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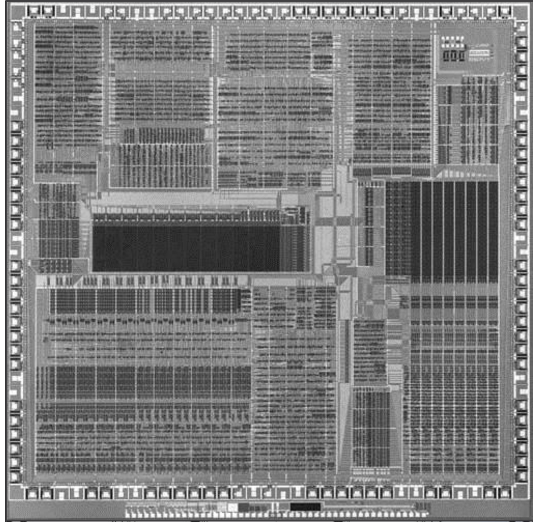
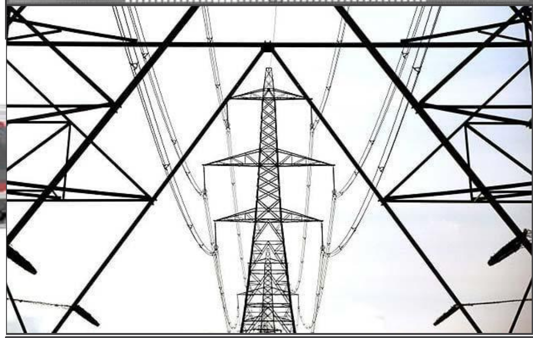
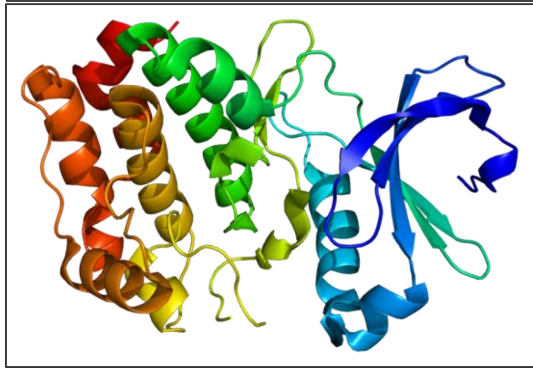
V1.2.2

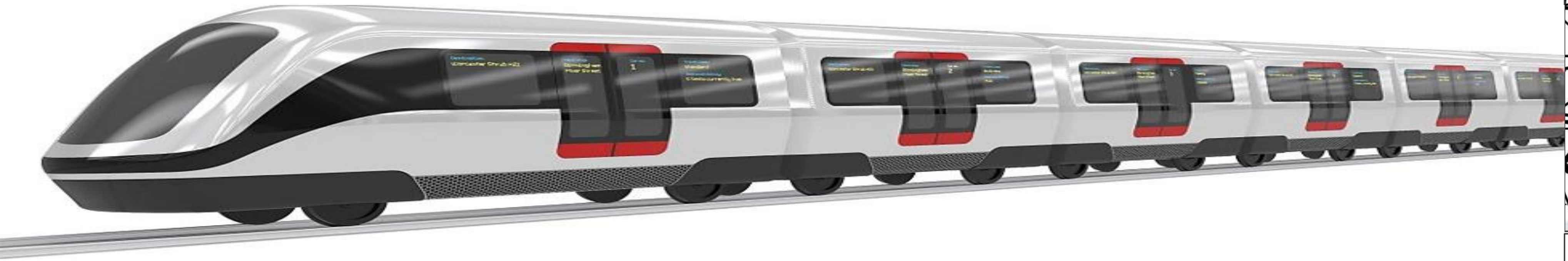
29th Annual INCOSE international symposium

Orlando, FL, USA
July 20 - 25, 2019









Impacts on SE Practice and Foundations: Model-Based System Patterns

www.incose.org/symp2019

Abstract

- The INCOSE MBSE Patterns Working Group pursues the use of model-based, configurable, re-usable representations of systems, as encodings of knowledge about general system families, product lines, or other recurring similar systems.
- After practicing the related approach for two decades, we have seen many helpful benefits on systems engineering practice over diverse types of systems.
- The MBSE Patterns perspective also has deep connections to the history of the physical sciences, and offers insights on how Systems Engineering's scientific and mathematical foundations can be strengthened by existing history, and better connected to foundations of existing and emerging engineering disciplines.
- This presentation briefly reviews both pragmatic impacts on Systems Engineering practice and on the scientific and mathematical foundations of Systems Engineering and Systems Science.
- Implications are summarized for Systems Practitioners, Educators, and Researchers.

Contents

- INCOSE MBSE Patterns Working Group
- Patterns in Engineering and Science
- S*Metamodel, S*Models, S*Patterns
- Pragmatic: Results in Engineering Practice
- Theoretic: Phenomena Key to Strengthened Foundation for SE
- Implications for Practitioners, Educators, and Researchers
- Q&A

- References

INCOSE MBSE Patterns Working Group

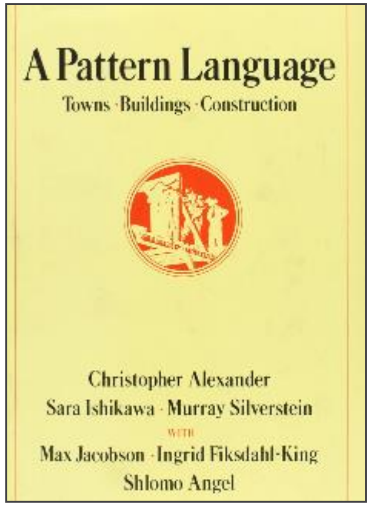
- This WG is concerned with *model-based expression of recurring patterns in and across systems*.
- Active since 2013--initially as INCOSE MBSE Patterns Challenge Team, then as MBSE Patterns Working Group.
- Meetings at IS2019: Sunday pm and Monday pm.

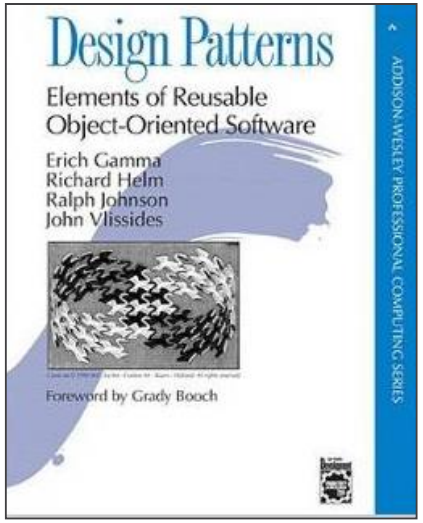
Patterns in Science and Engineering

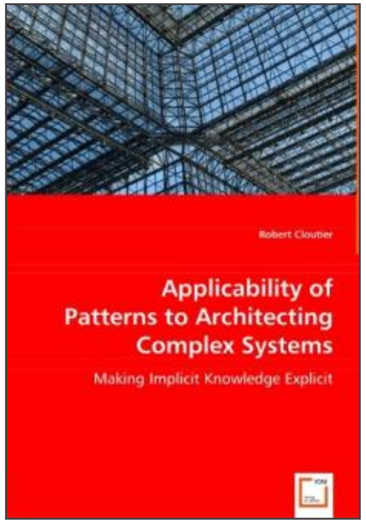
- In most uses of the term, “patterns” are recurrences or regularities (across time, space, etc.) which have a fixed (recurring) portion and a variable (parameterized or configurable) portion:
  – Aircraft, beetles, thunderstorms, customers, automobiles, adversaries, seasons, beers, planets, airports, engineering processes and tools, . . .
- In the history of the physical sciences, study of observed patterns in Nature led to discovery of physical laws, leading to related abilities to predict, analyze, understand, and engineer.

Different historical “Engineering “Patterns”

- The term “pattern” appears famously, repeatedly, and *in different ways*, in the history of Engineering, such as civil architecture, software design, and systems engineering:



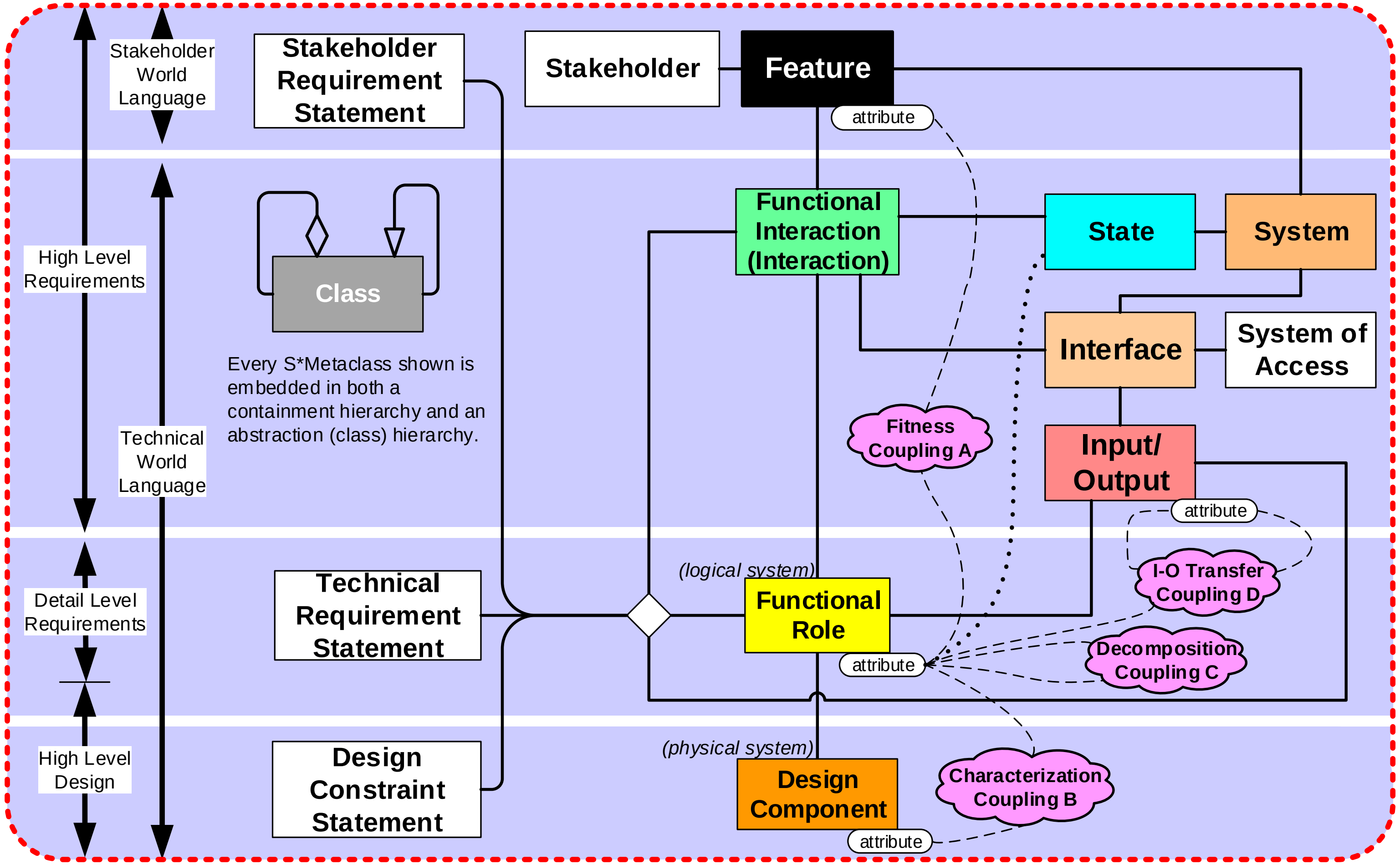




- However, *the patterns of interest to the INCOSE Patterns WG* are, more narrowly:
  - Model-Based (not prose templates) and formally configurable
  - Based on a specific minimal metamodel (model framework) grounded in physical science
  - Are “whole system” frameworks, not just component or subsystem patterns
  - Include all information of interest in life cycles, not just architectural frameworks or ontologies
  - Referred to as S*Patterns for reasons we will see

S*Metamodel, S*Models

- **S*Metamodel**: The *smallest set* of modeled concepts found necessary for purposes of engineering & science, over system life cycles.
- Not specific to any modeling tool or language; instead mapped to each, creating a transportable universal underlying representation.
- **S*Model**: Any model, in any language or tool, consistent with the S*Metamodel.
- S* short for "Systematica"



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

Examples:
http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:pbse_tutorial_glrc_2016_v1.7.4.pdf

S*Metamodel, S*Models

What Is the Smallest Model of a System?

