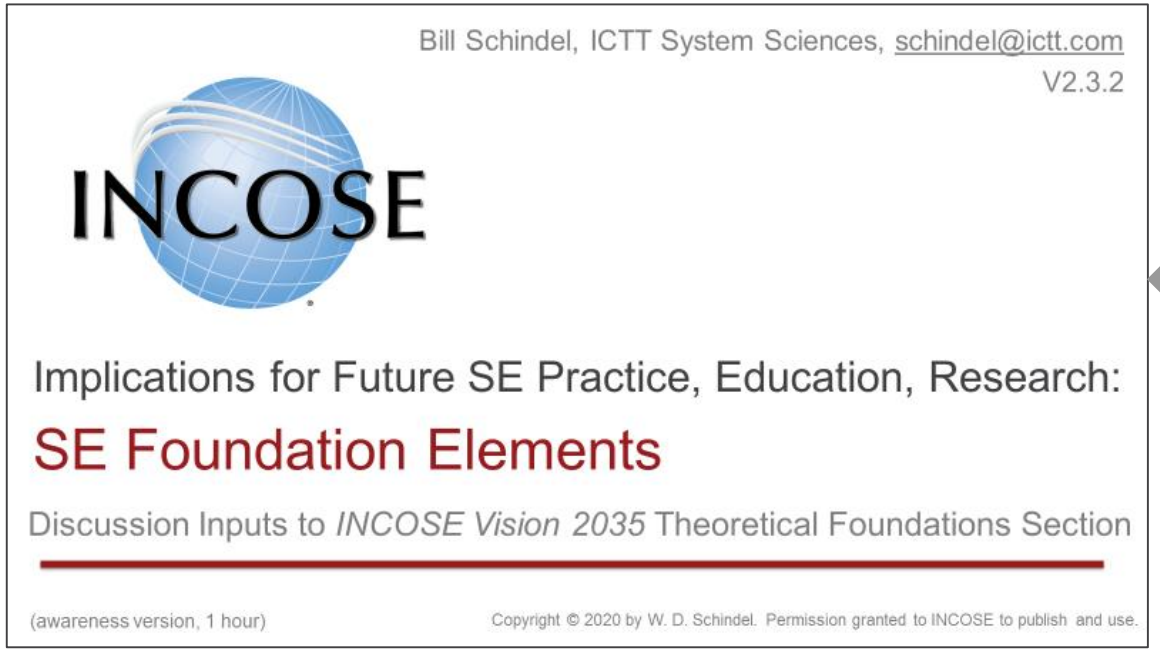
Bill Schindel
ICTT System Sciences
schindel@ictt.com
V1.2.2

SE Foundation Elements:

What are the implications of the Foundation Phenomena for SE *practice*, *education*, and *research*?

INCOSE Crossroads of America Chapter Meeting
June 9, 2020

At the April, 2019, INCOSE Crossroads of America meeting, we reviewed three asserted Foundation Phenomena important to Systems Engineering:

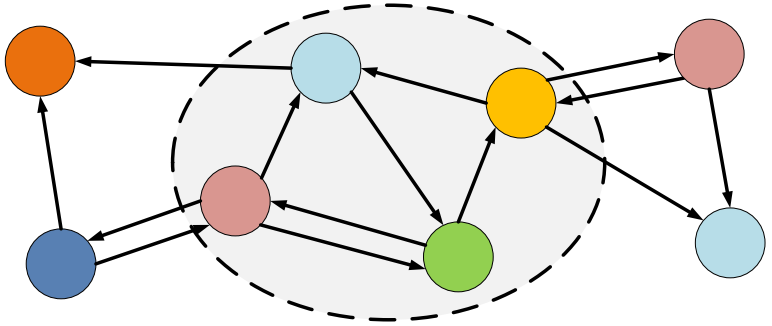


From April, 2019 meeting

https://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:science_math_foundations_for_systems_and_systems_engineering--1_hr_awareness_v2.3.2a.pdf

