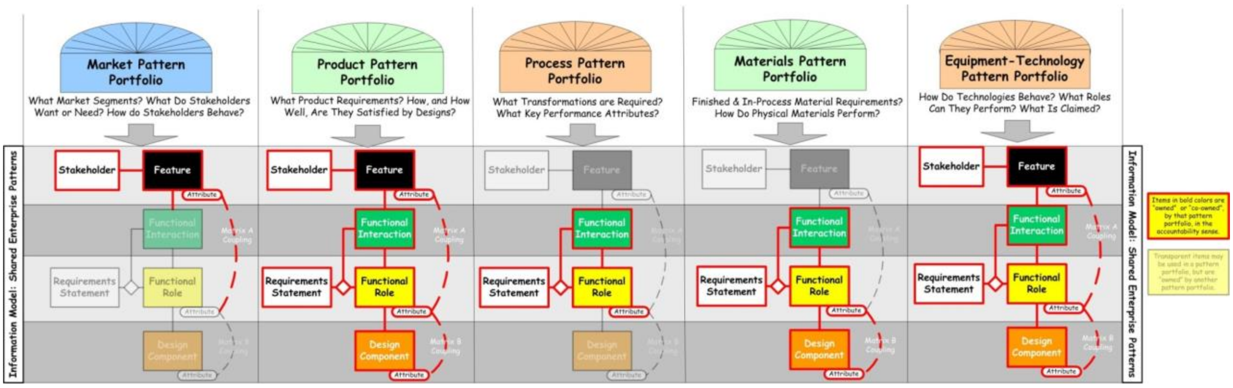
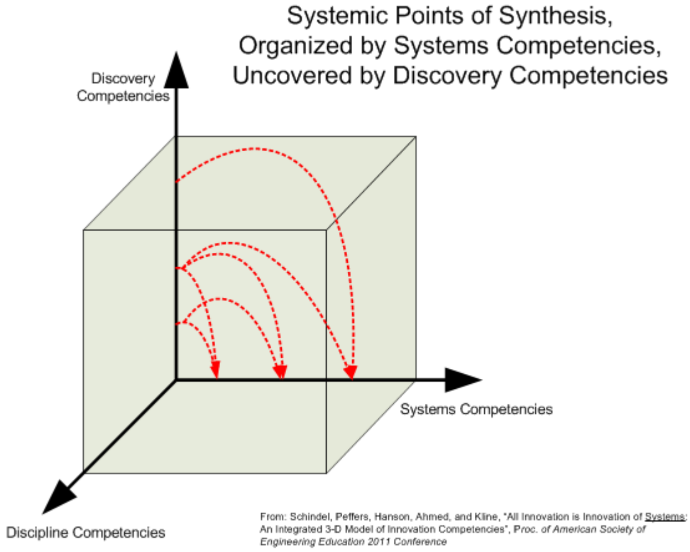


Figure 9: Conceptual Data Model of Multiple Domain Portfolios

Improving Innovation Competencies

Human competency in innovation is vital to well-being (Lechleiter, 2010). This paper argues that for many major innovations, system purpose must be discovered over time, not just negotiated at the beginning of a project in the traditional way. This requires competencies for the innovative systems engineer that go beyond the minimum set of traditional systems engineering competencies.

Figure 10 illustrates a 3-D framework of Innovation Competencies that includes not only Discipline Competencies and Systems Competencies, but additionally the Discovery Competencies (Dyer, Gregersen, Christensen, 2009; Schindel, Ahmed, Kline, Peffers, Hansen, 2011). These Discovery Competencies include experimentation, keen observational skills, asking questions, and seeking the widest view of the environment.



From: Schindel, Peffers, Hanson, Ahmed, and Kline, "All Innovation is Innovation of Systems: An Integrated 3-D Model of Innovation Competencies", *Proc. of American Society of Engineering Education 2011 Conference*

Figure 10: An Innovation Competencies Framework

The Systems Competencies, strongly based on model-based organization of systems information, helps to organize both the questions (holes) and answers (insertions) of the Discovery Competencies in the same framework. By using the S*Metamodel, the Systems Competencies inform us of all the conceptual components we should be prepared to question, discover, populate, vary, and select. The Discovery Competencies (Dyer, et al 2009) provide us with the tools to perform that discovery. Together, they reinforce each other. A portfolio database organized as suggested by Figure 9 provides for the accumulation of "learning islands" that can progressively be connected in a combinatorial fashion and enable more effective innovation.

Accordingly, methods such as (IDEO, 2011; Kelley, 2011, 2005) advocate "Learn, Look, Ask, and Try", in a discovery-oriented fashion. All this suggests a richer context for innovative systems engineering.

