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V1.3.2

Implications for Future SE Practice as a Discipline:

Three Elements of a Science of Systems

Abstract

- The traditional engineering disciplines are supported by companion physical sciences, each with a focal phenomenon. But Systems Engineering had a different kind of origin in the mid twentieth century. Instead of a scientific phenomenon, its focus was process and procedure for improved technical integration of the traditional engineering disciplines with each other and with stakeholder value. More recently, *INCOSE Vision 2025* has called for a strengthened <u>scientific</u> foundation for SE, even as SE also becomes more subject system model-based. A number of paths toward such a system science have been pursued or proposed. How might we judge the value of what has been identified or pursued so far?
- Following millennia of slower progress, in only 300 years the ("other") physical sciences and engineering disciplines that they support have transformed the quality, nature, and possibilities of human life on Earth. That global demonstration of the practical impact of science and engineering provides us with a benchmark against which we may judge the <u>practical</u> value of candidate system sciences. We should demand no less if we claim scientific equivalence.
- This talk will briefly point out three key components of proposed scientific foundations for systems, each emphasizing historical basis in the other disciplines, and note areas of their practical impacts on future SE practice as a phenomena-based discipline:
    1. **<u>The System Phenomenon</u>**: What is the "hard science" phenomenon of systems?
    2. **<u>The Value Phenomenon</u>**: What is the engineering bridge to subjective value?
    3. **<u>The Trust Phenomenon</u>**: How to award and exploit trust in critical models?

Recalling Some "Old Fashioned" Mathematics

Bill's drink of choice

The Old Fashioned

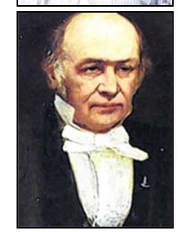
As learned from the the
world's best Old Fashioned drink maker

Bill's dad, age 92 years

Number of 92 year lives
since the work of . . .

Noether's Theorem,
Emmy Noether,
just 1 lifetime ago

Hamilton's Principle,
William Hamilton,
just 2 lifetimes ago



Newton's Laws, Calculus,
Isaac Newton,
just 3.5 lifetimes ago

Also "Old Fashioned": the technical basis of what we will discuss here . . .

Contents

- Background
- The System Phenomenon, with implications
- The Value Phenomenon, with implications
- The Trust Phenomenon, with implications
- What you can do
- References

INCOSE *SE Vision 2025 :* A call for stronger SE foundations

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Systems Engineering Foundations

Shoring Up the Theoretical Foundation

FROM

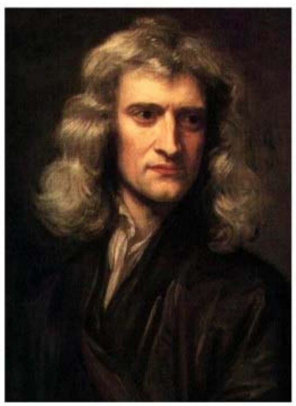
Systems engineering practice is only weakly connected to the underlying theoretical foundation, and educational programs focus on practice with little emphasis on underlying theory.

TO

The theoretical foundation of systems engineering encompasses not only mathematics, physical sciences, and systems science, but also human and social sciences. This foundational theory is taught as a normal part of systems engineering curricula, and it directly supports systems engineering methods and standards. Understanding the foundation enables the systems engineer to evaluate and select from an expanded and robust toolkit, the right tool for the job.

Two “Phase Changes” in Technical Disciplines

1. Phase change leading to traditional STEM disciplines:
   - – Beginning around 300 years ago (Newton’s time)
   - – Evidence argued from efficacy “step function” impact on human life



2. Phase change leading to future systems disciplines:
   - – Beginning around our own time
   - – Evidence argued from foundations of STEM disciplines

<u>Phase Change 1 Evidence</u>: Efficacy of Phenomena-Based STEM Disciplines




In a matter of a 300 years . . .

- the accelerating emergence of Science, Technology, Engineering, and Mathematics (STEM) . . .
- has lifted the possibility, nature, quality, and length of life for a large portion of humanity . . .
- while dramatically increasing human future potential.
- By 20th Century close, strong STEM capability was recognized as a critical ingredient to individual and collective prosperity.

Emergence of Science and Engineering

- The “hard sciences”, along with the “traditional” engineering disciplines and technologies based on those sciences, may be credited with much of that amazing progress, as well as challenges.

- How should Systems Engineering be compared to engineering disciplines based on the “hard sciences”?

Three elements of a science of systems

- **The System Phenomenon**: Each of the traditional physical sciences is based on a specific physical phenomenon (mechanical, electrical, chemical, etc.) and related mathematical formulation of physical laws and first principles. What is the equivalent “hard science” phenomenon for systems, where is its mathematics, and what are the impacts on future SE practice?
- **The Value Phenomenon**: Engineers know that value is essential to their practice, but its “soft” or subjective nature seems challenging to connect to hard science and engineering phenomena. What is the bridge effectively connecting these, where is the related mathematics, and what are the impacts on future SE practice?
- **The Trust Phenomenon**: The physical sciences accelerated progress in the last three centuries as they demonstrated means for not just the discovery of Nature’s patterns, but also the managed awarding of trust in them. What is the scientific basis of such group learning, and how does it impact the future practice of SE?

Phenomena-Base Engineering Disciplines

- The traditional engineering disciplines have their technical bases and quantitative foundations in the hard sciences:

Engineering Discipline	Phenomena	Scientific Basis	Representative Scientific Laws
Mechanical Engineering	Mechanical Phenomena	Physics, Mechanics, Mathematics, . . .	Newton's Laws
Chemical Engineering	Chemical Phenomena	Chemistry, Mathematics. . . .	Periodic Table
Electrical Engineering	Electromagnetic Phenomena	Electromagnetic Theory	Maxwell's Equations, etc.
Civil Engineering	Structural Phenomena	Materials Science, . . .	Hooke's Law, etc.





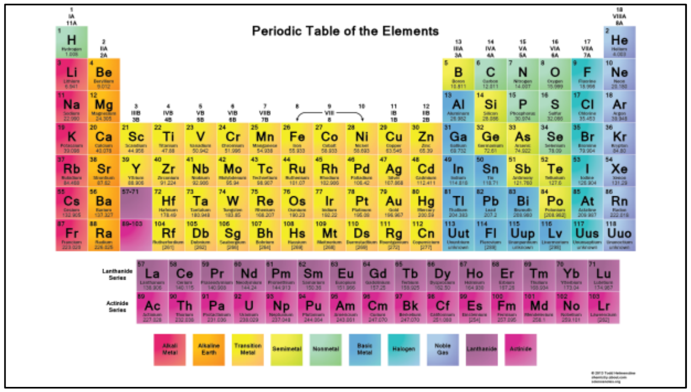
The Traditional Perspective

- Specialists in individual engineering disciplines (ME, EE, CE, ChE, etc.) sometimes argue that their fields are based on:
  - “real physical phenomena”,
  - physical laws based in the “hard sciences”, and first principles,
- sometimes claiming that Systems Engineering lacks the equivalent phenomena-based theoretical foundation.

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

$$\frac{N_b}{N_a} = \left(\frac{g_b}{g_a}\right)\left(e^{-(E_b - E_a)/kT}\right)$$

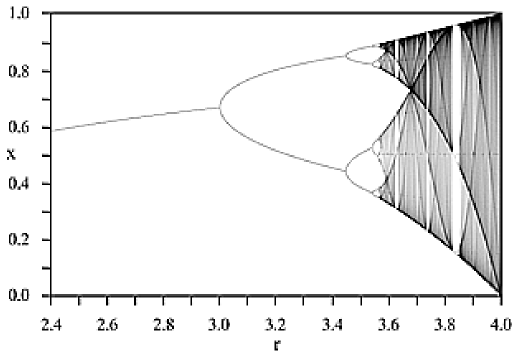
$$H(t)|\psi(t)\rangle = i\hbar \frac{\partial}{\partial t}|\psi(t)\rangle$$

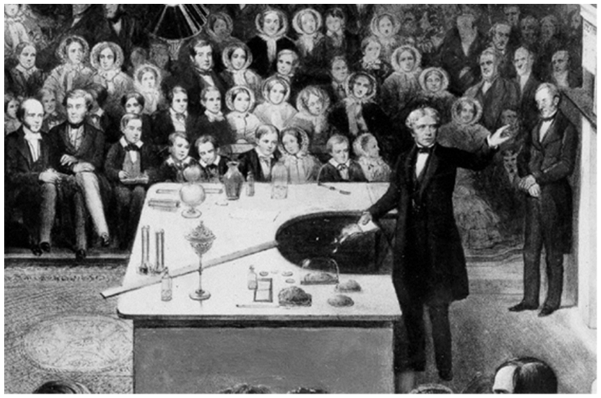


- Instead, Systems Engineering is sometimes viewed as:
  - Emphasizing process and procedure
  - Critical thinking and good writing skills
  - Organizing and accounting for information
- But not based on an underlying “hard science”

Traditional Perspective, continued

- That view is <u>perhaps</u> understandable, given the first 50 years of Systems Engineering
- "Science" or "phenomenon" of generalized systems have for the most part been described on an intuitive basis, with limited reference to a "physical phenomenon" that might be called the basis of systems science and systems engineering:
  - For example, emergence of patterns out of agent interactions in complex systems
  - Fascinating, but not yet the basis of generations of life-changing human progress such as has marked the last 300 years



However . . .

