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Systems of Innovation II: The Emergence of Purpose

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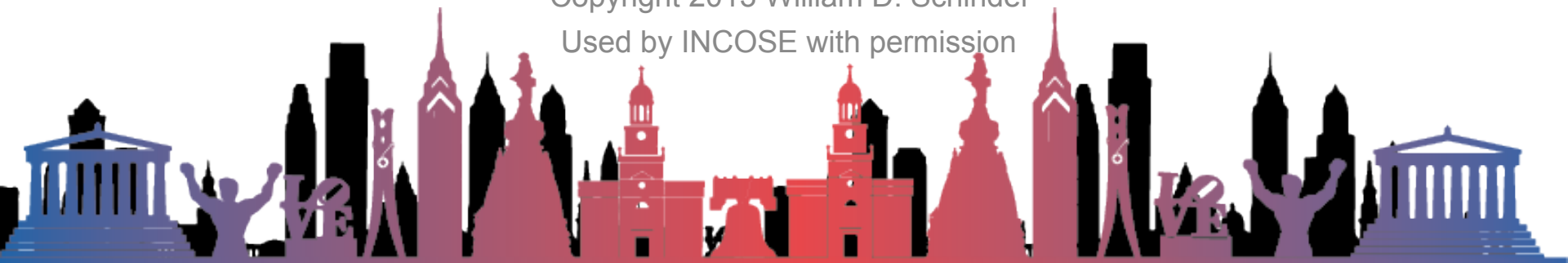


Abstract

- 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 Pattern. Practical benefits include insights into the nature of innovation across these domains, improving ability to perform innovative systems engineering.

Contents

- Introduction
- Elementary Systems
- The Systems of Innovation Pattern
- The Emergence of Purpose
- Accumulation & Representation of Discovery Experience (Learning)
- Improving Innovation Competencies
- Insights and Implications

How did I get trapped in this subject?

What Is A Healthy System?

What Is System Purpose?

What Are System Pathologies?

Improved Innovation Insight

Bill

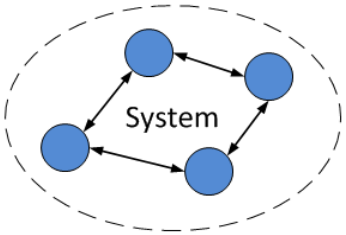
SE Definitions of "System" Frequently Include Purpose

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."

By contrast, Biology has a long history and literature of excluding purpose, teleology, finality, etc. from the evolutionary framework for living systems.

Elementary Systems

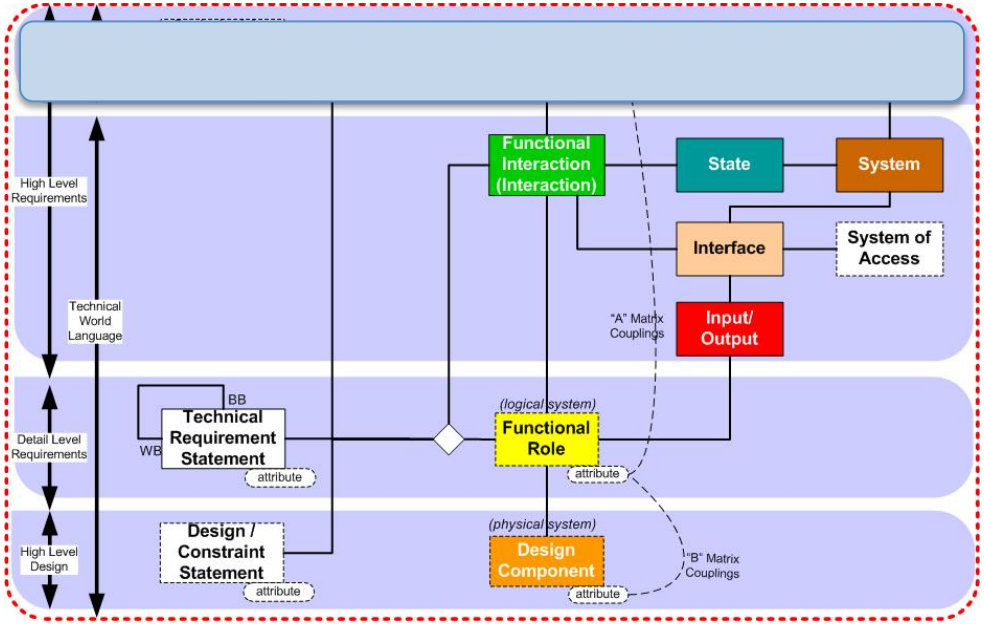
- A different starting point: We'll argue here that innovation competency of engineers is improved by using a different starting point.
  - Definition: A system is a set of interacting components.



- 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.