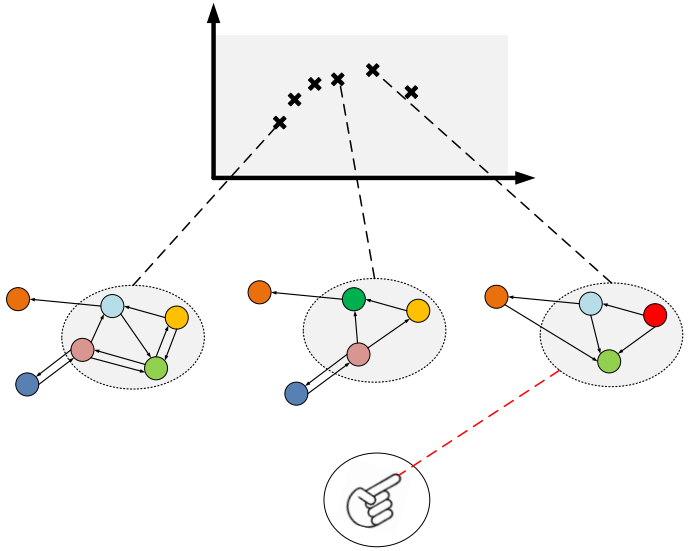
- In tonight's (June 9, 2020) meeting, we'll focus on some of the apparent implications of those phenomena, for practice, education, and research.
- Let's briefly refresh on the three claimed observable phenomena from that material, before we focus on those implications . . .

1. The System Phenomenon



Interacting system components, IO exchange, state dependency and impact, emerging system-level parameters and behaviors.

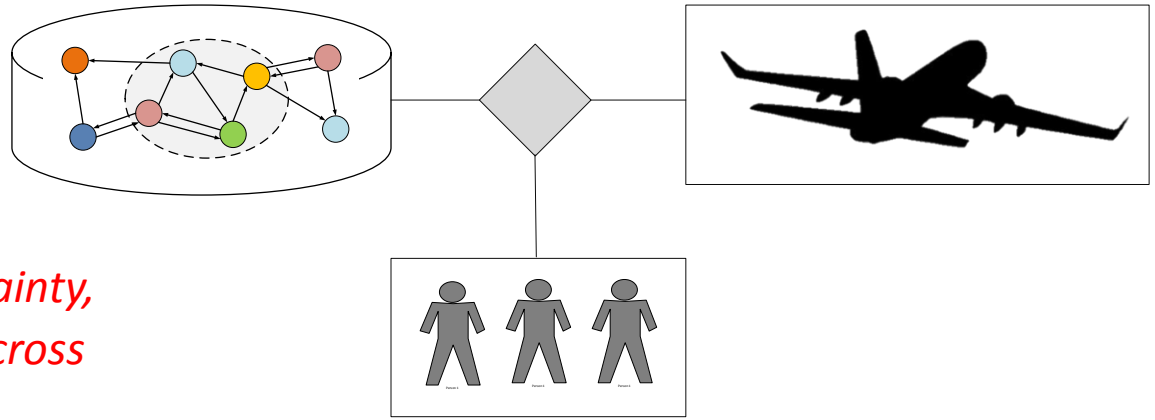
2. The Value Selection Phenomenon



Value is expressed and defined by selection -- of system instance, form, and parameter values.