Insights and Implications

1. The foundation concept of Elementary System can be defined without reference to the concept of purpose, while still retaining for study some of the most fundamentally important systems properties that create challenges and opportunities for engineers and scientists.

2. Purpose of an elementary system can thereafter be defined from concepts emerging in a larger elementary system (the System of Innovation), including both cases of selection-driven adaptation as well as other forms of adaptation.

3. A more pervasive than traditional view of the idea of selection in both human-designed and other systems can be used to improve our understanding of design as exploration, supported by discovery and selection.

4. This perspective can be used to expand the tasks and competencies of the human designer, to include an integrated family of Innovation Competencies, of which the Systems Competencies traditionally emphasized for systems engineers are an important but incomplete subset, and the Discovery Competencies should also be integrated.

5. Innovation, seen in the large, does not proceed linearly from stakeholder needs to solutions, nor is solution synthesis the only iterative aspect. Innovators should be equally prepared to synthesize or target new stakeholders, who may not know they are stakeholders; synthesize needs that may not yet be known to stakeholders; synthesize environmental actors and new interactions with them, with new synthesized system roles, and requirements; as well as the more traditional synthesis of logical architectures and the physical technologies to which they are allocated. There are different techniques and tools for these activities.

6. The specific role in innovation of accumulated experience is under-represented in traditional systems engineering process descriptions. Informed by nature, the explicit use of system patterns across the whole innovation domain improves its effectiveness, whether as the discovered patterns of science or the applications of Pattern-Based Systems Engineering.

7. Among the system patterns to be understood is the very pattern of innovation itself (the Systems of Innovation Pattern), in which purpose arises, facilitating the study of innovation and its effectiveness.

8. Pathology, like purpose, does not appear in the underlying definition of Elementary System, but arises within classes of similar systems, in the same framework. Both purpose and pathology gain their meaning and significance in the larger System of Innovation in which they emerge.

References

Alon, U. 2007. *An Introduction to Systems Biology: Design Principles of Biological Circuits*, Chapman & Hall/CRC.

Arthur, B. 2009. *The Nature of Technology: What It Is and Why It Evolves*, Free Press.

Rogers, E. 2003. *The Diffusion of Innovations*. Free Press.

Basalla, G. 1988. *The Evolution of Technology*, Cambridge U. Press.

Beihoff, B., and Schindel, W. 2011. “Systems of Innovation I: Summary Models of SOI Health and Pathologies”, Paper presented at the INCOSE International Symposium, July.

Brand, S. 1994. *How Buildings Learn: What Happens After They’re Built*, Viking.

Carroll, S. 2005. *Endless Forms Most Beautiful: The New Science of Evo Devo*. New York: Norton.

Darwin, C. 1859. *On the Origin of the Species By Means of Natural Selection*. London: John Murray.

Dyer, J., Gregersen, H., Christensen, C. 2009. “The Innovator’s DNA.” *Harvard Business Review*, December.

French, M. 1988. *Invention and Evolution: Design in Nature and Engineering*, Cambridge U. Press.

Goldberg, D. 2002. *The Design of Innovation*, Boston: Kluwer.

Goldberg, D. 1989. *Genetic Algorithms In Search, Optimization, and Machine Learning*, Addison-Wesley.

Google. 2012. “Our History In Detail”. Last accessed 08 November. www.google.com/about/company/history

Gould, S. 1971. “D’Arcy Thompson and the Science of Form”, in *Form and Its Alternatives* in *New Literary History*, Vol. 2, No. 2, pp. 229-258.

-----. 1997. "The exaptive excellence of spandrels as a term and prototype" *Proceedings of the National Academy of Sciences USA*. 94: 10750-10755.

-----. 2002. *The Structure of Evolutionary Theory*. Cambridge, Mass: Belknap Press of Harvard University Press.

Gould, S. and Lewontin, R. 1979. "The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptationist Programme". *Proc. Roy. Soc. London* B 205. pp. 581-598.

Gould, S.J., and Vrba, E. 1982. “Exaptation: A Missing Term In The Science of Form”, *Paleobiology*, 8(1):4-15

Haskins, C., ed. 2010. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*. Version 3.2. Revised by M. Krueger, D. Walden, and R. D. Hamelin. San Diego, CA (US): INCOSE.

History of Web Advertising. 2012. “The History of Web Advertising”. Last accessed 08 November. www.ehow.com/about_5290228_history_advertising.html

IDEO. 2003. “IDEO Method Cards”, William Stout Architectural Books, ISBN 10 0954413210.

INCOSE SSWG. 2012. “Systems of Innovation Web Site of the INCOSE System Sciences Working Group (SSWG) Web Site”. Last accessed 8 November. https://sites.google.com/site/syssciwg/projects/o-systems-of-innovation

ISO and IEC (International Organization for Standardisation and International Electrotechnical Commission). 2008. ISO/IEC 15288: *Systems and software engineering —System life cycle processes*.