- The same might be said of physics before Newton, chemistry before Lavoisier & Mendeleev, electrical science before Faraday & Maxwell, etc.
- Moreover, Systems Engineering is also undergoing a “phase change” that might be compared to the emergence of phenomena understanding in the other engineering disciplines . . .

MBSE, PBSE: A Phase Change in Systems Engineering

While models are not new to STEM . . .

- Model- Based Systems Engineering (MBSE): We increasingly represent our understanding of systems aspects using explicit models.
- Pattern-Based Systems Engineering (PBSE): We are beginning to express parameterized family System Models capable of representing recurring patterns.
- This is a much more significant change than just the emergence of modeling languages and IT toolsets, provided the underlying model structures are strong enough:
  – Remember physics before Newtonian calculus

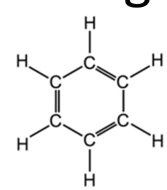


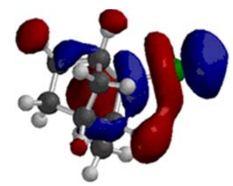
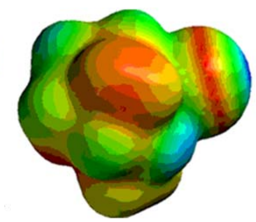
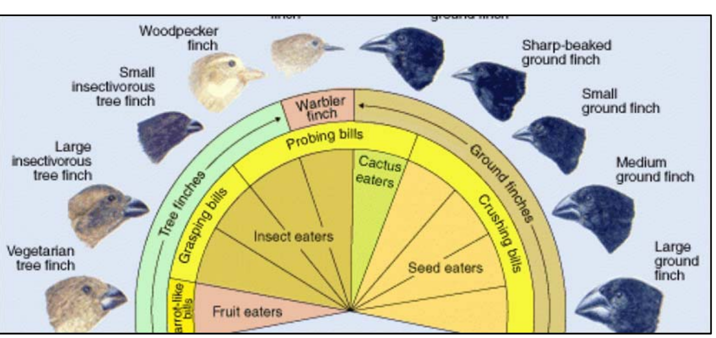


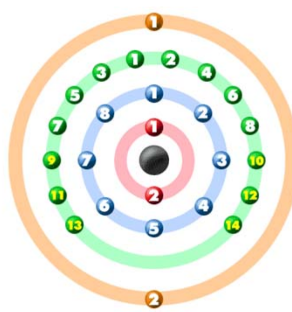

Patterns

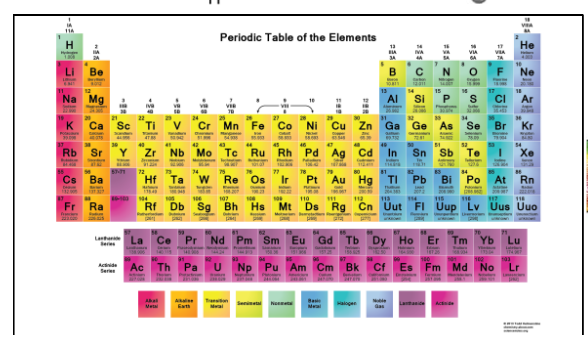
July 18 - 21, 2016

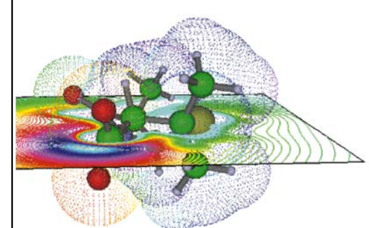
- All “patterns” are recurrences, having both fixed and variable aspects.
- The heart of physical science’s life-changing 300 year success in prediction and explanation lies in recognition, representation, exploitation of recurring patterns.
- Noether’s Theorem & Hamilton’s Principle: Substantial math basis for all the physical laws: Newton, Maxwell, Mendeleev, Schrödinger, . . .

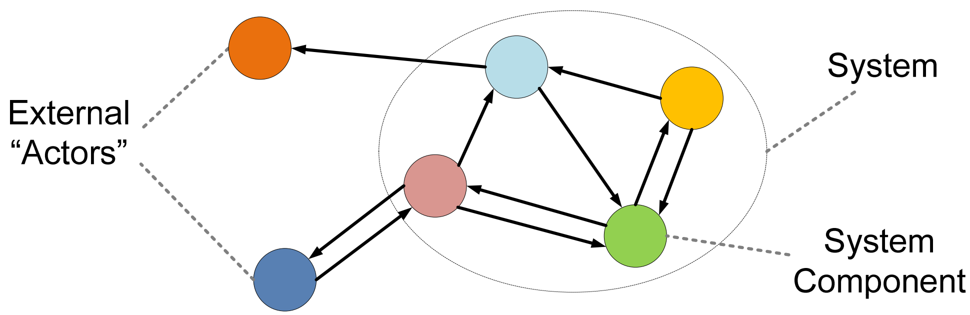


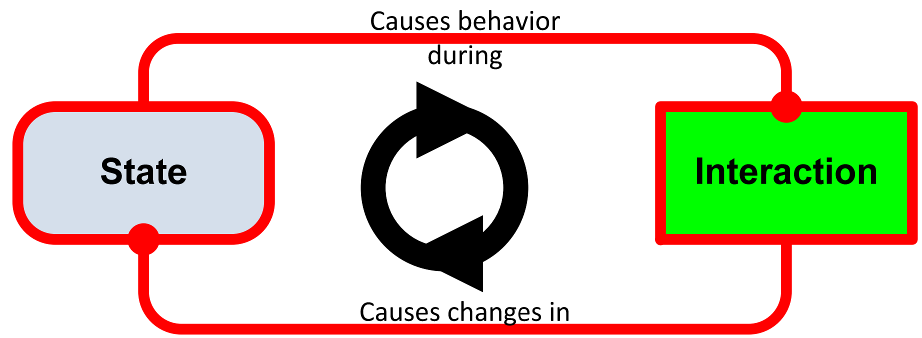





The System Phenomenon

- *In the perspective described here*, by System we mean a collection of interacting components:



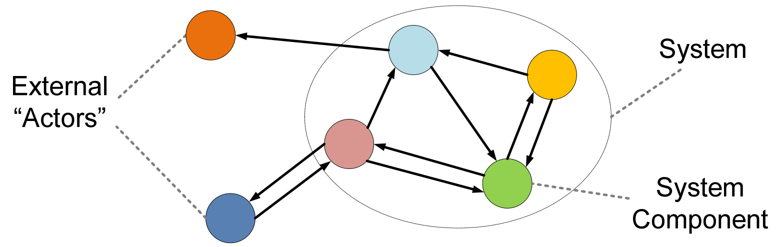


- By “interacting” we mean the exchange of energy, force, material, or information (input-outputs) between system components, . . .
- . . . through which one component impacts the state of another component.
- By “state” we mean a property of a component that impacts its input-output behavior during interactions.
- So, a component’s “behavior model” describes input-output-state relationships during interaction—*there is no “naked behavior” in the absence of interaction*.
- The behavior of a system as a whole involves emergent states of the system as a whole.

The System Phenomenon

- Phenomena of the hard sciences are in each case instances of the following "System Phenomenon":
  - *behavior emergent from the interaction of behaviors (phenomena themselves) a level of decomposition lower.*
- For each such phenomena[1], the emergent interaction-based behavior of the larger system is a stationary path of the action integral:

$$\mathcal{S} = \int_{t_1}^{t_2} L(x, \dot{x}, t)\, dt$$



(Hamilton's Principle[1])

- Reduced to simplest forms, the resulting equations of motion (or if not solvable, empirically observed paths) provide "physical laws" subject to scientific verification—an amazing foundation across all phenomena.

(1) When stated with rigor, special cases for non-holonomic constraints, irreversible dynamics, discrete systems, data systems, etc., led to alternatives to the variational Hamilton's Principle—but the ***interaction-based structure*** of the System Phenomenon remained, and the underlying related Action and Symmetry principles became the basis of modern theoretical physics.

The System Phenomenon

- Each of the so-called “fundamental” phenomena law mathematical expression (Newton, Maxwell, Schrodinger, et al) is derivable from the above.
- So, instead of Systems Engineering lacking the kind of theoretical foundation the “hard sciences” bring to other engineering disciplines, . . .
  - It turns out that all those other engineering disciplines’ foundations are themselves dependent upon the System Phenomenon (as stated by Mach and many others who followed).
  - The underlying math and science of systems provides the theoretical basis already used by all the hard sciences and their respective engineering disciplines.
  - It is not Systems Engineering that lacks its own foundation—instead, it has been providing the foundation for the other disciplines!

The System Phenomenon

It is not Systems Engineering that lacks its own foundation—instead, it has been providing the foundation for all the other "hard" disciplines!