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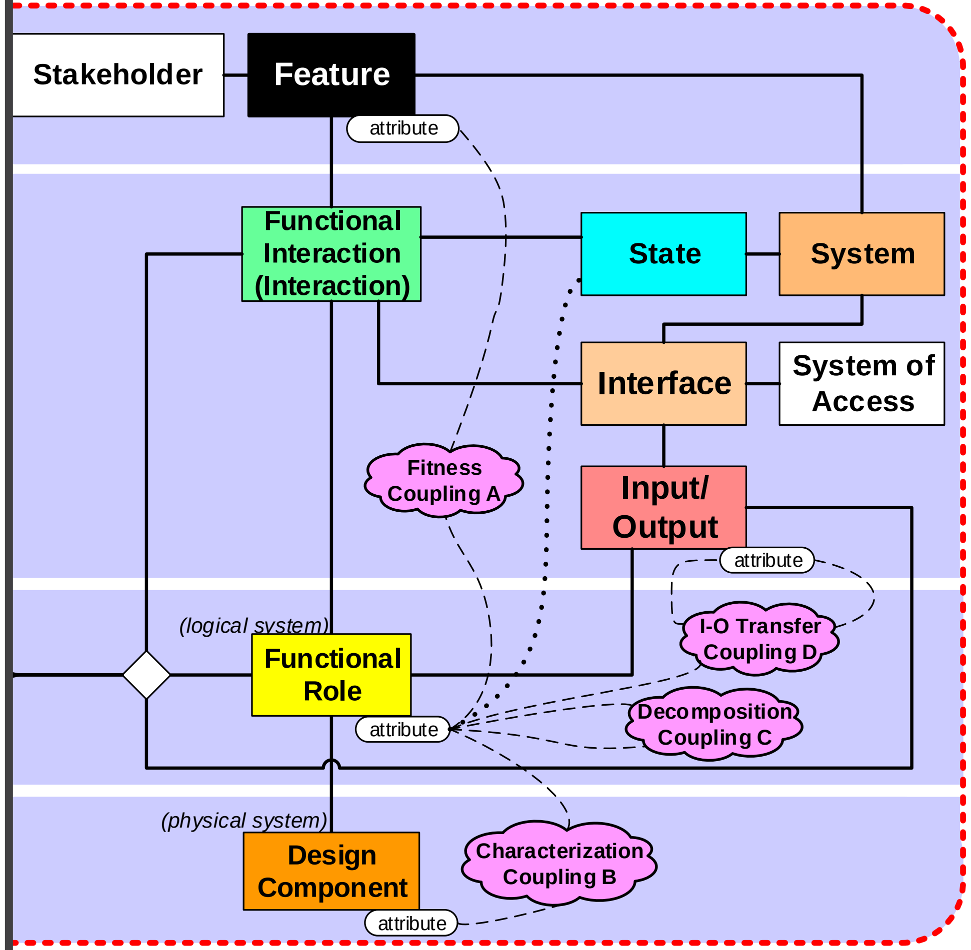
Abstract. How we represent systems is fundamental to the history of mathematics, science, and engineering. Model-based engineering methods shift the nature of representation of systems from historical prose forms to explicit data structures more directly comparable to those of science and mathematics. However, using models does not guarantee simpler representation--indeed a typical fear voiced about models is that they may be too complex.

Minimality of system representations is of both theoretical and practical interest. The mathematical and scientific interest is that the size of a system's "minimal representation" is one definition of its complexity. The practical engineering interest is that the size and redundancy of engineering specifications challenge the effectiveness of systems engineering processes. INCOSE thought leaders have asked how systems work can be made 10:1 simpler to attract a 10:1 larger global community of practitioners. And so, we ask: What is the smallest model of a system?

Introduction and Background: Size Matters!

Representation Size, Purpose, Traditions. This paper discusses possible (and potentially least) upper bounds on the sizes of effective representations of systems, *for the purposes of systems engineering*. Compared to traditional systems engineering approaches, it draws more directly on scientific traditions for representing behavior as physical interaction. Systems engineering is still young, and its connections to supporting sciences is still evolving rapidly.

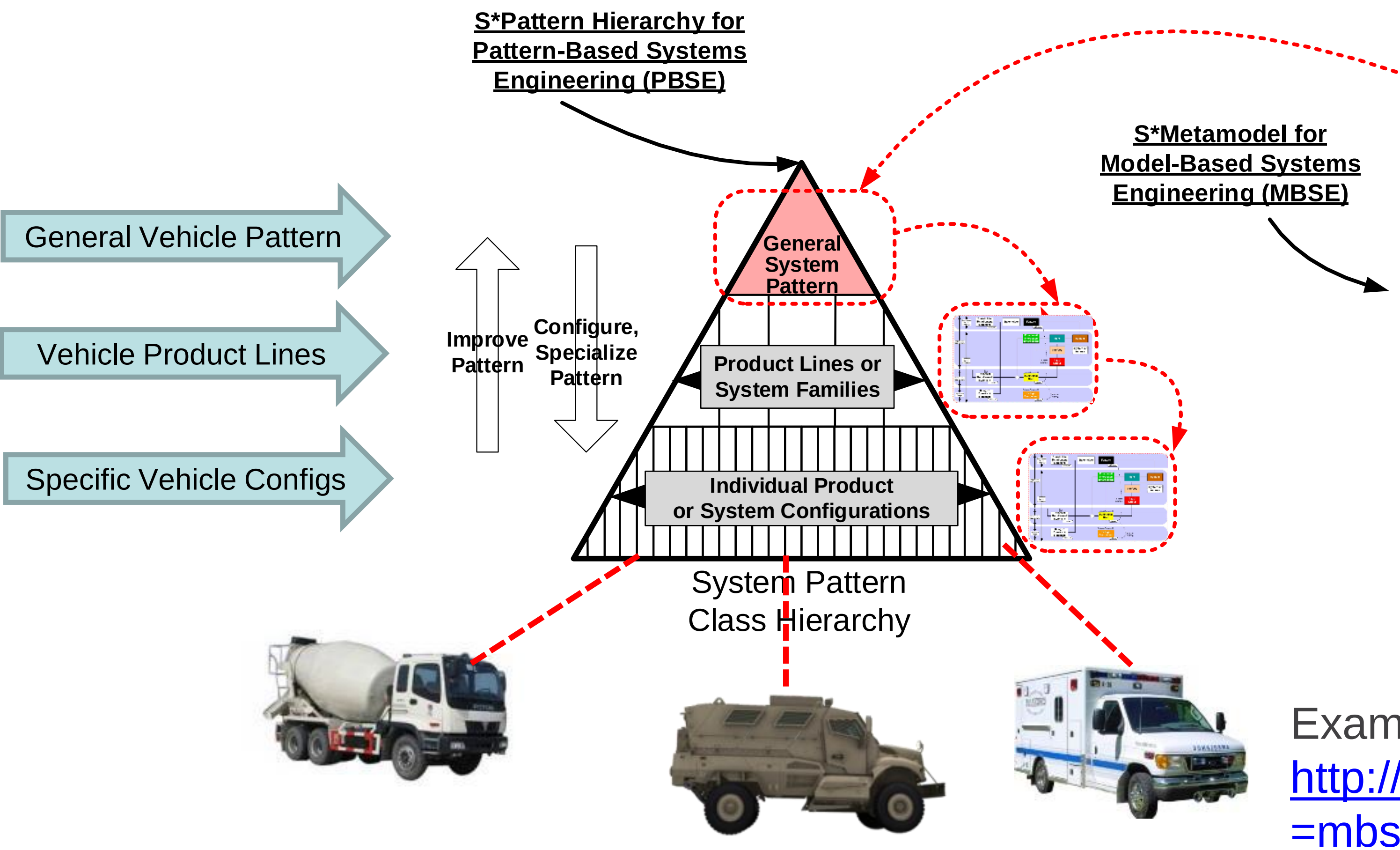
Language and Compression. This subject may appear to be related to the language used to

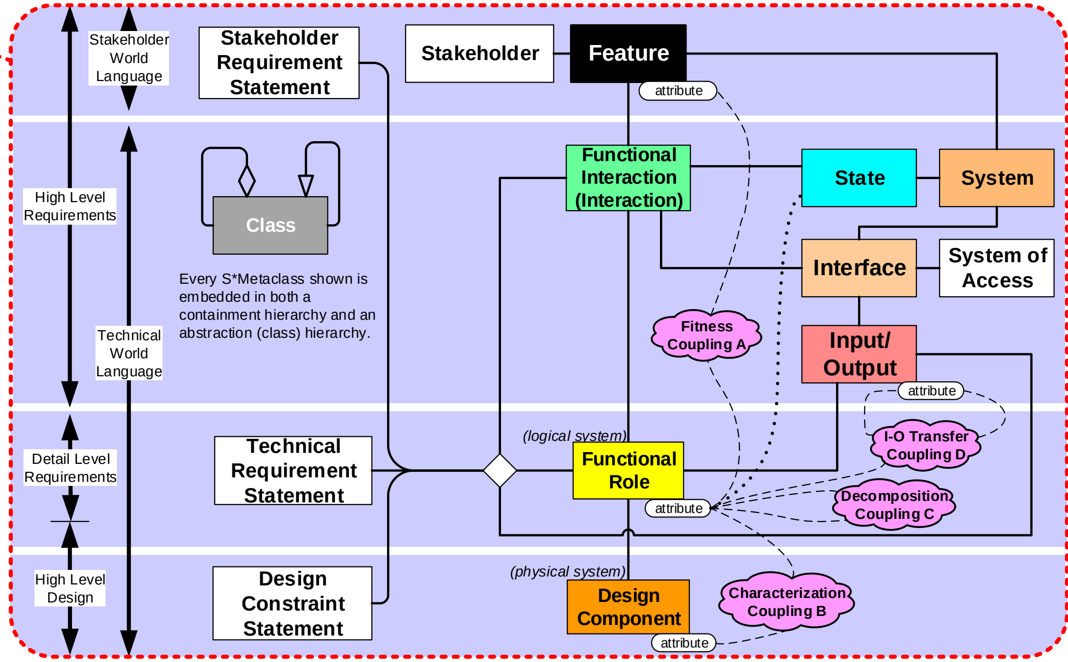


informal summary pedagogical diagram
Metamodel includes additional details.)