System Models, Using MBSE

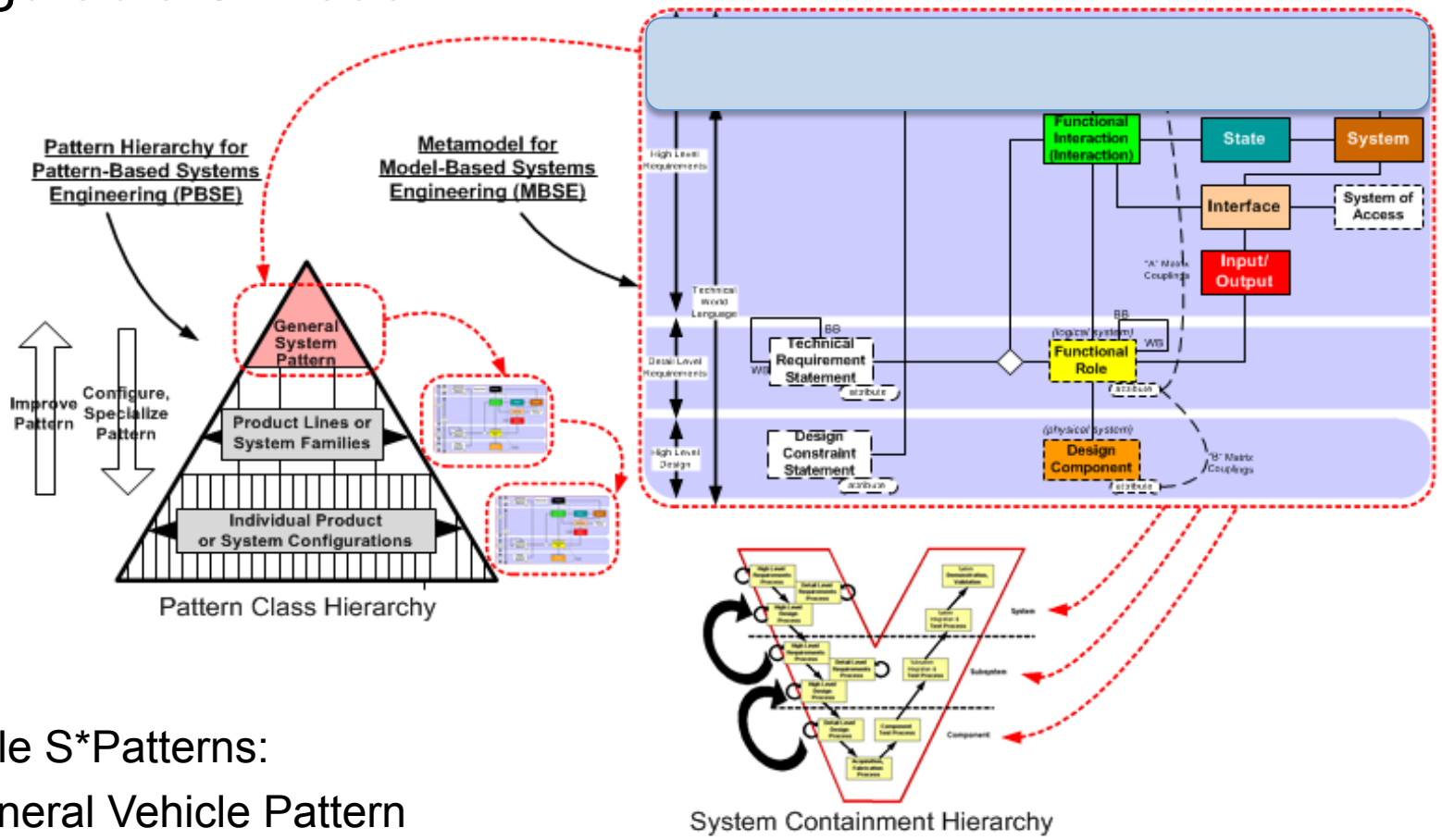
- An S*Model is any MBSE system model consistent with the S*Metamodel:



- Functional Interaction (Interaction): An exchange of energy, force, mass, or information by, in which one entity changes the state of another. 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

System Patterns, Using PBSE

- Describing families of systems, an S*Pattern is a re-usable, configurable S*Model:

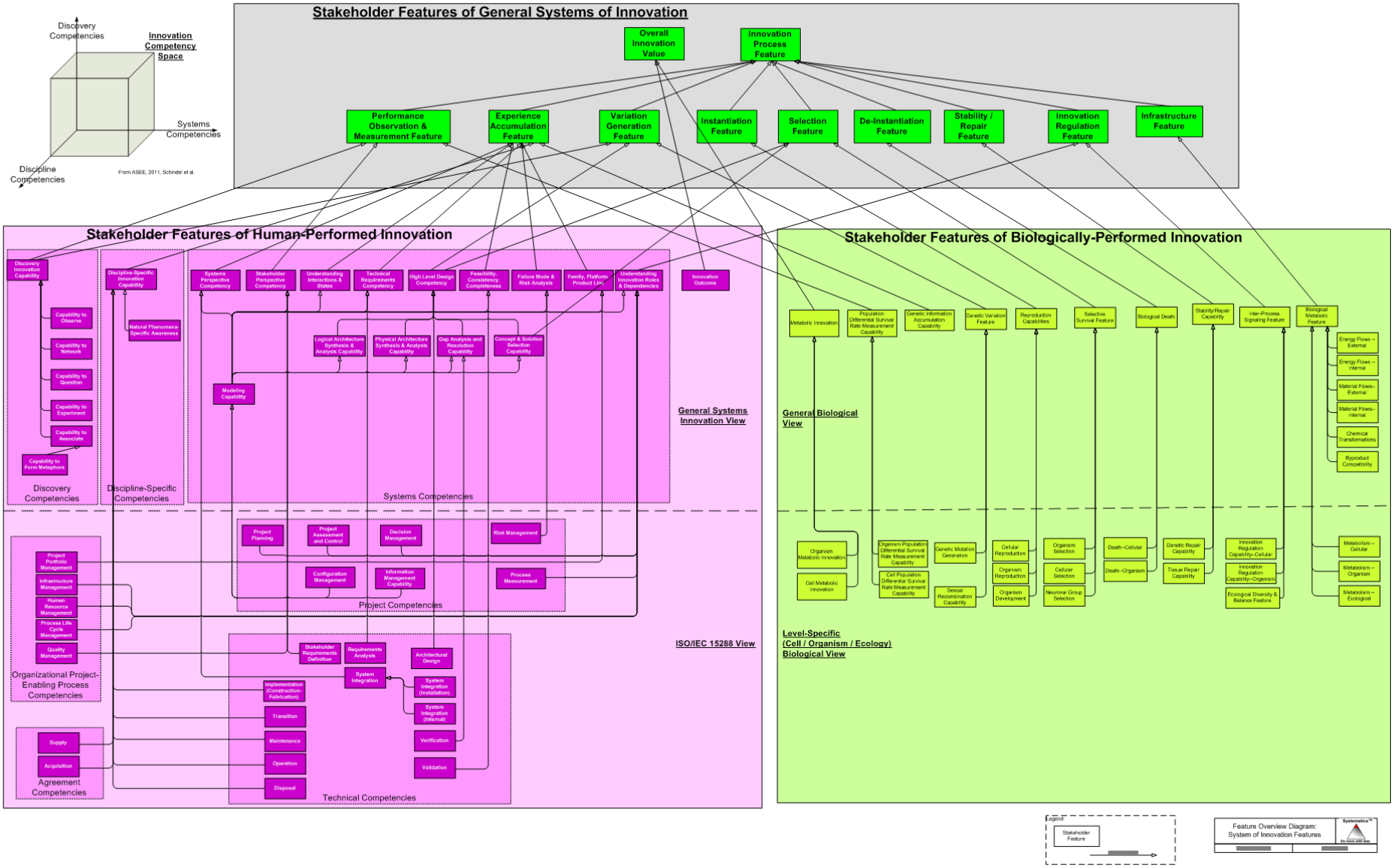


- Example S*Patterns:
  - General Vehicle Pattern
  - General Manufacturing System Pattern
  - Systems of Innovation Pattern