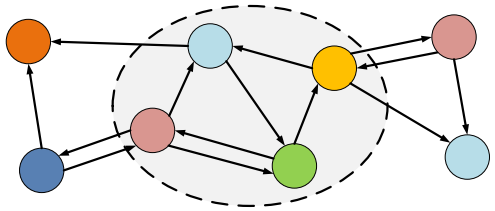
Three Observable Foundational Systems Phenomena

3. The Model Trust by Groups Phenomenon



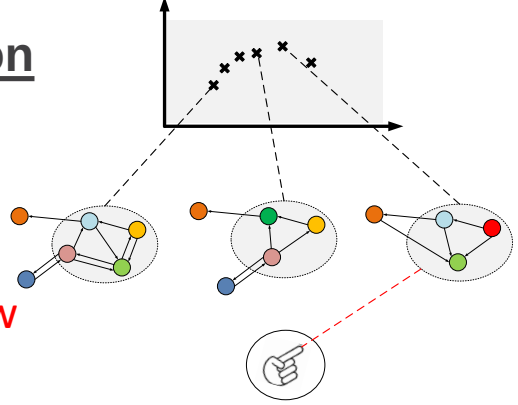
Model improvement based on empirical observation, shared learning, managed model uncertainty, shared human trust in a model across a group of interacting humans.

1. The System Phenomenon



- What interaction-based behavior occurs? What causes it? What larger structure emerges?
- How to represent quantitative and qualitative aspects?
- **Foundations**: Newton, D'Lambert, Hamilton, Riemann, Noether, Lanczos, Prigogine, Marsden, Bloch, Morse, Fredkin, Toffoli, Feynman; **Example**: Hamilton's Principle

2. The Value Selection Phenomenon

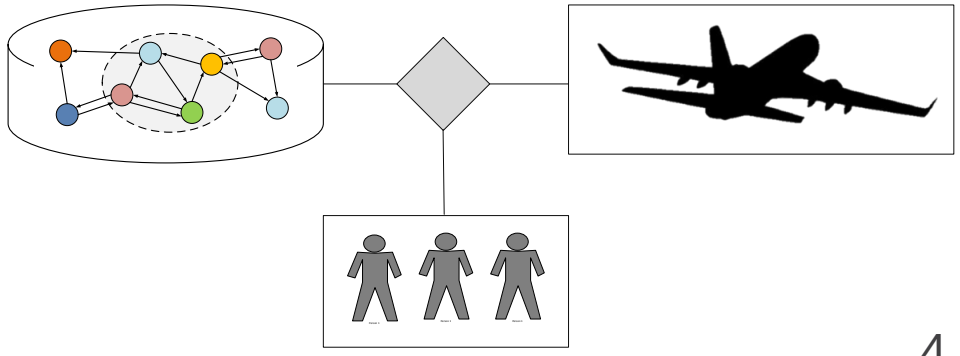


- What chain of selections occur, and by what (human, other) agencies? What ecosystem population proliferates? How much variation will a niche support?
- What does the selection agent "pick"? What is optimization? What are the value-based trade-offs and aspects at risk?
- **Foundations**: Darwin, Gould, Pareto, Wilson, MacArthur, von Neuman, Morgenstern, Simon, Laffey, Goldberg, Kimura, Kauffman; **Examples**: Markets; Genetic Algorithms

Three Observable Foundational Systems Phenomena

- What is the community's intended use of a model? What are the risks of trusting the model for that purpose? What is the provenance and credibility of the model for that purpose? How was that credibility established and how is it maintained and advanced?
- How is trust conveyed? Who speaks on behalf of trusting or interpreting the model? What is their influence on the group's trust of the model? What are the dynamics of the state of the group's trust?
- **Foundations**: Bayes, Jaynes, Tversky, Kahneman, Pentland, Oberkampf, Arrow; **Example**: Maximum Entropy Principle.

3. The Model Trust by Groups Phenomenon



The System Phenomenon: Implications for Practice

Representing the System Phenomenon:

- *Explicit Interactions must be central to every system behavior model*: Nature has no known "naked behavior" in absence of interactions, beginning with system context (environment). Representation of (both discrete and continuous) *state is likewise essential to every system model*. Modeling frameworks, metamodels, schema, and ontologies should support explicit interactions and states as central.
- Historical *distinctions between "system models" and "physics-based simulation models" can be reduced*, improving their integration.