S*Patterns

- An **S* Pattern** is a configurable, re-usable S* Model. It is an extension of the idea of a Platform (which is a configurable, re-usable design) or Enterprise / Industry Framework.
- The Pattern includes not only physical Platform information, but all the extended system information (e.g., pattern configuration rules, requirements, risk analysis, design trade-offs & alternatives, decision processes, etc.):





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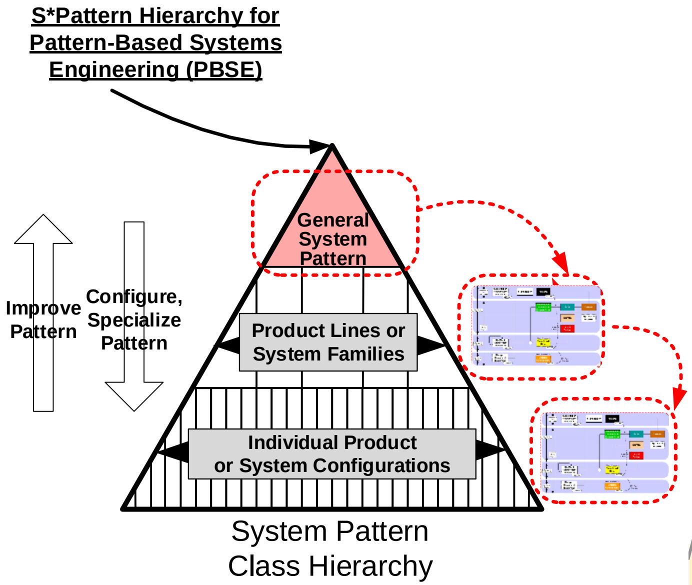
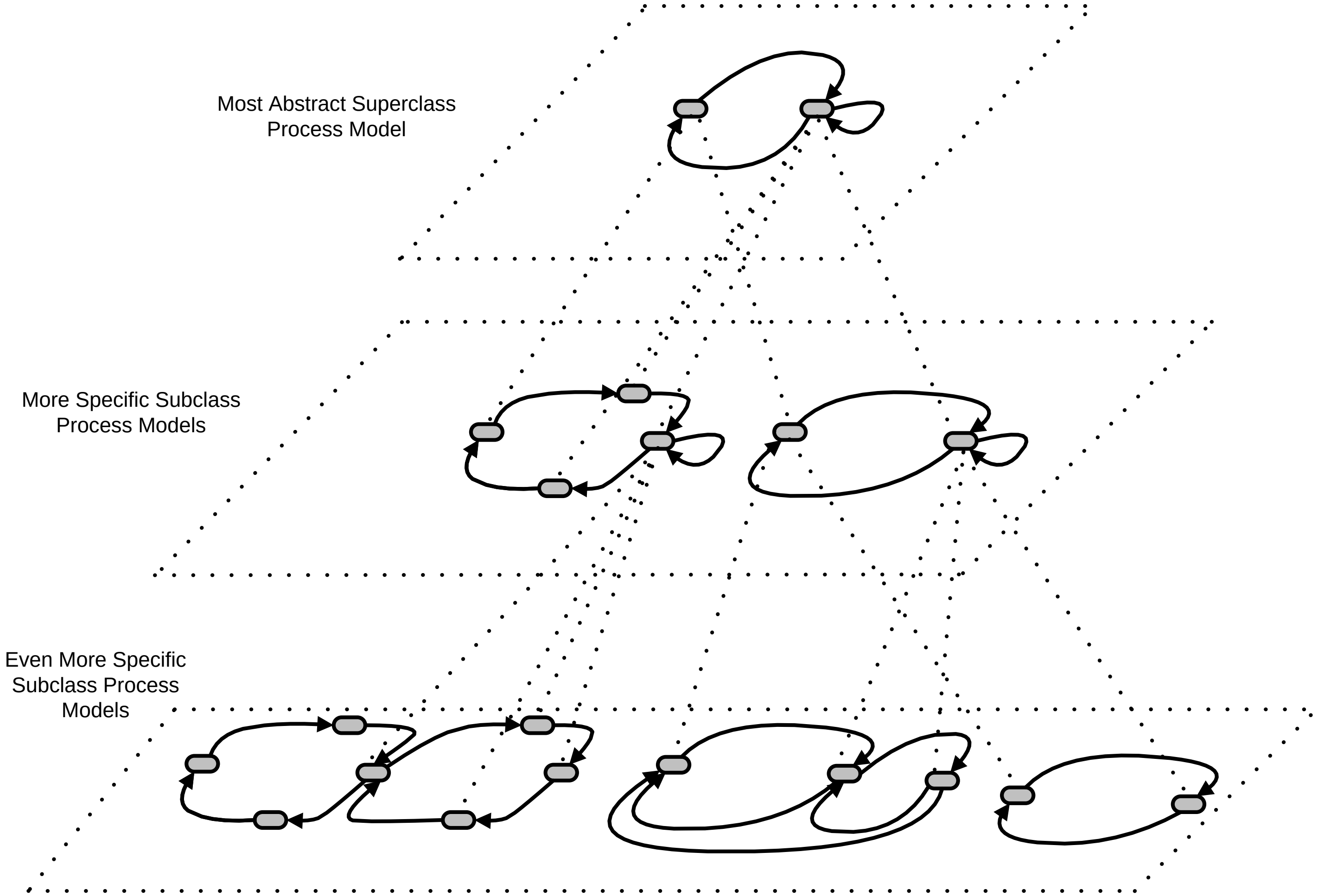
(formal S*Metamodel includes additional details.)

Examples:
http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:pbse_tutorial_glrc_2016_v1.7.4.pdf

S*Patterns: Gestalt Rules

- Graph-based rules that express the *system holistic* aspect of conformance of a specialized system S*Model to a generalized system S*Pattern.
- Applies to all S*Metaclasses and S*Metarelationships.
- State Machine example shown.



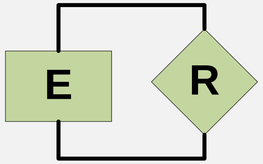


Emergence of Patterns from Patterns: S*Pattern Class Hierarchy

More General

Definition of **Relational Modeling Paradigm**

Entity-Relationship Paradigm

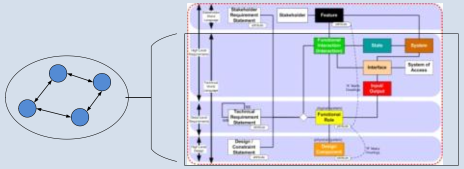


E=Entity
R= Relationship

Structured or unstructured semantic web

Minimal System S*Metamodel: Definition of (Elementary) System, Material Cause

S*Metamodel Core



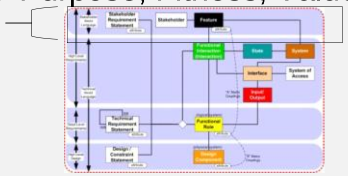
Core S*Metamodel

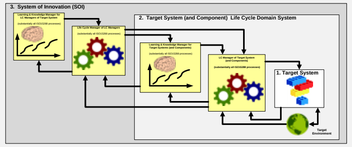
Smallest model of a system, for engineering or science

Emergence & Definition of **System of Innovation**, Fitness, Value, Purpose, Stakeholders, Agility, Final Cause, Formal Cause, Efficient Cause, Intelligence, Management, Science, Living Systems

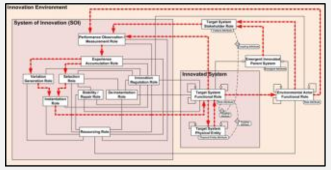
EI Pattern, SOI Pattern, Fitness, Value

S*Purpose, Fitness, Value

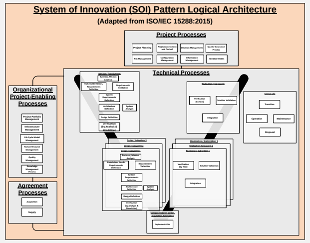




Agile Sys Life Cycle Pattern



System of Innovation Pattern



ISO 15288 System Life Cycle Mgmt Pattern

Emergence & Definition of **Domain Specific Systems**

Domain Specific Pattern

- Terrestrial Vehicle Domain Pattern
- Manufacturing System Pattern
- Product Service System Pattern
- Space Tourism Pattern
- Electrical Power Domain Pattern
- Aircraft Flight Control Pattern
- Medical Device Pattern
- Distribution System Pattern
- Socio-Technical Pattern
- Critical Infrastructure Domain Pattern

More Specific

Pragmatic: Results in Engineering Practice

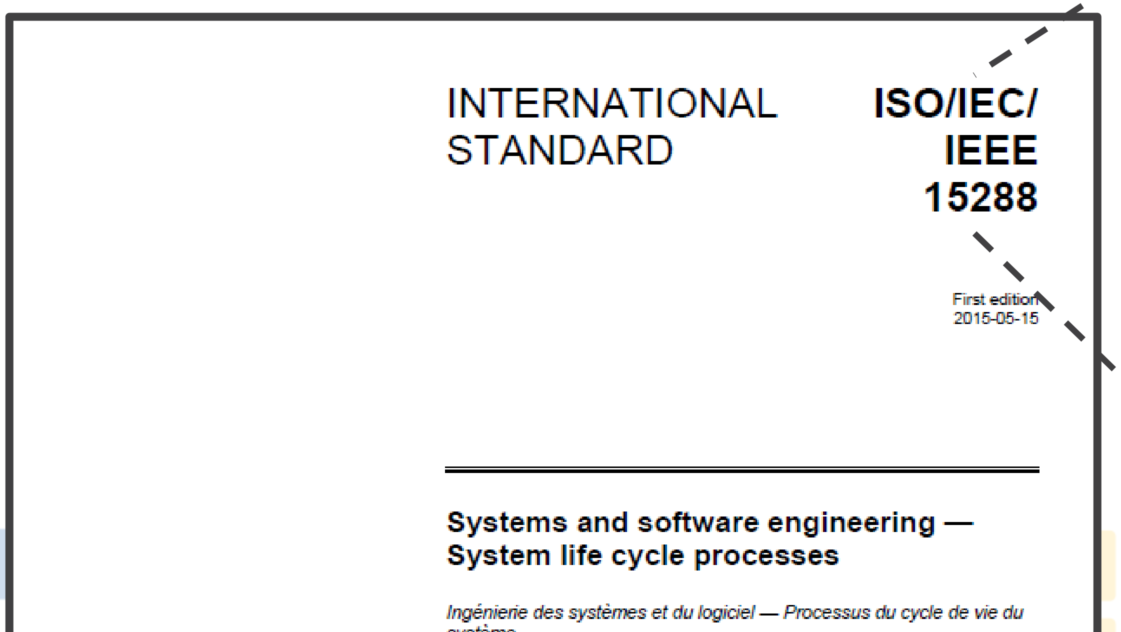
Sampling: Twenty years of patterns, across diverse domains, reducing time, effort, risk