Systems of Innovation (SysInnov) Pattern

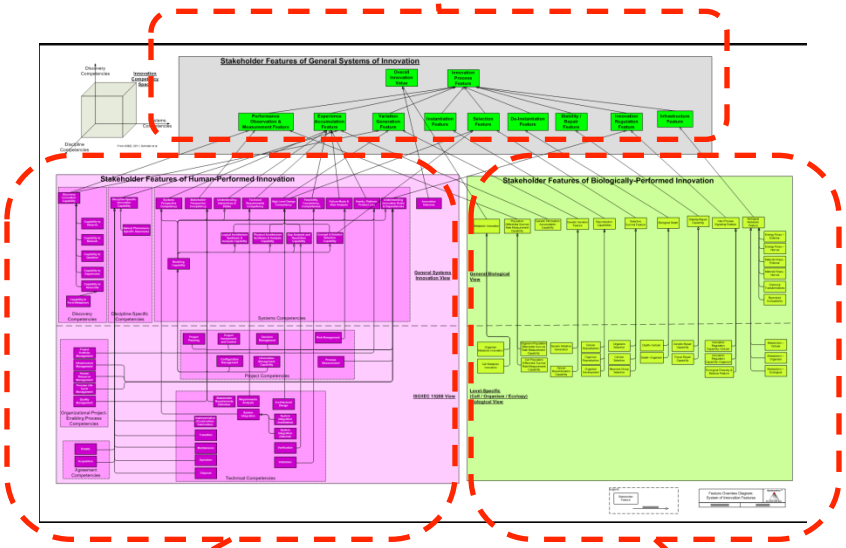
- A general pattern describing innovation as it occurs in nature without human intervention (e.g., evolutionary biology), as well as human-performed innovation (e.g., engineering):
  - Descriptive, not proscriptive: Specializes differently to describe typical human-performed engineering versus innovation in nature.
- Generated within the INCOSE System Sciences Working Group (SSWG), as a sub-project of Dr. Len Troncale's Systems Pathologies Project:
  - Beihoff & Schindel, "Systems of Innovation I: Summary Models of SOI Health and Pathologies", IS2013 Proceedings

SysInnov Pattern: Features



SysInnov Pattern: Features

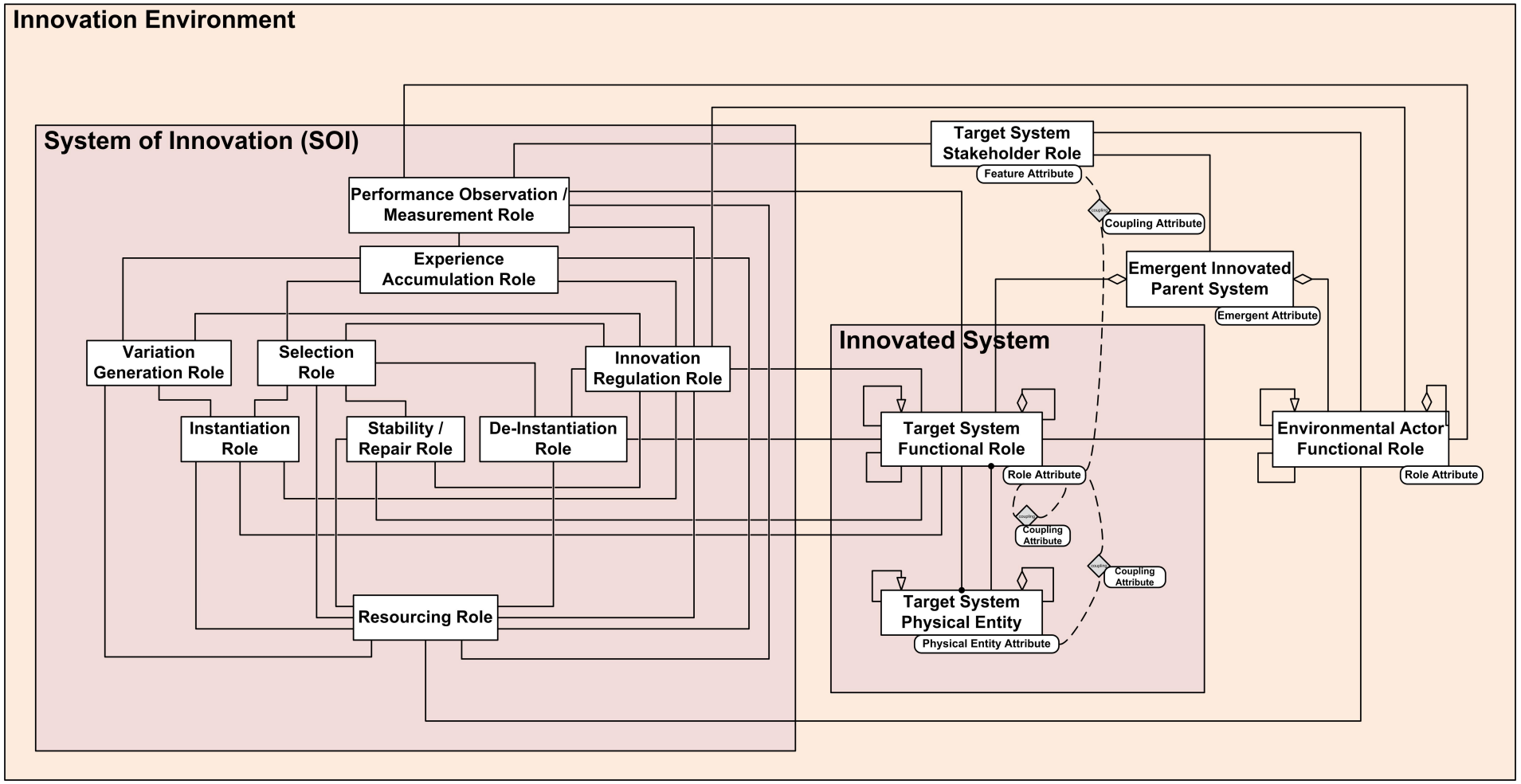
Features of General System of Innovation