Multiple domain-specific frameworks necessarily continue to emerge:

- Emergent domains and domain specific languages/ontologies arise for each new case of cross-domain interactions. *Efforts to create and sustain frameworks must recognize continuous creation of new domains is inherent to nature of systems*.
- Small underlying foundational framework content is important, but *the main continuing work is needed for domains which continue to emerge*.

The System Phenomenon: Implications for Education

- Experience has shown that *undergraduates across different engineering disciplines can profitably learn the creation of consistent "tiny system models" focused on the System Phenomenon-*-initially as a construction skill, and later progress to a deeper understanding of the abstract concepts represented, as a discipline with a set of consistency rubrics.
- These can be learned in early year classes and practiced further in subsequent capstone design courses. Undergrad Education Pioneers: See related ASEE and other papers and reports by Rose-Hulman Institute of Technology faculty (Kline, Simoni, Bernal, et al).
- These skills do not necessarily require use of advanced modeling tools.

The System Phenomenon: Implications for Research

- One of the main implications of the System Phenomenon and its historical foundations back to W.R. Hamilton concerns an apparent imbalance of current systems community research attention on generalized system phenomena and principles versus domain-specific system phenomena. There appears to be more interest in the INCOSE, ISSS, and related systems community segments in general systems theory research into foundations, but *more attention is needed for continuously emerging domain-specific systems theory research*.
- Support that this situation is a mistaken (over) allocation of research attention to the "general foundations" is provided in the related foundation phenomena package, and closely related to a seemingly near equivalent historical situation in physical science in the 1970's--when Nobel Laureate P.W. Anderson wrote his famous "More Is Different" paper noting the same problem in physical science. (*Physics does not make chemistry unnecessary!*)

The Value Selection Phenomenon: Implications for Practice

Representing the Value Selection Phenomenon:

- *Understand the difference between models of valued performance* (the delivery of value during performance) *and models of value selection* (which defines value). *Nature has no known "naked value" In the absence of selection agency*.

Representing valued performance:

- SE models must represent performance behavior twice—once as objective value-agnostic technical performance and once as (potentially subjective) components of stakeholder valued performance (stakeholder Features, the trade space scoreboard of selection).

Integrate the disparate implications of value for consistency and simplicity:

- The only basis for optimality, design decisions is stakeholder Feature space. *The only risk is risk to stakeholder Feature space*. *The only motivation for variant configurations is selectable benefit in stakeholder Feature space*.
- Accordingly, *value optimization, product line partitioning, failure modes and effects analysis (FMEA) or other risk analyses, and agile experiments are all performed on the basis of the same stakeholder Feature value space*.

The Value Selection Phenomenon: Implications for Education

- The *use of formal engineering classroom educational experiments leading to selection (or de-selection) based on results for engineering educational components* has been reported by Dr. Jon Wade, former CTO of the SERC.
- Formal system pattern-based representation of the system of engineering education itself, including the delivered value feature space encountered by its stakeholders has been reported by Rose-Hulman Institute of Technology (ASEE publication, Kline and Schindel)
- Dr. Jon Wade has reported on and encouraged use of the pattern of engineering practice advancement through engineering educational coursework and partnering enterprises, as studied for the VLSI Engineering revolution pioneered by Carver Mead and Lynn Conway.

The Value Selection Phenomenon: Implications for Research

- The Value Selection Phenomenon results in generation of populations of variant configurations of systems (in autos, aircraft, pharmaceuticals, retail distribution systems, manufacturing technologies, software platforms and applications, hardware components, etc.). Related questions of interest in the engineering and business community are concerned with *the number of variants required to cover a market niche of interest*, overly segmenting product lines, how many competitors a market can support, etc.
- Historical pioneering historical research into other related domain systems illustrate lines of research that could be further pursued to address the above questions:
  - The landmark publication in biology empirical study of niche capacity is The Theory of Island Biogeography, by MacArthur and Wilson, 1967 and later.
  - Applying the theoretical tools of statistical mechanics to population partitions has been illustrated by E.T. Jaynes, in “Information Theory and Statistical Mechanics I and II”, 1957 and later.