Medical Devices Patterns	Construction Equipment Patterns	Commercial Vehicle Patterns	Space Tourism Pattern
Manufacturing Process Patterns	Vision System Patterns	Packaging Systems Patterns	Lawnmower Product Line Pattern
Embedded Intelligence Patterns	Systems of Innovation (SOI) Pattern	Consumer Packaged Goods Patterns	Orbital Instrument Pattern
Product Service System Patterns	Product Distribution System Patterns	Plant Operations & Maintenance Patterns	Oil Filter Product Line Pattern
Life Cycle Management System Patterns	Production Material Handling Patterns	Engine Controls Patterns	Military Radio Systems Pattern
Agile Systems Engineering Life Cycle Pattern	Transmission Systems Pattern	Precision Parts Production, Sales, Engineering Pattern	Higher Education Experiential Pattern
Trusted Model Repository Pattern	Interface Families Pattern	Model VVUQ Pattern	Generalized Bracket Pattern

An engineering question leading to MBSE patterns interest

- The SE “Vee” diagram, ISO 15288, the *INCOSE SE Handbook*, numerous textbooks, and many other guides from NASA, DoD, and defense and commercial enterprises, spell out at great length “how to do Systems Engineering”.
- These good resources appear to describe all the things we would need to do if we did not have any prior knowledge of a system or its domain, to learn about the mission situation, environment, stakeholder, discover requirements, technologies, etc.
- But, on one subject they are relatively silent:

  “What about what we already know?”

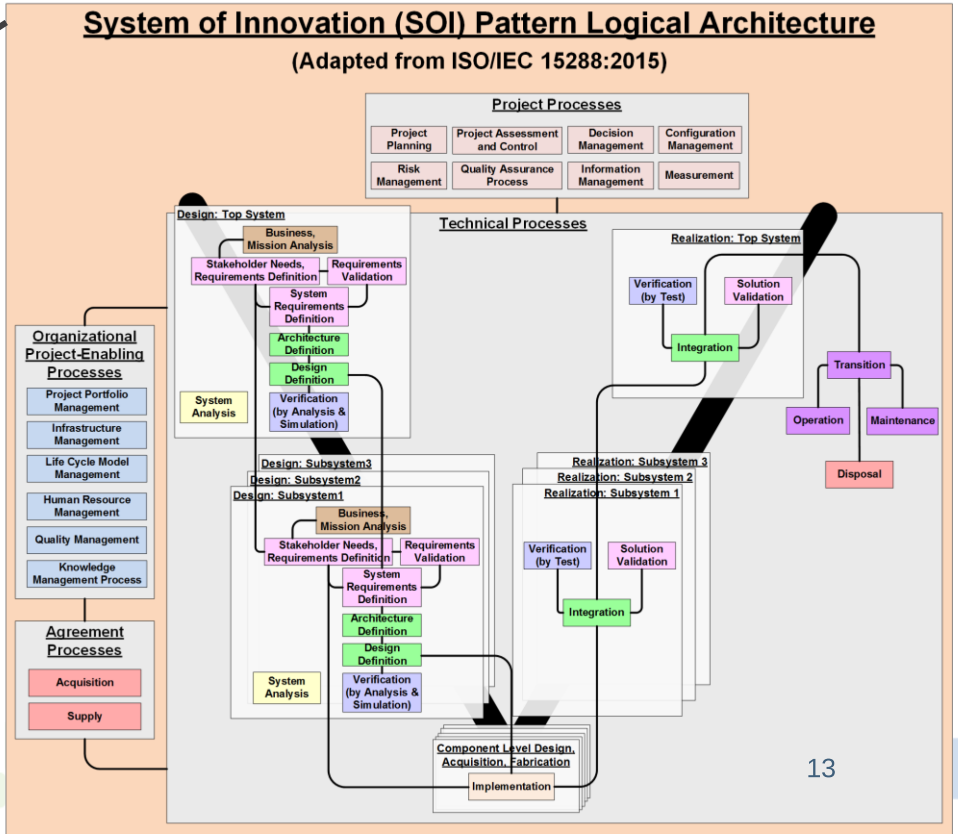

INTERNATIONAL STANDARD

ISO/IEC/ IEEE 15288

First edition 2015-05-15

Systems and software engineering — System life cycle processes

Ingénierie des systèmes et du logiciel — Processus du cycle de vie du système



Theoretic: Three Phenomena Key to Strengthening Foundations for SE

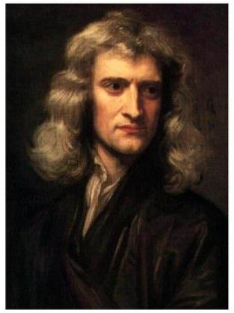
Today's Discussion

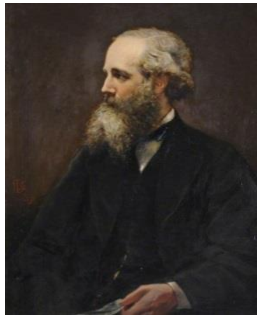
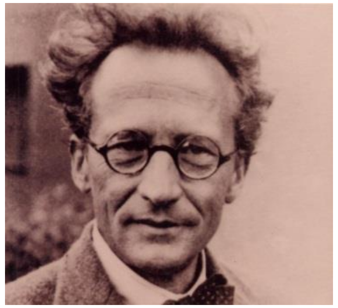
- **The System Phenomenon**: Each of the traditional physical sciences is based on a specific physical phenomenon (mechanical, electrical, chemical etc.) and related mathematical formulation of physical laws and first principles. What is the equivalent "hard science" phenomenon for systems, where is 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-Based 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.



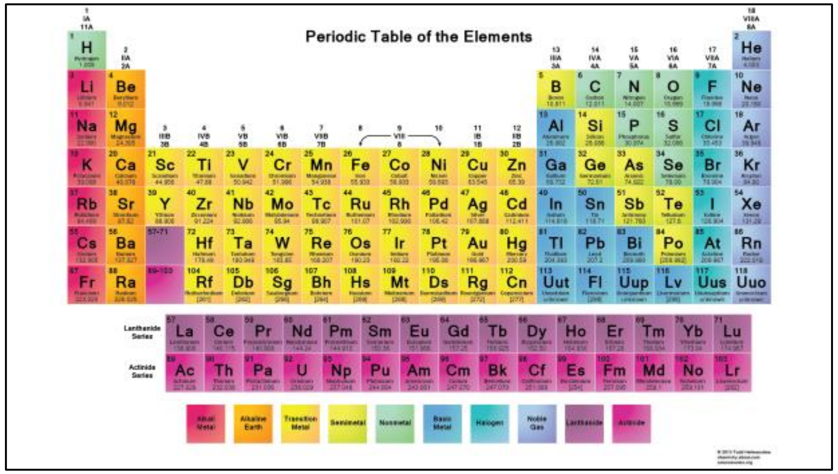
Traditional Perspective on SE

- Specialists in individual engineering disciplines often argue their fields are based on:
  - "real physical phenomena",
  - "physical laws" based in the "hard sciences", and first principles, . . .
- . . . sometimes also arguing that Systems Engineering lacks the equivalent phenomena-based theoretical foundation.

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

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

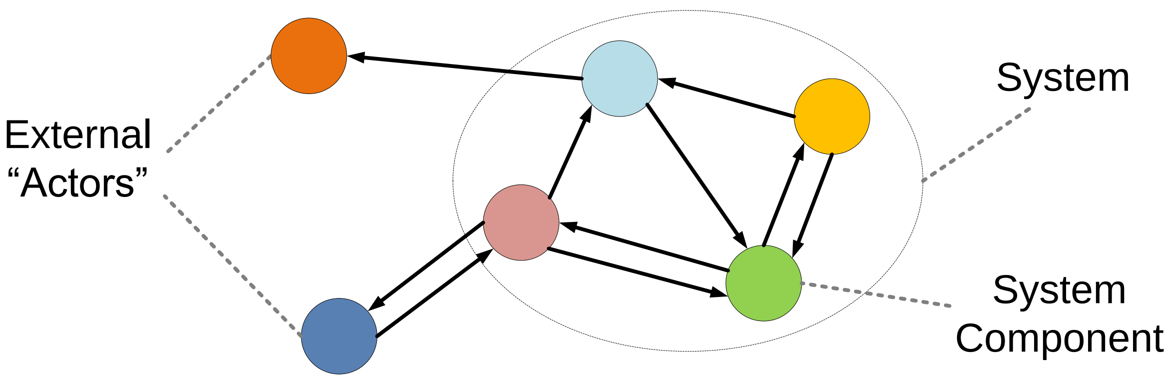
$$H(t)|\psi(t)\rangle = i\hbar \frac{\partial}{\partial t}|\psi(t)\rangle$$

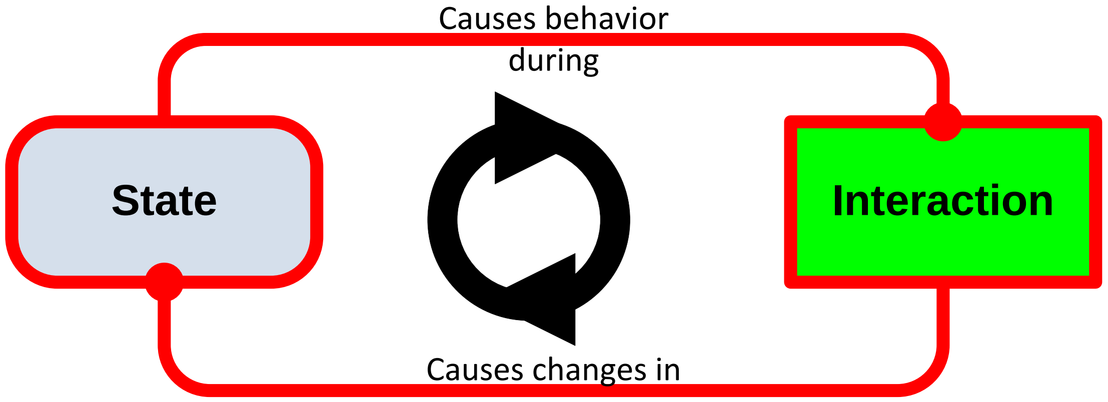


- Instead, Systems Engineering is sometimes viewed as:
  - Emphasizing process and procedure in its literature
  - Critical thinking and good writing skills
  - Organizing and accounting for information
  - Taking a holistic view
  - Integrating the work of the other engineering disciplines and stakeholder needs
- But not based on an underlying "hard science" like other engineering disciplines

Patterns Push Back: Formalizing System Representations

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

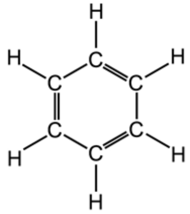


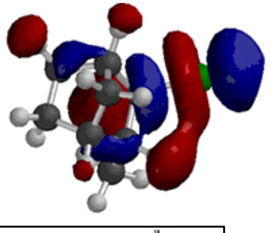


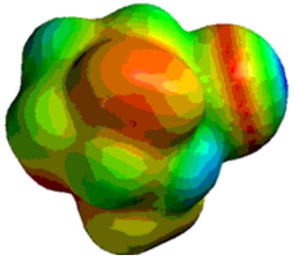
- By “interacting” we mean the exchange of energy, force, material, or information (all of these are “input-outputs”) between system components, . . .
- . . . through which one component impacts the state of another component.
- By “state” we mean a property of a component that impacts its input-output 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.