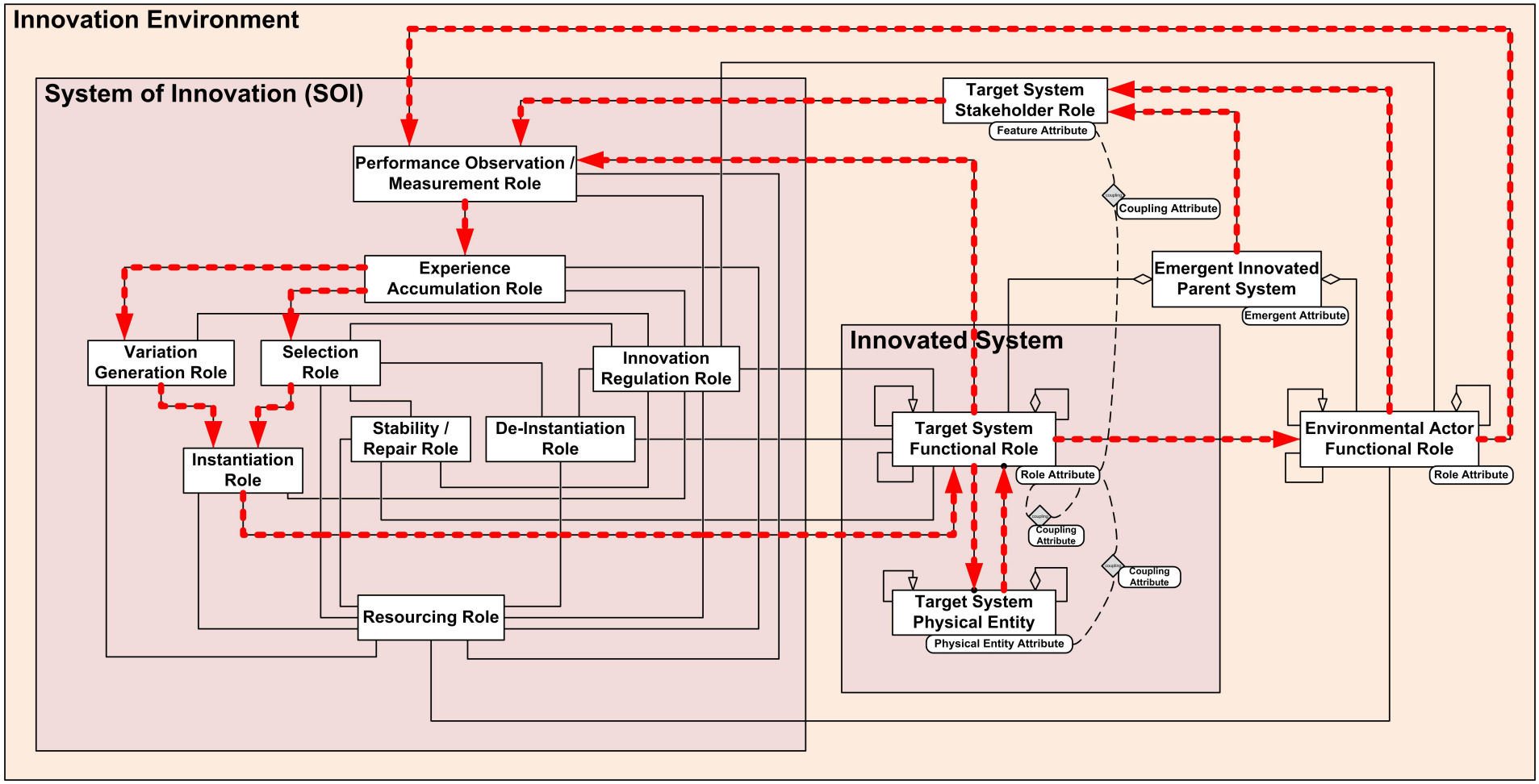
Features of Human-Performed Innovation (incl. 15288)

Features of Biologically-Performed Innovation

SysInnov Pattern: Logical Architecture



Innovation Signaling Pathways & Loops



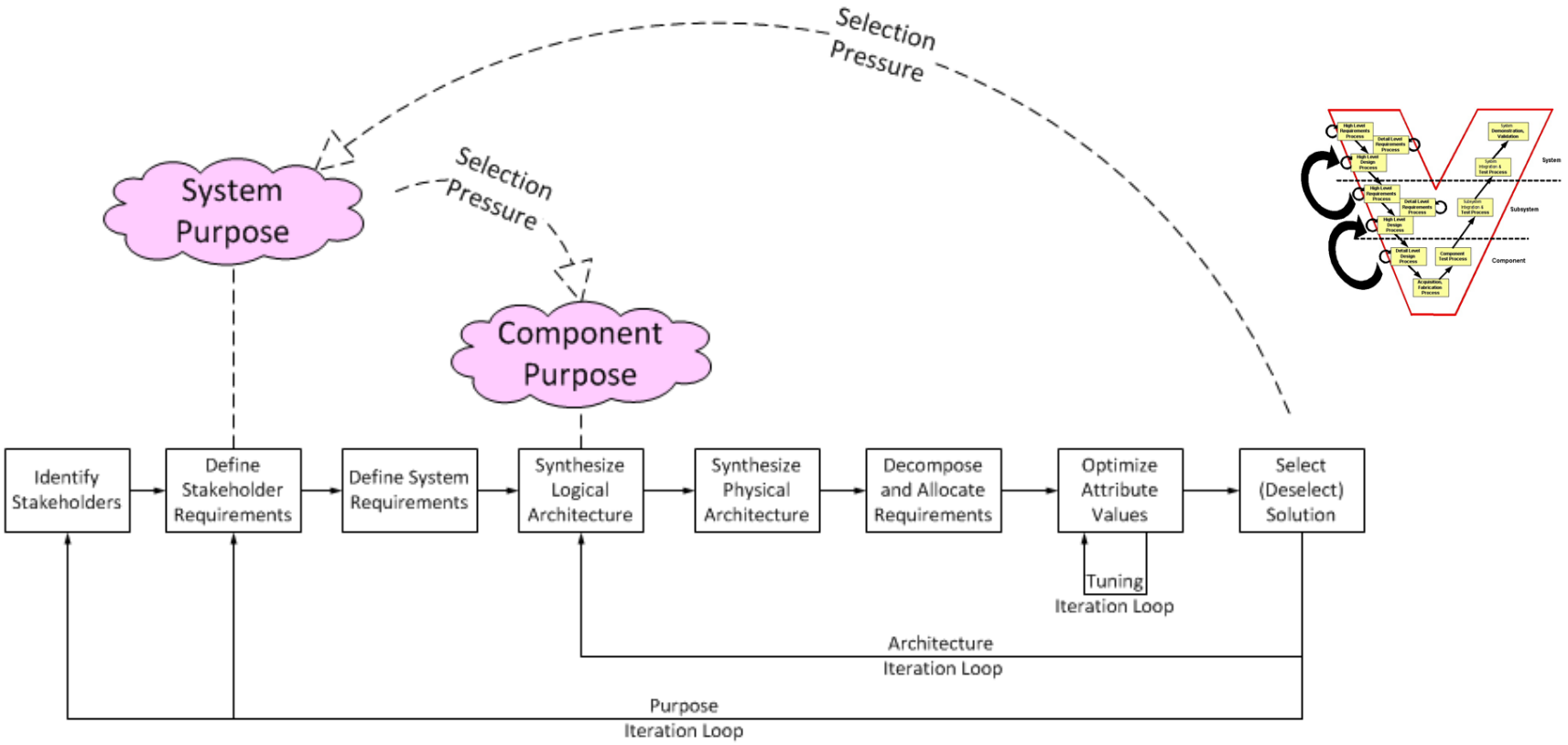
Engineer's View of Purpose in Systems (in no particular order)

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

Traditional Emphasis on "Up Front"

- SE rightly treats the identification of system stakeholders, their needs and priorities, and system requirements as important to identify early:
  - Some of the key values of SE are avoiding downstream costs of failing to successfully identify these early enough.
  - However, ...