Kauffman, S. 1993. *The Origins of Order: Self-Organization and Selection in Evolution*, New York: Oxford U. Press.

Keller, E. 2003. *Making Sense of Life: Explaining Biological Development with Models, Metaphors, and Machines*, Harvard U. Press.

Kelley, T. 2001. *The Art of Innovation*. New York: Doubleday.

Kelley, T. 2005. *The Ten Faces of Innovation*, New York: Doubleday.

Kineman, J. 2011. “Relational Science: A Synthesis”, *Axiomathes*, DOI: 0.1007/s10516-011-9154-z.

Lander, A. 2004. “A Calculus of Purpose”, *PLoS Biology*, Vol 2, Issue 6, June pp. 712-714.

Lechleiter, J. 2010. “America’s Growing Innovation Gap”. *The Wall Street Journal*, Opinions. July 9.

Meyer, M., and Lehnerd, A. 1997. *The Power of Product Platforms*, New York: The Free Press.

NASA (National Aeronautics and Space Administration). 2007. *NASA Systems Engineering Handbook*. NASA/SP-2007-6105

Petroski, H. 1993. *The Evolution of Useful Things*, Knopf.

Reinganum, J. 1981. “On the Diffusion of New Technology: A Game Theoretic Approach”, in *Rev. of Economic Studies*, pp. 395-405.

Rogow, G. 2011. “Soft Landing: New Bouncer at Aussie Bars: Rubber Mats”, *The Wall Street Journal*, October 15.

Rosen, R. 1991. *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life*, New York: Columbia U. Press.

Schindel, W. 2005a. “Requirements Statements Are Transfer Functions: An Insight From Model-Based Systems Engineering, *Proceedings of INCOSE 2005 Symposium*.

-----. 2005b. “Pattern-Based Systems Engineering: An Extension of Model-Based SE”, INCOSE IS2005 Tutorial TIES 4.

-----. 2011a. “What Is the Smallest Model of a System? *Proceedings of INCOSE 2011 Symposium*.

-----. 2011b. “Dark Patterns”, *Proc. of the INCOSE 2011 Great Lakes Regional Conference*.

-----. 2012a. “Introduction to Pattern-Based Systems Engineering”, INCOSE Finger Lakes Chapter Webinar.

-----. 2012c. SAMPE Paper, “Integrating Materials, Process & Product Portfolios: Lessons From Pattern-Based Systems Engineering”, Proc. of the Society for the Advancement of Materials and Process Engineering (SAMPE), Baltimore.

Schindel, W., and Peterson, T. 2012. “Pattern-Based Systems Engineering: A Workshop”, *Proc. of the INCOSE 2012 Great Lakes Regional Conference*.

-----. 2013. Tutorial--“Introduction to Pattern-Based Systems Engineering (PBSE): Leveraging MBSE Techniques”, *Proceedings of the INCOSE 2013 Symposium*, June, 2013.

Schindel, W., and Smith, V. 2002. “Results of Applying a Families-of-Systems Approach to Systems Engineering of Product Line Families”, SAE International, Technical Report 2002-01-3086.

Schindel, W., Peffers, S., Hanson, J., Ahmed, J., Kline, W. 2011. “All Innovation Is Innovation of Systems: An Integrated 3-D Model of Innovation Competencies”, *Proceedings of the 2011 Conference of the American Society for Engineering Education (ASEE)*.

Search Engine History. 2012. “Search Engine History”. Last accessed 08 November. www.searchenginehistory.com

Smart, J. 2009. “Evo Devo Universe? A Framework for Speculations on Cosmic Culture”, in *Cosmos and Culture: Cultural Evolution in a Cosmic Context*, Dick and Lupisella, eds., NASA.

Smolin, L. 1997. *The Life of the Cosmos*, Oxford U. Press.

Thompson, D. 1917. *On Growth and Form*. Cambridge U. Press.

Troncale, L. 2011. “Would a Rigorous Knowledge Base in Systems Pathology Add Significantly to the SE Portfolio?” *Proceedings of the 2011 Conference on Systems Engineering Research*.

Troncale, L., Beihoff, B., Schindel, B. 2011. “System Sciences Working Group: Projects Status Report”, INCOSE SSWG.

Wikipedia. 2012. “Function (biology)”. Last accessed 08 November. http://en.wikipedia.org/wiki/Function_(biology)

Biography

William D. (Bill) 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, aerospace, telecommunications, and consumer products businesses. Schindel earned the BS and MS in Mathematics, and is an INCOSE CSEP.

V1.3.6