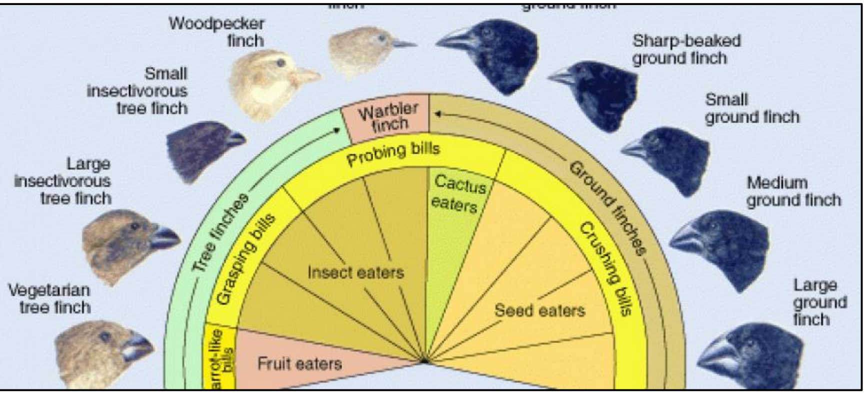
Patterns: At the heart of scientific laws

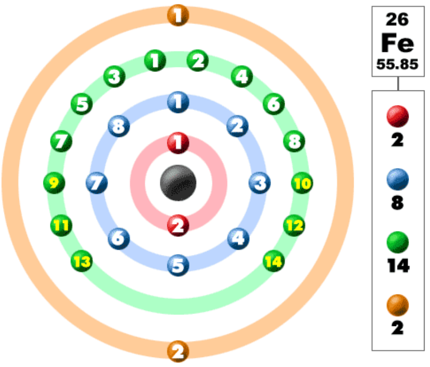
- All "patterns" are recurrences, having both fixed and variable aspects.
- The heart of physical science's life-changing 300 year success in prediction and explanation lies in recognition, representation, exploitation of recurring patterns.
- Noether's Theorem & Hamilton's Principle: Substantial math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

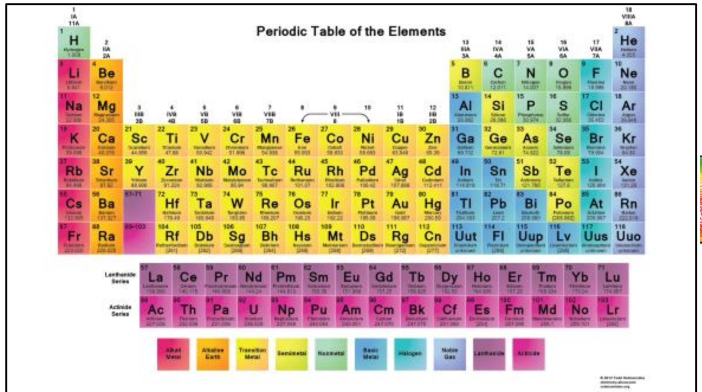


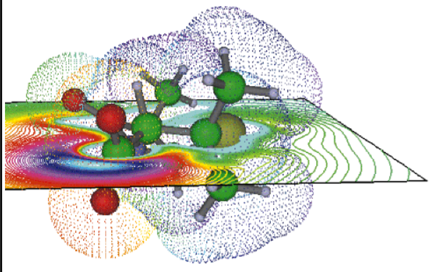








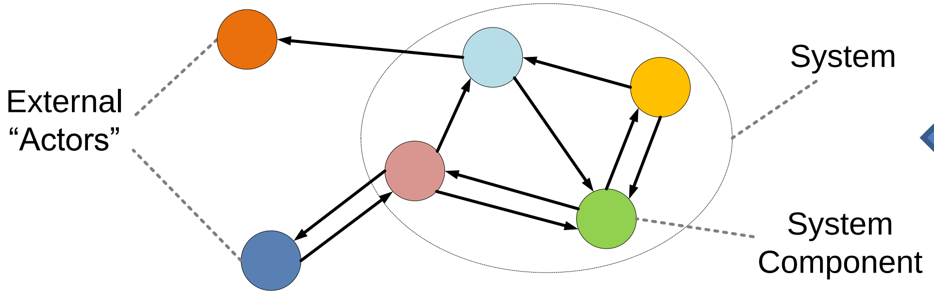




The System Phenomenon

- Phenomena of the hard sciences in all instances occur in the context of special cases of the following "System Phenomenon":
  - *behavior emergent from the interaction of behaviors (phenomena themselves) a level of decomposition lower.*
- For each such phenomenon[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] as inductive ladder)

- Reduced to simplest forms, the resulting equations of motion (or if not solvable, simulated/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. See later.

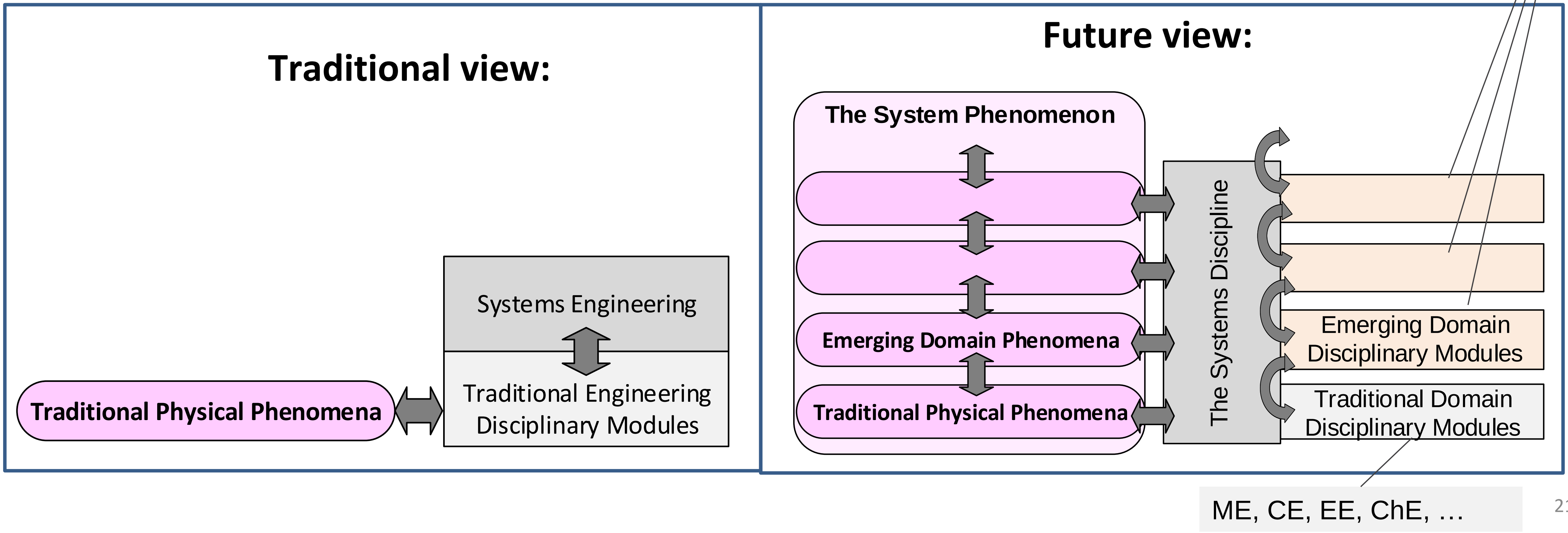
The System Phenomenon: Conclusion

- Each of the so-called "fundamental" phenomena-based laws' mathematical expression (Newton, Maxwell, Schrodinger, et al) is derivable from the above—as shown in many discipline-specific textbooks.
- 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 Planck 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!
  - This opens a new perspective on how Systems Engineering and Systems Science can relate to the other, better-known disciplines, as well as future domains . . .

The System Phenomenon and its supporting mathematics (Hamilton et al) provide the inductive ladder explaining theory of each new level in terms of the previous:

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



Max Planck on Hamilton's Principle (aka Principle of Least Action)

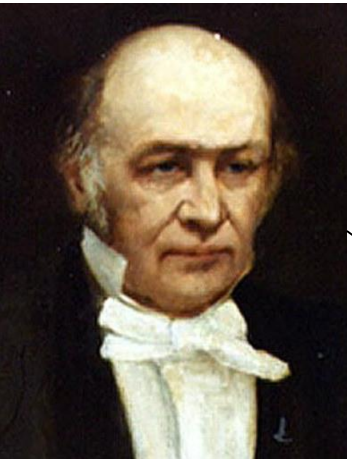
"It [science] has as its highest principle and most coveted aim the solution of the problem to condense all natural phenomena which have been observed and are still to be observed into one simple principle, that allows the computation of past and more especially of future processes from present ones. ...Amid the more or less general laws which mark the achievements of physical science during the course of the last centuries, the principle of least action is perhaps that which, as regards form and content, may claim to come nearest to that ideal final aim of theoretical research."

Max Planck, as quoted by Morris Kline, *Mathematics and the Physical World* (1959) Ch. 25: From Calculus to Cosmic Planning, pp. 441-442

Mathematics for the System Phenomenon: Building on Hamilton's Principle

- The System Phenomenon is a more general pattern than the mathematics of the original Hamilton's Principle :
  – Reviewing the conceptual framework of the System Phenomenon should convince you that it is much more general in scope than the setting for the original formulation of Hamilton's Principle (continuous, conservative phenomena).
  – Sure enough, more generalized mathematical treatments were discovered later, and in one important case earlier.
  – It was remarkable (to Max Planck and many others) that the Principle of Least Action was already sufficient to provide the mathematics from which can be derived the fundamental equations of all the major branches of physics…but...
- We are interested in engineering of more general types of systems, and...
- The more general Interaction model framework of the Systems Phenomenon is further supported by all the following later mathematical constructions and their discoverers . . .