Purpose Discovery/Iteration Loop



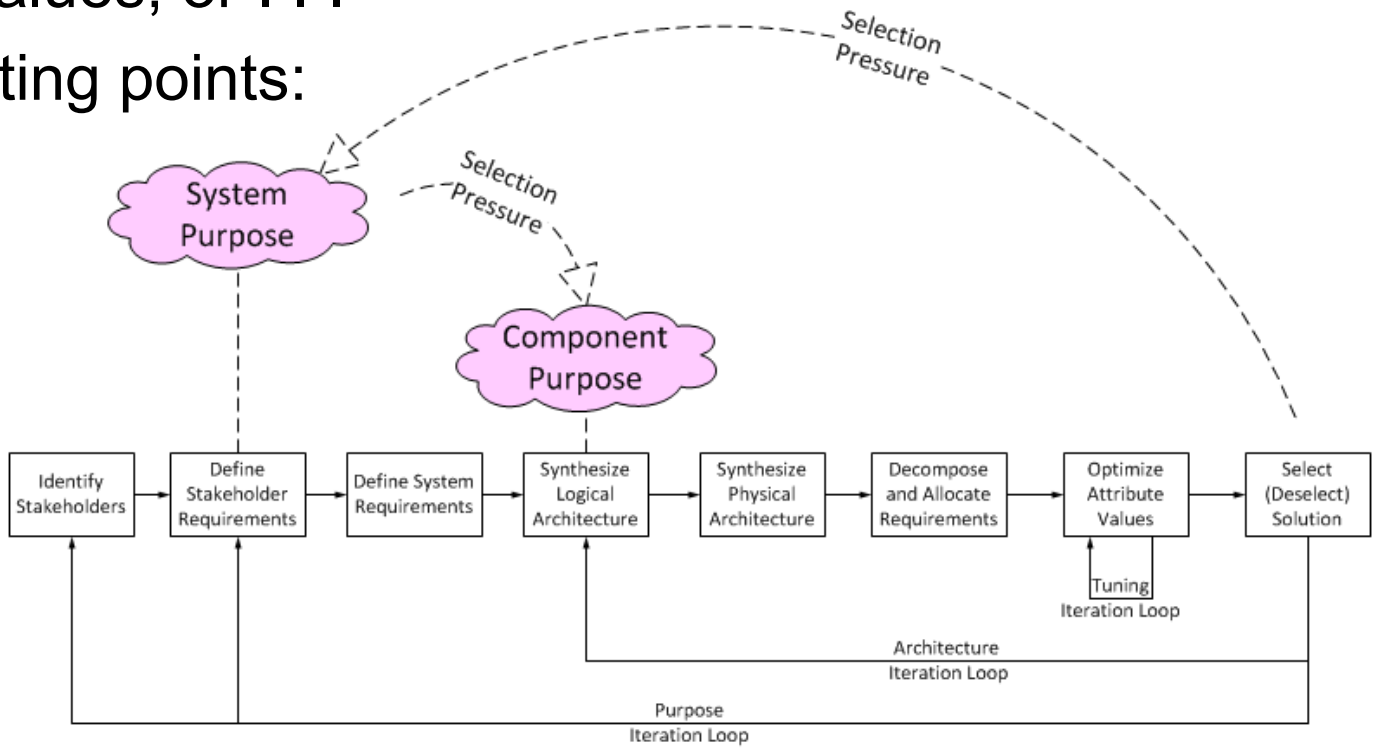
- Physical architecture / design solution is not the only thing that we discover or synthesize . . .
- Stakeholders, needs, requirements, and even system purpose are likewise subject to iterative discovery.

System Purpose

- We use a broader definition of the purpose of a system:
  - 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.
- Note that this definition does not require that purpose be fully determined before a system is synthesized, conceptually or even physically.
- It means the entire innovation cycle—not just later design stages--involves synthesis.
- And, it covers both human-engineered and other systems.