The Model Trust by Groups Phenomenon: Implications for Practice

Two cases of the Model Trust by Groups Phenomena concern the Engineering & Life Cycle Management Ecosystem (System II) that delivers and manages System I:

- First, shared trust in models of System I are critical to the success of System II. But additionally, shared trust in current and future vision models of System II as a system in its own right are critical to realizing the vision.

Effective learning exhibits behavior improvement, not information accumulation:

- Accordingly, *the configuration of learned general models for specific projects should be an in-line task to initiate a project, not an optional scan of past reports*.
- Recognize that *social networks as well as quantitative measures bear on shared human trust* required for both cases. Explicit models of patterns of learned experience apply to both cases.

Information Debt, Cost of Model Credibility, framework of model VVUQ --MBSE models are not exempted from need for managed credibility for their intended use:

- *Utilize group-accepted explicit Credibility Assessment Frameworks (CAFs) to capture and communicate the basis of assertions of model credibility*. CAFs should recognize the role of social physics in the Model Trust by Groups Phenomenon, with appropriate model trust networks, views, curators, trusted interpreters.
- Diverse models proliferate. *Utilize explicit uniform Model Wrapper (Model Characterization Pattern) metadata to label diverse model portfolios for effective management and sharing, as to their subject, scope, intended use, credibility, and other aspects*.
- Understand the *exploitation of repeat use modeled patterns as learning and risk management proxies and reducers of Cost of Credibility* over the model life cycle.

The Model Trust by Groups Phenomenon: Implications for Education

- The methods of model VVUQ are currently subject of relatively complex references in the form of books and standards. *There is a need to make this subject more accessible to students and practitioners* at less then the doctoral level. Work by organizations such as ASME, V4I, and INCOSE may help, but there is a significant need for improved educational material of a more accessible nature.
- There is a *need to improve understanding of the differences between and uses of (a) (Bayesian) uncertainty or confidence versus (b) (random process frequentist) probability*, as encouraged by Dr. Chris Paredis, Clemson U., among others. (See E.T. Jaynes.)
- In undergraduate engineering education, faculty represent a social network with both individualistic and shared beliefs. One of the findings of the work reported (above) by Rose-Hulman Institute of Technology is that the use of the "tiny models" approach allowed multiple faculty there to have more inter-operable frameworks of representation for student projects, thereby allowing more faculty to team across projects and lower peak faculty workloads, as well as improve uniformity of experiences by students.

The Model Trust by Groups Phenomenon: Implications for Research

- One *research opportunity concerning group trust in models is this INCOSE Vision 2035 initiative itself*--to engage the community in a conversation leading to a consensus (group trust) in certain (model-based) theoretical foundations of SE. *Experiments and capture of related empirical data present research opportunities for theory as well as experiment*. See also the social physics aspects next below.
- *This phenomenon recognizes/includes two "gaps": (a) the difference between model prediction and empirical data, and (b) the difference between what models different people in a group believe.* Although the history of physical science brings to mind (a) first, the impact of (b) in the history of science has been profound. Consider Galileo versus the Church on the model of Earth-Sun-Planets; consider the studies by T. S. Kuhn on the history of physics and the scientific community. His later "essential tension" work has inspired inclusion of hysteresis models in this space.
- *The mathematics of model VVUQ shows up in study of (a) (think E.T. Jaynes). But what is the mathematics of (b)?* Here the more recent "social physics" modeling work by Sandy Pentland and others is available, starting with Ising physics inspired models and encouraged by the rise of newer social media and interactions.
- Current work on shared model trust impact of Credibility Assessment Frameworks (CAFs) and Model Characterization Patterns likewise offers research opportunities in this area.