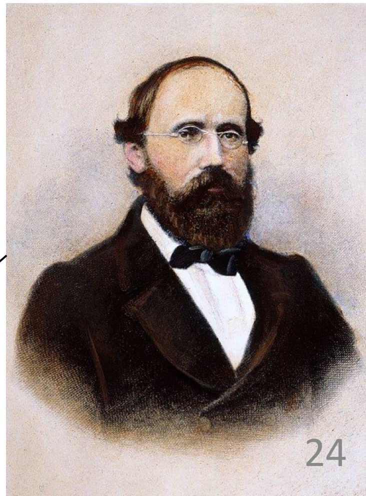
The System Phenomenon, Building on Hamilton's Principle



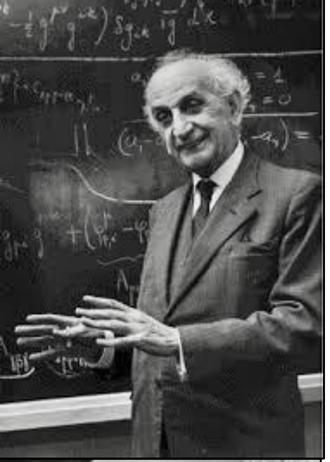
- **<u>Hamilton's Principle</u>**: Was already strong enough to generate all the fundamental phenomena of physics, from Newton through Feynman

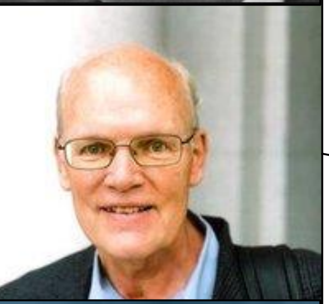
- **<u>Noether's Theorem</u>**: Deeper insight into the connection of Hamilton's principle to Symmetry and Conservation Laws

- **<u>D'Lambert's Principle</u>**: Older than Hamilton, but wider in scope than Hamilton's Principle, adding non-holonomic constraints, dissipative systems



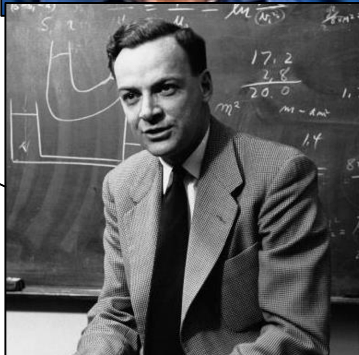
- **<u>Bernhard Riemann</u>**: Embedded Manifold spaces further generalize representation of complex dynamics.





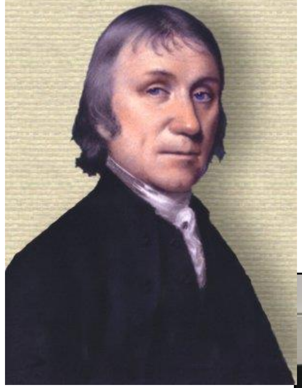

The System Phenomenon,
Building on Hamilton’s Principle



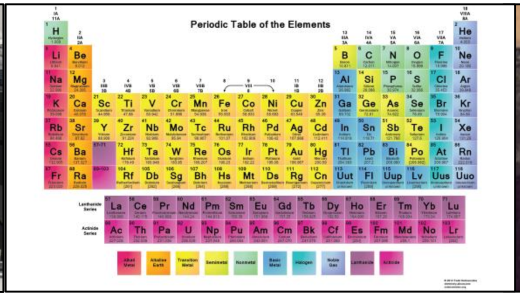
- **Cornelius Lanczos**: Master elucidator of Analytical Mechanics
- **Prigogine, Sieniutycz, Farkas**: Irreversible and large scale thermodynamic systems
- **JE Marsden**, **A Bloch**, **Marston Morse**: Non-Holonomic Control Systems, Discrete Mechanics; Symbolic Dynamics, Discrete Hamilton’s Principle; Discrete Noether’s Theorem
- **Ed Fredkin**, **Charles Bennett**, **Tomas Toffoli**, **Richard Feynman**: Information Systems and Automata

Historical Example 1: Chemistry

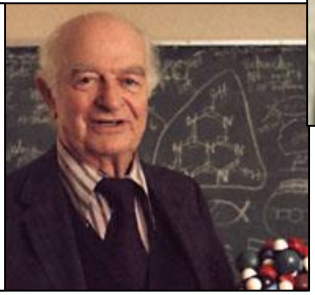


Priestley : Oxygen

Modern Chemist



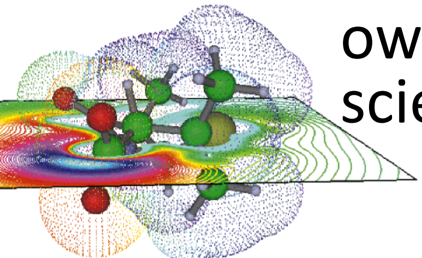
Periodic Table of the Elements

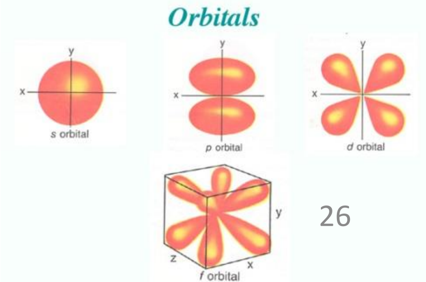


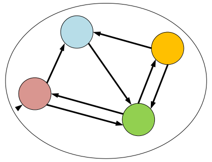
Pauling: Chemical Bond

Mendeleev: Periodic Table

- Chemists, and Chemical Engineers, justifiably consider their disciplines to be based on the “hard phenomena” of Chemistry:
  - Chemical Bonds, Chemical Reactions, Reaction Rates, Chemical Energy, Conservation of Mass and Energy.
- But, those chemical properties and behaviors are emergent consequences of <u>interactions</u> that occur between atoms’ orbiting electrons (or their quantum equivalents; also the rest of the atom).
- These lower-level <u>interactions</u> give rise to <u>patterns</u> that have their own higher-level properties and relationships, expressed as “hard science” laws.







So . . .

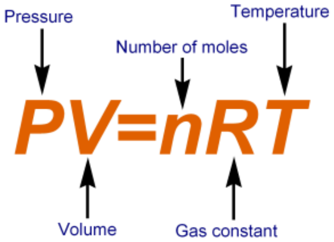
- The "fundamental phenomena" of Chemistry, along with the scientifically-discovered / verified "fundamental laws / first principles" are in fact . . .
- Higher level emergent <u>system patterns</u>

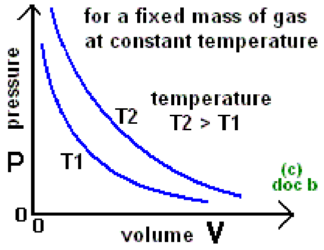
  arising from <u>interactions</u>, and . . .
- Chemistry and Chemical Engineering study and apply those <u>system patterns</u>.

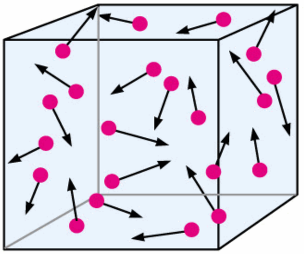
Boyle

Historical Example 2: The Gas Laws and Fluid Flow

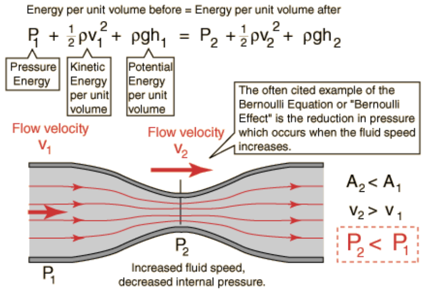
Daniel Bernoulli

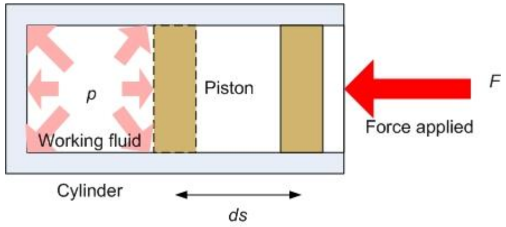






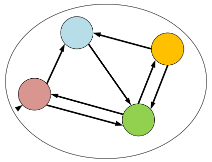
- The discovered and verified laws of gases and of compressible and incompressible fluid flow by Boyle, Avogadro, Charles, Gay-Lussac, Bernoulli, and others are rightly viewed as fundamental to science and engineering disciplines.
- But, all those gaseous properties and behaviors are emergent consequences of <u>interactions</u> that occur between atoms or molecules, and the containers they occupy, and the external thermal environment
- These lower level <u>interactions</u> give rise to <u>patterns</u> that have their own higher level properties and relationships, expressed as "hard sciences" laws.



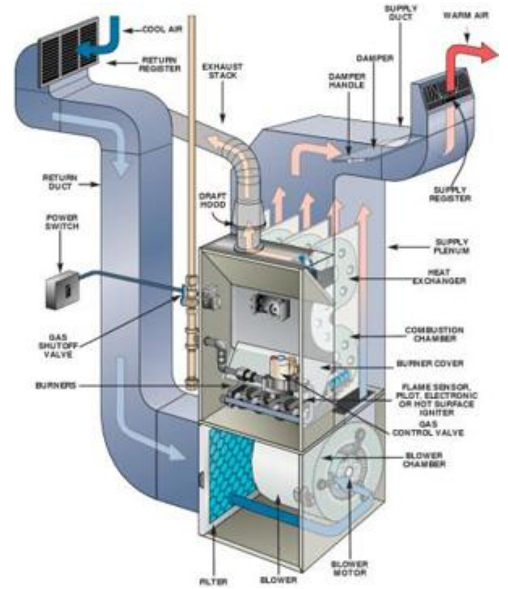


Boltzmann

Gas Laws, continued



So . . .



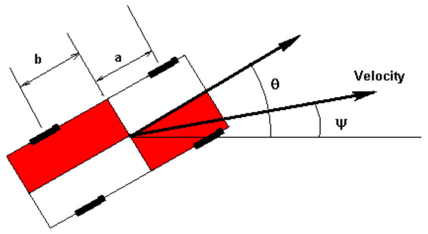
- The "fundamental phenomena" of gases, along with the scientifically-discovered / verified "fundamental laws and first principles" are in fact . . .
- higher level emergent <u>system patterns</u>

  so that . . .

- Mechanical Engineers, Thermodynamicists, and Aerospace Engineers can study and apply those <u>system patterns</u>.