A traditional view:

Systems Engineering

Traditional Engineering Disciplines

Traditional Physical Phenomena

Our view:

Emerging Engineering Disciplines

Traditional Engineering Disciplines

Systems Engineering Discipline

The System Phenomenon

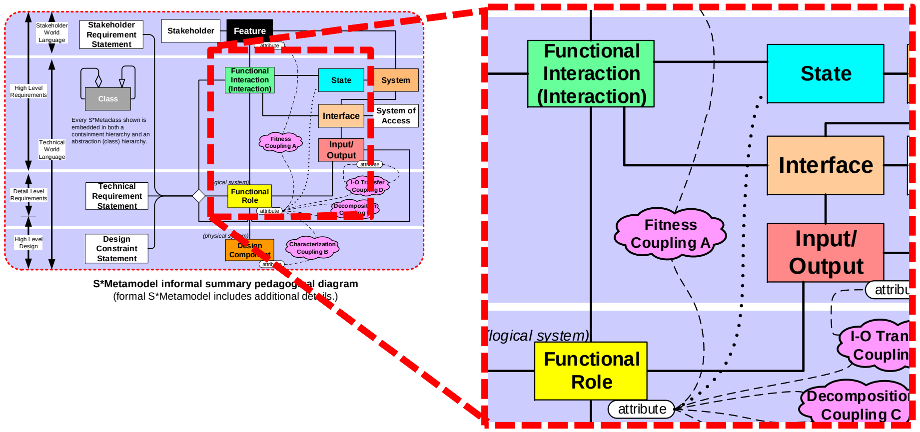
Future

- Distribution networks
- Biological organisms, ecologies
- Market systems and economies
- Health care delivery
- Systems of conflict
- Systems of innovation

Recent

- Ground Vehicles
- Aircraft
- Marine Vessels
- Biological Regulatory Networks

Implications for SE practice



- No matter what your modeling language or tools--Interactions are not optional or peripheral, but central to system models:
  - Are Interactions central to <u>your</u> models and thinking?
  - Are you integrating or dividing?
  - There is no “naked behavior”—it all occurs in interactions.
- The distinction between “system models” and “other discipline models” is largely an accident of history and enterprise organization, not Nature.
- Emergent domain phenomena and languages at each level:
  - From gas laws to plate tectonics to cosmological scales

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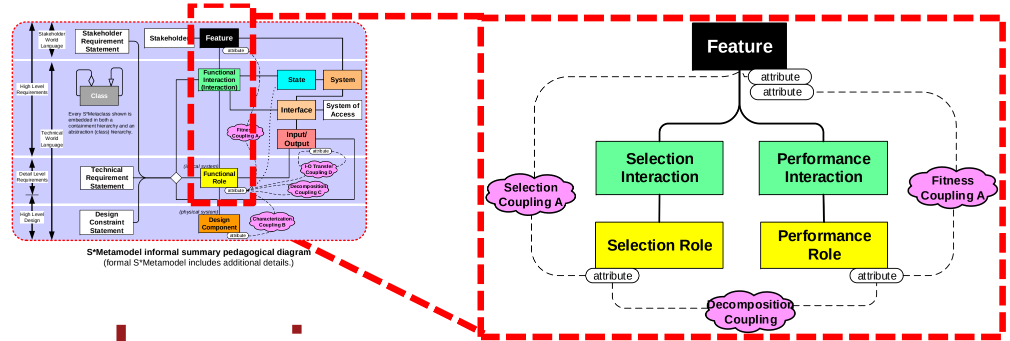
Even if value (both human-based and otherwise) seems elusive or subjective, . . .

– The <u>expression</u> of value is always <u>selection</u>:

Settings	Types of Selection	Selection Agents
Consumer Market	Retail purchase selection	Consumer
Military Conflict	Direct conflict outcome; threat assessment	Direct engagement; commander
Product design	Design trades	Designer
Commercial Market	Performance, cost, support	Buyer
Biological Evolution	Natural selection	Environment
Product Planning	Opportunity selection	Product Manager
Market Launch	Optimize choice across alternatives	Review Board
Securities Investing	What to buy, what to sell, acceptable price	Investors
College-Student Matching Market	Selection of individuals, selection of class profile, selection of school	Admissions Committee; Student & Family
Life choices	Ethical, moral, religious, curiosities, interests	Individual
Democratic election	Voting	Voters
Business	Risk Management, Decision Theory	Risk Manager, Decision Maker



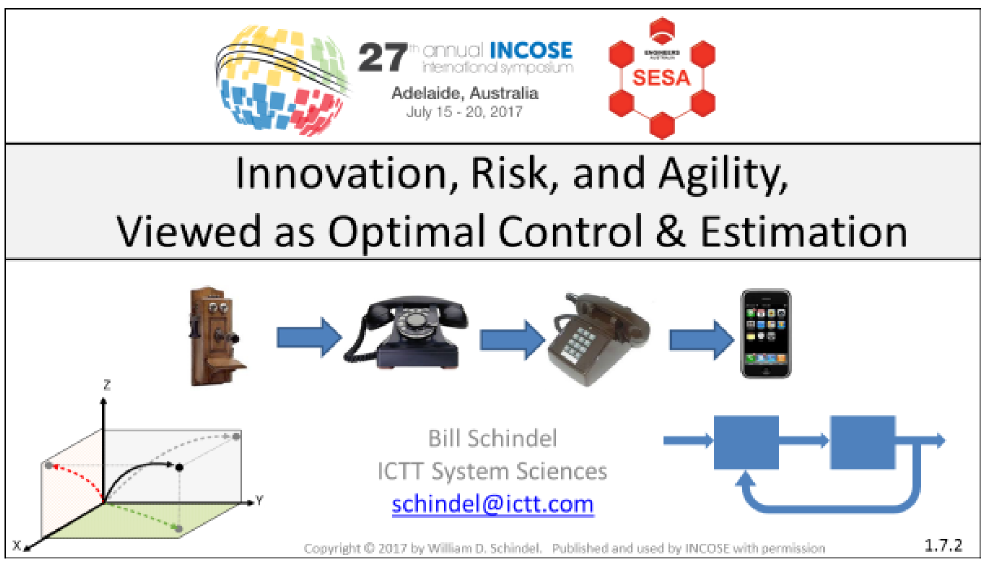
S*Metamodel informal summary pedagogical diagram
(formal S*Metamodel includes additional details.)

The bridge to value: Innovation Steering Mechanism

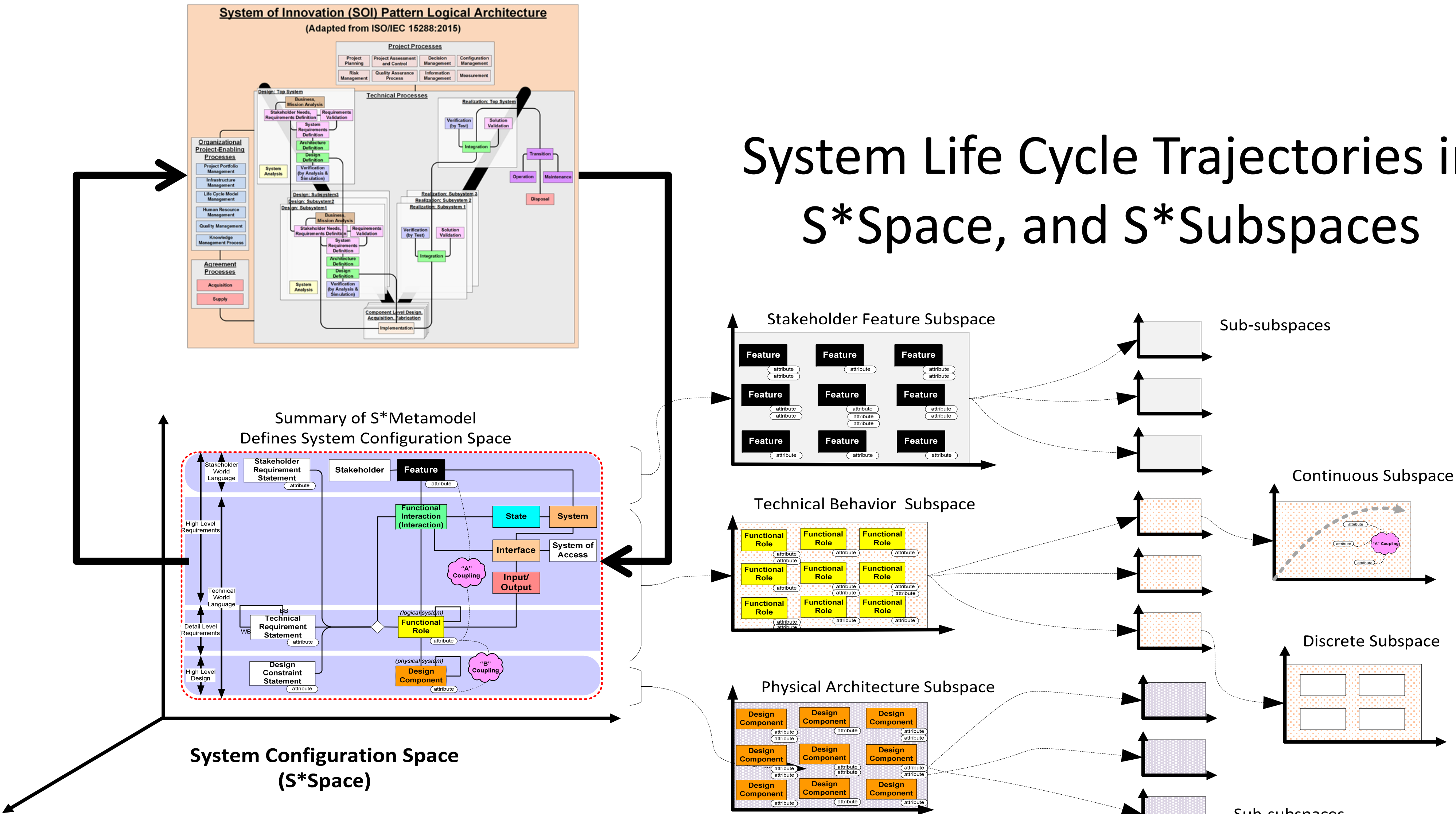
- Interactions connect to Value two very different ways:
  - Performance Interactions (real or imagined, present, past, or future) ***embody*** Value from Performers;
  - Selection Interactions (human or otherwise) ***express*** the Values of a Selection Agent
- Selection is itself an Interaction:
  - Studying the downstream system effects of selection is feasible
  - Studying the upstream mechanisms of selection is likewise feasible
  - Bridges upstream technical performance, downstream technical consequence

Where Do Systems Come From and Go? System Life Cycle Trajectories in S*Space

- Configurations change over life cycles, during development and subsequently
- Trajectories (configuration paths) in S*Space
- Effective tracking of trajectories
- History of dynamical paths in science and math
- Differential path representation: compression, equations of motion



System Life Cycle Trajectories in S*Space, and S*Subspaces



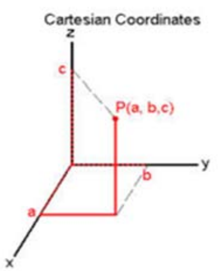
Maps *vs*. Itineraries -- SE Information *vs*. SE Process

Itinerary ≠ Map!