Discussion—your feedback on the implications

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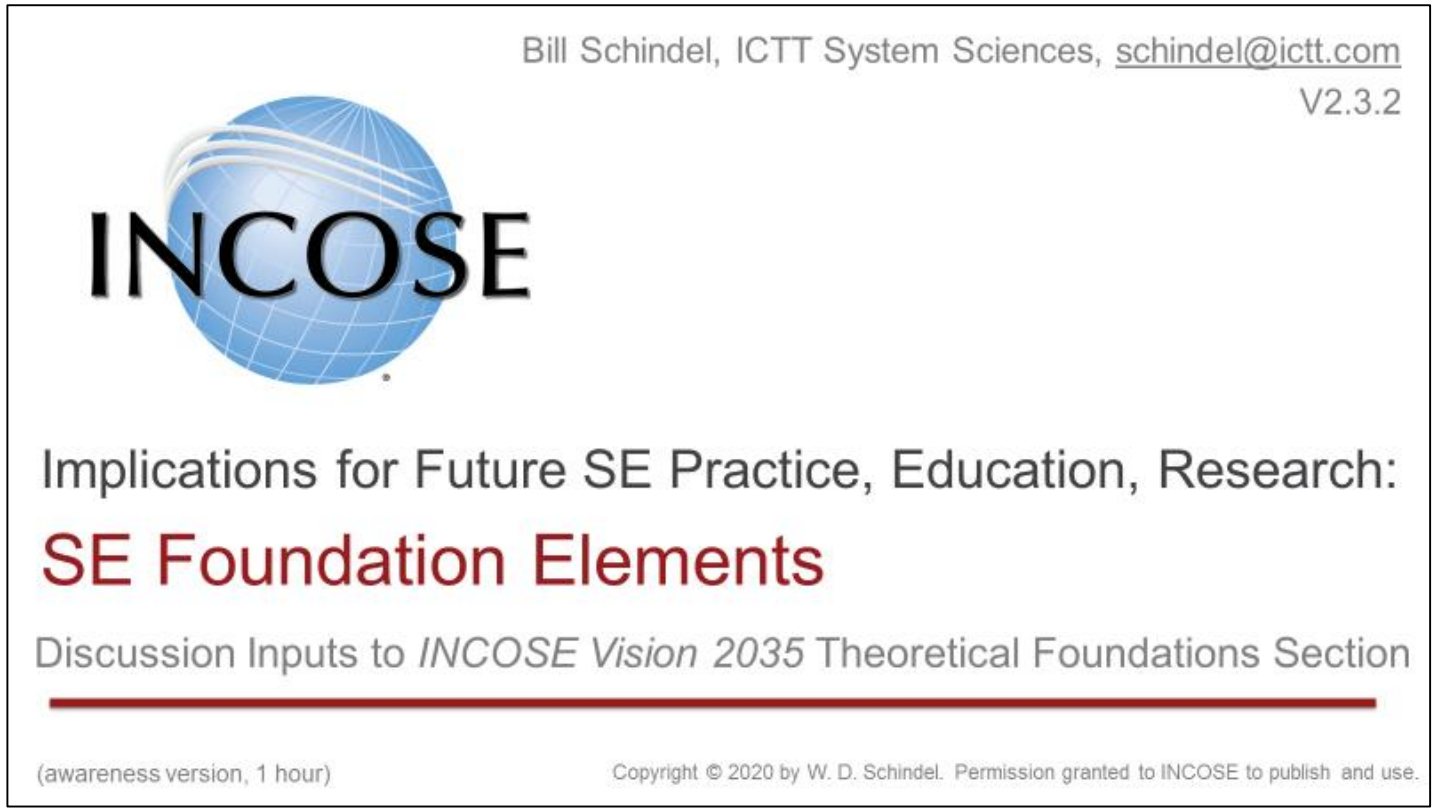
You can also write to Bill Schindel at Schindel@ictt.com

References—multiple references provided in:



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