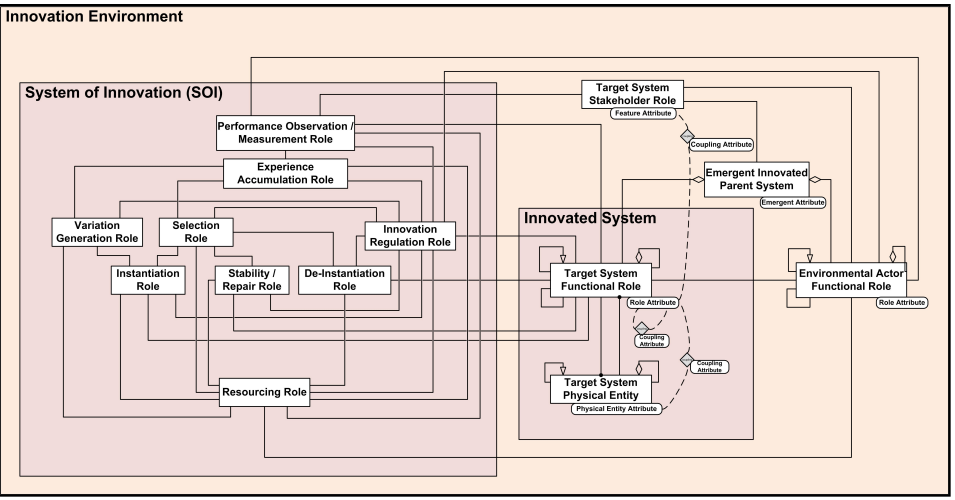
System Purpose

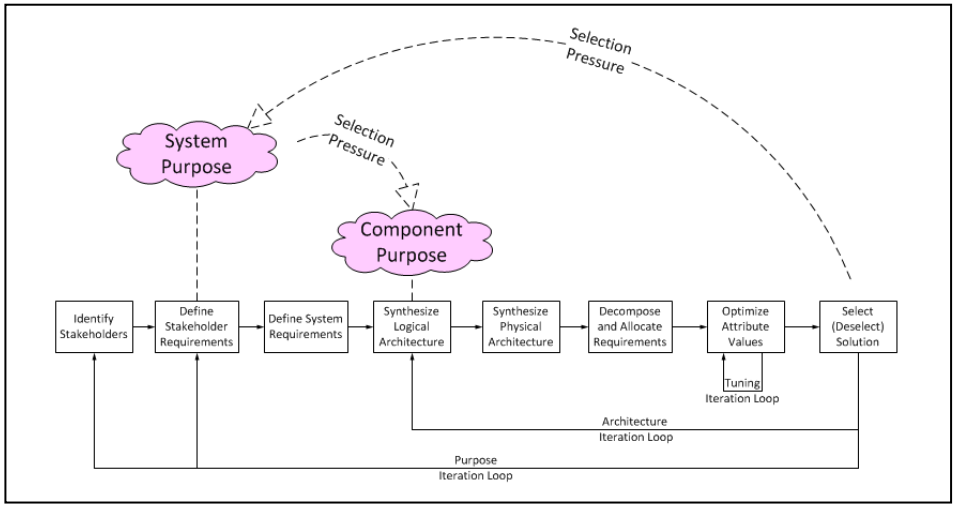
- This means there is no single “innovation starting point”:
  - We can start with a physical phenomenon and go looking for applications and stakeholders, or, . . .
  - We can start by identifying classes of stakeholders (those with capital to spend, or those underserved, etc.) and seek out their values, or . . .
  - Other starting points:



The Emergence of Purpose

- The result is that *purpose emerges as a systemic property of the entire cycle and extended Innovation Environment:*





- 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.

Example 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)

Example 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.

Example 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).

Example 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.