(What am I doing?) *(Where am I?)*

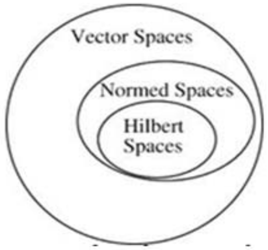
When they eventually did emerge, maps represented a newer idea of the nature of "where".

- The SE Process consumes and produces information.
- But, SE historically emphasizes process over information. (Evidence: Ink & effort spent describing standard process versus standard information.)
- Ever happen?-- Junior staff completes all the process steps, all the boxes are checked, but outcome is not okay.
- Recent discoveries about ancient navigators: Maps *vs*. Itineraries.
- The geometrization of Algebra and Function spaces (Descartes, Hilbert)
- Knowing where you "really" are, not just what "step" you are doing.
- Knowing where you are "really" going, not just what "step" you are doing next.
- Distance metrics, inner products, projections in system configuration S*Space.



Rene Descartes
1596 - 1650

Geometrization of Algebra, by Rene Descartes

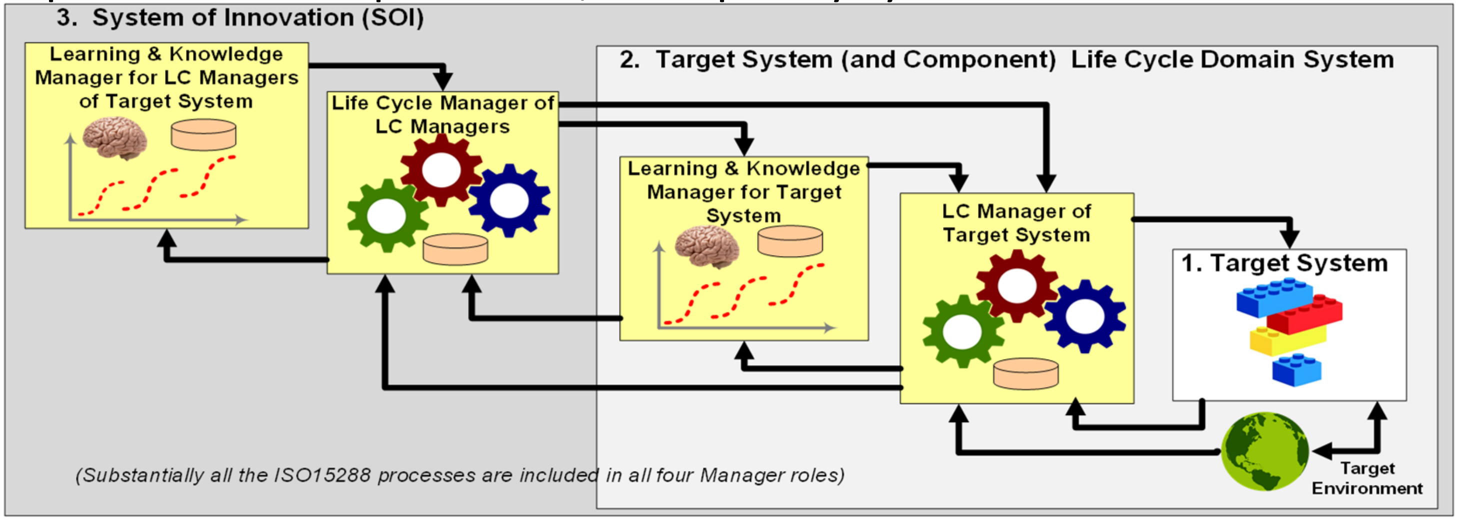


David Hilbert
1862 - 1943

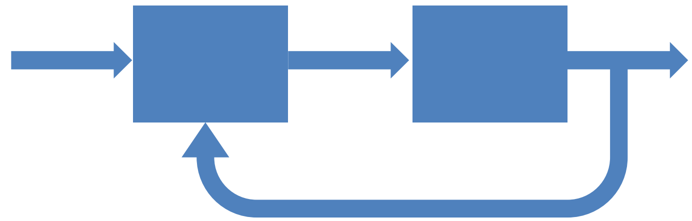
Geometrization of Function Space, by David Hilbert

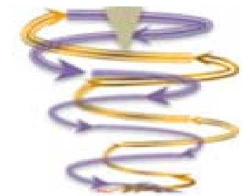
The Guidance System: Including the System of Innovation In the Model

- A complex adaptive system reference model for system innovation, adaptation, operation/use/metabolism, sustainment, retirement.
- Whether 100% human-performed or automation-aided, various hybrids.
- Whether performed with agility or not, 15288 compliant or not, informal, scrum…
- Familiar example in agile software methods: "WSJF" criteria for picking next increments
- Whether performed well or poorly.
- Includes representation of pro-active, anticipatory systems.



What Optimal Control and Estimation Theory Tells Us





- 50+ years of successfully applied math, used in other domains:
  - Norbert Wiener (time series, fire control systems, feedback control, cybernetics), Rudolph Kalman (filtering theory, optimal Bayesian estimation), Lev Pontryagin (optimal control, maximum principle), Richard Bellman (dynamic programming), others.
  - Applied with great success to fire control systems, inertial navigation systems, all manner of subsequent domain-specific feedback control systems.
- Model-Based Filtering Theory and Optimal Estimation in Noisy Environment:
  - Estimation, from noisy observations, of current state of a modeled system that is partly driven by random processes, optimized as to uncertainty.
  - Control of a managed system's trajectory, optimized as to time of travel, destination reached, stochastic outcomes.

Is it Plausible to Apply Optimal Control to the Innovation Process?

Aspect of Common Theoretical Framework	Application to a Vehicle Guidance System	Application to a System of Innovation
Overall domain system	Propelled airborne vehicle guidance to moving airborne target	Development of new system configuration for a system of interest
The controlled system	Airborne Pursuit Vehicle	The development process
Control system	Flight control system and pilot sometimes	Development management & decision-making process
Other actors	Target, atmosphere	Stakeholders, operating environment of system of interest, suppliers
State space in which controlled performance occurs	Vehicle position in 3-D geometric space	Configuration space of system of interest, including its features, technical requirements, and physical architecture
Driving processes	Target dynamics, pursuit thrust, flight control surface movements	Stakeholder interest, supply chain
Random aspects of driving processes	Buffeting winds	Stakeholder preferences, competition, technologies
Observation process model	Radar tracking of moving target, sensor characterization	Status reporting, market feedback, development status report process
Random disturbances of observation processes	Sensor errors	Inaccuracies or unknowables in development status; sampling errors
Environmental Conditions	Target maneuvers; atmospheric effects	Market or other environmental conditions;
Control input	Flight control surface orientation	Management direction; resources
Objective function to optimize	Time to target	Time to market; Competitive Response Time; Innovated System Performance; Innovation Risk vs. Reward
Dynamical model	Ballistic Flight, Atmospheric Effects, Thrust	Coupled development processes
Outcome risk	Risk of missing airborne target	Risk of innovation outcomes across stakeholders

Optimal Control and Estimation Problem Frameworks

- Optimal control problem, in continuous deterministic form:

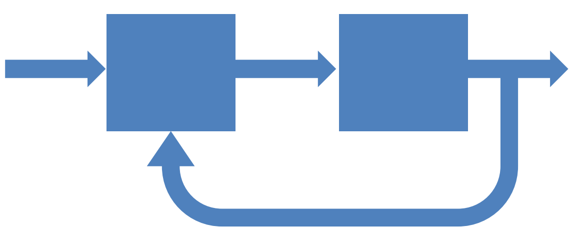
  System defined by:

  $$\dot{X} = f(X, U)\,, \quad X \in Rn$$

  system state X(t) and control U(t);

  Find an optimal control U(t) that minimizes:

  $$\int_0^T g\big(X(t), U(t)\big)dt$$



Optimal Control and Estimation Problem Frameworks

- Optimal estimation/filtering problem, in discrete time form:

System state X_n, driven by random process W_n :

$$X_{n+1} = \Phi_n X_n + \Gamma_n W_n$$

and monitored through observable Z_n, with that observation corrupted by random process V_n:

$$Zn = H_n X_n + V_n$$

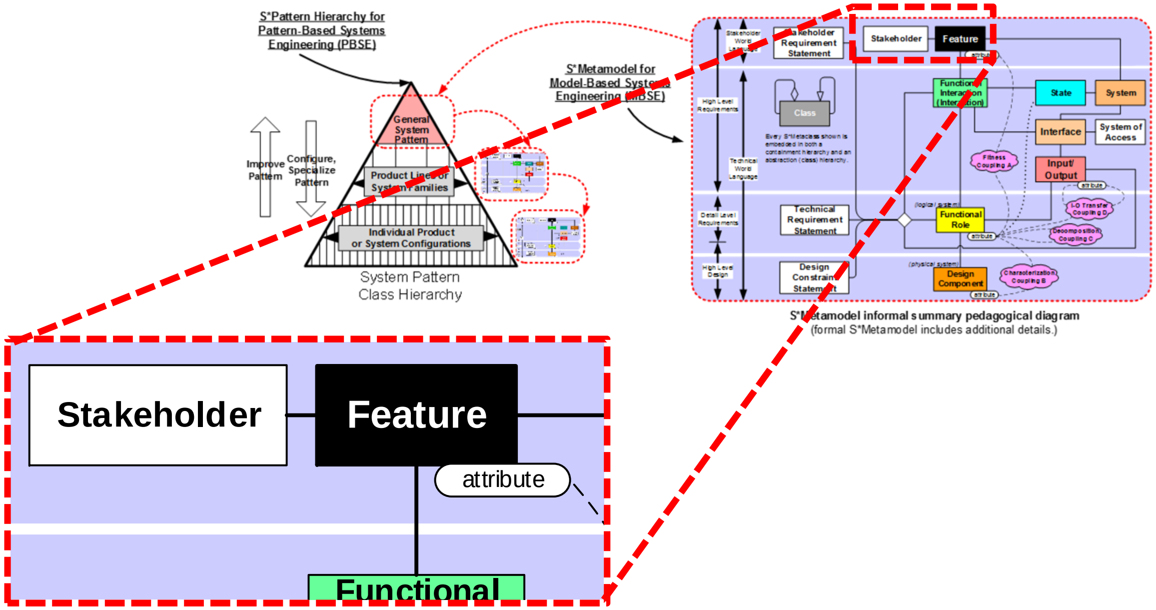
and having $var(W_n) = Q_n$ *and* $var(V_n) = R_n$

Assuming a previous estimated system state $\hat{X}_n$, find an optimal next estimate $\hat{X}_{n+1}$ minimizing $P_{n+1} = var(\hat{X}_{n+1} - X_{n+1})$

Implications for Agile Innovation to Product or Process: Execution as Well As Strategy

- Existing Pattern Configuration Envelopes:
  - Discovering and representing explicit System Patterns (S*Patterns), to increase agility of innovation: Leveraging what we know to lower risk, improve cost, speed of response, time to market, competitiveness;
  - These gains are available within the configurable space (envelopes) of those S*Patterns, by exploiting what "we" already "know";
- Expanding Pattern Configuration Envelopes:
  - Patterns are initially discovered and later expanded in envelope size by the exploratory learning part of the configuration trajectories;
  - Creating new higher level domain specific sciences by agile pattern extraction—the process of science, great success of the last 300 yrs.
  - Underlying patterns as Accelerators; Fields and Attractors.
- Improved intuition, as well as discipline, about direction and decision.
- Potential for automated support of direction analysis decisions.
- Environmental & opponent trajectories; game theory, differential games.
- Applies to innovations in the SOI itself, not just in the Target System

More implications for SE Practice



- Each S*Pattern creates a domain-specific language (DSL), including the "value space", characteristic of that domain.
- We also use the same consistent value space for very "different" things:
  1. Optimization, frontiers, decision-making, trades, selection
  2. "E" of FMEA—effects of failures, penalties, only things that can be at risk, risk management, project management
  3. Partitioning of platform configuration space for covering variant minimization

Three elements of a science of systems INCOSE

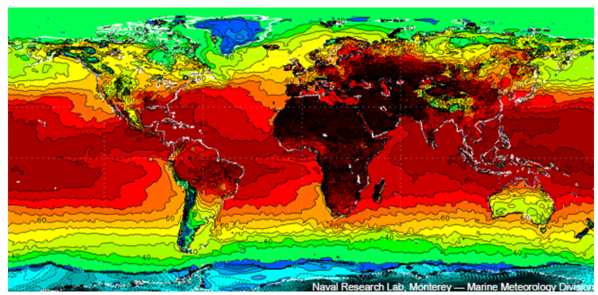
- **<u>The System Phenomenon</u>**: Each of the traditional physical sciences is based on a specific physical phenomenon (mechanical, electrical, chemical, etc.) and related mathematical formulation of physical laws and first principles. What is the equivalent "hard science" phenomenon for systems, where is its mathematics, and what are the impacts on future SE practice?
- **<u>The Value Phenomenon</u>**: Engineers know that value is essential to their practice, but its "soft" or subjective nature seems challenging to connect to hard science and engineering phenomena. What is the bridge effectively connecting these, where is the related mathematics, and what are the impacts on future SE practice?
- **<u>The Trust Phenomenon</u>**: The physical sciences accelerated progress in the last three centuries as they demonstrated means for not just the discovery and model-based expression of Nature's patterns, but also the managed awarding of trust in those patterns. What is the scientific basis of such group learning, and how does it impact the future practice of SE?

Learned models from STEM (~300 years) offer a most dramatic example of positive collaborative impact of effectively shared & validated models

- Effective Model Sharing:
  - We cannot view MBSE as mature if we perform modeling “from scratch”, instead of building on what we (*including others*) already know.
  - This is the basis of MBSE Patterns, Pattern-Based Systems Engineering (PBSE), and the work of the INCOSE MBSE Patterns Working Group.
  - S1 Patterns are built directly into future S2 project work of other people—effective sharing only occurs to extent it impacts future tasks performed by others.
  - This sharing may occur across individuals, departments, enterprises, domains, markets, society.
  - It applies not only to models of S1 (by S2), but also models of S2 (by S3).
- Effective Model Validation:
  - Especially when shared, models demand that we trust them.
  - This is the motivation for Model Validation, Verification, and Uncertainty Quantification (Model VVUQ) being pursued with ASME standards committees.
  - Effectiveness of Model VVUQ is essential to MBSE Maturity.
  - Because Model VVUQ adds significantly to the cost of a trusted model, MBSE Patterns are all the more important—the IP of enterprises, industries.

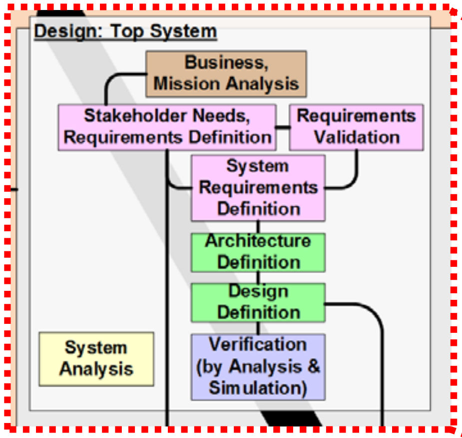
If we expect to use models to support more critical decisions, then we are placing *increased trust in models*:

- Critical financial, other business decisions
- Human life safety
- Societal impacts
- Extending human capability