More Recent Historical Examples

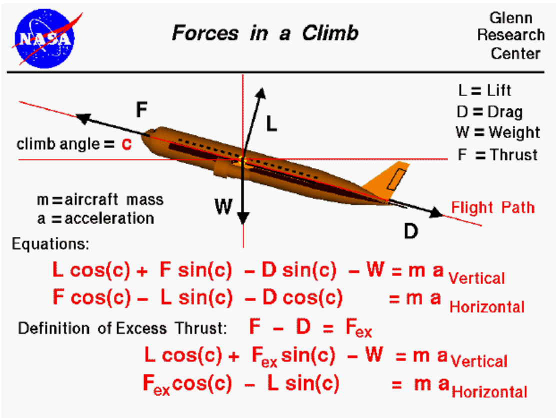
- Ground Vehicles
- Aircraft
- Marine Vessels
- Biological Regulatory Networks

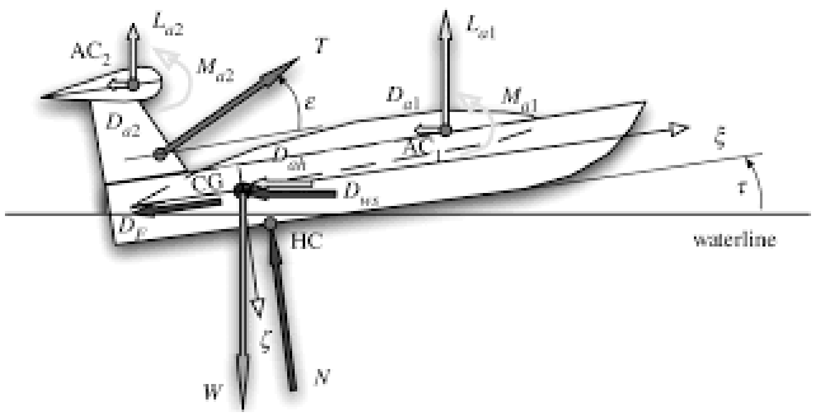


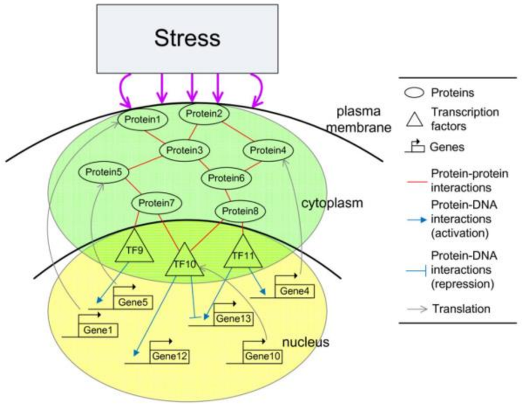
Dynamics of Road Vehicle

Denoting the angular velocity ω, the equations of motion are:

$$\frac{d\omega}{dt} = 2k\frac{(a-b)}{I}(\theta-\psi) - 2k\frac{(a^2+b^2)}{VI}\omega$$
$$\frac{d\theta}{dt} = \omega$$
$$\frac{d\psi}{dt} = \frac{4k}{MV}(\theta-\psi) + 2k\frac{(b-a)}{MV^2}\omega$$

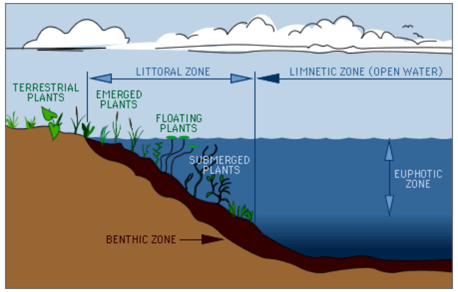


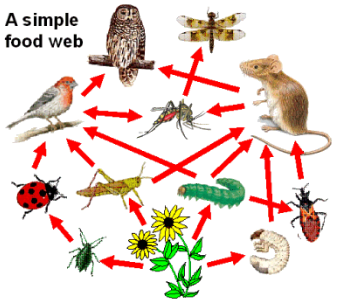


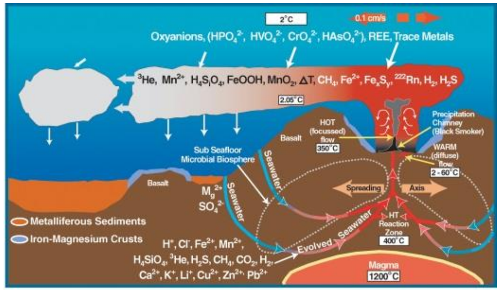


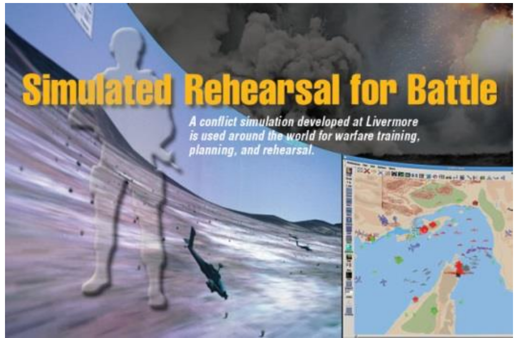
Future Examples

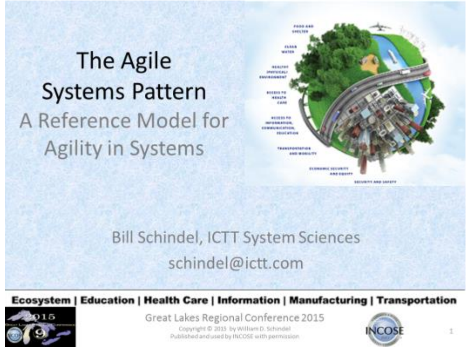
- Utility and other distribution networks
- Biological organisms and ecologies
- Market systems and economies
- Health care delivery, other societal services
- Systems of conflict
- Agile innovation







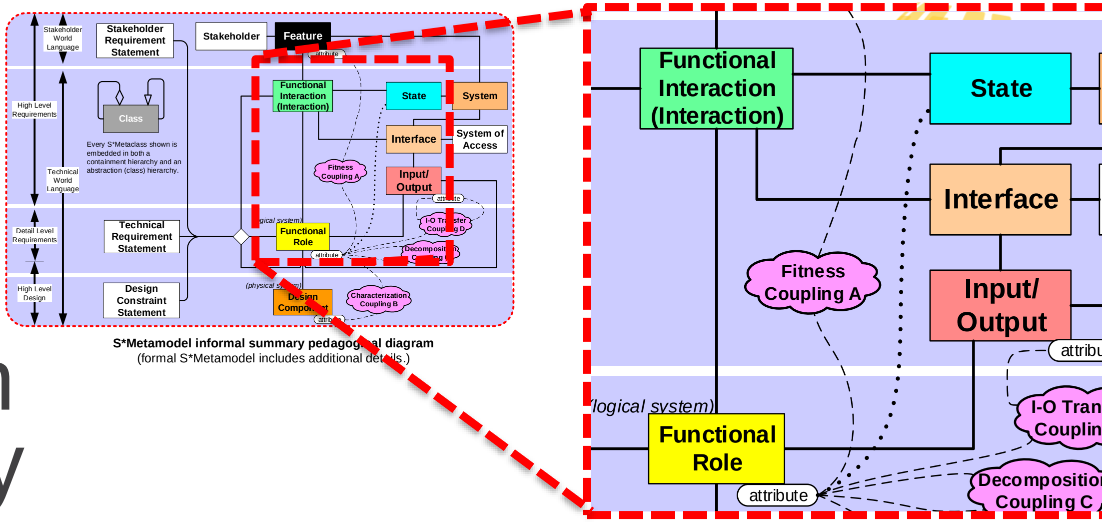




Implications for Practitioners, Educators, Researchers

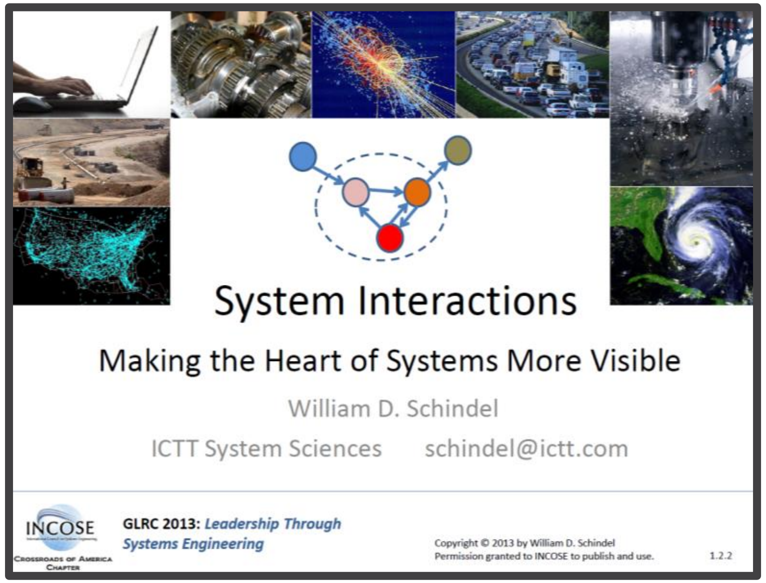
1. Representing the System Phenomenon
2. The burden of model credibility
3. Systems education for all engineers
4. Systems research frontiers, needs, and opportunities

1. Practitioners: Representing the System Phenomenon

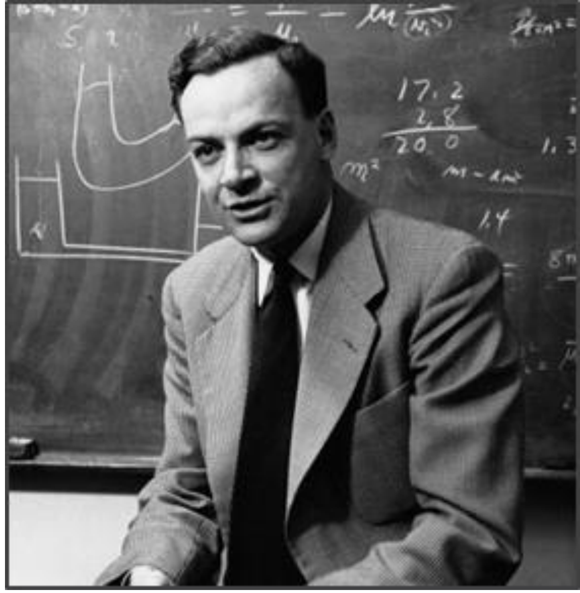


S*Metamodel informal summary pedagogical diagram
(formal S*Metamodel includes additional details.)

- <u>Interactions</u> are the phenomenon center of three centuries of highly impactful science and engineering.
- They should appear center stage in every system model
- They more impactful on engineering analysis than unipolar Functions (Functional Roles) alone.
- No “naked behavior”.
- Because of the System Phenomenon.