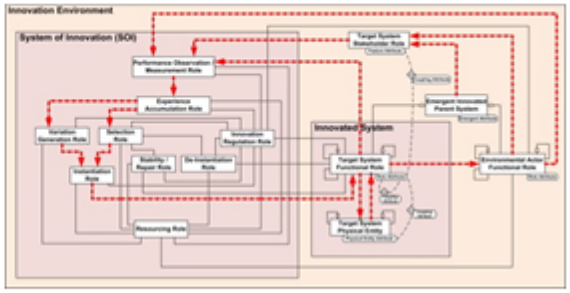
Example 5

- From Entrepreneurial Business:
  - Lean Start Up
  - Pivoting

Emergence Levels Summary

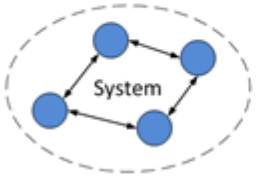
Definition of Purpose

SOI Pattern

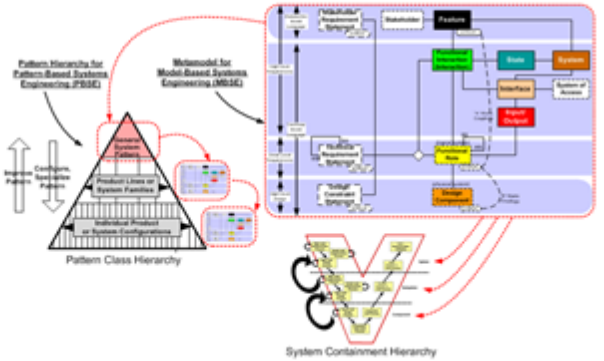


Gives Rise To

Definition of (Elementary) System



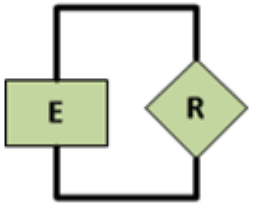
S*Metamodel

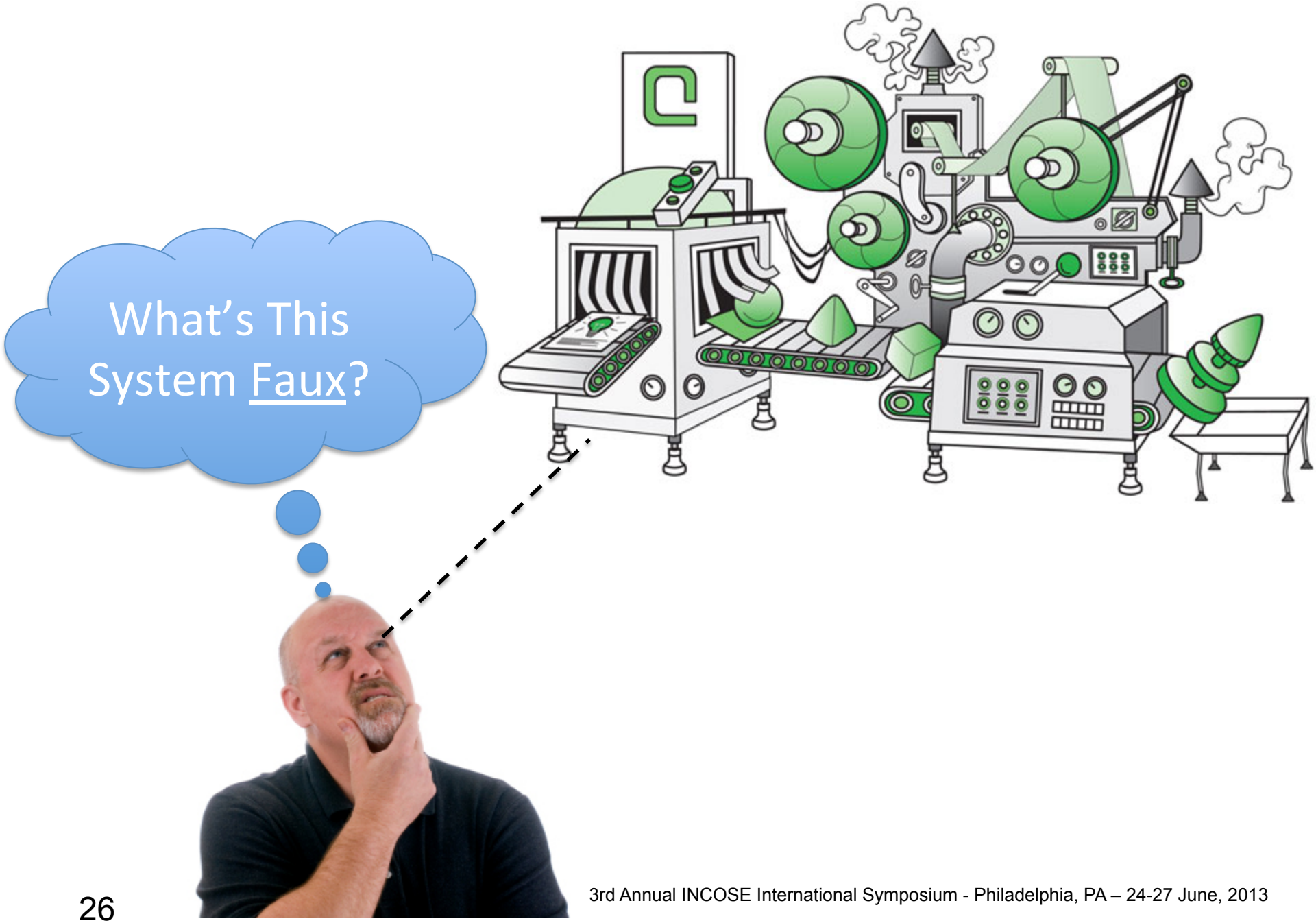


Gives Rise To

Definition of Relational Modeling

Entity-Relationship Paradigm




What's This
System Faux?

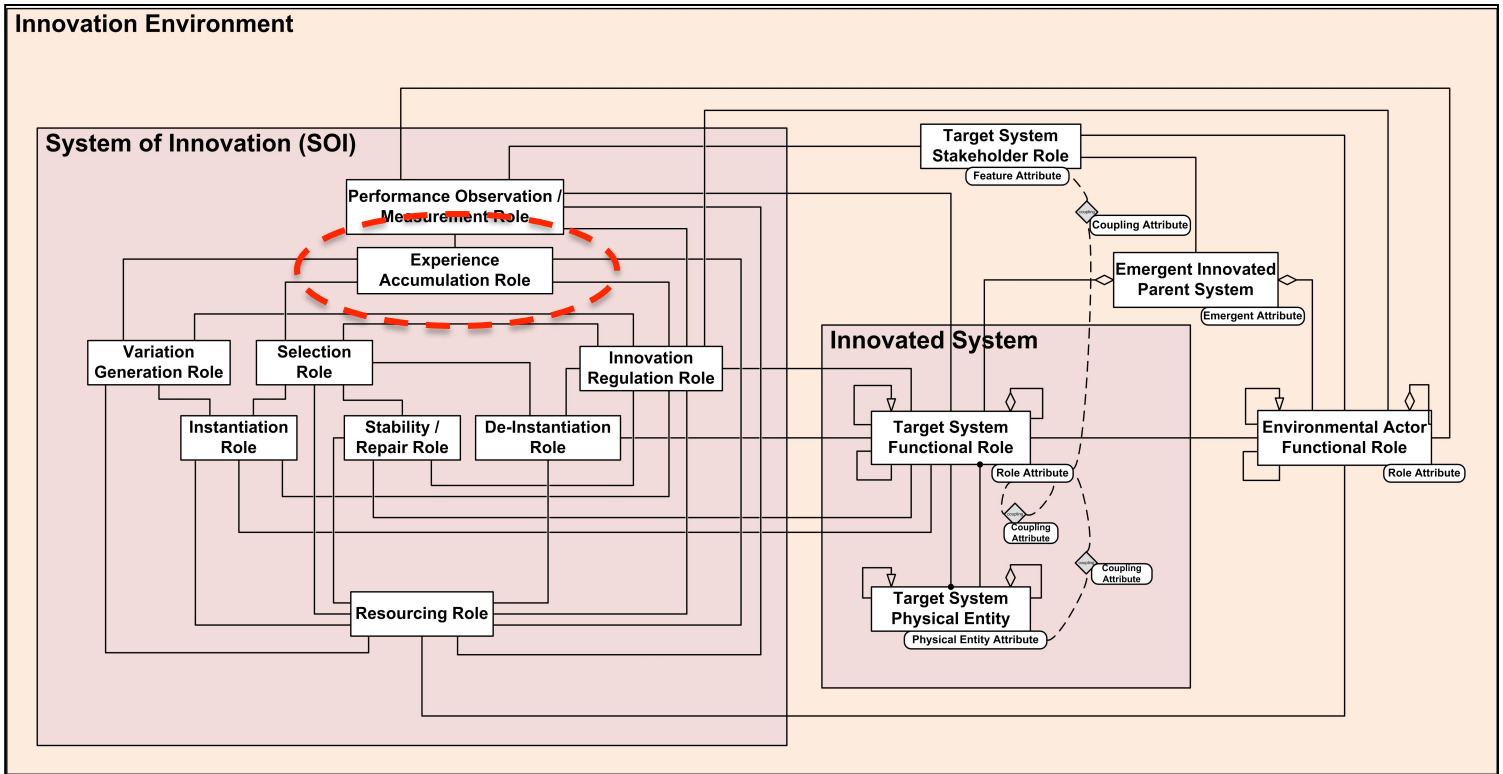
Emergence of Pathologies

- Two approaches we have taken in this project to defining system pathology:

1. 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.
2. any failure of a system, or system component, to perform its purpose(s) in a manner typical of others of the same type in like circumstances.

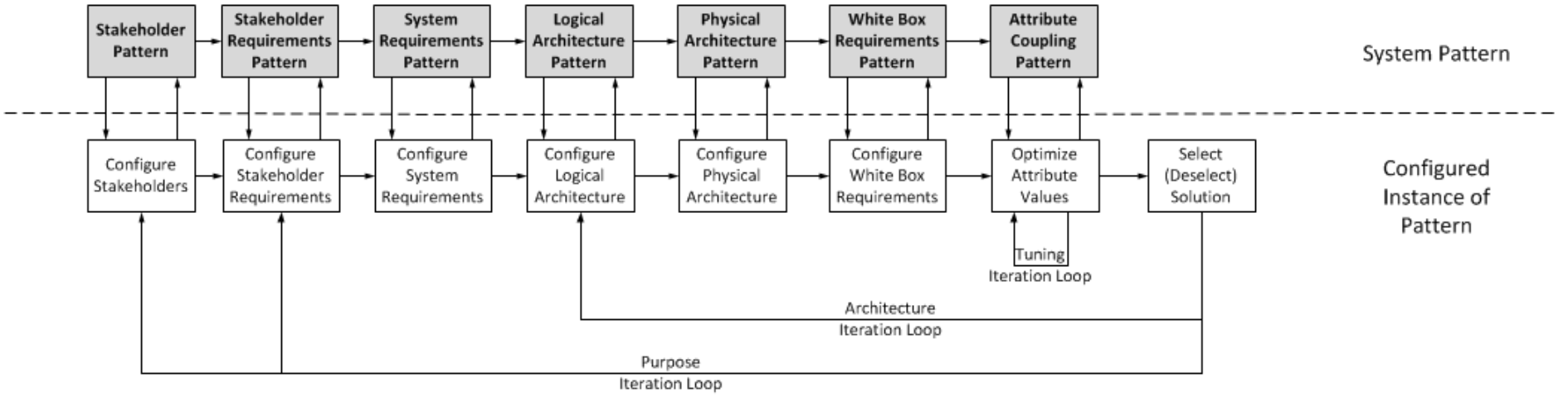
Accumulation & Representation of Discovery Experience (Learning)