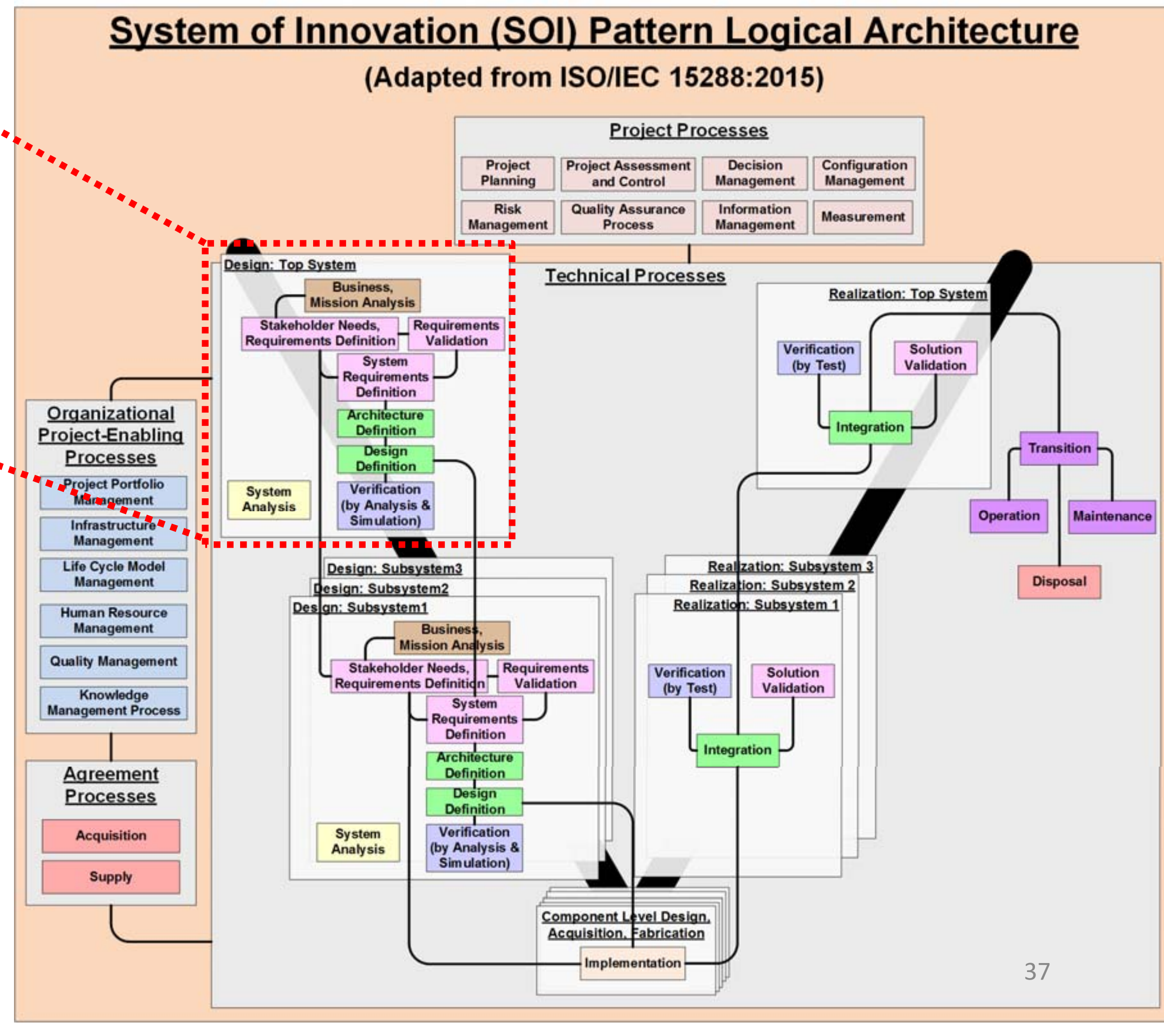
- Related risks require that we characterize the structure of that trust and manage it:
  - The Validation, Verification, and Uncertainty Quantification (VVUQ) *of the models themselves*.

Models trusted--for what <u>purposes</u>?

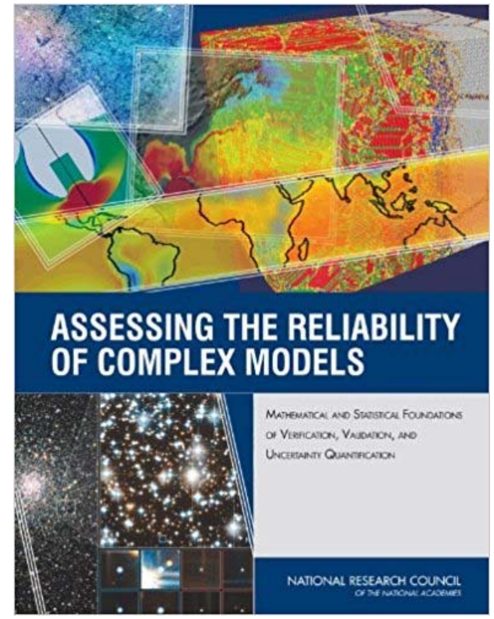


<u>*Potentially*</u> for any ISO 15288 processes:

- If there is a net benefit . . .
- Some more obvious than others.
- The INCOSE MB Transformation is using ISO 15288 framework as an aid to migration planning and assessment.
- Notice that ISO 15288 tells us all the things we do if we start with no knowledge of the target system; but…
- <u>*What about what we already know?*</u>



Quantitative Fidelity, including Uncertainty Quantification (UQ)



- There is a large body of literature on a mathematical subset of the UQ problem, in ways viewed as the heart of this work.
- But, some additional systems work is needed, and in progress, as to the more general VVUQ framework, suitable for general standards or guidelines.

General structure of uncertainty / confidence tracing:

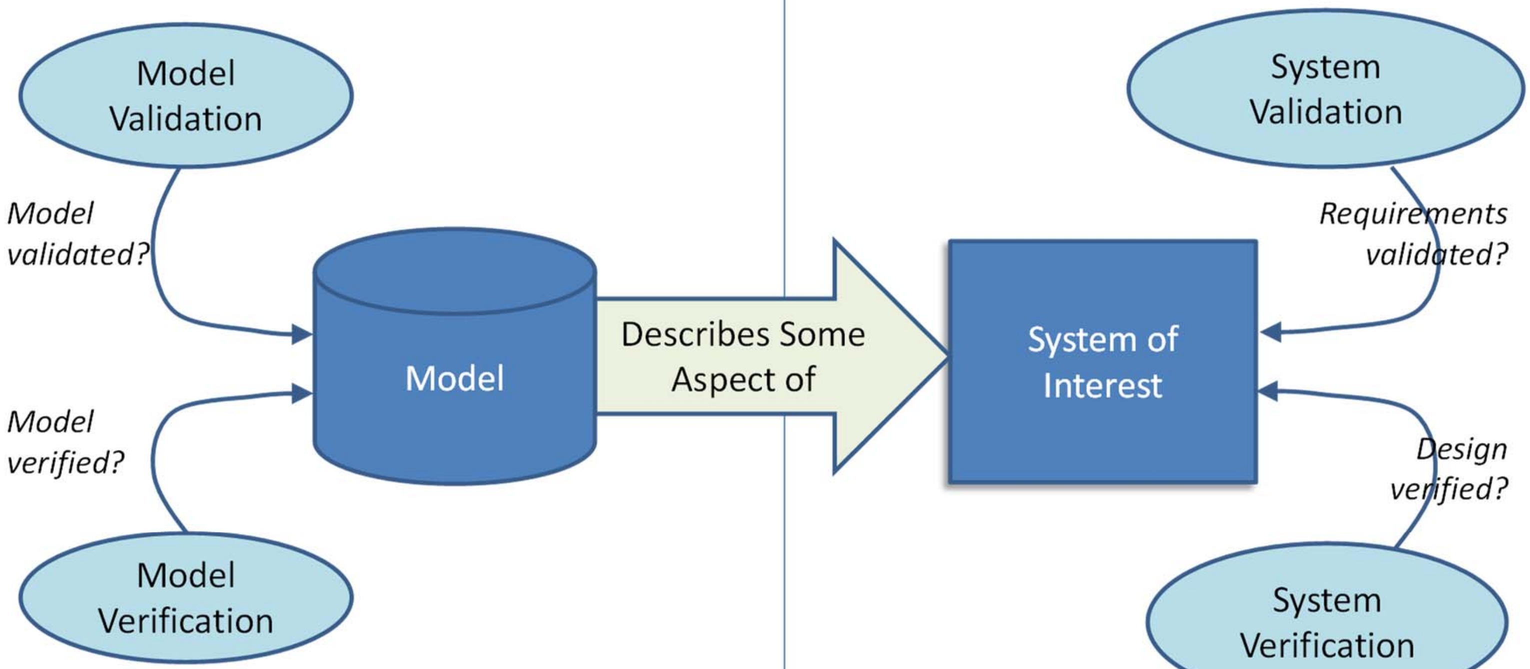
- Do the modeled external Interactions qualitatively cover the modeled Stakeholder Features over the range of intended subject system situations of interest?
- Quantify confidence / uncertainty that the modeled Stakeholder Feature Attributes quantitatively represent the real system concerns of the subject system Stakeholders with sufficient accuracy over the range of intended situation envelopes.
- Quantify confidence / uncertainty that the modeled Technical Performance Attributes quantitatively represent the real system external behavior of the subject system with sufficient accuracy over the range of intended situation envelopes.

V&V of *Models*, Per Emerging ASME Model V&V Standards

Does the Model adequately describe what it is intended to describe?

V&V of *Systems*, Per ISO 15288 & INCOSE Handbook

Do the System Requirements describe what stakeholders need?



Does the Model implementation adequately represent what the Model says?

Does the System Design define a solution meeting the System Requirements?

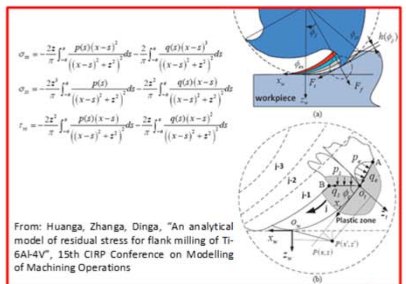
Don't forget: A model (on the left) <u>may</u> be used for system verification or validation (on the right!)

Related ASME activities and resources

- ASME, has an active set of teams writing guidelines and standards on the Verification and Validation of Computational Models.
  - Inspired by the proliferation of computational models (FEA, CFD, Thermal, Stress/Strain, etc.)
  - It could fairly be said that this historical background means that effort was not focused on what most systems engineers would call "system models"
- Also conducts annual Symposium on Validation and Verification of Computational Models, in May.
- To participate in this work, in 2016 the speaker joined the ASME VV50 Committee on behalf of INCOSE:
  - With the idea that the framework ASME set as foundation could apply well to systems level models; and . . .
  - with a pre-existing belief that system level models are not as different from discipline-specific physics models as believed by systems community.
- Also invited sub-team leader Joe Hightower (Boeing) to address the INCOSE IW2017 MBSE Workshop, on our related ASME activity.