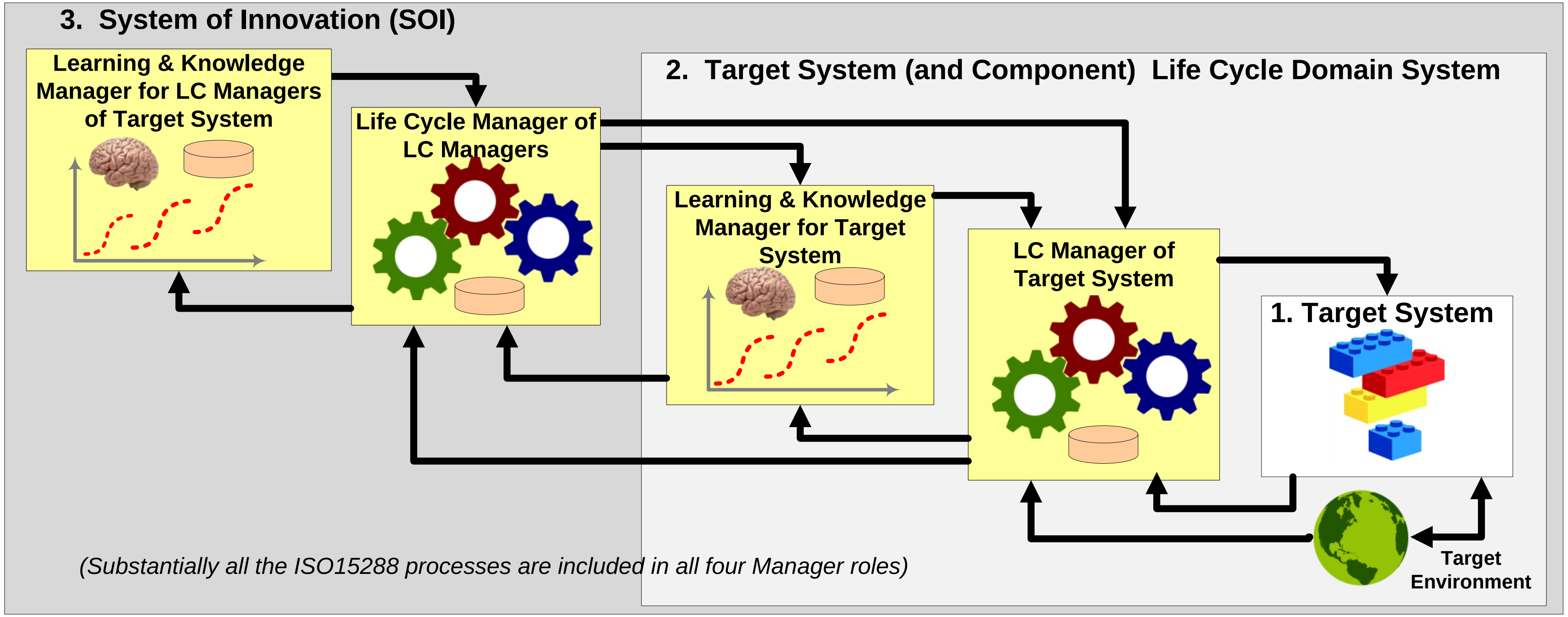
2. The burden of model credibility

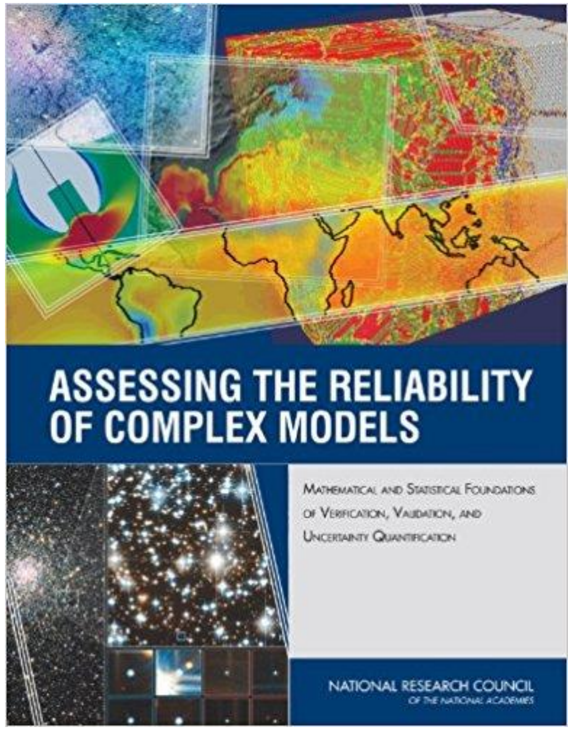


"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong."

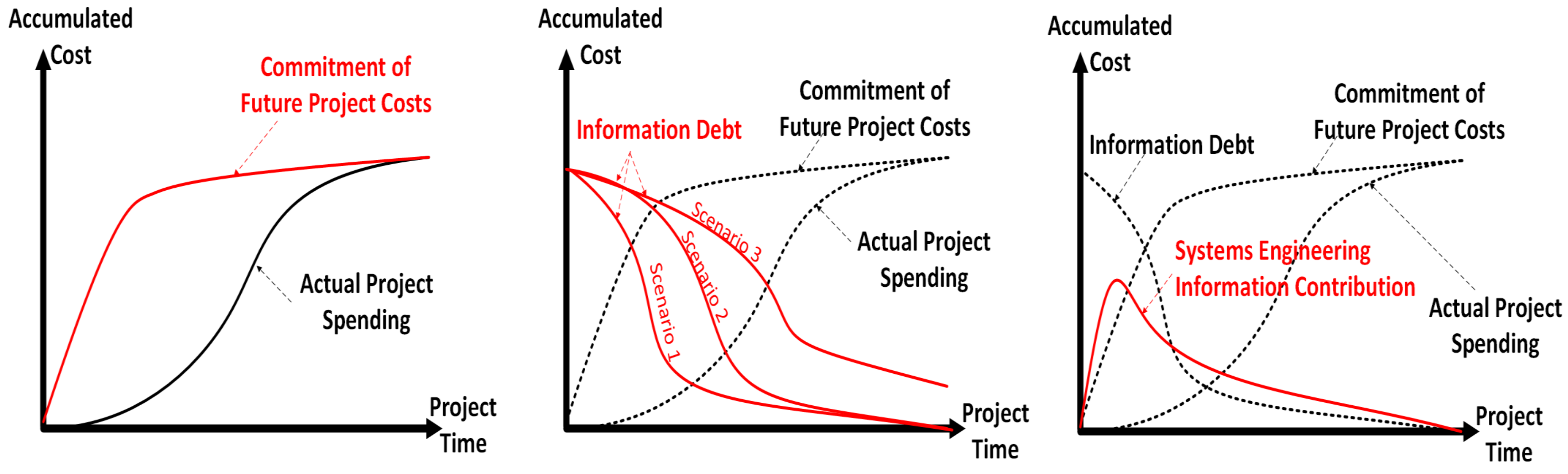
– Richard P. Feynman

(MBSE Models are not exempt. See current ASME VVUQ work joined by INCOSE, FAA, FDA, NRC. Leverage of trusted shared Patterns.)





- Pattern data as IP, and a proxy for group learning:
  - Information Debt, not just Technical Debt, as a foundation of adaptive, agile innovation.
  - Patterns can be capitalized as financial assets under FASB 86.
- “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

From Dove, Garlington, and Schindel, “Case Study: Agile Systems Engineering at Lockheed Martin Aeronautics Integrated Fighter Group”, from *Proc. of INCOSE 2018 International Symposium*, 2018, Washington.

3. Systems education for all engineers

- “Tiny” system models (including interactions, value) build system skills for undergraduate engineering students across disciplines—not just for SE majors.
- Particularly effective in cross-disciplinary programs.
- Model-making as a skill first, later building deeper system sense.

26th Annual INCOSE International Symposium (IS 2016)
Edinburg, Scotland, UK, July 18-21, 2016

Helping Undergraduate Students of any Engineering Discipline Develop a Systems Perspective

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ASEE

Paper ID #19345

Development of Enhanced Value, Feature, and Stakeholder Views for a Model-Based Design Approach

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He is currently an associate with IOI Partners, a consulting venture focused on innovation tools and systems. Prior to joining Rose-Hulman, he was a company co-founder and Chief Operating Officer of Montronix, a company in the global machine monitoring industry.

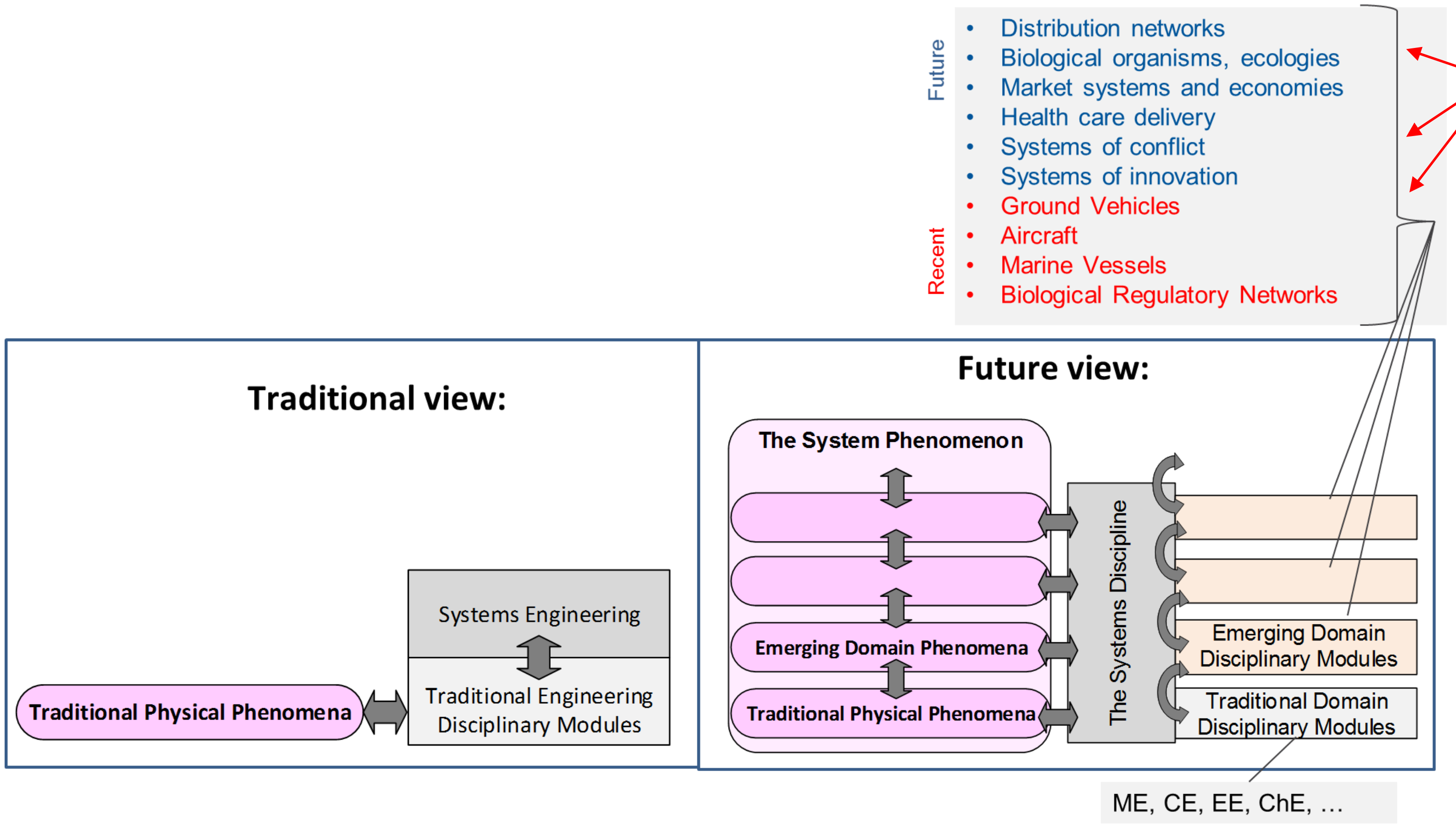
Bill is a Phi Beta Kappa graduate of Illinois College and a Bronze Tablet graduate of University of Illinois at Urbana Champaign where he received a Ph.D. degree in Mechanical Engineering.

Mr. William D. Schindel, ICTT System Sciences

William D. Schindel is president of ICTT System Sciences, a systems engineering company, and devel-

4. Systems research frontiers, needs, and opportunities

Abstract Theories of Systems: A great deal of math/science already exists here (even if overlooked) from 300 years of progress. Better we should be learning it and using it than searching for a replacement. Better to invest more systems research in the emerging domains' system phenomena.



Each emerging domain framework has its own patterns of foundational structures. (Same as chemistry, gas laws, electromagnetics, etc.) There are countless research opportunities to discover those system domain patterns and their related mathematics, and apply them for the good of each domain.

Questions, Discussion

References

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Strengthening the Foundations of SE

From:
INCOSE SE Vision 2025: A World in Motion

Page 40

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.