- "Discovery" of purpose, as well as other information, is less valuable if we don't remember what we discovered, and have to re-discover it:
  - Discovery without learning is sub-optimal.
  - The SysInnov Pattern includes Experience Accumulation as a vital role:



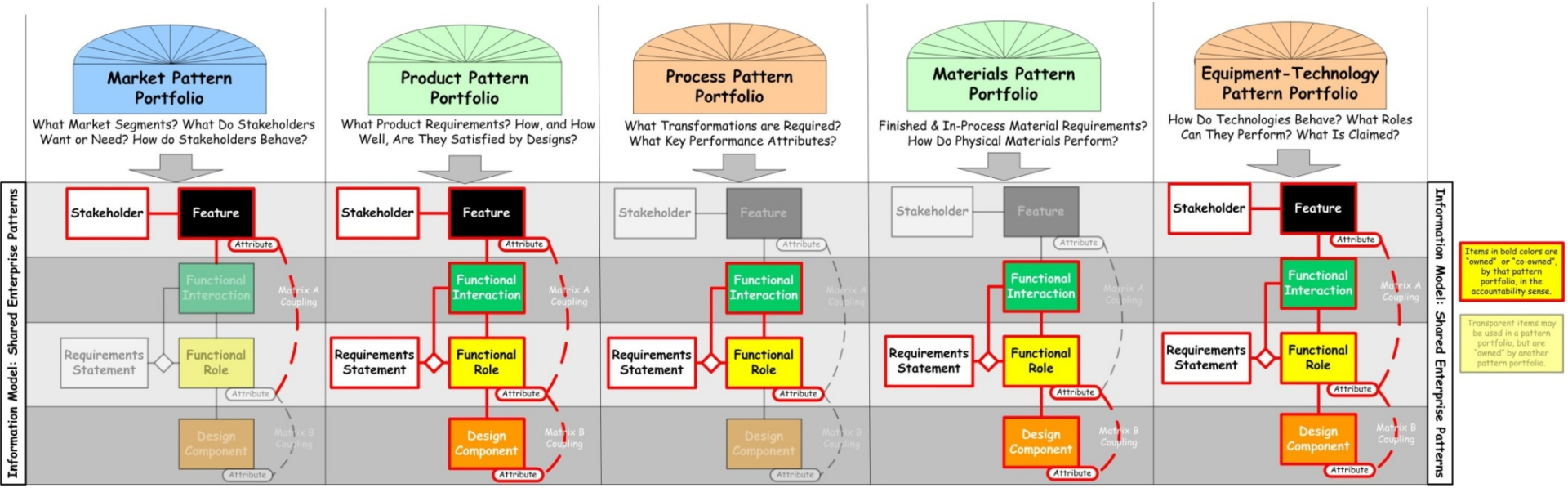
Accumulation & Representation of Discovery Experience (Learning)

- Pattern-Based Systems Engineering (PBSE) is an extension of Model-Based Systems Engineering (MBSE):
  - Accumulating re-usable, configurable system models.
  - For use in families, product lines, platforms:



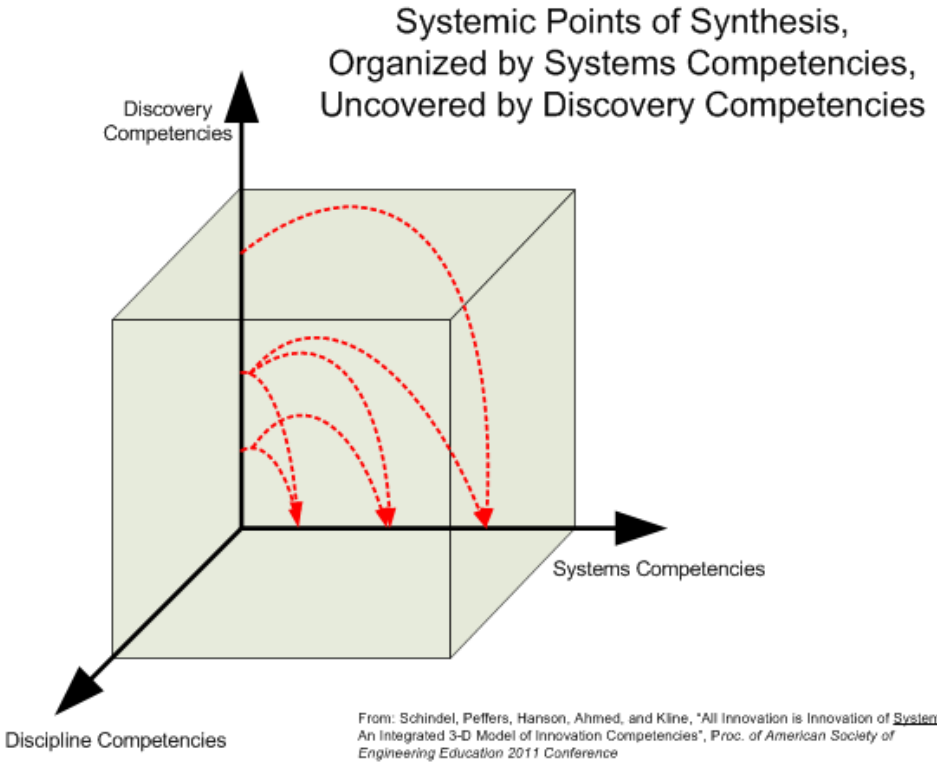
Accumulation & Representation of Discovery Experience (Learning)

- Emergence of <u>portfolios</u> of standard modules, components, and sub-systems:



Improving Innovation Competencies

- Sometimes, purpose and certain other aspects need to be discovered, not just arrived at by deduction reasoning.
- This requires Innovation Competencies that go beyond traditional views of Systems Engineering:



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*

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.

Insights and Implications

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.

Insights and Implications

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.

Survey

Please take the time to rate this presentation by submitting the web survey found at:

www.incose.org/symp2013/survey

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