Physics-Based Model

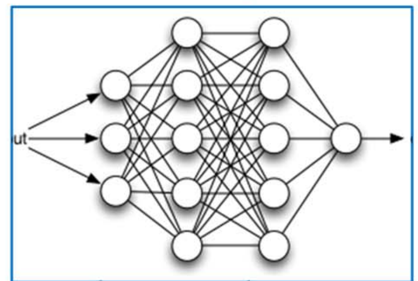
- Predicts the external behavior of the System of Interest, visible externally to the external actors with which it interacts.
- Models internal physical interactions of the System of Interest, and how they combine to cause/explain externally visible behavior.
- Model has both external predictive value and phenomena-based internal-to-external explanatory value.
- Overall model may have high dimensionality.



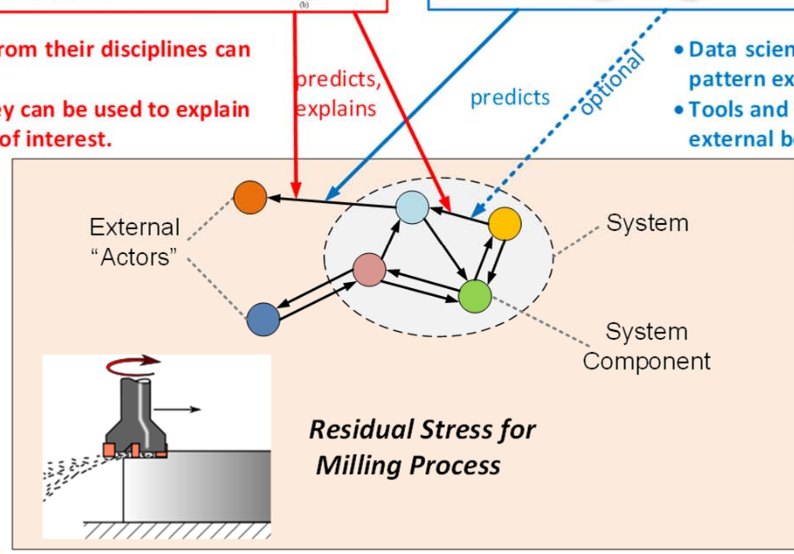
- Physical scientists and phenomena models from their disciplines can apply here.
- The hard sciences physical laws, and how they can be used to explain the externally visible behavior of the system of interest.

Data Driven Model

- Predicts the external behavior of the System of Interest, visible to the external actors with which it interacts.
- Model intermediate quantities may not correspond to internal or external physical parameters, but combine to adequately predict external behavior, fitting it to compressed relationships.
- Model has external predictive value, but not internal explanatory value.
- Overall model may have reduced dimensionality.

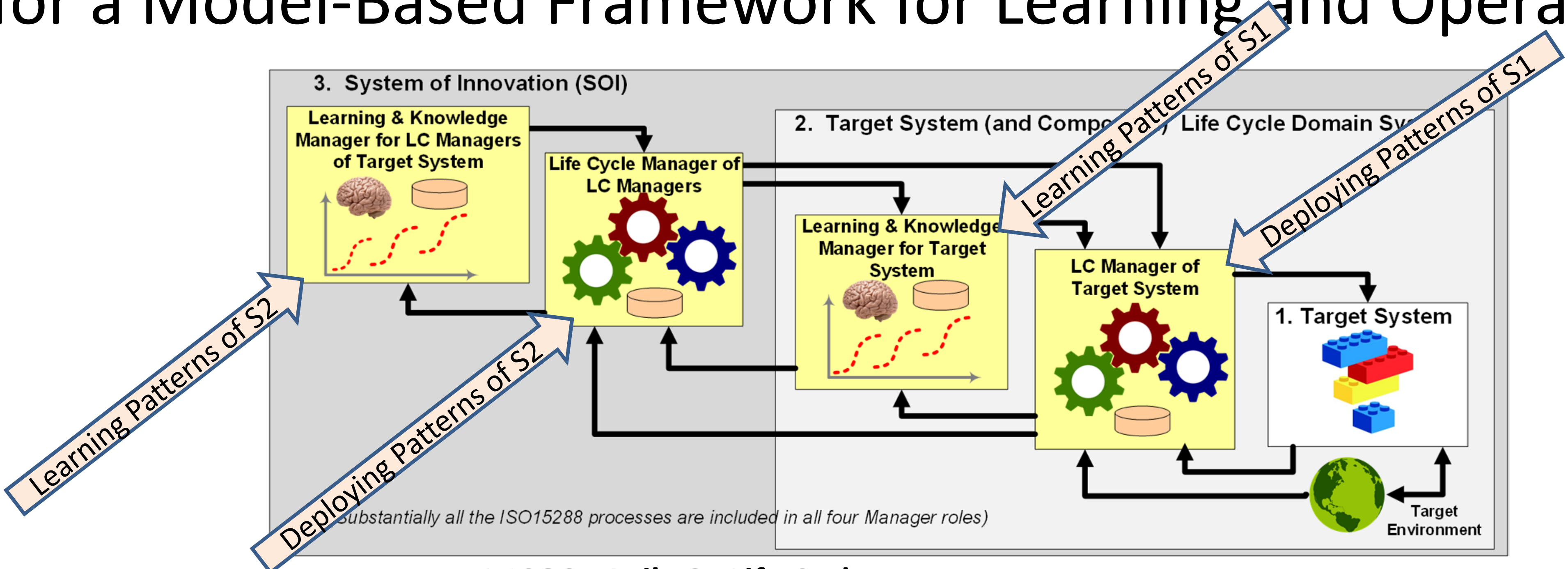


- Data scientists and their math/IT tools can apply here (data mining, pattern extraction, cognitive AI tooling).
- Tools and methods for discovery / extraction of recurring patterns of external behavior.



Real Target System Being Modeled

Increased Cost of Credibility of a Model: Creates Pressure for a Model-Based Framework for Learning and Operating



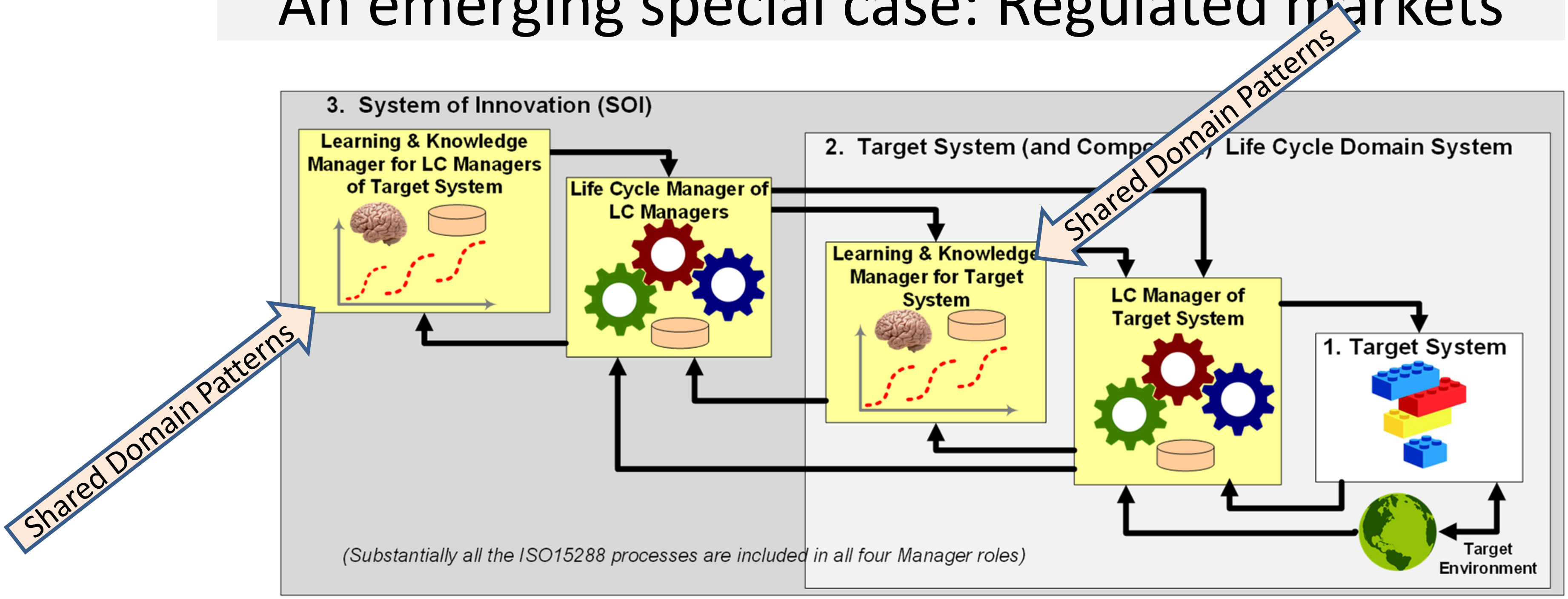
INCOSE Agile SE Life Cycle Management Pattern

System 1: The target system of interest (e.g., a product system)

System 2: The (ISO 15288) life cycle management systems for System 1, along with the rest of System 1's target operating and life cycle environment

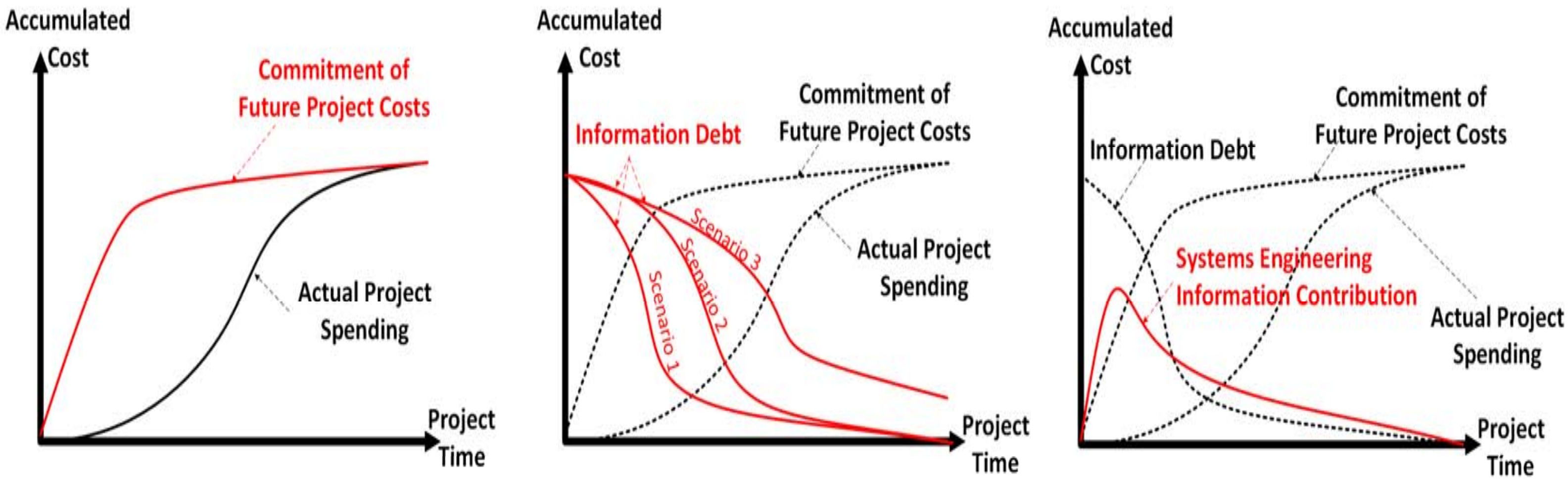
System 3: The life cycle management systems for System 2

An emerging special case: Regulated markets



- Trusted shared MBSE Patterns for <u>classes</u> of systems: Address rising cost of trusted models
- Configurable for vendor-specific systems, including proprietary aspects
- With Model VVUQ frameworks lowering the cost of model trust for increasingly complex and accelerating regulatory submissions and analyses
- Vision: Application to situations such as the Boeing 737 MAX design, analysis, submission (vision of V4 Institute, semantic technologies, etc.)

- Pattern data as IP:
    - Information Debt, not just Technical Debt, as a foundation of agile innovation
    - Patterns can be capitalized as financial assets under FASB
- “Patterns as capital” changes the financial logic of project level SE “expense”

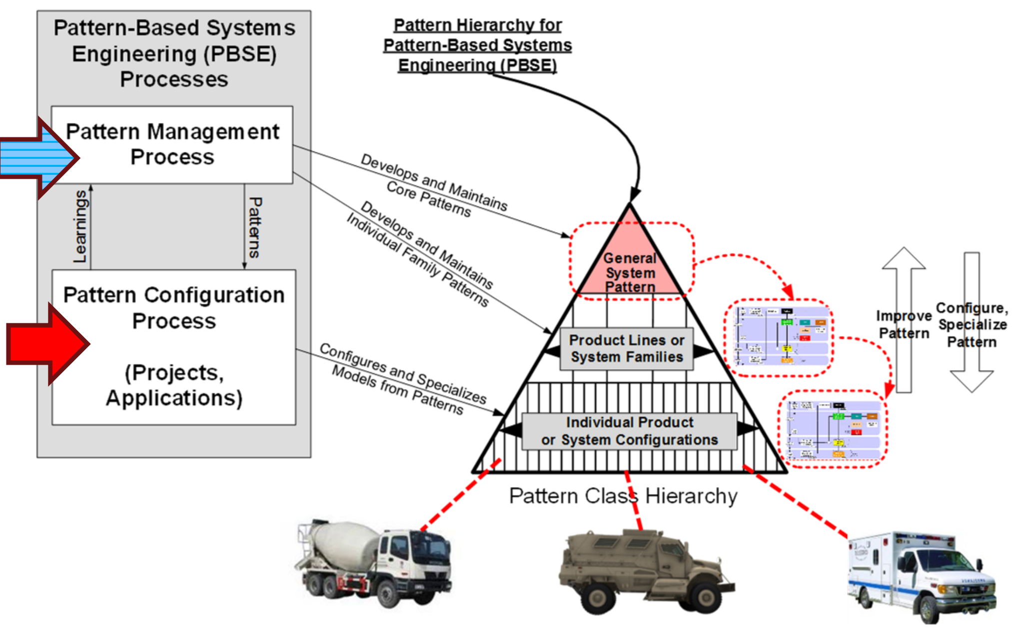


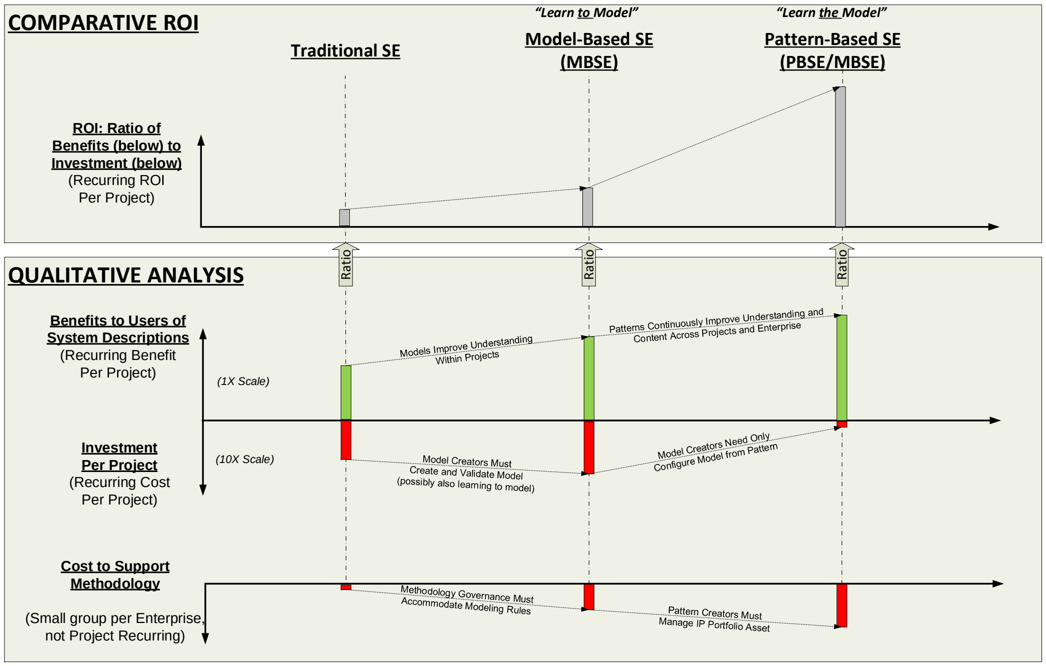
(a) When Project Costs Are Committed versus Incurred

(b) Information Debt is Reduced Over the Course of Project

(c) Systems Engineering Information Is Generated to Reduce Information Debt

Payoff: Rapidly Configuring Trusted Models from S*Patterns





- Generates high quality first draft models from patterns in 10% of the time and effort to generate "traditional" models of lower quality and completeness.
- Most planned S*Patterns take less than 90 days to generate to point of first use, via "Uncover the Pattern" (UTP) Project
- Thereafter, S*Pattern becomes the point of accumulation of future group learning--the "muscle memory" that is automatically consulted in each future project.

Cultural challenges

- Everyone / every project wants to build their own models:
  - Condemned to learning the same lessons, making the same mistakes, low-grade learning curves
  - Innovation with the brakes on
- Incommensurability of personal or local paradigms:
  - T. Kuhn on incommensurable frameworks in technical communities
  - Reference frameworks, ontologies, beliefs, world views
  - My way or our way?

Implications

- Learn about and apply the existing body of theory and practice for V&V of models.
- System models are part of this! Scientifically-based trust is not awarded just by convincing someone your model looks good.
- Increased V&V for critical models will raise the cost of those models
- This makes the use of trusted patterns more justifiable, and the sharing of patterns more attractive
- The effective learning location to place patterns is squarely in the path of project start-up, based on configuring project models from patterns
- VVUQ of models is connected to model intended uses, risks
- Consider joining related community activities of ASME Model V&V Committee, INCOSE Patterns Working Group, V4 Institute

1. The System Phenomenon: What is the “hard science” phenomenon of systems?
2. The Value Phenomenon: What is the engineering bridge to subjective value?
3. The Trust Phenomenon: How to award and exploit trust in critical models?

Q&A, Discussion

Reference Starting Points—Including Bibliographies

The System Phenomenon

http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:isss2018_07.24.2018_plenary_schindel_v1.2.7.pdf

http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:system_interactions--making_the_heart_of_systems_more_visible_v1.2.2.pdf

The Value Phenomenon

https://www.researchgate.net/publication/281688634_Systems_of_Innovation_II_The_Emergence_of_Purpose

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The Trust Phenomenon

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The INCOSE Patterns Working Group

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The INCOSE ASELCM (System of Innovation) S*Pattern

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